GIS for Irrigation Management in Irrigation Associations

Wei-Taw Lin[2]、Yi-Fong Ho[2]、Ming-Daw Su[1]

1.Dep. of Bioenvironmental Systems Engineering, National Taiwan University, Taipei, TAIWAN 10617. Email: sumd@ntu.edu.tw

2.Dep. of Irrigation and Engineering, Council of Agriculture, Executive Yuan, Taipei, TAIWAN 10014. Email: lwt@mail.coa.gov.tw, yifong@mail.coa.gov.tw

Abstract

Water management is an important issue in Taiwan because the water supplies become scarcer due to rapid growths in water demands and the in-uniform distribution characteristics of precipitation among temporal and spatial aspects. Water management in agricultural sector becomes the focus in this campaign due to its large share in the total water use. There are seventeen irrigation associations in Taiwan who are responsible for the irrigation water managements. Most of the data involving in the irrigation management such as soil, cropping pattern, canal network have spatially distributed properties. This spatial information is traditionally managed using paper maps. The Geographic Information System (GIS) is an efficient and effective tool for managing these spatial data sets as the GIS technology become well-developed and more economically available. A tremendous amount of efforts have been invested in the last decade for leading the GIS technology into irrigation associations. This paper summaries some of the GIS-based applications that have been developed for irrigation management practices including digital maps, mobile GIS for on-site investigation, Irrigation and drainage canal network management, and irrigation planning.

Keyword: Geographic Information System (GIS), Irrigation management,
Agricultural water conservancy /

1.Introduction

Although Taiwan has abandon water resources with an average annual rainfall of about 2500 mm, the differences between wet (May-Oct) and dry (Nov.-Apr.) seasons are manifest due to the uneven distribution among spatial and temporal aspects. The dense population and booming growth in commercial and industrial activities make the water allocation among different water use sectors an important and controversial issue. The efficiency and effectiveness of water management are continuous concerns for regional development. Agricultural water use sector, with a 60% share of the total water use, becomes a focus in this discussions for improvement of the regional water management.

The managements of agricultural water are commanded mainly by the 17 Irrigation

Associations (IAs). The IAs have to maintained soil, crop, distribution canal network, administration and climatic data for this heavy and complicated task of irrigation management. Most of these data are temporally and spatially distributed. Maps are traditional tools for this data management. The use of maps for managing spatial data can be traced back thousands of year. Although the cartographic technology progresses remarkably, there still are many defects such as difficulties in storage, search, query, analysis, presentation and reproduction for using paper maps.

The technology of Geographic Information System (GIS) was developed for the effective management of spatial data. The applications of GIS on natural resources management and urban development planning have been increased in the last two decades due to the advancements of information technology and the decreases in cost of software and hardware. With its powerful capacity for management and analysis of spatial data, GIS becomes an important tool in irrigation management. This paper descries the recent applications of GIS to irrigation planning and management, such as map management, irrigation demand planning, canal network management and field data collection at Irrigation Associations in Taiwan.

2.GIS Fundamentals

It a long quest for a better tool than paper maps in managing spatial data. The information systems were flourished from the developments of computer technology. Most of the information systems in the early stage, such as Management Information System (MIS), were mostly for the manipulation of numeric and alphanumeric data. The closed linkage of spatial distributed data and image data with the management of natural resources and regional planning creates the needs for a technology to incorporate these spatial data and imageries with the traditional MIS. The GIS integrates the MIS, CAD, Topology and Statistics into an effective tool for the acquisition, storage, retrieval, analysis and display for the spatial data. The GIS is not necessarily an independent discipline but integrations or applications of information science with other disciplines. The GIS can be deemed as a special information system for spatial data.

GIS is a product integrating the technologies of digital computing, computer graphics, database, remote sensing and spatial statistics and analysis. GIS can be effectively applied to tasks such as natural resource planning and management. Spatial database such as soil, rainfall, geology, land use, transportation, topography, demography and socioeconomic can be implemented for better decisions in resource or facilities planning and management.

