F.X. Suryadi, PhD

LN0111/02/1

GIS and Computer Modelling for Water Management Systems

GIS and Computer Modelling for Water Management Systems

TABLE OF CONTENTS Page

1. GEOGRAPHICAL INFORMATION SYSTEMS (GIS)

1.1 Introduction to GIS

During the 1980s, advances in computer hardware, particularly processing speed and data storage; catalysed the development of software for handling spatial data. The emerging capabilities for graphical display played an important role in the development. One of the significant products of this period of rapid technological change was Geographical Information System (GIS). The impact of GIS has been widely felt in all fields that use geographic information , in resource management , land use planning, transportation and in many application in the geosciences and elsewhere.

What is GIS

A GIS is a computer system for managing spatial data. The word *geographic* implies that locations of the data items are known, or can be calculated, in term of geographic coordinates (latitude, longitude). Most GIS are restricted to data in two spatial dimensions, although some systems of particular interest have true three-dimensional capabilities and can represent objects such as mining and geological planning.

The word *information* implies that the data in a GIS are organised to yield useful knowledge, often as coloured maps and/or images, but also as statistical graphics, tables and various on screen responses to interactive queries. The word *system* implies that a GIS made up from several interrelated and linked components with different functions. Thus, GIS have functional capabilities for data capture, input, manipulation, transformation, visualisation, combination, query, analysis, modelling and output.

Geographical Information Systems (GIS) are to paper maps what word processors are to manually typed reports, and much, much more (Maune, 1996). Rather than manual drafting of traditional maps or technical drawings, semi-automated techniques to capture spatial (geographic) data in digital form, for ease of update, correction and printing on demand.

A GIS is a computer-based system for capturing and processing spatially distributed data of geographic nature (Mohan, 1991). According to Eastman (1993) a GIS is a computer-assisted system for the acquisition, storage, analysis and display of geographic data (topography, climatology, land use planning, soil type, water management zoning, etc.). The core of the system is the database, a collection of maps and associated information in digital form. Since the database is concerned with earth surface features, two elements can be distinguished i.e. the coordinates and the attribute of each point.

A GIS consists of a package of computer program with a user interface that provides access to particular functions. GIS are computer tools for manipulating maps, digital images and tables of geocoded (geographically located) data items, such as the results of a soil survey. GIS are designed to bring together spatial data from diverse sources into a unified database, often employing a variety of digital data structures , and representing spatially varying phenomena as a series of data layers. All of which are in spatial register, meaning that they overlap correctly at all locations.

GIS is filling a very real need in the face of the rapid growth of digital spatial data in the geosciences. Many spatial data sets are now being generated by government agencies, private companies and also university researchers, and they would be ineffectively used and result in wasted resources without good systems of data management.

GIS has made a tremendous impact in many fields of application, because it allows the manipulation and analysis of individual 'layers' of spatial data. GIS provides tools for analysing and modelling the interrelationship between layers. The user or planner needs to understand the spatial relationship between all the various kinds of spatial data that they have collected.

Furthermore, computers allow large amounts of descriptive (non-geographic) data, including digital images, to be stored in related databases for query and analysis. Therefor, rather than requiring humans to read, interpret, and analyze paper maps, GIS technology enables computers to interactively perform logical analysis of digital spatial data (topography, land use, drainage performance) linked to digital descriptive data. As with paper maps, the combination of digital spatial and descriptive data is the key to create intelligent data for automated or semi-automated computer processing.

Before widely-available commercial GIS appeared on the scene in the late 1980s, most planners working with multiple spatial data sets were doing their work on light tables. A

relatively small proportion of the planner community was computer-oriented, working mostly with mainframe computers and locally-developed software.
GIS technology is still in its infancy, with the majority of applications being carried out by specialists. However, GIS has the potential to change the geological workplace drastically. In a few short years, the personal computer has virtually eliminated the typewriter and the hand calculator from the office, and GIS is likely to replace the light table and the map cabinet. Like many fields where computer are employed, GIS has the potential to free the user from the technical, slow, laborious problems of data handling, and to enhance the capability for creative data analysis, modelling and interpretation.

1.2 Purpose of GIS

The ultimate purpose of GIS is to provide support for making decisions based on spatial data. The planner or designer may use GIS to assemble data in the form of any potential map to decide alternative future development. Sometimes the purpose of using a GIS is to support general research. In this lecture an example and exercise will be presented on a land suitability analysis for agricultural development of a tidal lowland area.
Application of a GIS achieves their major goals through one or more of the following activities with spatial data: organisation, visualisation, query, combination, analysis and prediction.

Data organisation

Anyone who has collected large quantity of data for a particular purpose known the importance of data organisation. Data can be arranged in many different ways, and unless the organisation scheme is suitable for the application at hand, useful information can not be easily extracted. Computer and GIS can not directly be applied to the real world. A dta gathering step comes first. Digital computer operates on numbers and characters held internally as binary digits. The real world phenomenon of interest must, therefor, be represented in symbolic form. The abstraction process of representing any property of earth's surface in a computer-accessible form involves the use of symbolic models.
The principal characteristic for organising GIS data is spatial location. Without knowing the locations of sampling or collected data, the interpretation of spatial patterns and relationships with other spatial data, can not be established.

Visualisation

The graphical capabilities of computers are exploited by GIS for visualisation. Visual display is normally carried out by using the video monitor, but other output devices such as colour printers are used for hardcopy display. Humans have an extra-ordinary ability to understand complex spatial relationships among the related parameters visually, whereas the same information may be quite unintelligible when presented as a table of numbers. Visualisation is achieved in GIS with colour and symbols.

Spatial query

Visualisation reveals spatial pattern amongst collections of organised data items. However, visualisation is not so helpful for answering questions about special instances in the data, such as the value of particular data items. Spatial query is a complementary activity to data visualisation.

Combination

The ability to combine and merge spatial data sets from quite different sources and display and manipulate combinations can often lead to an understanding and interpretation of spatial phenomenon that are simply not apparent when individual spatial data types are considered in isolation. For example by superimposing a topographical map on a soil types map, it may become clear that a particular spot is suitable for a particular agriculture development.
One of the really powerful features of GIS is the ability to link several map algebra statements together to form more complex algorithms. Several images and tables of attribute data can be combined in a single processing step.

1.3 Modelling and analysis with GIS

Modelling and analysis are the process of inferring meaning from data. They are often carried out visually in a GIS, as already indicated. Modelling and analysis in a GIS can also be carried out by measurements, statistical computations, fitting models to data values and other operations.
Spatial modelling and analysis in a GIS sense means simply the analysis of spatial data. For example, the area cross table calculation of two maps may lead to useful conclusions about the relationship between the two maps.

Prediction

The purpose of a GIS study is often for prediction. For example a number of data layers should be considered for land suitability analysis as a new map or image. Such a map/image may then be used as a basis for development planning decisions or land-use decisions such as 'Is the region suitable for agricultural development and what type of agriculture should be planned?' Prediction in a GIS involves the use of map algebra for defining symbolic models that embody the rules for combining data layers together.

Database management systems

Another important relative of GIS is database management systems (DBMS). DBMS are computer systems for handling any kind of digital data. A database is a collection of inter-related data and everything that is needed to maintain and use it (Bisland, 1989). A DBMS is a collection of software for storing, editing and retrieving data in a database. Some form of database management system lies at the heart of any GIS, and many commercial GIS are explicitly linked to a particular DBMS. Many of the data collected by engineers are stored as tables of numbers and text. When the location of each site is recorded by a pair of spatial co-ordinates (i.e. a vector), such tables comprise one of the most important inputs to GIS. Databases are large collections of data in a computer, organized so that they can be expanded, updated, and retrieved rapidly for various uses. A GIS database is composed of sets of spatial (geographic) and descriptive (non-geographic) data managed by the computer software. Spatial data are digital representations of geographic features on, above, or beneath the earth's surface which can be used to generate a map or to display a map-like image on a computer screen. Spatial data must include geo-referenced coordinates in order to display the relative locations. Descriptive data describe attributes, characteristics, qualities or relationship of geographic features and may include scanned images, such as digital pictures of houses, bridges, or other features.

Modelling is used to support and extend GIS spatial analyzes. GIS has provided an infrastructure for the analysis and evaluation of complex spatial problems in new and exciting ways. For example, hydrologic or watershed erosion/sedimentation models describe the relationship of slopes, soil types, vegetation cover and land use characteristics of watershed. Water management zoning models describe relationship of hydro-topographical conditions, soil types and its requires water management systems. Drainage and flood control model to predict the hydraulic performance of the systems on the environment and man's use of that environment.

Today's GIS trends are directly influenced by two main driving forces, i.e.:

- The computer evolution which drives development of GIS towards an increasing degree of integration of different aspects;
- The increased demand for management of spatially distributed data and the need to solve the complex natural resources problems through spatial modelling techniques.

GIS is rapidly becoming a standard tool for the management of natural resources, included water resources. It is used to assist decision makers by indicating various alternative development plans in real lie situations and it has a capability to model the potential outcome for a series of development scenarios (Meijerink, 1985 and Brower, 1993).
The modelling principles with a GIS are presented in Figure 1. From Figure 1, it will be clear that a GIS should be supported by a proper database. Nowadays, it is difficult to think of resource planning without a GIS.

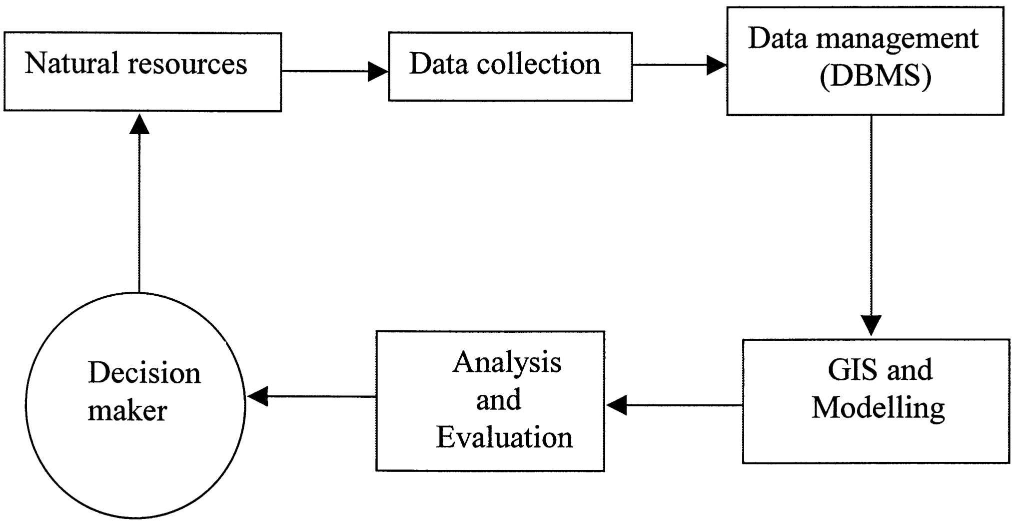


Figure 1. GIS and modelling in a planning process of natural resources development

Other software
Other programs often used in association with GIS for specialised tasks are spreadsheets and statistical programs, particularly for multivariate analysis and also expert system.

1.4 Spatial data models

Models are simplification of reality and the real world is so complicated. The components of the models are spatial objects, approximating spatial entities of the real world. They are represented on the map by graphical symbols. The key for understanding the symbols is recorded, at least in part, in the map legend. On the other hand, a computer file containing a digital representation is also a symbolic model of the same piece of the real world, with a further process of abstraction from graphical symbols to digital codes. The key for communicating the meaning of the digital data is an essential part of the data sets itself. The value of a spatial data set is not simply whether the digital format is understood by the software. Unless the rules for measurement and organisation of data are clearly established, the data are of limited use, except possibly to the individual or organisation who generated them.

A straight forward example of a digital computer file containing a grid of elevation values, often called a digital elevation model (DEM) which is comparable to a topographical map. A DEM is also an example of a symbolic model to the real ground surface. The cell of the grid are the spatial objects, whose values are symbolised by numbers in the data file. In this case, the data definition and data organisation requires less interpretation than any other for example a geological map.

The process of defining and organising data about the real world into a consistent digital data set that is useful and reveals information is called data modelling (Peuquet, 1984, Goodchild, 1992). The logical organisation of data according to a scheme is known as a data model.
Data can be defined as verifiable facts about the real world. Information is data organised to reveal patterns, and to facilitate search. Spatial information is difficult to extract from spatial data, unless the data are organised primarily by spatial attributes. Also, because of the nature of digital computers, data items must be identified as discrete spatial objects in order that they can be manipulated and computed digitally. Geographical space must, therefor, be represented discretely, because spatially continuous fields, such as temperature fields, can not be stored digitally as continua. All spatial data models make use of discrete spatial data objects, such as points, lines, polygons, volumes and surfaces. Spatial objects are characterised by attributes that are both spatial and non-spatial, and the digital description of objects and their attributes comprise spatial data sets.

Spatial data can be organised in different ways, depending on the way they are collected, how they are stored, the amount of interpretation added to them, and the purpose to which they are put. The vector and raster models are the commonly recognised schemes for spatial data organisation in a GIS. The vector model divides the world into points, lines and polygons bounded by lines, whereas the raster model uses cells or pixels as spatial units.

Spatial objects

The real world exhibits properties that are either spatially continuous, like temperature, or discontinuous like the state of matter-solid, liquid and gas. Thus, gravity measured from place to place is a continuous field variable, whereas many soil types are discontinuous. Where discrete spatial entities occur in the real world, they can be treated as natural spatial objects, generally irregular in shape, in a data model. For variable that are, in reality, spatially continuous, space must be divided into discrete spatial objects that can be either be irregular or regular in shape. A lattice of sampling points (or equivalently a grid of square cells or pixels) is a collection of regularly-shaped imposed objects.

Continuous fields can also be divided into naturally-shaped irregular objects bounded by contour lines.

Spatial objects can be grouped into points, lines, polygons, surface and volumes, varying in spatial dimension as illustrated in Figure 2.

