A MULTIPLE RESOURCE WILDLANDS INFORMATION SYSTEM FOR ENVIRONMENTAL IMPACT ASSESSMENT MODELING

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Introduction

Today's forest resource managers and wildland use decision makers operate within a dynamic and challenging environment. Not only are they concerned with the dominant problem of allocating a relatively fixed forest land base to satisfy spiraling demands for a set of competing and often times conflicting uses, they must also cope with the exploding technology of new planning systems, the need to consider environmental amenities, the active participation of concerned citizens in resource planning, and the action of highly organized pressure groups. All of these factors (and more) have added new dimensions to the resource manager's decision-making framework. Consideration of these factors has stimulated the need for comprehensive forest land-use planning and for the detailed analysis of expected social, economic, and environmental impacts associated with various land uses and forest management practices.

The College of Forest Resources, University of Washington, is currently engaged in a research project which has as its central objective the development of a general methodology for evaluating the physical, economic, and environmental consequences of alternative land-use

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decisions and resultant manipulations of the forest ecosystem. Because of the scope and complexity of this task, as well as the necessity to assume a holistic rather than an elemental approach, the methodology of systems analysis and operations research has been adopted.

Funded by a National Science Foundation grant under the auspices of the Research Applied to National Needs program, the specific objectives of the project revolve around the development of a multi-resource system model that interfaces with an automated information storage and retrieval system. The system model is composed of a series of subsystem models which include forest production processes, recreation supply processes, fish and wildlife supply processes, and atmospheric and hydrologic processes. Manipulations of the ecosystem are assessed in relation to their impacts on land, water, and air resources, as well as the production of utilizable goods and services. Since many of the manipulations generate nonpoint sources of pollution, a large portion of the program is directed at modeling these processes.

The multi-resource model being developed is cast in the form of a multi-decision maker simulation model to focus attention on critical land-use decisions and to aid in the transfer of knowledge to appropriate decision makers. The development of the system simulation model, the subsystem models, and the resource data base constitute only part of project activities. In addition to the above, the project involves the development of computer mapping and graphic display systems, and special land-use modeling studies in both rural and wildland areas.

The area selected for calibration and testing of the models developed by the project is the Snohomish River Basin located on the west slope of the Cascade Mountains in western Washington. This basin of approximately

1.2 million acres drains into Puget Sound at Everett, Washington. With the exception of agricultural activities along the flood plains and the land devoted to urban development in the Seattle-Everett metropolitan area, the basin is covered by forests. These forest lands are used for a multiplicity of purposes including timber production, outdoor recreation, water, fish, wildlife, and the generation of outstanding scenic amenities. Hence, the basin provides an ideal area for evaluating models developed by our project--the Snohomish Valley Environmental Network (SVEN).

The subject of this paper concerns the resource data base and information storage and retrieval system which has been developed to support model development and to operate in concert with the system simulation model. Following a discussion of natural resource information systems in general, a brief description of the SVEN information system is presented. This is followed by a discussion of computer requirements, limitations, and capabilities of the system.

Natural Resource Information Systems

As outlined above, one of the principal goals of the SVEN project is to predict the environmental impacts associated with a variety of forest land uses and resource management manipulations. The acquisition or development of a natural resource information system capable of supporting the assessment of environmental impacts at various levels of temporal and spatial resolution was deemed a necessary prerequisite for attaining the project's goals. A review of the literature revealed a vast array of information storage and retrieval systems capable of processing geographically-based information. While it is beyond the scope of this paper to review each of these systems individually, selected characteristics common to all of the systems are discussed below.[1]

In general, two approaches are commonly used for constructing computer compatible natural resource information systems. These two basic systems are referred to as: 1) cell systems and 2) polygon systems.

Cell Systems: Cell systems are constructed by dividing the area to be coded into a series of fixed and/or variable sized squares or rectangles. A set of characteristics or attributes representing the contents of a particular cell is then either manually or automatically transferred from the source document and entered into the system. Since the boundaries of a cell are permanent, updates which alter the contents of a cell only affect the attributes of the cell and not its locational coordinates. Therefore, updating may be performed very rapidly.

Not only are cell systems conducive to rapid updating, they also permit the complete description of a specific parcel of land to be stored on, and retrieved from, computer data files in a single access. As discussed later, most polygon systems stratify data prior to storage, thus necessitating multiple accesses to retrieve a complete description of any specific parcel of land.