The choice of the GIS software is an important issue for sucessful GIS implementation. There are many considerations for software choice including: market share, the capacity of data exchange with other software, future expansion, application development support and ease of use. The main data format is another important concern. There are two major formats in GIS: vector and raster. In raster system, the area is uniformly divided into grids with attributes such as elevation, rainfall or land use categories assigned to each grid cells to represent the phenomena in the real world. Data resolution is represented by the size of the grids. More information of the real world can be preserved as the grid size becomes smaller. In vector data system, the spatial information is expressed by discrete spatial features such as points, lines and polygons. A spatial relationship description scheme called Topology is used to record the locations of these spatial objects and the relationships among them. There two data formats have its own advantages as well as drawbacks. Raster data is good for description of continuously varied geographic phenomena such as terrain, vegetation and precipitation. Vector data format is more suitable for data with definite position and boundary such as land parcel or administration boundaries, land use zoning, buildings and traffic networks. Most of the spatial information in irrigation management, such farmland parcels, irrigation management unit, canal network, distribution and regulation structures are appropriate to be handled using vector data format.

After more than 30 years of development and evolution, GIS has been successfully implemented in various applications of resource development and management: such as water and land resources, transportation and other public facilities. The project of National Geographic Information System (NGIS) has been promoted and implemented for more than a decade in Taiwan. Nine major Spatial Databases have been established covering aspects of natural and biological resources, environment and ecology, topography, transportation, social and demography. Assorted applications are also developed, some of them are internet based, on these spatial databases for improvement of the efficiencies and effectiveness in spatial decisions.

The Decision Support System (DSS) is to provide the decision makers with impact information as results of different decision scenarios instead of a single optimal solution. Related databases and model bases are constructed into the DSS to assess the impacts under different decision scenarios. User interface is an important component in DSS for scenario setups and results presentation. The Spatial DSS (SDSS) is a special kind of DSS that tries to link the concept of Decision Support with GIS technology for more effective spatial data processing to make better spatial decisions.

A pilot model for regional irrigation water planning which integrated spatial database with region irrigation demand estimation models and map-based Graphic User Interface (GUI) is also presented in this paper for demonstration of the SDSS applications.

3.Maps System for Irrigation Associations

There are currently 17 Irrigation Associations (IA) in Taiwan. The total command areas are more than 380 thousands hectares excluding two small urban IA in Taipei Metropolitan. There are more than 70 thousands of irrigation canals with a length longer than 60 thousand kilometers managed by the IAs. There are also numerous other facilities like reservoirs, head works, gates, flumes and culverts associated with the irrigation systems. The major mission for the IAs is to maintain appropriate field water condition for crop production through irrigation and drainage. A vast amount of data and information are needed to accomplish this goal. These data and information include farm parcel, soil, climate, cropping pattern, water supply and quality, irrigation and drainage canal network.

Some of the administration processes in IAs have been computerized in the last two decades. Some databases have been established for MIS applications as personnel and accounting administration. But most of the spatially distributed information is still managed through the use of paper maps. GIS is gradually introduced into IAs since 1998 to integrate maps with the existing MIS databases. There are already some theme map layers established, including administration regions, farmland parcels, canal network and regulating and control facilities. Some maps from NGIS spatial databases are also comprised for use in irrigation management. This NGIS data include topographic maps, traffic networks, land use maps, reservoirs, digital terrain model, aerial photos and satellite images. Some of these data may not directly related to irrigation management, but detail spatial information is helpful for orientation as well as other related field work.

Vertical and horizontal structures are implemented for establishing the framework of digital maps as shown in Fig. 1. The region is divided into equal area mosaic units in horizontal structure for easier management. Spatial features with same properties, such as road, soil and building are collected into themes in vertical structure. As the digital map framework is established, a map can be composed by identifying the spatial extent in horizontal structure and also the needed layers in vertical structure.

To facilitate the management of spatial information for irrigation management in IAs, a maps management system has been developed under MS Windows environment. Through the use of map-based GUI as shown in Figure 2, spatial information can be more effectively and efficiently managed. Other than basic GIS functions, this map management system provides the users with friendly and practical tools for spatial queries and map output. A large map like that in A0 size can be divided into smaller A4 size sub-maps in case that the irrigation workstation is not equipped with large size plotter.