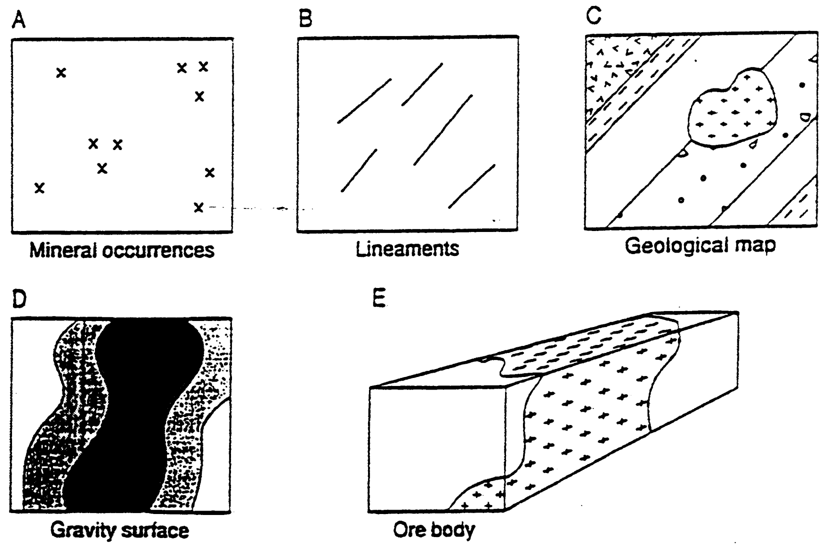


Figure 2. Points, lines, polygons, surface and volumes, varying in spatial dimension

In reality, many spatial objects in the real world have fractional spatial dimensions. When a natural line object is measured at progressively larger scales, its length increases as greater detail becomes apparent.
Besides their dimensionality, spatial objects can also be grouped according to whether they are 'natural' or 'imposed'. Natural spatial objects correspond to discrete spatial entities recognisable in the real world, like a river. Imposed spatial objects are artificial or man-made entities, like a property boundary, or a pixel.

A key difference between the raster and vector data models is that the raster model uses regular imposed spatial objects, whereas the vector model uses irregular spatial objects that can be either natural or imposed. The vector model employs a boundary representation of area objects, because each object is different from the next, whereas the pixels or cells in a raster are constant in size and shape and do not require individual boundary definitions. See Figure 3. In either model, a spatial object is assumed to have properties that are homogeneous, so that a single object is described by attributes that are constant for the whole object.
Spatial objects may also be simple or compound. A compound object is composed of two or more simple objects. For example, a system of interconnected lakes may be regarded as a compound object, composed of a collection of lakes that are simple objects. An irregular object such as a polygon on a map may be a simple object in a vector representation. However, in raster representation, the same polygon may be composed of several pixels, so the object is now compound, composed of simple objects (pixels) having attributes in common.

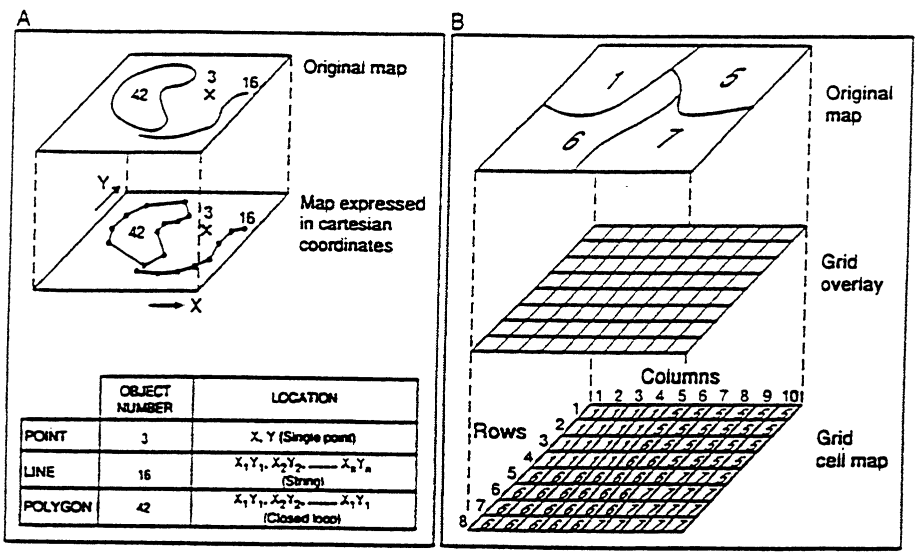


Figure 3. A spatial object is assumed to have properties that are homogeneous

1.5 Raster and vector spatial data models

The raster model is particularly well suited for subdividing spatially continuous variables, like the gravity field, for digital computers. The raster can be represented as a rectangular matrix of numbers. See Figure 4, that is a two-dimensional array and can be stored on a disk with a simple file structure, with straight forward addressing of pixels by sequence in the file. Many output devices are based on rasters, such as video display monitors, line printers and inkjet plotters. The raster model is used for digital images, digital image processing and analysis are well established disciplines with a broad range of applications in remote sensing, computer vision and other areas.
On the other hand, vector model is well suited for representing maps. Points, lines, polygons and symbols on maps are difficult to capture with fidelity in a raster without making the pixels very small, resulting in a very high storage costs.

Raster and vector models can be differentiated on the basis of how they represent space, as well as by the type of spatial objects they use. Spatially referenced data is often confused with geo-referenced data and geo-coded data. Spatially referenced data have known locations in three dimensional space, on, above, or beneath the earth's surface. Geo-referenced data pertains to the relationship between x/y or x/y/z coordinates on a paper map or scanned image and known real-world geographic coordinates. Geo-coded data maintain linkage between spatial and descriptive data by geographic coordinates (latitude/longitude) or another real-world addressing scheme, as opposed to link numbers or other non-geographic identifiers.

Digital data types

Spatial data digitally describe the map, technical drawing, or other graphic features, where every point can be geo-referenced.

Spatial data

Raster data consist of geo-referenced pixels or grid cells of uniform resolution. A pixel (picture element) is the smallest indivisible element of a digital image. Somewhat different from a pixel, a grid cell is one element of a matrix formed by horizontal and vertical lines at user-defined spacing. One grid cell could be defined to equate a 30-by-30 m^2 area on the ground, or any other grid cell size the user selects. Raster grid cells are often used to display soil types, geology, vegetation classification, land use, land classification, and natural features that do not need to be depicted with smooth lines and curves. Rater data are normally displayed in colors representing differing image characteristics for each pixel or differing values for the attributes describing each grid cell. Vector data consist of x-y coordinates defining the locations of point, line and area features. Vector data are displayed with different colors, line styles (solid, dashed, dotted, etc.), line weights (thickness'), and symbols. Figure 4 presents these two common types of spatial data, raster and vector.

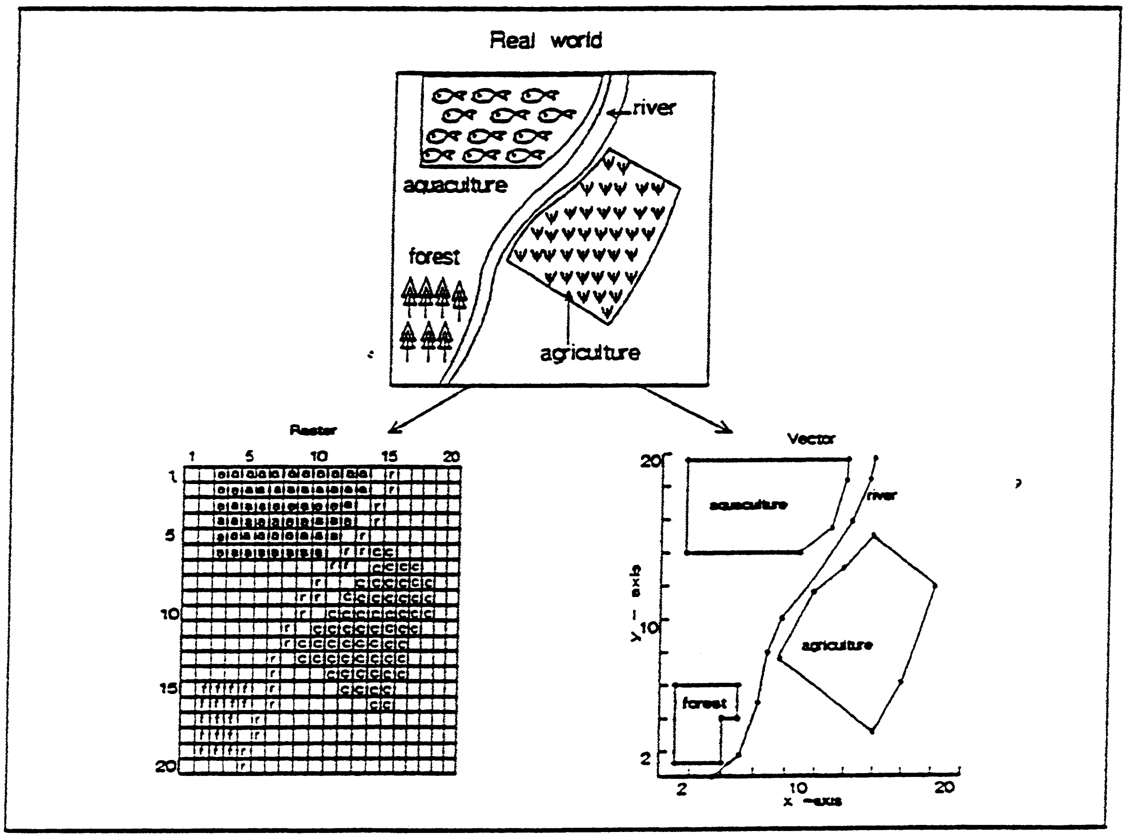


Figure 4 GIS spatial dat: (raster and vector)

GIS terminology

A GIS is defined as a computer hardware/software system that captures, stores, manages, manipulates, analyzes, displays, and/or prints spatially referenced data for planning, managing, and decision making.

Topological, topologic, and topology all pertain to the building of 'topo logic' into GIS data. Topology is the relationship between different features based on their geographic location. Topology defines the way in which points, lines and area are digitally formed and connected so that logical relationships (adjacency, proximity, and connectivity) can be automatically determined by GIS software. With topological data structure, nodes are established at end points and interceptions of lines; lines, which normally include intermediate shape points (vertices), are connected to nodes; the beginning, end, and direction of each line is defined, along with areas to the right and left of each line; and polygons are specifically defined by the bounding lines. Topological data structure allows for efficient data storage, since a feature's coordinates only need to be listed once, not many times, as long as that feature can be later defined by its relationships to other features.

Attribute data management

In image representation one is concerned with characterization of the quantity that each pixel represents (Jain, 1989). Attribute data for a GIS can be stored either in raster images, attribute files or in dbase files. Especially for raster images, OVERLAY, UPDATE and RECLASS modules are the primary tools to be used for editing attribute values. In the systems there should also be a possibility to convert from one system to another. In general, this converting procedure can be illustrated in Figure 5.

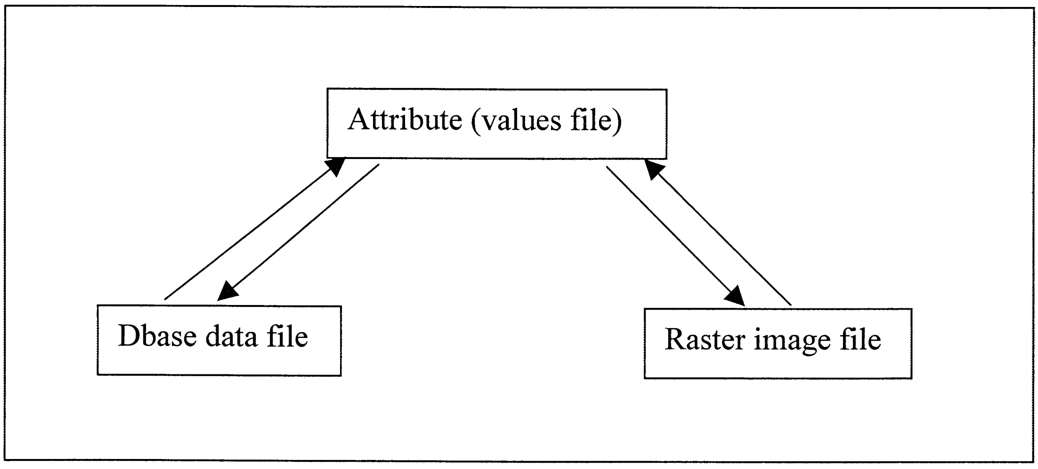


Figure 5. Conversion process of attribute data

Data input

Before doing any modelling, required data must be input to the systems. In a GIS this task is time consuming. Entering data should be done by taking into consideration possible error and the degree of expected accuracy. Several ways for data input are available, i.e. keyboard entry, manual digitizing, scanning and downloading existing data files.

Map algebra

Map algebra refers to the use of image files as variables in normal arithmetic operations. This is also an advantage of a GIS where full algebraic operations on a set of images are possible (+, -, *, /). Here, the main modules are:

Overlay:

'thematic mapping' consists of overlaying maps of different attributes but corresponding to a same area of interest (Fabbri, 1991). Overlaying of maps will result in the creation of new spatial entities which undertake mathematical operation between two image files. The values assigned to a certain location are computed as a function in one or more of the existing maps. By overlaying, a new data set containing new areas is formed. Three types of overlay operations are available, i.e. arithmetical, logical and conditional. This capability has perhaps the greatest attraction of GIS and the most important one is in defining procedures, rules or algorithms which lead to a meaningful combination of several different spatial data. The intersection of two or more domains by overlaying is a special case of operation that can be used to analyze spatial data distribution. For each map, each pixel has its coordinates and attributes (x, y and z). By overlaying two or more images, a new attribute for each pixel can be generated as a function of attributes from those related maps. This new attribute can be defined as:

$U = f\{A, B, C, \dots)$

Where:

f	:	function that has yet to be defined;
A, B, C, …	:	values of the attributes defining the first, second, third, …

Scalar:

Can be used to mathematically change every pixel in an image file by a constant;

Reclassification and transformation:

Are used to reassignment and modify thematic values of every pixel in an existing image. The process involves looking at the attribute for a single data layer and assigning an additional attribute. Typical example of reclassification and transformation are classifying an digital elevation map with a certain high interval and reclassifying a soil type distribution map.

Cross table calculation:

Which performs 'condition-implied action', in case combination plays an important role, this module will often be used in a modelling with GIS.

For these operations, both the usual Boolean operator which is based on the Boolean logical operator AND and OR as well as a 'Fuzzy' set can be applied. In Boolean images, there is only yes/no (zero or one) information will be applied (Eastman, 1993).