Perhaps the greatest disadvantage of a cell system concerns the loss of information which normally accompanies the transfer of data from a resource map to the computer data file. While the selection of a small cell size will minimize some of this loss (at increased cost), it is

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[1]While not reviewed in this paper, a partial list of available natural resource information systems is included in the Bibliography.

virtually impossible to represent geographic features described by points or line segments using a cell system. A second disadvantage is that any given cell system will only partially satisfy users operating at different levels of management where different types of planning are being performed. This occurs because cell size is largely determined by the information requirements of the principal user groups of the system. Other users with different requirements may desire information gathered using an alternative ccell size. This makes it difficult to build a universally accepted cell system.

Polygon Systems: Polygon systems are characterized by groups of irregular sized and shaped cells. Typically, a separate overlay, profile or file is constructed for each attribute to be included in the information system. Because boundaries of cells are variable and irregular in shape, it is necessary to store considerable locational information in addition to the attributes or characteristics describing the contents of each cell.

skip Two general methods exist for storing and processing polygon data. These are referred to as: 1) the complete polygon approach and 2) the line segment approach. In the complete polygon approach each polygon is stored as a string of coordinates with each coordinate pair representing a vertex of the polygon. In the line segment approach each polygon is defined and stored as a string of line segments with the locational coordinates of each line segment stored separately. Whereas, this latter approach allows line segments common to two or more polygons to be stored only once, the complete polygon approach requires that line segments common to two or more polygons be stored several times. While more efficient in a storage sense, the line segment approach is more complicated and requires additional processing time to construct polygons.

In general, a polygon system permits considerable flexibility in terms of spatial resolution, accommodates the use of automatic digitizing equipment in transferring data from base maps to computer data files, permits the representation of point and line as well as area information, and provides easily interpretable information of considerable value to managers at different levels of management. Perhaps the greatest disadvantages of a polygon system are the time and cost involved in repeatedly updating the data base to reflect changes in the boundaries or contents of a cell.

It was for this latter reason that the SVEN project opted to build its resource data base using a variable-size cell system. While this approach does not retain many of the desirable features of the polygon system, it does better accommodate efficient storage, retrieval, and updating of information. Since our principal goal is to develop a methodology for evaluating alternative forest land-use decisions for forest planners and decision makers, and since our multi-resource system model is designed to update the resource data base during each simulated time cycle, a variable-size cell system was deemed most appropriate.

Based upon our experience and knowledge to date we feel that if a generalized, multi-purpose, computer compatible information system, is desired that the polygon system should be carefully considered. This is especially true if graphical displays are an important design criteria and/or if a truly operationally-oriented system is desired. However, if an information system is required to support broad scale forest land-use planning or if an analytical decision-making tool is to interface directly with the information system we feel that a cell system is superior.

SVEN Information System

A brief overview of the entire SVEN information system is presented below. This in turn is followed by a more detailed discussion of selected components of the system. Readers interested in the details of computer file structure are encouraged to read these latter pages.

Overview of System:

Cell File: A variable cell size system was developed to describe the resources of the Snohomish River Basin. After considerable deliberation, a basic cell size of 40 acres was selected. A set of 45 attributes is currently used to describe the contents of each of these cells. Table 1 contains a list of the information currently contained in the cell file. As shown, these attributes relate to either a) cell identification, b) physical description, c) soils data, or d) timber inventory. For convenience, the basin has been subdivided into 20 major watersheds which provide the primary key when locating any specific cell within the basin.

Stream File: Operating in conjunction with the cell file is a stream file. This file contains locational and identifying information for each stream in the basin. Operating in conjunction with the cell file, the stream file provides the capability for routing water flow throughout each major watershed. Streams are located within each 40 acre cell by using an interior set of 12 grid points. Thus, we are able to locate streams to approximately the nearest 300 feet. For those cells not containing a stream, a pointer to the cell into which the water will flow is stored. Using the stream file, we are able to reconstruct the mini-watershed which surrounds any selected cell. This provides the capability for assessing the impact of nonpoint sources of pollution on stream quality at any chosen point. The stream file also permits the assignment of attributes to each stream segment contained in the file. Currently, only locational and identification information is contained in this file. Other attributes such as stream flow histories, fisheries potential, stream gradient and stream bed gravel condition will be added as the information becomes available. Presently, most of these data are not available for the majority of the streams in the basin.