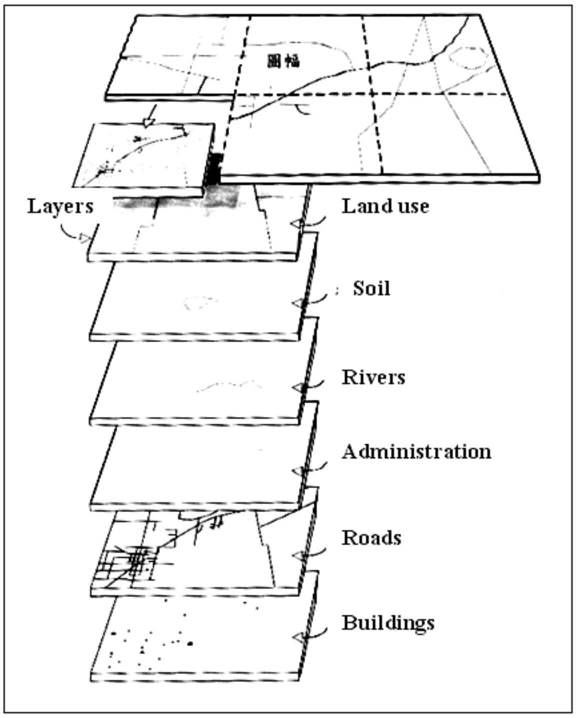


Fig. 1 The vertical and horizontal structure of digital map system

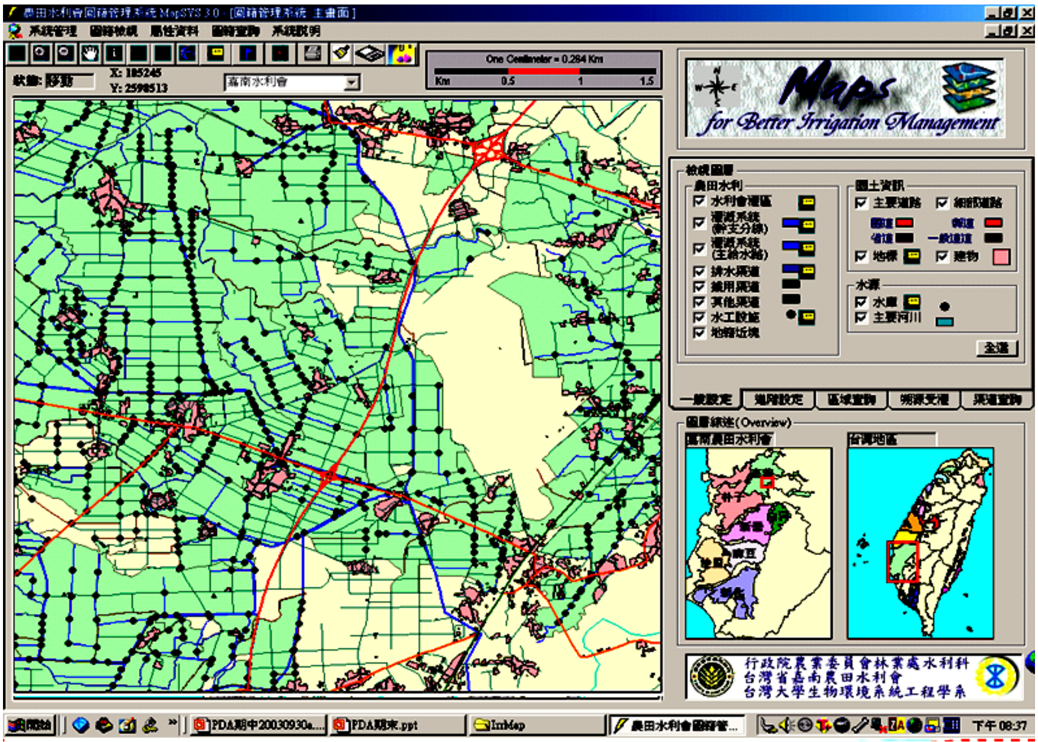


Fig. 2 Map Management System

4.Irrigation Demand and Schedule Planning

The IA estimates the farm irrigation requirements based on related farm data before planting in each season and make up the irrigation plan accordingly. The related farm data include soil, cropping pattern, climate and canal network. These data have considerable variation and complexity. It takes a lot of man power and cost in completion of these irrigation plans. As the cropping patterns changed to adapt the impacts from the join of Taiwan into WTO, it may be more difficult and costly for the IAs to make up the irrigation plan every year. A computerized system to aid the IAs in irrigation planning become more urgently needed as the variations of spatial data as the cropping patterns become more rapid and complicated.

Related spatial database must be firstly established in the development of this computer-aided irrigation planning system. Irrigation requirement estimation models are also needed to be incorporated with the spatial database for regional irrigation estimations.

The system was developed using *ESRI Arc/View* GIS software for spatial data management, *MS Access* for database implement, and object oriented programming language *Visual Basic* and *Arc/View Avenue*. The *MS Access DBMS* was also used as bridge between Geo-database and *Visual Basic* to integrate all the necessary data for irrigation demand estimations. The system framework is presented as shown in Figure 3. There are components of *spatial information tools*, *irrigation demand estimation models*, *databases of model parameters and geo-information*, and *user interfaces*. The component of *spatial information tools* provides GIS utilities for spatial information query, display and