Spatial interpolation:

In a classical way it is clear how the contours on a topographical map can be constructed by following lines of equal height. The pattern can be seen and can be verified and corrected based on the real situation. But in case of point observations like soil type, land erosion, land subsidence, etc., the actual pattern of variation can not be seen but can only be sampled at a set of points. To study the spatial patters and to enable spatial combinations of various types of data, they have to be combined and converted within an image data base. An interpolation procedure should be used. The value of a property between data points can be interpolated by fitting a plausible model of variation to the values at the data points and then calculate the value at the desired location (Burrough, 1986). The principle of spatial interpolation is presented in Figure 6. For example there are five data points with known x and y coordinates and the magnitude of the variable z at the related locations.

The general form of the equation for interpolation at a particular point is as follows:

$$z_n = \Sigma\ \omega_i\ z_i$$

where:

z_n = estimated value of the interpolation at any point with coordinates x_0, y_0 ;

ω_i = weight of the sampling point i;

z_i = observed value of the attribute at point I, with coordinates x_i, y_I .

To determine the weighting factor ω, various techniques can be used, for example interpolation uses the principle that the known values in the locality, surrounding or neighborhood are of more relevance than those further away and weights will be given to the surrounding points (e.g. six surrounding points).

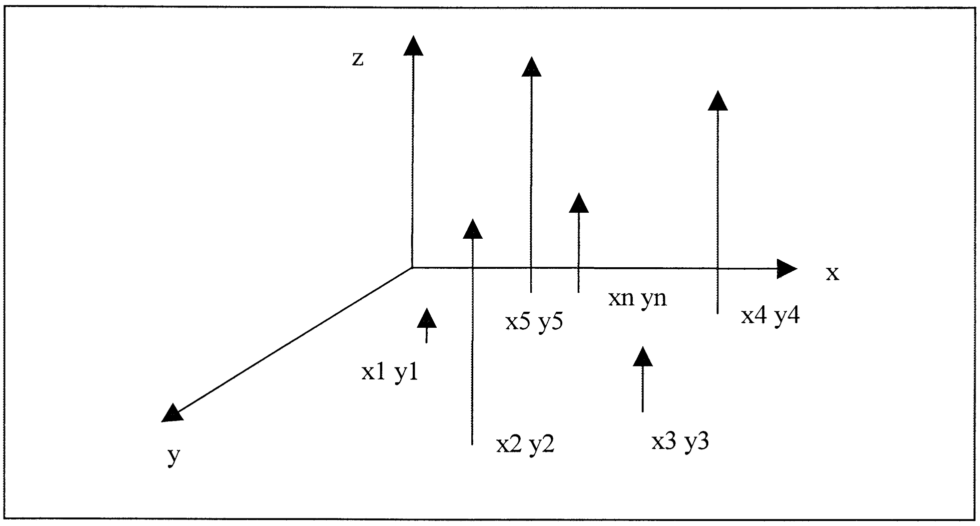


Figure 6. The spatial interpolation based on known surrounding points

Area calculation:

Can be used to calculate area of each class or category based on the number of pixels for each class. This routine will be very useful one to calculate and to compare the effect of any natural resources management strategy. For example in the exercise, this routine will be used to calculate the area of each land suitability class.

An example of the GIS modelling in this lecture is to derive the land suitability and water management zoning of the agricultural project area. To derive the land suitability and water management zoning of the area several parameters of the area have to be evaluated i.e. topographical conditions, soil types, salinity and hydraulic systems. See Figure 7.

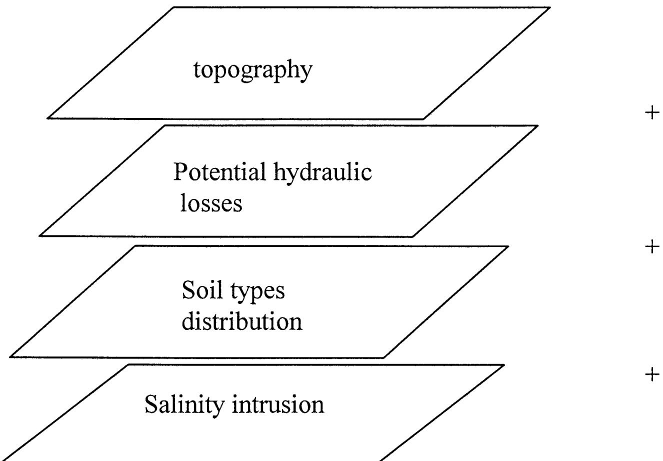


Figure 7. Overlaying procedure for land suitability and water management zoning

2. LAND SUITABILITY AND WATER MANAGEMENT ZONING IN TIDAL LOWLANDS

2.1 Lowland development

Lowland areas are either water logged, or temporarily or permanently covered with a water layer. Tidal lowlands are lowlands where the incoming water originates from rainfall and/or tides.

Tidal lowlands which are close to the sea and influenced by the vertical tides, rank amongst the world's best agricultural resources. Development of tidal lowlands is actively pursued in many countries all over the world as a way of relieving land pressure. This is not an easy task because it covers various disciplines, such as: water management, soil science, agronomy, engineering, economy, ecology and sociology. For the future development, Segeren (1983) and Verhoeven (1983) stated that one of the possible options is development in sparsely populated areas within densely populated regions.

2.2 Potentials and Constraints

The development of tidal lowlands for agricultural development has been successfully carried out in various parts of the world for many countries. Within the context of the agricultural development in general, there is a potential but the natural environment requires investment levels and a management which may create constraints in possible alternatives for development.

Potentials:

- Soils are mainly clays, which make them productive after reclamation, unless they are covered by peat;
- Rainfall amount and distribution in the wet season are adequate for one rainfed crop;
- If additional irrigation is introduced (low lift pumping), wetland rice will provide a high yield under proper water management. This alternative may in future prove to be a feasible development option;
- If drainage measures are taken, upland crop cultivation, such as cassava, maize and soybeans, will be possible. Perennial crops like coconut and oil palm, may grow well.

Constraints:

- Tidal lowlands are located in remote areas, hindering supply of inputs and marketing of products;
- Close to river mouth, salinity may create problems for agriculture and drinking water, especially during the dry season;
- A substantial part of the tidal lowlands are covered by (potential) acid sulphate soils and/or peat soils. Soil development takes time before a stable situation is reached. The water management infrastructure has to be adjusted to the changing conditions;
- In many tidal lowlands, lack of supporting data, mainly related to the soil conditions, hydro-topographical conditions and land suitability conditions.

2.3 Hydro-topographical conditions

The agricultural potential in tidal lowlands is mainly determined by soil qualities and farm water management practices based on the relationship between hydrology and topography. This relationship is referred to as hydro-topography. Hydro-topography can be defined as the field elevation in relation to high river or canal water levels at the nearest open water or intake point. And is expressed by the number of tidal irrigation during the wet and the dry season. In this case, when the hydro-topography concept was introduced, the starting point was the irrigation possibility due to the tides. During high tides, water will regularly flow into the fields, and during low tides water will be drained to the rivers. Next to that, tidal fluctuations of river/canal water levels are dampened in the hydraulic system, whereas, in addition, water level may be manipulated by the operation of hydraulic structures. The actual hydro-topographical conditions of a field depend on the following factors:

- Tidal river/canal water level, which depend on the tidal characteristics in the river mouth and on the river discharge from upstream (seasonal changes);
- Hydraulic dampening or amplifying of the tides due to the hydraulic characteristics of canals and control structures and the enlargement of the storage volume during tidal irrigation and drainage;
- (gradually) Changing field level and topography due to land subsidence, disappearance of peat layers, etc.

The hydro-topography is not uniform and constant in time and space. In this respect, GIS will be a useful tool to be used for analysis and evaluation of hydro-topographical conditions. For example it varies with micro-level variations of the topography. However, the hydro-topographical conditions define the range of agricultural and water management practices available to the farmers.
For example, in Indonesia, four hydro-topographical categories are identified (after Euroconsult, 1993):

- A: tidal irrigated areas, in both wet and dry season;
- B: tidal irrigated areas, only in the wet season;
- C: areas just above ($\leq$ 0.50 m) the average high water level in wet season;
- D: high areas, water levels independent from tidal influence.

To determine the hydro-topographical conditions of an area, the basic concept is a combination of statistical analysis of the tidal characteristics in the area and a hydraulic computation (potential hydraulic losses) in the system. The main difficulty in using the classical way of analysis is that an overall classification of the area can be obtained but that the distribution of the hydro-topo conditions in space can not be made or it is too difficult. In fact in reality the hydro-topographical conditions have spatial distribution characteristics.

The identification of hydro-topographical categories is the first step in delineating water management zones. In order to answer the question 'what kind of agricultural development would be feasible for the area', other factors must also be taken into account i.e. the salinity intrusion in the dry season, soil properties (i.e. peat or clay), and the tidal range. Before applying a water management zoning, a land suitability zoning should be established which requires a systematic and comprehensive analysis.

2.4 Land suitability and water management zoning modelling with a GIS

The land suitability and water management zoning is one of the thematic information in relation to the agricultural potential of an area (Kucera, 1993). They are based on a lot of information with special distribution characteristics which have to be taken into account i.e. topography (digital elevation), hydraulics, soil, salinity and cropping systems. By using all this information, the risk of misuse in land utilization can be minimized and sustainable development of the area can be promoted.

Once the land suitability and water management zoning is available, they will be very useful for the decision maker in his/her consideration on the development plan of the area. The information is dynamic in term of space and time and can be defined as development itself (Despotakis, 1991). The land suitability and water management zoning modelling with a GIS is illustrated in Figure 8. The main parameters for this application are:

- Topography (digital elevation);
- Irrigability and drainability (potential);
- Soil types (peat and/or acid sulphate soil);
- Salinity intrusion.

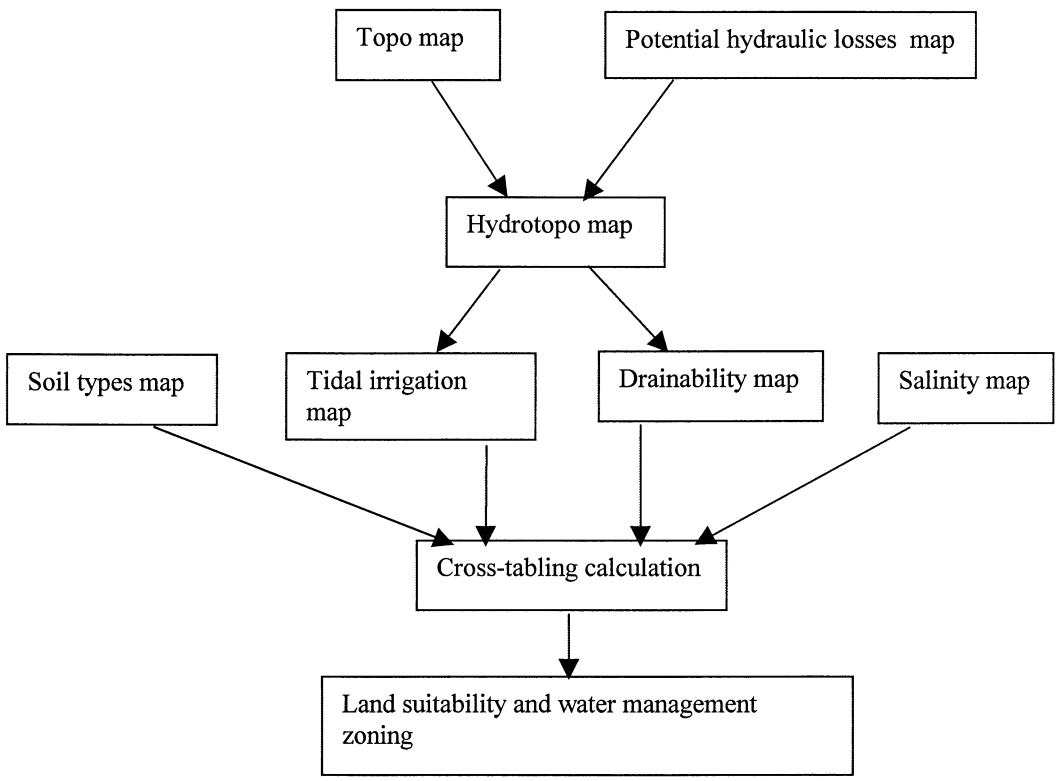


Figure 8. Land suitability and water management zoning modelling with GIS

In relation to the possible errors with the application of a GIS, it is clear that the accuracy of the data should be considered carefully on their variations. In this respect the main modules which will be applied are:

- Creating images for each particular parameter which will influence the land suitability and water management zoning analysis, i.e. tidal irrigation, drainability, soil types and salinity intrusion;

- Reclassification operation which involves the (re)assignment of thematic values to the categories of an existing definition e.g. creating the hydro-topographical map based on the topographical map and (potential) hydraulic conditions of the area;
- Overlaying technique which is based on the relationship among the parameters (adding, multiplication, dividing, maximizing and minimizing) based on their analytical relationship;
- Cross table calculation (combination) based on the result of the overlaying technique;
- The area of each zone can be calculated easily by using an 'area' routine.

Hydro-topographical map

To prepare a hydro-topographical map, two different images are needed, i.e. a topographical (digital elevation) map and a hydraulic damping factor map. Hydraulic damping factors or hydraulic losses are calculated by considering the water management system (canals and its control structures). For this purpose, a hydraulic computation is needed, for example using DUFLOW or other computer program.

To create the hydraulic damping factor map, a distance-weighted average interpolation method can be used. When these two images are available (digital elevation and hydraulic damping factor), the hydro-topographical image can be created by the overlaying technique, based on the criteria which has been discussed previously.

To calculate the potential hydraulic losses (spatial distributed) in the water management system, a special way is introduced where the hydraulic losses in the system are added to the topographical conditions. See Figure 9. An imaginary ground elevation image is created which is higher than the actual condition.

Then by re-classification which is based on the tidal characteristics in the main canal/stream, a hydro-topographical image can be produced. This method will be very useful, especially if a large area has to be covered. Finally, based on this hydro-topographical conditions, two other different images can be created, i.e. tidal irrigation and drainability of the area.