Soils File: The soils found in the basin have been aggregated into 42 classes according to depth, texture, structure, gravel content, and permeability. This static file is referenced by using the average soil type contained in the cell file for any particular cell. This information has been useful during model development as well as during the running of the simulation model. Additional soils data reflecting a subjective assessment of sedimentation yield potential, capacity to retain chemicals, and potential for regeneration are also stored on the cell file.

History File: In addition to the above files, several additional items of information are combined and stored on a history file. Briefly, these are: a) watershed summaries of selected attributes (for example, deer populations), b) recreation facilities information concerning the location and characteristics associated with recreation facilities, c) a history of manipulations occurring during the simulation, and d) economic and demographic trend data.

File Manipulation and Mapping: A series of approximately 50 computer programs have been written to create, update, edit, and retrieve information from the resource data base. Most of these are best viewed as service programs which provide a much needed capability for efficient manipulation during model development and running of the simulation model.

One additional capability we have developed deals with the production of resource maps. Using the line printer and a set of Boolean operations, maps are produced which show the status of 40 acre cells in any one of the 20 watersheds. A transparent plastic overlay with watershed boundaries, roads, streams, lakes, topographic features, and locational grids is superimposed over the computer produced watershed map to facilitate interpretation. While the resolution of these maps is not equal to that produced by more sophisticated graphics equipment, the maps are produced quickly and cheaply, and interface effectively with the resource data base.

Details of System:[2]

[2]A user's manual describing the SVEN Information System is also available from the authors.

Cell File:

As previously outlined, the cell file is the major file of the SVEN information system. Information in this file describes the average land, timber and soil characteristics for each cell in the Snohomish Basin. The file is designed to provide rapid storage, retrieval and updating of cell contents as well as to provide efficient data search and summarization capabilities.

As the system currently exists a maximum of 50 attributes may be stored for each cell. As shown in Table 1, only 45 of these are currently being used. Each attribute is allocated a specific number of bits according to its maximum possible value. These bits are in turn packed into computer words for more economical storage. The packing routine only functions on integer data. At present a maximum of six words of packed information may be used for each cell (CDC 6400 word length is 60 bits).

The packed cell data are stored on disk in section sized blocks. These blocks are the basic element of data transfer. A single block is kept in core in an array named CELL. The data for a particular cell within the section in core are located by the second subscript of the array. For example, cell number twelve would have its six words of packed data stored in locations (1,12) through (6,12). The locations corresponding to cells which do not exist or are not in that watershed are set to zero.

In order for the correct sections to be loaded into the CELL array a table of sections and pointers must be kept for each watershed. This table is an array called TOWNNDX. The first three words contain the township, range and section identifiers. The fourth word contains the

Table 1. Cell File Attributes.

Cell Identification

Watershed
Township
Range
section
Cell
Cartesian coordinates of cell

Soils data

Soil type
Site class
Sedimentation yield potential
Capacity to retain chemicals
Potential for regeneration

Physical Description

Cell size
Land use
Ownership
Cell description
Elevation
Slope
Aspect
Surface area of lakes
Feet of paved roads
Feet of mainline roads
Feet of secondary roads
Feet of temporary spur roads
Feet of streams
Feet of hiking trails
Feet of railroads

Timber Inventory

Type
Crown closure
Acres recent harvest
Acres re-growth
Age
Site index
Height
Basal area
Normal (100%) stocking
Number of trees
Av. diameter
Regeneration method
Fertilization method
Gross volume residue
Salvageable residue volume
Residue reduction method
Buffer strip protection
Size

relative disk sector at which the block of data is located. When a new section is requested this table is searched and the pointer used to read the correct data block.

The section index and cell data blocks are coordinated with the proper watershed through an index referred to as MASTER. This is an array containing a list of the watershed identifiers and the relative disk sector of the section indices. When data for a new watershed are requested this index is searched and the proper section index read.

These two indices and the cell data blocks combined with counters of the number of watersheds in the file and the number of sections in each watershed make up the cell file. Figure 1 illustrates the arrays mentioned above and Figure 2 illustrates the actual structure of the cell file.

Stream File:

The stream file serves as a storage area for information on stream locations and water flows. Each cell in a watershed is represented by either the location of a stream within the cell or with pointers defining the cell into which it drains. This provides the ability for locating a stream within a cell and for relating the cells, which are defined by political boundaries, to areas defined by natural boundaries.