processing. The component of *databases of model parameters and geo-information* maintains data for irrigation demand estimation. Scenarios with different cropping patterns and climatic conditions can be set up by user easily through the use of the map-based *user interfaces* component. The impact information such as water demands and its spatial distribution can be reported through tables, charts and maps. The decision makers can better understand the behaviors of the system and proper irrigation plans can be achieved with this aid.

5.Management of Canal Network

To provide adequate water at right time to the field for proper crop production is the main objective of IAs. This irrigation canal network is the basis for achieving this objective, so the management of this canal network becomes one of the important key practices in IAs. From the manager's perspective, water is diverted from the supply sources (a point spatial feature) and flows through the distribution canal network (line spatial features) to the farms (polygon spatial features). The canal network data structure is important for mastering the spatial distribution of the water demand and supply and also for the irrigation planning and management practices.

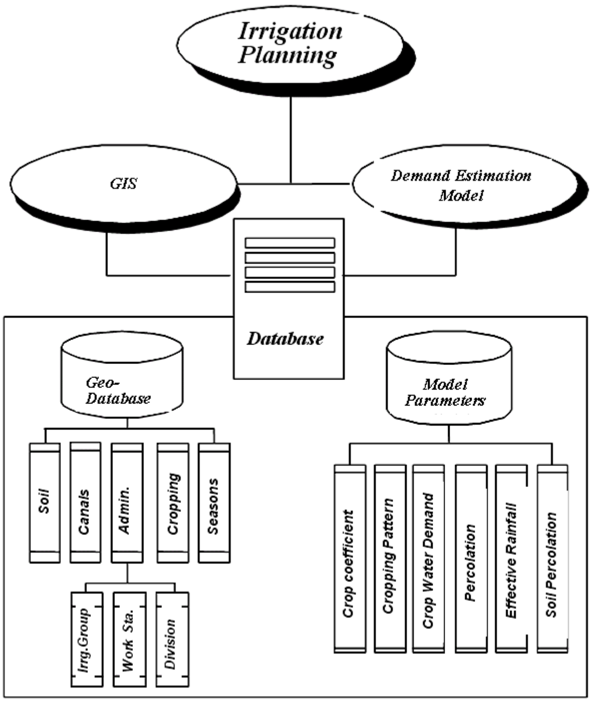


Fig. 3 Framework for GIS-Aided irrigation planning

Take the *ChiaNan* Irrigation Association as an example, the command area, which is the largest one of the 17 IAs in *Taiwan*, covers four administration areas of *ChiaYi County, ChiaYi City*, *Tainan County* and *Tainan City*. The irrigation water is originated from TsengWen and WuSanTo Reservoirs and is distributed through complex canal network. The canal system has a total length of 19.22 millions meters, with 27 mainlines, 86 sub-mainlines, 254 laterals and numerous small ditches. A better management system is needed for effectively manage this complex information.