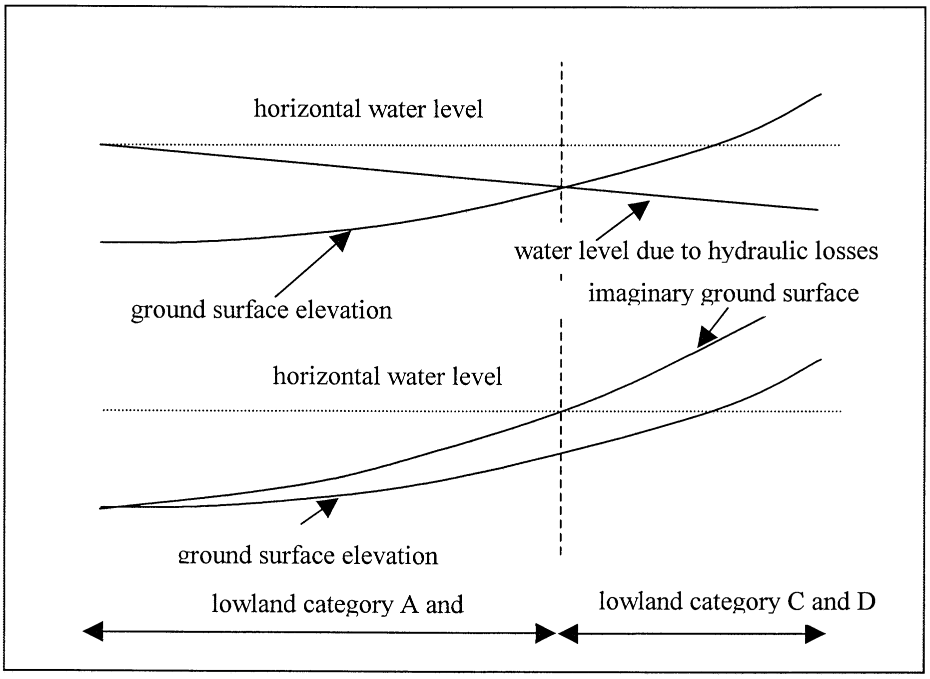


Figure 9. Schematic representation of the procedure to compensate hydraulic losses by using an imaginary topo-map principle

Tidal irrigability

For agricultural development purposes, tidal irrigation depth is defined as the water layer where there is tidal irrigation. To calculate these tidal irrigation possibilities in relation to agricultural development, the criteria as given in Table 1 are used. The tidal irrigation depth classification is not the only factor for deriving the water management zoning of the area. Other factors which have to be considered are: potential drainage, salinity intrusion and soil types.

Tabel 1. Tidal irrigation depth classification

Class	Tidal irrigation depth (m)	Cultivation
1	> 0.25 (above the ground surface)	Not suitable
2	0.0 – 0.25 (above the ground surface)	Rice crops
3	< 0.0	Dry land crops

Potential drainage or drainability

To prepare a drainability (potential drainage) image, two different images are needed, i.e. a topo map and a hydraulic damping factor map. When these two images are available, the drainability image can be created by the overlaying technique, based on the drainage classification. An example of the drainage classification is presented in Table 2.

Tabel 2. Drainage depth classification

Class	Drainage base depth (m)	Cultivation
1	Above the ground surface	Not suitable
2	0.0 – 0.20 – surface)	Rice crops
3	0.20 – 0.40 – surface	Dry land crops
4	0.40 – 1.00 – surface	Tree crops
5	> 1.00 – surface	Not suitable

Peat depth

The peat depth from the surface is also one of the important factors determining the suitability of the area for agricultural development. Based on the peat depth, four categories are defined as follows in Table 3:

Table 3. Peat depth categories

Category	Peat depth (m from the surface)
1	< 0.25
2	0.25 – 0.50
3	0.50 – 0.75
4	> 0.75

Acidity hazard

The acidity hazard is also an important factor for determining the suitability of the area for agricultural development. The acidity hazard or the depth of acid sulphate soil layer is defined as the depth of pyritic layer from the surface. Based on the acidity hazard, four categories are defined as follows in Table 4:

Table 4. Pyritic depth categories

Category	Pyritic depth (m from the surface)
1	< 0.25
2	0.25 – 0.50
3	0.50 – 0.75
4	> 0.75

Salinity intrusion

Salinity intrusion (during one hydrologic year) is also defined as one of the important factors for determining land suitability in lowland areas. Based on salinity intrusion problems in relation to the agricultural development, four categories are defined as follows in Table 5:

Table 5. Salinity intrusion categories

Category	The duration in one year
1	0.0 – 2.0 months
2	2.0 – 3.0 months
3	3.0 – 4.0 months
4	> 4.0 months

Based on these classification and water management components which are presented in Table 6 a land suitability classification for different crops can be derived as in Table 7. This land suitability zoning can be derived for present and potential conditions. Based on the land suitability criteria, a water management zoning of the area can be derived. This water management zoning will vary from one area to another, based on the influence of the water management system on the potential for agricultural development. All the factors have spatial characteristics which makes it complicated to calculate the overall land suitability in a classical way. Fortunately, with the development of the computer technology, the use of a GIS may solve this type of problems. By executing a spatial model of water management zoning a systematic map or image of the present status or the potential status can be obtained.

Table 6. Soil and water management components in relation to water management options

Water management Options and recommended crops	Special components For water management	Special components For soil management	On farm development
Wet Wetland rice	Prevent stagnant water, Leach of toxic materials Maintain high water level, Flood protection	Land preparation by Tractor/animal drought Periodic drainage and Sun drying	Land levelling Quaternary and field drains
Wet/dry Wetland rice and/or	In the wet season: -improve field drainage; -leach toxic materials;	Wetland rice: -land preparation by tractor or animal;	Land levelling and quaternary drains

dryland crops	in the dry season: -intensive shallow drainage; -prevent salinity intrusion	-periodic drainage and sun drying	
Dry Tree crops or Dryland rice – Dryland crops	Intensive shallow drainage Balance water retention with drainage of acid water	Tree crops: planting On low mounds	Quaternary and Field drains

Table 7. Land suitability zoning

Criterion	Category	Wetland rice				Other crops			
		Tidal irrigation		Rainfed		Dryland crops		Tree crops	
		Present	Potential	Present	Potential	Present	Potential	Present	Potential
Tidal irrigation depth	1. > 0.25 m	S2	S1	NA	NA	NS	NS	NS	NS
	2. 0.0 – 0.25 m	S1	S1	NA	NA	S3	S2	NS	NS
	3. < 0.00	S3	S2	S2	S1	S1	S1	S1	S1
Drainability	1. < 0.00	S3	S2	NS	S3	NS	NS	NS	NS
	2. 0.0-0.20 m	S2	S1	S3	S2	NS	S3	NS	NS
	3. 0.20-0.40 m	S2	S1	S2	S1	S3	S2	NS	S3
	4. 0.40-0.60 m	S2	S1	S3	S2	S2	S1	S3	S2
	5. > 0.60 m	S3	S2	NS	S3	S3	S2	S2	S1
Peat depth	1. < 0.25 m	S1	S1	S1	S1	S1	S1	S1	S1
	2. 0.25-0.50 m	S2	S1	S2	S1	S2	S1	S1	S1
	3. 0.50-0.75 m	S3	S2	S3	S2	S2	S1	S2	S1
	4. > 0.75 m	NS	NS	NS	NS	S3	S2	S2	S1
Acidity hazard	1. < 0.25 m	S3	S2	NS	S3	S3	S1	S3	S1
	2. 0.25-0.50 m	S2	S1	S3	S2	S2	S1	S2	S1
	3. 0.50-0.75 m	S1	S1	S2	S1	S1	S1	S1	S1
	4. > 0.75 m	S1	S1	S1	S1	S1	S1	S1	S1
Salinity intrusion	1. < 2 months	S1	S1	S1	S1	S1	S1	S1	S1
	2. 2-3 months	S2	S2	S1	S1	S1	S1	S1	S1
	3. 3-4 months	S3	S3	S1	S1	S1	S1	S1	S1
	4. > 4 months	NS	NS	S1	S1	S1	S1	S1	S1

Note: S1 = suitable;
S2 = nearly suitable;
S3 = marginally suitable;
NA = not applicable;
NS = not suitable.

3. HYDRAULIC INFRASTRUCTURES

Within a water management system, several hydraulic infrastructures could be applied i.e. sluices/gates, culverts and pumping stations in order to maintain the flow and/or water level inside the system. The main aspects of the water management system that are of importance:

- Water management system (canals and hydraulic structures);
- Upstream discharge (amount of water should be discharged);
- Inside water level;
- Outside water level in case of gravity drainage;
- Percentage of open water.

Design of water courses

The design of a main water management system may be, basically, divided into:

- Selection of type and layout of the system (location, elevation and alignment of the supply and drain canals, type and location of the hydraulic structures);
- Determination of the drainage modulus based on the hydrological conditions of the area;
- Determination of the hydraulic capacities of the different components of the system (hydraulic design).

Regarding the different data to be used in the studies three types of variability have to be taken into account i.e. variability caused by inaccuracies of the method applied, variability in space and variability in time.

In truly level areas without any general slope, the design of the main drainage system poses a real problem. The hydraulic gradient required for the flow can only be generated by a gradient in the water level artificially created by a draw down at the outlet (sluice or pumping station) and by allowing the water level in the drain at its upper end to rise. The total of both heads is limited to about 0.3 to 0.6 m.

For the design of the main water management system the reconnaissance level is used to investigate the required principal layout. During the reconnaissance level and the semi-detailed level, calculations are normally based on hydrological routing models, such as the rational formula, the Muskingum method, reservoir models or steady state hydraulic formulae. At the detailed level hydraulic unsteady flow models are nowadays increasingly applied (e.g. DUFLOW), especially when complicated network of urban and industrial areas are involved.

The discharge capacity of the main drainage system is normally such that a prescribed water level is not exceeded during a certain time at a certain return period. This, together with the accepted velocity in the different parts of the system, determines the cross-sections. The design procedure involves the following stages:

- Identification of the study area;
- Definition of natural drainage basin areas and drainage lines;
- Identification of the areas requiring drainage.

Identification may require field investigation including:

- Soil and land use surveys;
- Monitoring of groundwater tables;
- Soil and groundwater salinity measurements (if any);
- Assessment of water use intensities;
- Measurement of rainfall intensities and establishing rainfall patterns;
- Preliminary topographic surveys;
- Morphological changes (rivers or/and coastlines);
- Identifying approximate locations for drains;
- Examination of aerial photographs;
- Observations immediately following rainfall.

The next stage is the preparation of draft designs. More comprehensive investigative work follows and may include:

- Detailed grid survey;
- Detailed survey lines along proposed routes of drains;
- Negotiations regarding acceptable risk of inundation or drain failure to assist in the selection of the design storm in detailed design;
- Hydrogeological investigations including installation of test holes along drain routes, which are used for logging soil textures, observing groundwater tables and measuring groundwater salinity;
- Environmental impacts particularly relating to nutrient loads and possible effects on waterways, lakes (reservoirs) and estuaries.

Pumping stations

Nowadays generally diesel-engines and electro-engines have been or are being used as driving mechanisms. The following lifting devices are being used for the pumping of polders: paddle-wheel, open Archimedes screw, sucking-pump, suck-forcing pump, centrifugal pump, and screw pump.

Various methods have been used through the ages to determine the needed pumping capacity. The required power could be determined based on the driving mechanism and the transmission losses.

Pumps suited to most urban drainage conditions must operate efficiently while moving comparatively large quantities of water at low heads and also may be required to handle substantial amounts of sediment and trash in the effluent. For these reasons several types of pumps are used for drainage, of which, the most important are:

- Archimedean screw pump;
- Rotodynamic or centrifugal pump.

The more widely used rotodynamic (centrifugal) pumps consist of an impeller which rotates within a totally enclosing casing. The water is energized by the impeller blade through pressure and increased velocity within the casing which serves as a guide for flow into and out of the impeller. These are, according to the direction of flow through the pump, three principal types:

- Radial flow;
- Mixed flow;
- Axial flow.

Drainage by pumping

Pumped drainage is required in low-lying areas from which water is unable to drain by gravity because of inadequate outlets or because of backwater from storm or tidal flooding. A reliable and economical pumping plant requires detailed investigation and survey of site conditions for planning and design.

The essential items in both planning and design of pumping plants will include a determination of:

- Location of the pumping station for an effective outlet to the entire drainage system;

- Required water removal rate;
- Auxiliary drainage facilities (as dikes, reservoirs, sumps and gates) for protecting the stations and minimizing the pumping requirements;
- Kind, capacity, size and number of pumps;
- Power requirements;
- Housing and protection of the pumps and prime movers.

Need for pumping

Sites that require pump drainage occupy flat lowlands close to seas (coastal plains), tidal estuaries, lakes, or bottom land of large rivers, where the outlets are inadequate or not available. The time during which the station operates may vary from only a few days annually, to more extended periods of continuous operation such as during an extreme wet season.

Location of the pumping station

Pumping station locations are determined mainly by topography and groundwater conditions to which the drainage system layout must be designed. Normally the site will be at the lowest elevation of the area served and at or as close as possible to the best outlet. However, other factors to be considered in order to select the most advantageous site are:

- Availability of forebay storage;
- Required location of dikes;
- Accessibility of power lines and fuel supply roads and their adequacy for serving the plant;
- Adequacy for structural foundations;
- Groundwater levels and their fluctuations.

Incorporation of the pumping plant in the drainage system

In order to minimize the amount of water to be pumped, the runoff from all areas that can be drained by gravity should be diverted from the area served by the pumps. Where direct diversion around the pumped area is not feasible, the surface runoff occurring at the low outlet stages should be discharged by gravity through gates in the protecting dike bordering the pumped area as long as the outlet stages will permit. In some cases it may be necessary to carry upland runoff directly to the outlet between dikes constructed the pumped area.

Pumping plant capacity

The required capacity of pumping plants may be determined from:

- Drainage coëfficiënts applied to the areas served;
- Direct analysis using hydrologic procedures, included the empirical formulas;
- Hydraulic response of the systems.

The hydraulic design of water management systems and its response, included pumping stations can be checked and modelled carefully by using an unsteady flow model e.g. DUFLOW.

For selecting the capacity of the pumping plant the following factors should be taken into account:

- Size of the area served;
- Amount, rate and timing of rainfall and runoff;
- Soil, groundwater and topographical conditions;
- Seepage rates and hydraulic response related to the stability of the system.

Sump and intake design

The design of the sump depends on the type of installation and the number of pumps. Generally, the last 100 - 200 m of the approach drain should be straight and have inflow from the side, to make the flow towards the centrally installed pump uniform and undisturbed. The height of the inlet above the floor and the minimum depth of the water above this inlet are also critical factors, all affecting the pumping efficiency.

Gravity outlet

Gravity outlet structures can be either a drainage sluice with doors, a gated culvert, or a siphon. A drainage sluice consists of a weir and a set of doors. Each of the two doors hinge around a vertical axis, and are positioned in such a way that inner water can flow freely to the outer water, whereas they prevent a flow in opposite direction. Or a door hinges around a horizontal axis is also possible. Gated culverts are applied when the outlet structure does not have a navigation function. The cross section of culverts is usually circular, square or rectangular. An advantage of a culvert is that the top of the embankment will remain undisturbed.