To construct the data structure of the canal network is to record the related topology such as up-down stream relationships and flow directions through a coding system. A hierarchical coding system (as shown in Figure 4.) is used commonly for description of the tree type network. A flaw of this hierarchical coding system is that the levels of the hierarchy must be predetermined before the system will be implemented. If the determined numbers of level is too small, it may run out of space in a complex network system. On the contrary, if the numbers of level is left to big, it may result in many blank fields in the records. A more flexible topological coding structure was developed in this paper.

The irrigation canal network is a tree type network. Water flows from the supply source to mainline, and then to sub-mainlines and laterals subsequently. All canal reaches have only one upstream reach but may have more than one downstream reaches. Only the upstream reach ID (*Upperid* in Figure 5) is kept for each sections in the developed data system. As shown in Figure 5, the hierarchic relationship can be retrieved through the use of *Upperid*.

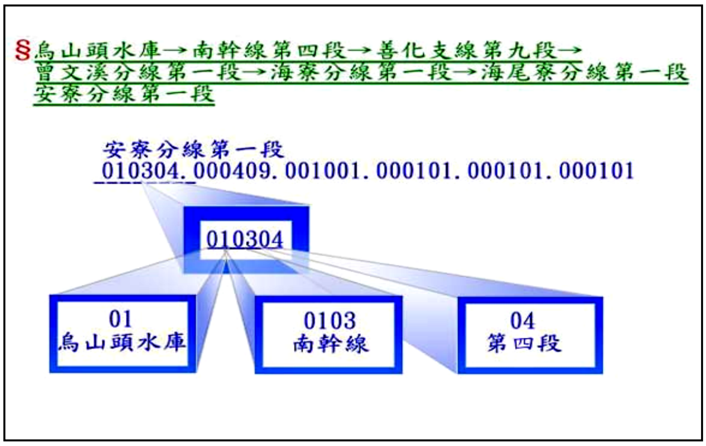


Fig. 4　Hierarchical coding structure for canal network

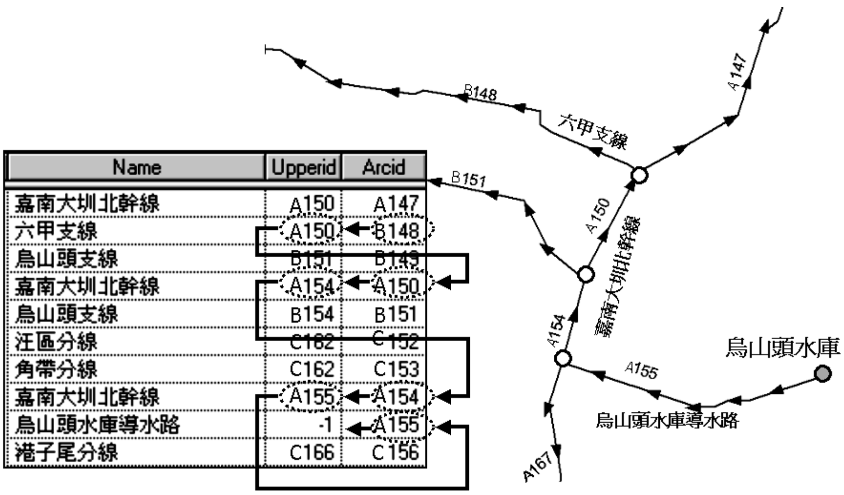


Fig. 5　Upstream-downstream relationships in canal network

An extra field in the network attribute table is needed to hold the information of the farm unit whose water is supplied by this canal section. The polygon theme of farm land is linked to the line theme of canal network through this code, as the example shown in Figure. 6. Through the use of this coding structure, the water supply source and all the flow-through canal reaches can be traced back and be identified for each farm. This capability of supply-source tracing can be very useful for water management practices at the Irrigation Associations. Other than supply source tracing, this coding system enable the manger to identify, at any point in the network, the areas which receive water delivered through this point. This function is useful when managing events such as shutting down a diversion gate for maintenance or assessing the coverage area in a water pollution hazard. The coding system was built with *Microsoft VB* and *ESRI MapObjects*.

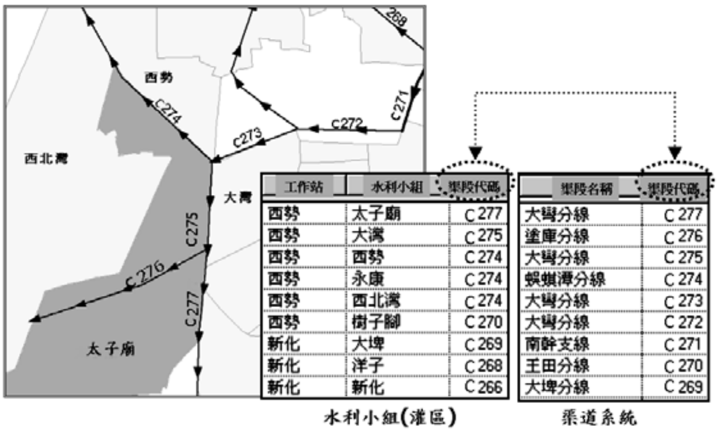


Fig. 6 Data connection between canals and farms (Example)

6.Mobile GIS and Field Data Collection

There are some other water management practices, such as regional drainage, pollution monitoring, that the IA managers have to participate with. These field practices usually need a lot of maps. Problems may be encountered that wrong maps be carried out or some maps be left behind in the home offices. Corrections or investigating information may be needed to be recorded on the maps and the original map files be updated after the manager getting back to office. These field investigation problems need to be solved. The mobile GIS as shown in Figure 7 that integrates *GIS* with *PDA* or *Tablet PC* is a possible answer to this problem. A subset of the original map database synchronized to PDA is brought to the field with a PDA version of GIS. The field work results are marked onto the digital maps directly and the original map data can be updated easily as the manager get back to the home office.

Other problem that a new manager may encounter is that he may get lost in the field as there is no clear spatial orientation aid (such as road intersections or street addresses) in the command area. The Mobile GIS can be equipped with a GPS module and help the manager to locate the target site very easily through the map and the GPS navigation.

Fig. 7　Mobil GIS integrating PDA, GIS and GPS

7.Assets Management

Irrigation Association is a non-governmental organization formed by farmers and its history can be dated back hundreds years ago. Most of the facilities and the necessary lands were donated by the farmers. The current scale of agricultural production decreases in the last several decades due to structural changes of socio-economical development. Some of the land spared from abandoned canal due to command area reduction may become available for other purpose use. Most of the properties of the IAs are scattered over the command areas. These assets are with different values and should be utilize accordingly. For example, some of the administration buildings are located in thriving and prosperous urban area. These buildings can be reallocated to suburban and those valuable lands be sold. This may improve the financial condition of some IAs that is poor financial condition.

Some of the ponds and canals may occupy private lands after hundred years of operations. Another task in assets management is to check thoroughly where the irrigation facilities trespass upon private lands. This task can be accomplished with less effort through the use of spatial analysis capability of GIS. These occupied properties should be purchased by IAs in the future. As shown in Figure 8, when the canal map is overlaid with map of IA asset, the private lands trespassed can be identified easily.