Design of discharge sluices

Agricultural lands or urban areas, which are located along rivers, lakes, estuaries or coastal areas, can be protected with dikes against flooding. In order to facilitate drainage of excess water from the protected area, the dikes are provided with outlet structures, which can be either sluices with doors, gated culverts, siphons and/or pumping stations. Water levels of the receiving water bodies (outer waters, like canals, rivers, lakes or seas) may vary, caused by for instance tides. Therefore, drainage might be temporarily restricted during periods of high outer water levels, which necessitates storage for accumulating drainage water (reservoir) inside the protected area. This storage can be realized in the soil, or the drains and/or in ponding areas.

The success of a gravity outlet structure depends on the volume of storage available in the area to be drained. The storage volume should be sufficiently large to store the accumulating excess drainage water during the closing period of the outlet structure. When storage in soils is neglected the available storage volume is the product of the wet surface area at a certain water level (ditches, canals and ponding areas) and the permissible rise of the inner water level. In particular the maximum allowable storage level can be considered of prime importance. In case a pumping station is applied, there is a relationship between the pumping capacity and the needed storage area.

Outer water levels may be under influence of tides, river floods, density currents, waves, wind set-up, storm surges, etc. The determination of design outer water level should be done carefully, especially if the combination of those phenomena should be taken into consideration. In fact, possible combinations of these phenomena occur in downstream reaches of rivers or delta areas. Three situations concerning the inner and outer water levels should be distinguished:

- The outer water level is always higher than the inner water level. In this case the water always needs to be removed from the drained area by means of pumps;
- The outer water level is always lower than the inner water level, which allows for drainage by gravity;
- The outer water level varies between the two situations described above, in which case gated structures are required, or a combination of such structures with a pumping station.

Inner water levels

The drainage system will have to convey, retain and store the drainage water from the fields in such a way that the inner water levels remain in between the following two boundaries:

Design Drainage Level, DDL

The design drainage level is the lower boundary of the drainage system. If the water drops below this level damage may occur, e.g. water stress to crops due to a too low groundwater table, pollution control, hampered navigation, and/or instability of side slopes (hydraulic response);

Maximum Allowable Storage Level, MASL

As the water level can not be kept at DDL constantly there is a necessity to define a highest boundary: the MASL. This boundary is equal to the DDL plus the maximum tolerable rise of the water level in the system. Exceeding this level will also lead to economic damage through, for instance, too high groundwater tables or even flooding, poor quality drainage water entering the fields, etc. The rise to MASL is therefore permitted during a limited period of time only. The determination of MASL is based on economic considerations: it is the level at which the investments needed in the drainage system outweigh the risk of economic losses.

Design of outlet structures

Selection of outlet location depends on hydrological considerations (tidal or non-tidal area), hydraulic conditions, topographical considerations (lowest spot of the area to be drained), soil mechanical considerations (foundation possibilities), effects of wave attack, sedimentation and scouring at the outer side of the outlet.

From a drainage point of view the location of outlets in tidal areas is generally most favorable in those areas with the lowest low water levels. The site should preferably be selected nearby a natural gully, so that optimum use can be made of the natural drainage characteristics.

The outlet itself should not be constructed in the gully as this might pose foundation problems, but just next to it and be connected to the gully by a short canal. If the outlet is discharges water directly to the sea, attention should be paid in relation to the morphological changes of the coastlines (littoral drift) which may affect the outlet function.

When the outer waters cause a prolonged period of impeded drainage, additional measures are needed to ensure drainage, such as the installation of additional pumps. Also the construction of a channel parallel to the river to a location further downstream might be an alternative. The slope of this channel should be smaller than the river bed slope, so that sufficient head may be obtained for realizing gravity discharge.

The outlet structure should be protected from waves by indenting the dike in a direction that depends on the predominant wave direction. However, problems due to sedimentation may occur then, for which additional measures are required, such as dredging and flushing. In case of draining on meandering rivers or on rapidly changing tidal forelands, locations which might be subject to scouring and/or meandering should be avoided, as both processes may affect the proper functioning of the outlet.

Crest level

The crest level of a outlet can best be chosen at a depth varying between 0.5 and 2.0 below the outer low water level. As a low crest level increases the capacity of the outlet, it is preferred to realize a lower crest level with the corresponding width, than a shallower and wider outlet. However, the construction costs may increase significantly with increasing crest depths. The stability of the side walls might be another restricting factor, in case the height of the side walls becomes large

in relation to the outlet width. Nowadays, to improve the side stability, the application of artificial materials i.e. geo-textiles can be considered.

Detention and retention ponds

To compensate for runoff intensification due to urbanization, stormwater could be stored in man-made basins within the catchment. The ponds can be sited in non-essential areas, e.g. parks, recreational grounds or parking lots (Miles, 1979). The storage may be provided in depressions, which can subsequently be drained (or water permitted to percolate or evaporate in isolated situations, termed dry basins). Alternatively, the storage may be in channel freeboard on ornamental ponds or recreational lakes (referred to as wet ponds).

Detention is the temporary storage of runoff such as in freeboards while *retention* involves the permanent diversion into evaporation or seepage ponds i.e. flow is not returned to the drainage system. Detention ponds are often referred to as on stream, or outlet controlled.

Retention can be at the outfall of the catchment, in which case a large-scale pond is often required such as a lake or in a park. The retention may be provided along the drains, or it may be at the head of the drains (on site). The latter may not require any single large volume; it may be sufficient to plant dense vegetation, till the land, or construct terracing. The difference between retention and detention storage based on their effect is illustrated in Figure 10 and Figure 11.

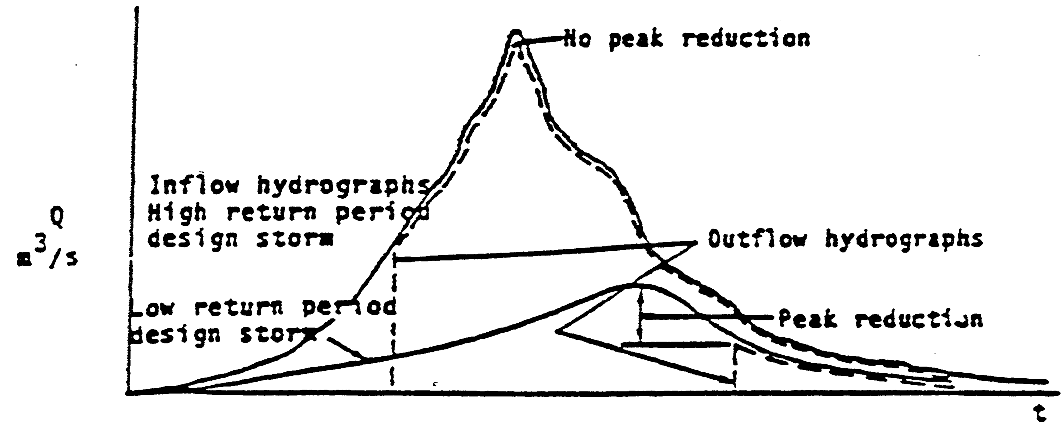


Figure 10. Effect of retention basin on drainage

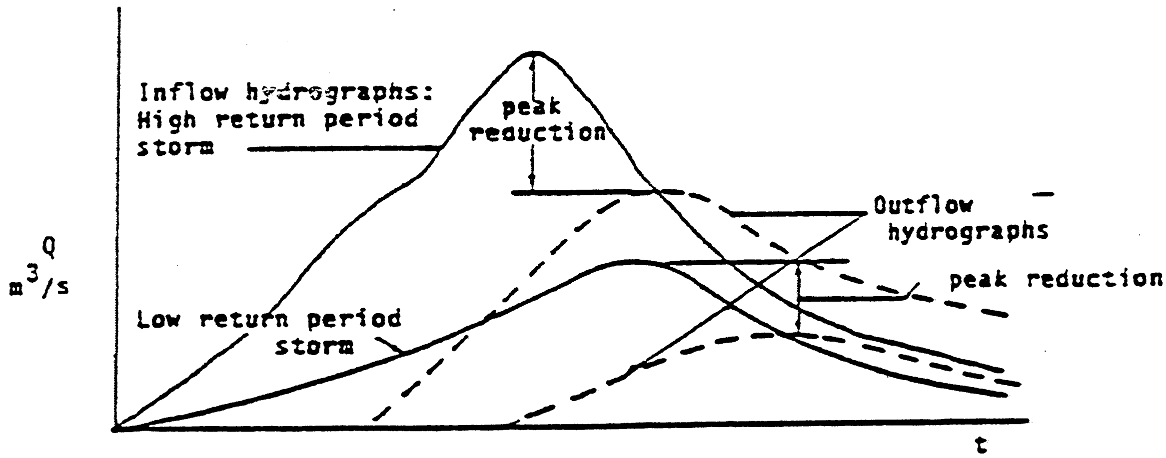


Figure11. Effect of detention basin on drainage

4. MATHEMATICAL MODELLING FOR WATER MANAGEMENT SYSTEMS

4.1 A mathematical model as an appropriate simplification of reality

A mathematical model is fitted to the real system (reality or prototype) by means of model identification (what type of model) and parameter estimation.
The most important points in the modelling study are:

- Define the problem clearly;
- Realize the applicability and limitations of the models;
- Schematize the real system in a correct and proper way in line with the model application;
- Consider the key data (parameters and properties) of the real systems correctly;
- Analyze and evaluate the modelling result correctly.

Certain problems in water management systems can be conveniently investigated by means of mathematical modelling. It is important to realize that the model is only a tool in a large process, which is usually a decision problem. The set up of the mathematical model should therefore be adopted to the purpose of the investigation.
A fundamental pre-requisite of any mathematical model is a satisfactory, quantitative mathematical description of the physical processes involved. The equations for water movement are generally so complicated and to solve those equations, numerical approaches in many cases are applied.

4.2 Basic equations

For unsteady open water flow modelling an ample quantity of literature is available. Internationally well known standard books are Mahmood (1975), Abbott (1979), Cunge (1980), Vreugdenhil (1990). The basic equations for unsteady open water flow are the Saint Venant equations which describe the conservation of mass and conservation of forces. These St. Venant equations can be expressed as (Mahmood *et al.*, 1975):

$$B\, \partial h/\partial t + \partial Q/\partial x = 0$$

and

$$\partial Q/\partial t + \partial\, \alpha Qv/\partial x + gA\, \partial h/\partial x + g|Q|\, Q/\{C^2 AR\} = 0$$

Where:

α = coriolis coefficient (-);
A = cross-sectional area (m^2);
B = storage width (m);
C = Chezy resistance coefficient ($m^{0.5}/s$);
g = acceleration due to gravity (m/s^2);
h = water level (m);
R = hydraulic radius = A/P (m)
t = time (s);
P = wetted perimeter (m);
Q = discharge (m^3/s);
x = longitudinal distance (m).

These equations are solved numerically for example by using a finite difference method.
The St. Venant equation can be solved numerically by using explicit as well as implicit schemes.

4.3 Choice and set up of model

Choice of model

The type of model chosen for a specific engineering problem should be related to the requirement of the problem. Models should not be more complicated than necessary. For example for a water management system in a canal network, one dimensional model can be applied, but for water management on the river flood plain, two dimensional mathematical model should be used.

Set up of the model

The activities needed in helping you to model your specific problem into a mathematical model application are briefly:

- to decide on what phenomena are important and should be represented in the model (water movement, salinity, sediment transport, water quality, etc.);
- to schematize the essential water management system (river stretches and canals) into a network of branches with one-dimensional flow, connected via nodes;

- to complete the network with other elements like hydraulic structures and lateral discharges, to define dimensions of typical cross-section for the branches, to give sediment characteristics, to define water quality processes, etc.;
- to define boundary conditions for water movements, salinity, sediment transport as well as water quality;
- to prepare initial conditions (realistic conditions) for starting the computation;
- to define the selected nodes and branches for output.

Model simulation

When the preparation is ready, the simulation of the model can be started. For this purpose, firt you should define some control data, i.e. computational period, time steps, output files, which numerical parameter values should be used (Φ, θ). Usually, the simulations will be carried out with different aims: firstly, to calibrate the model, secondly, to verify the model and thirdly, simulations related to the purpose of the project. As soon as the model produces useful results, it should be calibrated. This is usually necessary because empirical parameters are involved e.g. bottom roughness. Parameters can be adjusted to obtain reasonable correspondence between model results and prototype values. Of course the adjustment may not be extended beyond physically acceptable values. Sometimes, instead of calibration step, a sensitivity analysis will be done. In many cases, sensitivity analysis will be done if there is no actual data available e.g. design of a new canal system.

Once the coefficients and parameters are adjusted, comparison with a different set of prototype data should be made. If the model runs satisfactorily and well fitted with the measured prototype conditions without further adjustment, a reasonable confidence is gained for application the model to further design conditions.

Model calibration and verification

As far as it is possible, model calibration should be carried out. Model calibartion can be done by comparing flow measured and calculated flow parameters (water levels and discharges). After calibration, verification of the model can also be done by using aonther set of field data.

Analysis and evaluation of results

After finishing the simulations, the results should be analyzed and evaluated based on their hydraulic performance. The results can be presented in a table or graphical way.

4.4 Modelling of flood control and flood protection

Especially for lowland areas and waterlogged areas, protection from flooding is the most important step of the land development. In the case of river protection, flood control can be achieved by flood control works in the upstream part of the river with flood detention reservoirs as the most effective measures. Flood levels can also be reduced by measures near the lands to be protected, such as channel improvement (deepening, cut-offs, diversions), dikes and by-passes. Next to the flood protection works, possible side effects of any measure has to be taken into account, especially related to the morphological changes.

Flow routing

Flow routing through the water management system may be accomplished using any analytical or numerical methods. Difficulties may arise at the many junctions and hydraulic structures encountered in a sewer system. Most of these difficulties may be overcome through the use of more sophisticated hydraulic methods such as the St. Venant equations e.g. DUFLOW model.

River flood plain

The river flood plain is the area inundated when the so called bank-full water level is exceeded. It is often overgrown and it includes vegetated islands and/or other type of obstacles. It contributes to the conveyance and storage capacity of the water management system when it floods.

The river flood plains may have two main functions, viz.:

- Contribution to the discharge;
- Temporary storage for the flood volume (dampening of flood waves).

To model river flood plains a proper consideration and estimation on the roughness conditions are needed which based on the actual conditions of the flood plains and its land use (it may vary in space).

Zoning system on flood control

Based on the land use and levels consideration and its utility, a zoning concept can be introduced for a flood control system. The zoning system can prevent any conflict between different land users and can be used as a consideration to manage the water management systems in the related areas. An example of this zoning system is illustrated in Figure 12.

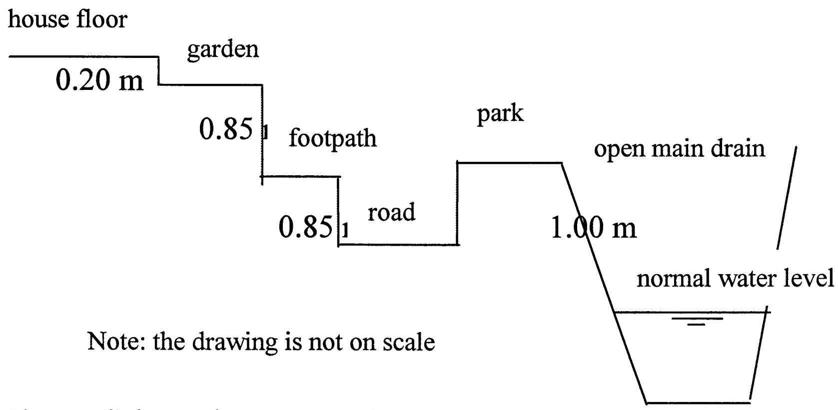


Figure 12. Schematic cross-section representing the levels for the zoning system

Pumping station

The pumping station is one of the hydraulic structures which will be discussed in the lecture. Th e pumping station is a structure controlled by the water level at only one side of the structure. The 'controlled' side can be upstream or downstream side and can be selected by the user.

For the pumping station the following input should be prepared by the user:

- Pumping capacity (m3/s and it is always positive);
- Control direction (upstream and downstream);
- The water level at which the pump will be started;
- The water level at which the pump should be stopped.

The head difference is defined as the water level at the suction side minus the water level at the delivery side.

The pumping direction is defined by the position of the start and stop level in opposite of each other and the control section. The direction will be defined in such a way that the pumped water will contribute in approaching the stop criterion at the control side. See Figure 13.

So one of the following four situations is possible for a pumping station:

- Control direction faces beginning of branch; pump direction towards branch end;
- Control direction faces beginning of branch; pump direction towards branch beginning;

- Control direction faces end of branch; pump direction towards branch end;
- Control direction faces end of branch; pump direction towards branch beginning.

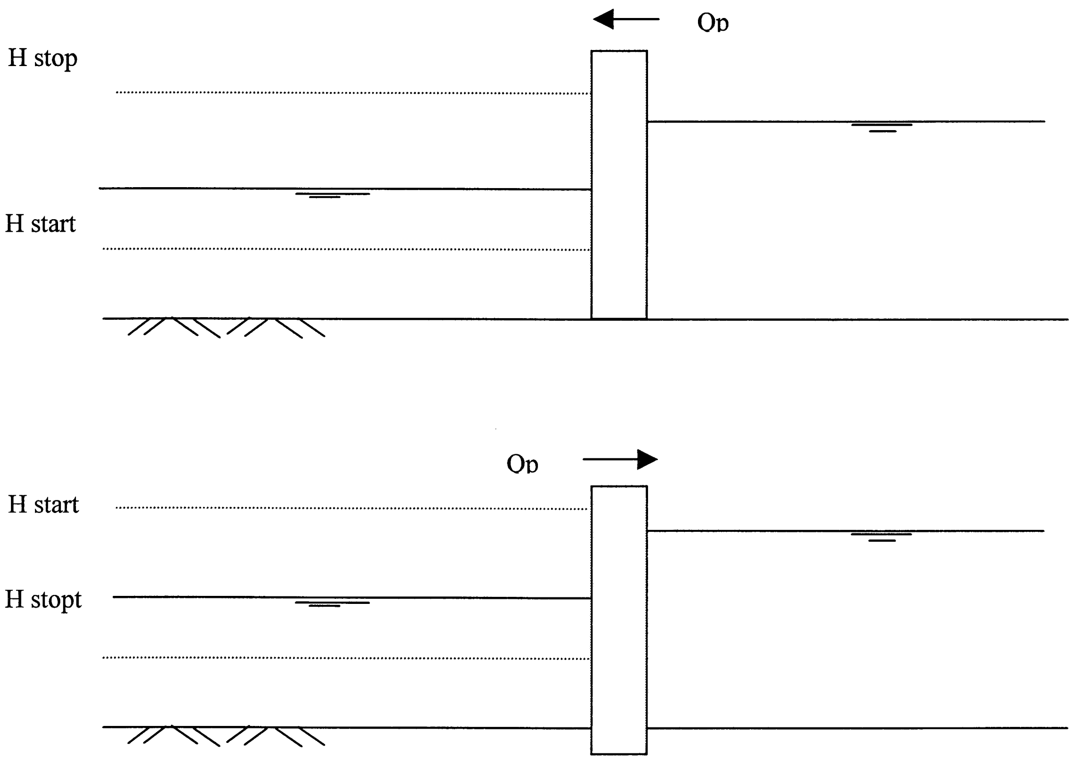


Figure 13. Flow direction and starting and stop control

When the actual water level is between the start level and stop level the following cases can be determined:

- If the last time that one of the two levels has been exceeded and the exceeded level was the stop level, the pump remains being stopped;
- If the last time that one of the two levels has been exceeded and the exceeded level was the start level, the pump remains working;
- At the start of the calculation in this situation the pump is stopped.

Operation of hydraulic infrastructure

The hydraulic infrastructure in a water management system with its water control structures plays a crucial role. A wide variety of structures can be used to control flow in water management system and each of wchich imposes a different relationship between water level and flow discharge. The properly operation of the hydraulic structures are needed (when and how) in order to reach the objective of water management system. This is mainly related to water supply/irrigation, drainage, flushing and flood protection.

The operation of a hydraulic infrastructure can also be modelled. The adjustable part of a hydraulic structure can be instructed to adjust according to certain rule, i.e. a controller adjusts the control parameter(s) of the related hydraulic structure. More than one controller can operate on the same hydraulic structure. However, a specific control parameter (gate width, crest level, discharge coefficient, etc.) can be steered by only one controller at a particular moment/time.
The controller function is activated once for each time step in the computational process. A controller can be activated by a trigger or a combination of triggers.

Hydraulic controller
A hydraulic controller is a relatively simple controller which can be used to operate a hydraulic structure a sa function of a specific hydraulic parameter. This parameter can be width or gate opening, crest height or discharge coefficient as a function of one of the following parameters:

- Water level at a specific location;
- Discharge at a specific location;
- Head difference over a hydraulic structure.

The computation is straight forward. First, the value of the hydraulic argument at the previous time step is determined. Next, the control parameter is computed by interpolation. In case of the discharge a user specified time lag with respect to the current time can be taken into account.

4.5 Modelling of tidal outlet

The computer program has been developed (IHE, 1990) and primarily as a tool in education with 3 objectives:

- To demonstrate the hydraulic functioning of the tidal outlet system;
- To show sensitivity of design parameters such as storage, crest width and crest level, etc.;
- To demonstrate effect of numerical parameters such as implicit versus explicit numerical schemes, solution method and the effect of the time step selection.

But the computer package may also be used as a (pre) design tool. But for this purpose it has limited flexibility.

Governing equations:

- Storage upstream of the outlet structure:

$$A\ \partial h/\partial t = Q_u - Q$$

- Discharge is given as:

$Q = 0$	for $h<h_c$ or h_s;	no flow
$Q = C_1*L*(h-h_c)^{\wedge}1.5$		free flow
$Q = C_2*L*(h_s-h_c)(2g(h-h_s))^{\wedge}0.5$		submerged flow

Where: $C_1 = m * \sqrt{(2g/3)}*2/3$

$M = 1$

And for compatibility of formulae:

$C_2 = C_1*1.5*\sqrt{(3/2g)}$

A = area storage basin (m^2);

h = water level in storage basin (m);

Q = discharge through the outlet (m^3/s);

h_c = crest level of the outlet structure (m);

h_s = downstream water level (m);

L = crest width (m).

Boundary conditions

- Discharge upstream of storage basin: Q_u = constant (m^3/s);
- Downstream of the outlet the tidal water level h_s (m);

Hs is composed of four tidal components: M2 (main lunar with a period of 12.42 hrs), S2 (main solar with a period of 12.00 hrs), K1 (sum/moon declination with a period of 23.93 hrs) and O1 (moon declination with a period of 25.82 hrs).

Solution methos

The differential equations describing water level changing is solved numerically with an implicit scheme h and Q simultaneously or with a explicit scheme by using the Euler method.

Input

Consist of:: Q_u = constant inflow to the basin (m^3/s);
A = storage area in the basin (m^2);
L = width of the outlet structure (m);
h_c = crest level of the outlet structure (m);
h = upstream and downstream bottom level (m);
h_0 = mean sea level (m);
a_1 = amplitude of the main lunar tide M_2 (m);
a_2 = amplitude of the main solar tide S_2 (m);
a_3 = amplitude of the sun/moon declination tide K_1 (m);
a_a = amplitude of the moon declination tide O_1 (m).

Time of computations;
Time step;
Method of computation: implicit or explicit.

Output: h,Q, h_s

The schematization of the model consists of two nodes only which is presented in Figure 14 below:

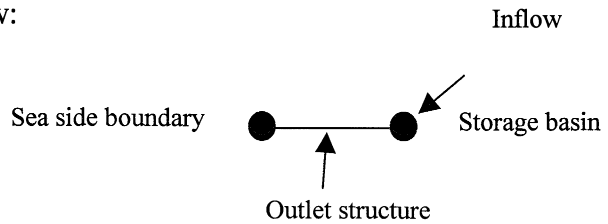


Figure 14. Schematization of the model

The schematization can be compared with the DUFLOW schematization which consists of three nodes instead of two nodes.

4.6 Modelling of urban drainage systems

Urban development is spreading over more and more of the earth's surface. The problem associated with urbanization are compounded as the density and extent of development proceeds (Schneider, 1975). The effect of particular concern is the elimination of most natural processes and their replacement by man-made streamlined procedures. Although the same physical principles hold as for elsewhere in the hydrologic cycle, urban areas are characterized by their open water, paved and unpaved areas. Thus the response of an urban area to rainfall is much faster than that of a rural area of equivalent area, slope and soils. The run-off volume from an urban area is larger because there is less pervious area available for infiltration. These characteristics are well illustrated in Figure 15.

In the development of new urban centers, hydrological knowledge of the areas is required at two stages (Shaw, 1983). The first is the planning stage when the general lay-out of the new town is being decided. Estimates of the discharge hydrographs (and corresponding stage-hydrographs) for chosen return periods are wanted at a few selected points on the natural courses, perhaps where bridges and other temporary storages are to be constructed, and certainly at vulnerable confluences of tributary streams. Knowing the proposed extend of the new urban area, initial flood and stage estimates may indicate that the existing river channel would not contain the expected enhanced flood flows.

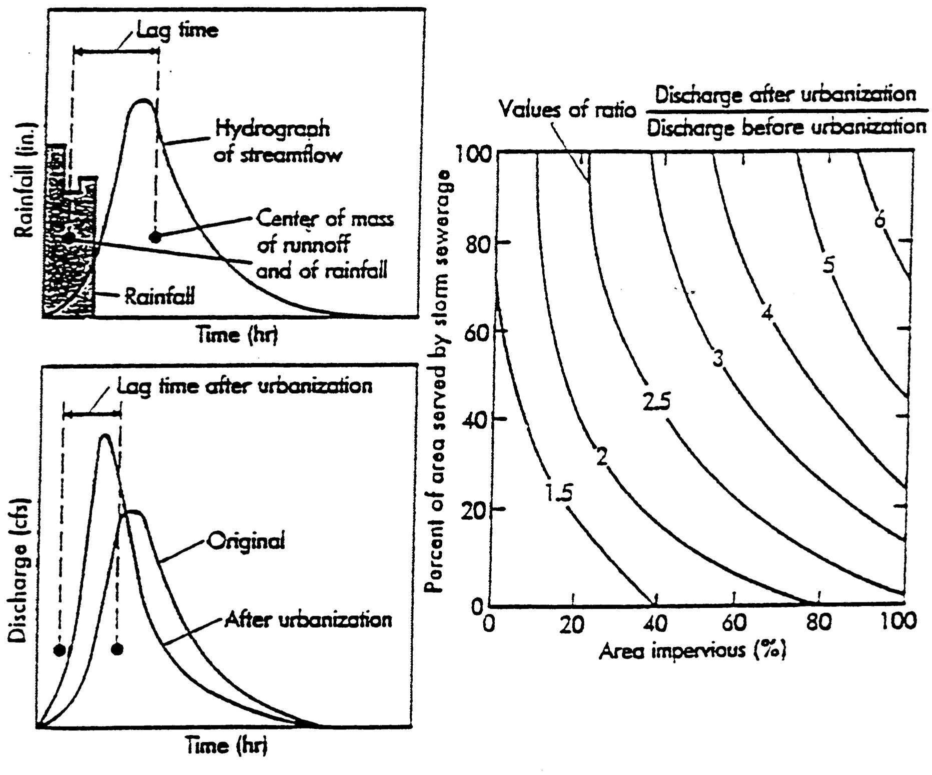


Figure 15. Effect of urbanization on urban run-off hydrograph (Leopold, 1968)

Then it may be thought expedient to improve the channel and/or to provide for flood water storage (temporary storage) in a retaining pond or lake. The second stage of hydrological involvement occurs at the detailing stage, the design of the sewer systems and open water areas to carry the surface water into the rivers or the sea.

The construction of a water management system is not the only way to avoid flooding or pollution. The day-to-day operation and maintenance or management of the catchment will have an important bearing on runoff quantity and quality (Stephenson, 1981). Regular cleaning could relieve the water management systems of a considerable load. The science of urban drainage has received considerable attention in recent years, especially in developed countries. Legislation has forced engineers to think carefully about the drainage process.

The open water areas consist of open canals and temporary storages (reservoirs). The paved areas generally consist of the roofs of houses and buildings, streets and squares. The unpaved areas consist of the green areas, parks and gardens.