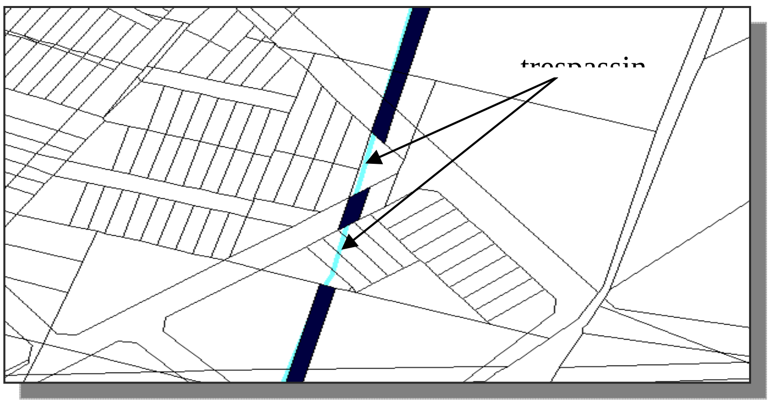


Fig. 8　Canal trespassing private farmland

8.Regional Water Planning

Because the large share of water use and the low market value of the produce, the agricultural water use sector is confronted by increasing pressures from other sectors of industrial and domestic asking for water right reallocation. The IAs are usually asked to spared irrigation water for water shortage mitigation during a drought. The irrigation planning and management must be integrated with the water planning and management of other water use sectors in the region.

The decisions in regional water resource planning and management are very complex ones. Although GIS can be used to manage the spatial data involved, assorted model for estimating water demand and water allocation and distribution are also needed. The property of non-structure in the decision making process of regional water resources planning and management make these complex problems even more complicated. The decision makers tend to over-simplify the problems as confronted with paradoxical situations. The decision quality and effectiveness may be decreased with this manner. Decision Support System (DSS) is a possible answer to this kind of predicaments.

An un-structural decision process is one that can not be solved with a predefined algorithm. This property is originated from the conflicted and controversial multi-attributes characteristics. Take an outpatient visit to a hospital as an example. A flowchart can be made and be followed for the process from the registration to the cahier checkout. The process has a definite start and end point and can be categorized as structured process. An example of the un-structural decision process is that of the drought allocation in regional water resource planning. There are many ways to cut down the regional water demand during a drought such as farmland fallow, water price regulation, pressure reduction in pipe lines and suspend water supply rotationally. These measures can be used individually or simultaneously. The resulting water demand reductions and the related socio-economical impacts will be different as different strategies are adopted. There is no straight forward procedure for a clearly superior decision in this process due to many complicatedly interrelated influencing factors and the natural of un-structural process.

DSS is an efficient and effective tool for the problem with non-structural property. A DSS is composed of three major components of *Database*, *Model Base* and *User Interfaces*. A typical framework of DSS is shown in Figure 9. The decision maker sets up a scenario that can be his candidate solution to the designated problem. Results or impact information under the set scenario are provided to the decision maker through the use of database and model base in the DSS. Another scenario can be set up again if the decision maker is not satisfied with the previous one after examination of the impact information. The complexity and the characteristics of the system may be recognized by the decision maker. A more effective and satisfied decision can be resulted from this what-if game.

A DSS is a tool for scenario-based decision processes. Searching an exact answer is not the goal of the DSS. Instead of providing a so-called best or optimal solution, the DSS equips the decision makers with tools for setting up different scenarios according to their judgments and review the resulting impacts. Through the what-if game-playing process, the decision makers gain more insight of the system so that a more effective decision can be made. An optimal solution is usually not realistic in practical situation because the complexity in the real world. The DSS is not to replace the decision maker with a single optimal solution, but help the decision maker to get a more satisfied and realistic compromised decision.

The SDSS integrates the database and model base that comprise the necessary data and model for spatial decision making. Flexible and friendly interfaces are provided for manipulating the environment for different scenarios set up. The scenario-based decision process not only enables the decision maker to make more effective and realistic decisions, but also provides a platform for negotiation in a conflict of interests that is very common in regional decision involving many stakeholders. An example for regional water planning decision during a drought is presented below to show the capability of a DSS.

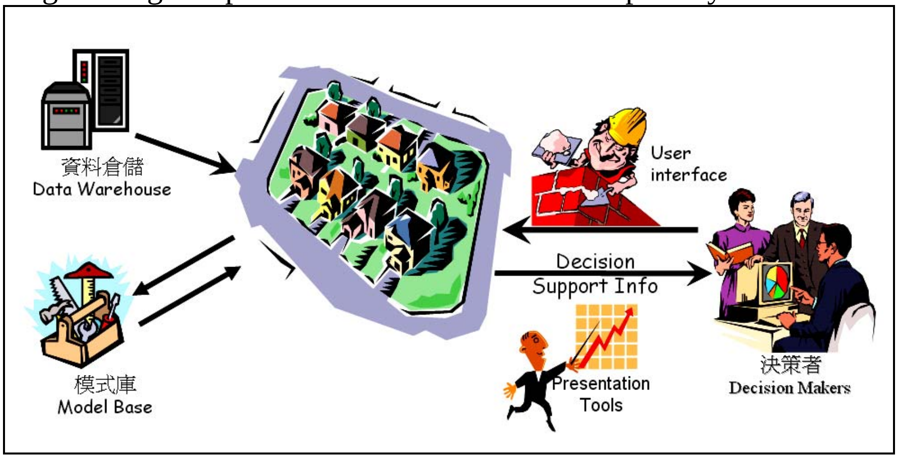


Fig. 9 Decisions based on scenario simulations

A hypothetic scene is used here as an example for the application of DSS to unstructured spatial decision. The irrigation manager of an IA is asked to spared 50 million cubic meters of water at certain price compensation for drought mitigation purpose. He may have to regulate the original cropping pattern so that the regional irrigation demand can be reduced. He may choose to switch some area from the planned crop into some other crops that may use less water or even into fallow to save more water. He may approach his solution through following concerns：

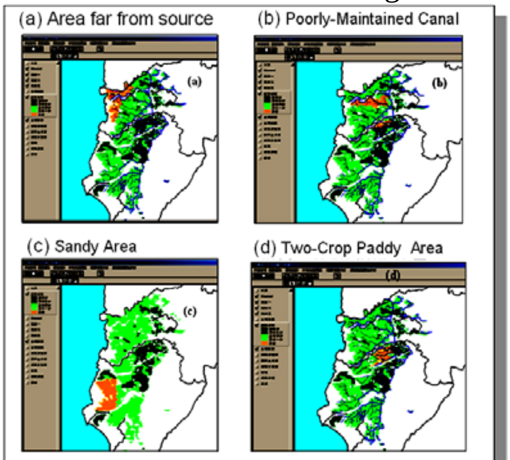
1. Conveyance loss in canal system：If the farms which are supplied water by poorly maintained canals are set fallow, extra water may be saved from the originally high conveyance loss in those canals.
2. The distance away from water source：As the distances of the farms from the water source becomes longer, the losses during the conveyance increase. If the distant farms stop growing crops, more water may be spared.
3. Potential of on farm percolation loss：The percolation losses for the farms with sandy soil are larger than those with silt or clayey ones. More water can be saved for unit fallow area in sandy soil region.
4. Magnitude of crop water use：Paddy fields use more water than upland crops. Water

may be spared by setting the paddy fields as fallow or being switched to other crops.

As shown in Figure 10, different scenarios of farm fallow can be set up. In Figure 10(a), the area that is farthest away from the supply source becomes fallow. The area irrigated by two poorly maintained canals stop irrigation as shown in Figure 10(b). The sandy area as shown in Figure 10(c) and area with two crops of paddy as shown in Figure 10(d) are set as fallow for more alternative studies. From the results presented at the lower part of Figure 10, the water saved in different scenarios is more or less the same but not the fallow areas. The area been affected is the smallest for the scenario (d). This over-simplified example gives a taste of how a decision support system can help the decision maker making better and effective decision with more insights of the system behavior instead of a single so-called optimal solution.

9.Conclusions

The practices in Irrigation Associations may influence the development and stability of society. Agriculture sector provided a sound foundation for today’s economical development in Taiwan. The irrigation management business is facing severe challenges from the changes in socio-economic environments. The Council of Agriculture started its promotion for computerization of practices in Irrigation Associations more than two decades ago. Applications were developed for personnel, payroll, accounting, and engineering managements. The GIS was led into irrigation management practice in recent years. Traditional paper maps are replaced by digital maps and spatial information processing tools. The integration of related MIS and GIS data as a spatial decision support system can improve the effectiveness of decisions in irrigation management.



Scenarios / Effects	Scenario (a)	Scenario (b)	Scenario (c)	Scenario (d)
Fallow Area (ha)	5735	5623	6814	3058
Water Saved M m^3	53	58	48	57

Fig. 10 Comparisons among different fallow scenarios

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