For the design of storm sewer systems several approaches are followed:

- a certain design discharge is given, which is mainly based on experience. The discharge is expressed in l/s/ha. Based on this input at each gutter, the available head between the gutter and the open water course, the required dimensions of the sewer pipes can be determined;
- application of a routing model to generate the inflow to the sewer system. The most well known routing model is the Rational method. With this method the travelling time from certain distances to the gutter is determined. For a certain schematized design rainfall pattern and runoff coefficients the transformation of rainfall to sewer inflow is determined. Based on this inflow pattern and the available head between the gutter and the open water course, the required dimensions of the sewer pipes can be determined;
- application of a reservoir model. In this approach the travelling times are neglected and only the storage is taken into account. Generally a non linear reservoir model gives the best results. Also in this case a design inflow pattern is generated. Based on this inflow pattern and the available head between the gutter and the open water course, the required dimensions of the sewer pipes can be determined;
- complete modelling of the rainfall runoff process by a physical model. In general this is only applied for research projects and not in practice;

- application of a real time control model which is more related to the operation of the drainage system;
- hydrodynamic modelling in order to simulate the hydraulic performance of the drainage systems and also hydraulic routing in the systems.

The rational method

The rational method dates from the 1850s in Ireland by an Irish enginer, Mulvaney (Dooge, 1973) and is called the Lloyd-Davies method in Great Britain. It is one of the simplest and best known methods routinely applied in urban drainage engineering, although it contains subtleties that are not always appreciated. Peak flows are predicted by the simple product:

$$Q_p = k_c \, C \, I \, A$$

where:

Q_p = peak flow (m^3/s)
k_c = conversion factor
C = run-off coefficient
I = rainfall intensity (mm/hr)
A = catchment area (ha)

The conversion factor $k_c = 0.00278$ to convert ha-mm/hr to m^3/s.

Due to assumption regarding the homogeneity of rainfall and equilibrium conditions at the time of peak flow the rational method can be used on areas less than about 2.5 km^2. Larger than that, the area should be subdivided into sub-catchments. This is including the effect of routing through drainage canals. Since actual rainfall is not homogeneous in space and time, the rational method becomes more conservative (i.e. it over predicts peak flows) as the area becomes larger.

All catchment losses are incorporated into the run-off coefficient C, which is usually given as a function of land use. When multiple land uses are found within the catchment, it is customary to use an area-weighted run-off coefficient. A better estimation would be obtained from measurements since it is often assumed that:

C = Run-off volume/Rainfall volume

The intensity I is obtained from an IDF analysis curve for a specific design return period under the assumption that the duration t_r equals the time of concentration t_c . This is physically realistic because the time of concentration also is the time of equilibrium, at which time the whole catchment contributes to flow at the outfall. To do the IDF analysis, continuous records of rainfall stations should be available. Based on the continuous rainfall data, different rainfall duration can be analyzed and the IDF curve can be constructed.

Intensity duration frequency (IDF) curves

The hydrological model selected to establish the rainfall-run-off relationship determines what type of data is required to generate the design storm. Simple types of models such as the rational method require simple intensity-duration frequency curves, whereas more sophisticated models require hyetographs or hydrographs as input. Intensity-duration-frequency curves present hydrologic data in another format for use as design storm information. Intensity duration frequency curves summarize conditional probabilities (frequencies) of rainfall depths or average intensities. Specifically, IDF curves are graphical representations of the probability that a certain average rainfall intensity will occur, given a duration; their derivation is discussed by MC Pherson (1978). These curves show precipitation intensity on the ordinate, duration along the absisca, and a series of curves representing individual storm frequencies. These curves are mainly used in conjunction with the rational method for determining peak run-off. The IDF data are properly applied in this case. An example of IDF curves is presented in Figure 16.

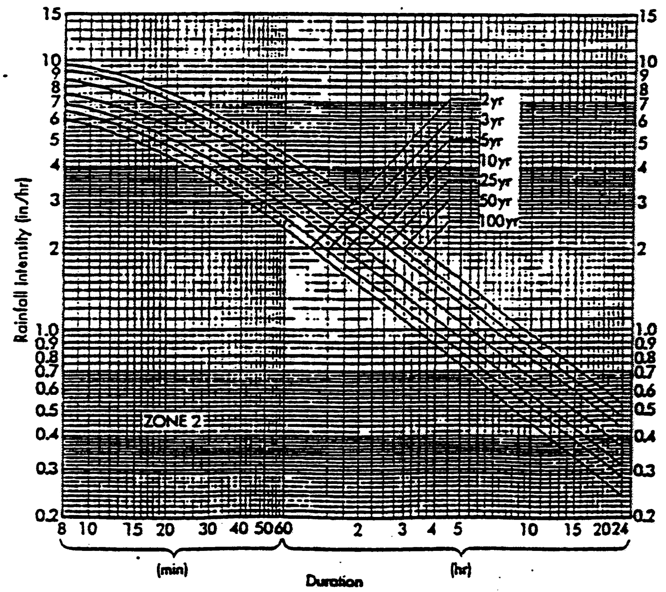


Figure 16. Intensity duration frequency curves for the Tallahassee region (Weldon, 1985)

Time of Concentration

The time of concentration t_c is as part of the development of kinematic wave theory. It is worth a brief review of the definitions of t_c since it is fundamental to much of the analysis in urban hydrology. There are two definitions (Bedient et al., 1988):

The time of concentration is the travel time of a wave to move from the hydraulically most distant point in the catchment to the outlet;

The time concentration is the time to equilibrium of the catchment under a steady rainfall excess, i.e. when the outflow from the catchment equals the rainfall excess onto the catchment.

The use of appropriate values for time of concentration t_c is very important, although it is hard sometimes to judge what is the correct value. Local data collection efforts can be used to calibrate the t_c so that it works properly with the calibrated run-off coefficients.

One of the approaches is that t_c is the sum of two flow times. The first is the initial time required for the surface run-off to reach the first swale, gutter, sewer, or channel. The second is the travel time in the conveyance elements.

$$t_c = t_0 + t_d$$

where:

t_c : time of concentration (minute);

t_0 : initial inlet or sheet flow time (minute);

t_d : travel time in a conveyance element (minute).

Findings the initial time seems to create the greatest amount of confusion and conflict. It can be estimated by the following equation (Sherman):

$$t_0 = K_u\,[1.8(1.1 + C)\,L^{0.5}]/S^{1/3}$$

Where:

K_u : 0.552 for SI unit;

C : run-off coefficient used for the 5-year storm;

L : length of overland flow (m);

S : average basin slope (%)

This equation should not be used for distance larger than 200 to 300 ft under urban conditions.

Travel time td is the time takes the flow to travel through the various conveyance elements to the next inlet or design point.

$T_d = L_c/v$

Where:

L_c : length of the channel (m);

v : flow velocity (m/s).

For combined sewer systems the same approaches can be followed. However in this case an extra load of a certain amount of l/s/ha is added for the wastewater. The transformation from sewer inflow to sewer outflow is generally approached with a reservoir type of model. In some cases non steady flow modelling through piped systems is done.

Maps, showing the layout of a drainage system, must give detailed information on the location of canal reaches and related structures. In urban areas this information will be given together with information on the paved and unpaved areas, location of houses and buildings, and may be also location of drinking water supply lines, electricity, telephone, etc.

5. EXERCISES

The exercises are arranged in a manner that attempts to provide a structured approach to the understanding of basic simple water management system modelling, unsteady open water management system and the application of a GIS on the design and evaluation of land suitability for agricultural development.

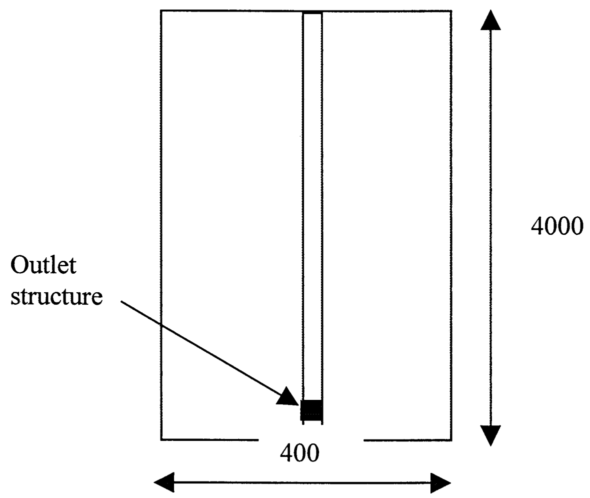
The exercises consist of :
Basic drainage computation, unsteady flow water management system modelling;
Modelling of the water management system with the application a GIS

Exercise 1: Basic drainage computation, unsteady flow computation

A tidal outlet will be desined for a tertiary unit of 160 ha (400 m x 4000 m). The rational method can be used to determine the peak discharge of the unit.

Q = CIA/360

Where: Q = peak discharge (m3/s);
A = serviced area (ha);
C = run-off coefficient = 0.85
I = rainfall intensity (mm/hr).

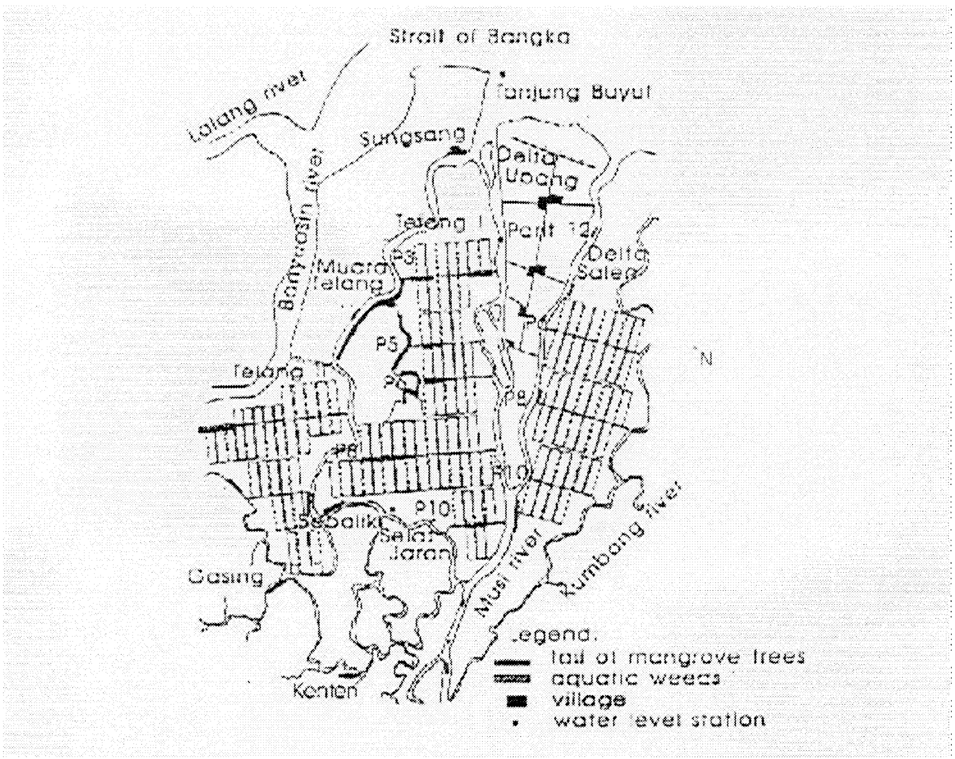


The drainage modulus is 4 l/s/ha. During the lecture, this exercise will be demonstrated and discussed.

Exercise 2:

Effects of operation rules on water management in a secondary block in tidal lowlands

The Telang I area is located in the district Musi Banyuasin in South Sumatra province between the Musi river in the East and the Telang river in the West. It covers an area of 26,680 ha (Euroconsult, 1993). The location of the Telang I scheme is presented in Fig. 1. The secondary block covers an area about 750 ha.



Telang I area, South Sumatra

Water management options are to a large extent determined by the prevailing soil and hydro-topographical conditions. These water management options can be translated into operation rules for hydraulic control structures, which finally can be used during operation of the system to serve as guidelines on water management for both field staff and farmers.

Soils

Two soil types can be distinguished in the project area:

- *fertile clay soils.* In these soils the pyrite layer is located at > 0.50 m-surface. These soils cover an area of about 710 ha, which is 95% of the total area;
- *acid sulphate clay soils.* If the pyrite layer is located at < 0.50 m-surface the soils are potential acid sulphate soils (Suryadi, 1996). These soils cover an area of about 40 ha, which is 5% of the total area.

This means that in most of the area there are fertile clay soils. Therefore only the water management for these clay soils will be discussed.

Successful agricultural production in tidal lowlands requires careful design, operation and maintenance of the water management systems. Several questions will have to be answered before designing a water management system, i.e.:

- what are the objectives for the development of the area;
- what are the soil types and what is their distribution over the area;
- how are the hydro-topographical conditions, the drainability and irrigability of the area and what are the consequences of this for the land use;
- what is the condition of the existing systems and of the area?

Water management systems

The water management systems mainly consist of a canal network and water control structures. Water management takes place at two levels, i.e.:

- *on-farm water management*, or micro water management, which determines directly the environment in which the crops grow;
- *main system water management*, or macro water management, which should enable a proper on-farm water management. It may also have functions of its own, such as transportation and domestic water supply.

On-farm water management has the following objectives:

- *short-term:*
  * ensure sufficient water for the crops;
  * drain excess rainwater from the fields;
  * prevent excessive weed growth (water layer on the field);
  * improve water quality;
- *long-term:*
  * promote soil ripening;
  * leach acidity and toxic elements from the soil.

In addition a consequence will generally be the gradual removal of organic soil layers.

The primary objective of the main system is to keep the water level as appropriate as possible in relation to the agricultural use. This implies that water management systems have the following objectives in support of on-farm water management:

- drain excess rain or flood water;
- prevent flooding;
- prevent salt intrusion;
- provide water for irrigation;
- prevent severe drops of the groundwater table;
- flush poor-quality water out of the soils and the canals;
- control canal water-levels;
- provide water for domestic purposes;
- maintain sufficient water depth for navigation.

For these purposes the water control structures play a crucial role.

Hydraulic boundary conditions

The range of options for water management is determined by the hydraulic boundary conditions. These consist of:

- the river with its daily tidal and seasonal water level fluctuations;
- drainage flows or runoff from surrounding lands.

Changes in the boundary conditions may occur as a consequence of large-scale changes in land use in the catchment, construction of reservoirs, construction of flood protection works, etc.

The daily high water levels in relation to the land levels determine the possibilities for tidal irrigation and flushing. Tidal irrigation requires flooding of the land during at least 4 or 5 days in an average spring/neap-tide cycle (Euroconsult et al., 1996). Taking into account unavoidable head losses in the canals between the river and the fields, this requires spring tide high water levels in the river to be well above the land levels. For flushing the high tide levels create the opportunity to fill the canal systems, with the possibility to release the water during the following low tide.

The daily tidal low and mean water levels determine the possibilities for:

- *drainage:* The ultimate drainage base is the tidal low water level in the river. The available drainage time is generally short. In practice, the lowest possible drainage level is somewhere between low tide and mean tide. For initial estimates of drainability, mostly the mean tidal level is assumed to be the drainage base, with an effective drainage time of 12 hours per day. Drainage below this level requires either very careful structure operation or pumping;

- *flushing of canals:* The larger the tidal range, the higher the potential flow velocities in the canals, the better the possibilities for flushing during low tide. Too high flow velocities may cause erosion of the canals and embankments.

In the fully tidal river reach seasonal fluctuations are small, with the dry-season tide levels normally a few centimetres lower than wet-season levels. These fluctuations cause, however, certain differences between wet and dry season in possibilities for tidal irrigation, flushing and drainage.

To design water management systems in tidal lowlands, the hydro-topographical conditions of the area would have to be used as the starting point (Suryadi, 1996). Hydro-topographical conditions are defined as the field elevation in comparison to river, or canal water levels in the nearest open water system. Hydro-topographical classification from the previous chapter will be used.

Water management zoning and land suitability

A significant part of the tidal lowlands consists of (potential) acid sulphate soils and/or peat soils. In order to eliminate the problems related to these soils (acidity, toxicity and land subsidence) adequate water management systems have been designed. The water management systems consist of open canals and water control structures (flap gates, stop logs and sliding gates) at secondary and/or tertiary levels. The tidal fluctuations in the rivers or in the main canals enable an operation of the water control structures in such a way that the water management objectives can be achieved.

Water management options in lowlands are to a large extent determined by the hydro-topographical conditions. In combination with a water management strategy this makes it in principle possible to subdivide an area into different land suitability zones the basis of more or less identical water management conditions. These Land Suitability Zones (LSZ) can be an effective useful indicator during the planning stage to delineate areas where similar water management conditions may be expected, as well as during operation of the system to serve as guidelines on water management for both field staff and farmers. To derive the land suitability

zoning for a tidal lowland area, a geographical information system (GIS) can well be used to obtain the required information.
Land suitability zoning should at least distinguish between the hydro-topographic categories (A to D) and the main soil characteristics. The drainability is important as well, but it may be difficult to determine this accurately.

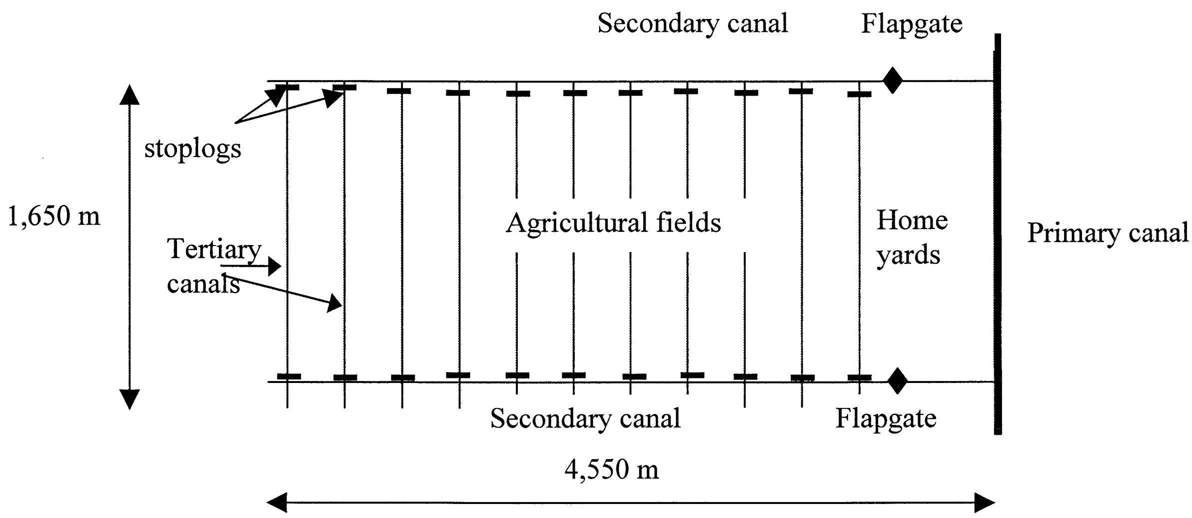
A secondary block water management systems
The secondary block covers an area of 26,680 ha. The reference evapotranspiration varies between 3.0 and 4.0 mm/day. Mean annual rainfall in most of the lowlands ranges between 2,000 and 2,500 mm. Monthly variations in average rainfall are important and determine the cropping seasons, in particular the possibilities for a second rainfed crop.

The secondary block of this case study fits in class B of the hydro-topographical classification. This means drainage during the wet season, and leaching and flushing of the canal system (Liakath et.al., 2001). Based on the climate and hydro-topographical conditions of the area, the cropping pattern is planned as follows:
- rice crop during the wet season;
- dry food crops during the dry season.

For each crop, different (ground)water level conditions are required:
- *rice:* 0.05 m-surface < (ground)water level < 0.10+surface;
- *dry food crops:* 0.20 m-surface < (ground)water level < 0.00 m+surface.

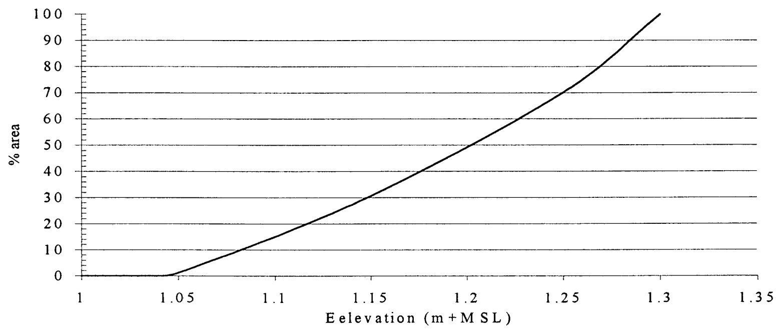
Problem definition
In relation to the hydro-topographical conditions and the two soil types, the following problem definition can be formulated:
- how to realise drainage during the wet season in order to control the water level in the field for rice, or the (ground)water table for dry food crops;
- in case during the dry season a certain (ground)water table has to be maintained, what water retention scenario will have to be applied. Conditions of stagnant water and deteriorating water quality, especially in areas with pyrite have to be prevented;
- how can leaching and flushing, as much as possible with rain water, during the wet and dry season be realised.

A solution to these main problems will have to result in a proper operation rule.



Schematic lay out of the secondary block

The area-elevation curve is presented in the following Figure. From this Figure it can be derived that more than 80% of the area is below 1.26 m+MSL. The digital elevation data are available in Annex 1.



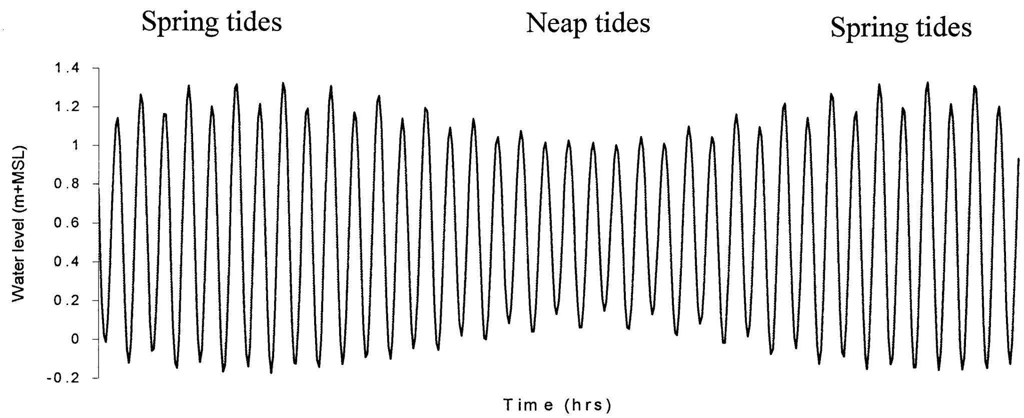
Area-elevation curve

Boundary conditions:

- a simplified sinusoidal water level at the downstream boundary, which covers a period of 20 days. The simplified water level is presented in Fig. 9;
- an actual maximum 5-day rainfall (1991) which is based on a 10 year return period as shown underneath is used for the whole block;

Day	Rainfall (mm)
1	33.2
2	159.3
3	10.8
4	15.8
5	20.5

The rain will start at the time where the high water spring tide also occurs in the main canal. For the dry season conditions, zero rainfall was used.



Simplified tidal fluctuation at the downstream boundary condition

Water management options:

- *rice in the wet season: drainage and flushing*

  The operation rule for the flapgates in the secondary canals and the stoplogs in the tertiary canals should be based on the following requirements:

  * if the water level in the secondary canal is lower than 0.26 m+MSL: keep the flapgate closed;
  * if the water level in the secondary canal is higher than: 0.26 m+MSL: let the flapgate operate according to the tidal fluctuation;
  * the stoplogs should be set at 0.36 m+MSL. This implies that during low water, in the tertiary canals there is still 0.10 m water layer (the bed elevation of tertiary canals are at 0.26 m+MSL).

- *dry food crops in the dry season: water retention*

  The operation rule for the flapgates and the stoplogs should be based on the following requirements:

  * if the water level in the secondary canal is lower than 0.75 m+MSL: keep the flapgate open when the water level in the primary canal is higher and closed for the remaining time;
  * if the water level in the secondary canal is higher than: 0.75 m+MSL: let the flapgate operate according to the tidal fluctuation. From time to time let the water level in the secondary canal rises to 1.05 m+MSL during high tide in order to supply water and to be able to create flushing of the system during low tide;
  * the stoplogs in the tertiary canal will be set at 0.86 m+MSL.

- *rice in the dry season: irrigation by pumping*
  The operation rule is very simple and pumping station will be used:
  * if the water level in the secondary canal is higher than 0.80 m+MSL and the water level in the tertiary canal is less than +1.00 +MSL: to pump water from the secondary to the tertiary;
  * if the water level on the field is higher than +1.30 m+MSL: stop pumping.

By applying this operation rule, water retention can be realised in the canal system and oxidation or over drainage can be avoided. The DUFLOW model has been used to simulate flows and water levels in the secondary block. The following characteristic input data have been used:

- *canal dimensions:*
  * secondary canal: length 4,550 m, cross section bottom width 3.00 m, depth 2.50 m, side slope 1 : 1, roughness coefficient of Manning 0.025;
  * tertiary canal: length 1,650 m, cross section bottom width 1.00 m, depth 1.00 m, side slope 1 : 1, roughness coefficient of Manning 0.025;
- *average ground elevation:* 0.70 m+MSL;
- *water control structures:*
  * secondary canals: both the supply and the drainage canal: flap gate, sill 0.50 m-MSL, gate width 2.0 m, gate height 1.5 m;
  * tertiary canal: stoplog, sill 0.20 m+MSL, gate width 1.0 m, gate height 1.0 m;
- *operation rules:* as described before for rice and dry food crops;
- *downstream boundary conditions:* water level fluctuations during 2 weeks period which covers spring tides and neap tides as well;
- all the tertiary canal storage is schematised in the field branch.
- *upstream boundary conditions:* zero inflow from outside;
- *evapotranspiration:*
  * rice: 5 mm/day and dry food crops: 3 mm/day.

The objective of the modelling is to check the hydraulic performance of the water management system based on the proposed operation rules. This covers two different seasons with two different goals, wet season and dry season.

Assignments:

- Please derive the land suitability zoning image based on the land suitability criteria which are available in the previous chapter;
- Please simulate the water management systems for the wet and dry season as well and use the control structure function for the simulation;
- Evaluate the results of your land suitability zoning and the hydraulic performance of the system.

Prepare your report.

REFERENCES

Aronoff, S, 1991
Geographic information systems: a management perspective.
WDL publications, Ottawa, Canada.

Bedient, P.B. and W.C. Huber, 1988
Hydrology and Floodplain Analysis, chapter VI: Urban Hydrology. Addison Wesley Publishing, Ontario, Canada.

Bonham-Carter, G.F., 1994
Geographic Information Systems for Geoscientists, Modelling with GIS. Pergamon, Canada

Burrough, P.A., 1991
Principles of geographical information systems for land resource assessment. Clarendon Press, Oxford, UK.

Eastman, J.R. 1993
Idrisi, version 4.1, Technical Reference.
Clark University, Massachusetts, USA.

International Institute for Land Reclamation and Improvement (ILRI), 1987
Lowland Development in Indonesia. Proceedings Symposium Lowland Development in Indonesia – Jakarta, August 1986, Wageningen, The Netherlands.

Liakath Ali, Md., F.X. Suryadi and Bart Schultz, 2001
Water Management objectives and their realization in tidal lowland areas in Bangladesh and Indonesia.
18th ICID Congress, Montreal, Canada.

Meijerink, A.M.J., H.A.M. Brouwer, C.M. Mannaerts, C.R. Valenzuela, 1994
Introduction to the use of Geographic Information Systems for practical hydrology
Unesco IHP – IV M2.3 and ITC Publication, Enschede, the Netherlands

Schultz, E., 1993
Land and water development: finding a balance between implementation, management and sustainability. International Institute for Infrastructural, Hydraulic and Environmental Engineering, IHE Delft, The Netherlands.

Segeren, W.A. and F.X. Suryadi, 1995
The use of GIS to identify water management zones in tidal lowlands.
Lowland Development Seminar in Indonesia, Jakarta, Indonesia.

Smedema, L.K. and D.W. Rycroft, 1983
Land drainage, planning and design of agricultural drainage systems.
Batsford Academic and Educational Ltd, London, UK.

Shaw, E.M., 1983
Hydrology in practice.
Van Nostrand Reinhold, UK

Stephenson, D., 1981
Stormwater hydrological drainage.
Development in water science, no. 14, Elsevier, Amsterdam, The Netherlands.

Suryadi, F.X., 1996
Soil and water management strategies for tidal lowlands in Indonesia.
PhD dissertation, Delft University of Technology - IHE Delft, A.A. Balkema, Rotterdam, The Netherlands.

Urbonas, B.R. and L.A. Roesner, 1993
Handbook of Hydrology, chapter 28, *Hydrologic Design For Urban Drainage and Flood Control.* Mc Graw Hill Inc, New York, USA.