The basic data grouping in the stream file are stream segments. A stream segment is defined to be the internodal portion of a stream or that portion lying between two stream junctions. Each stream segment is given a number which is unique within that watershed. All cells through which a stream segment passes and all cells draining into that stream segment comprise the data block for that segment. These data blocks along with

Figure 1. Cell File Arrays

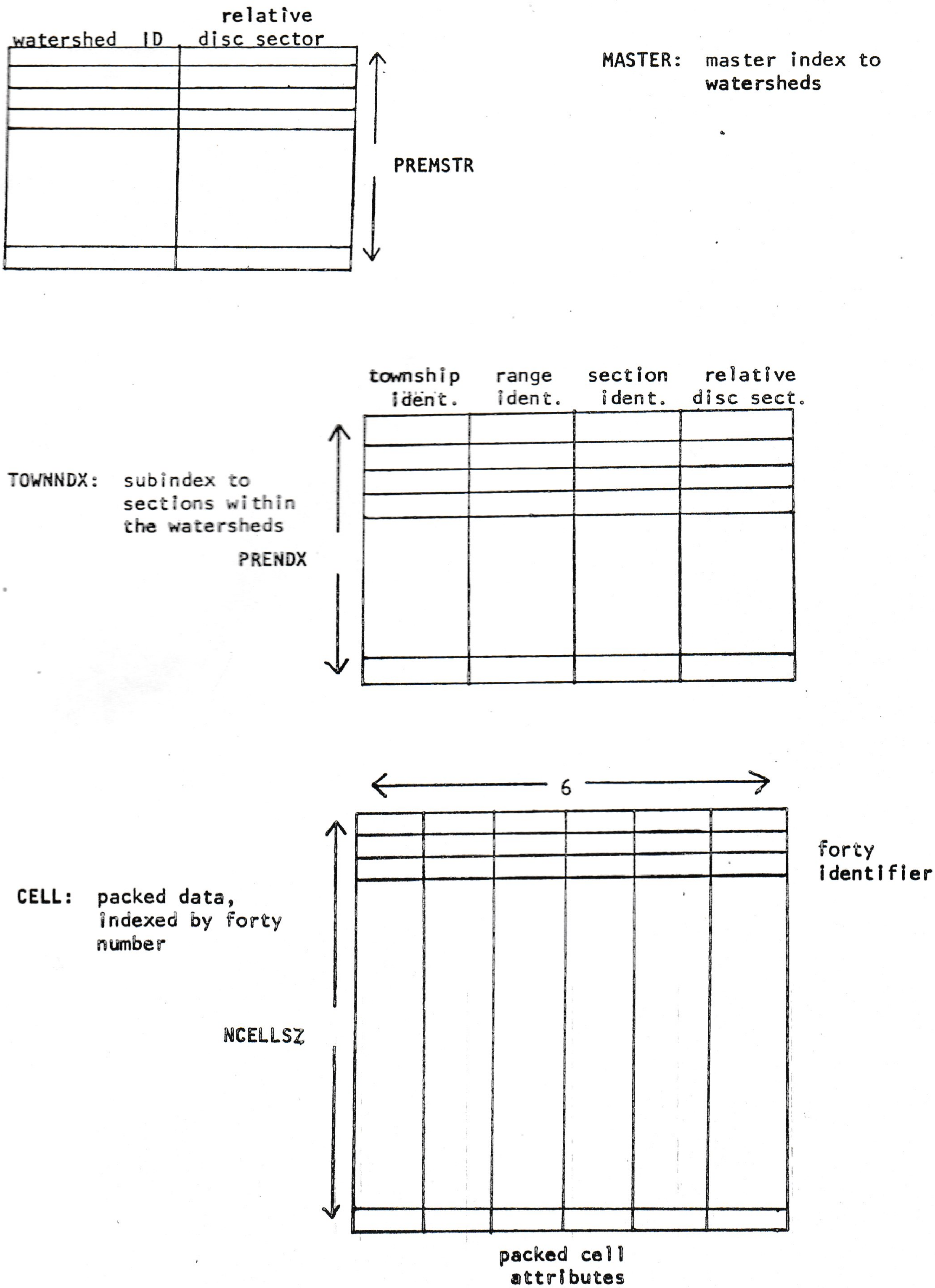
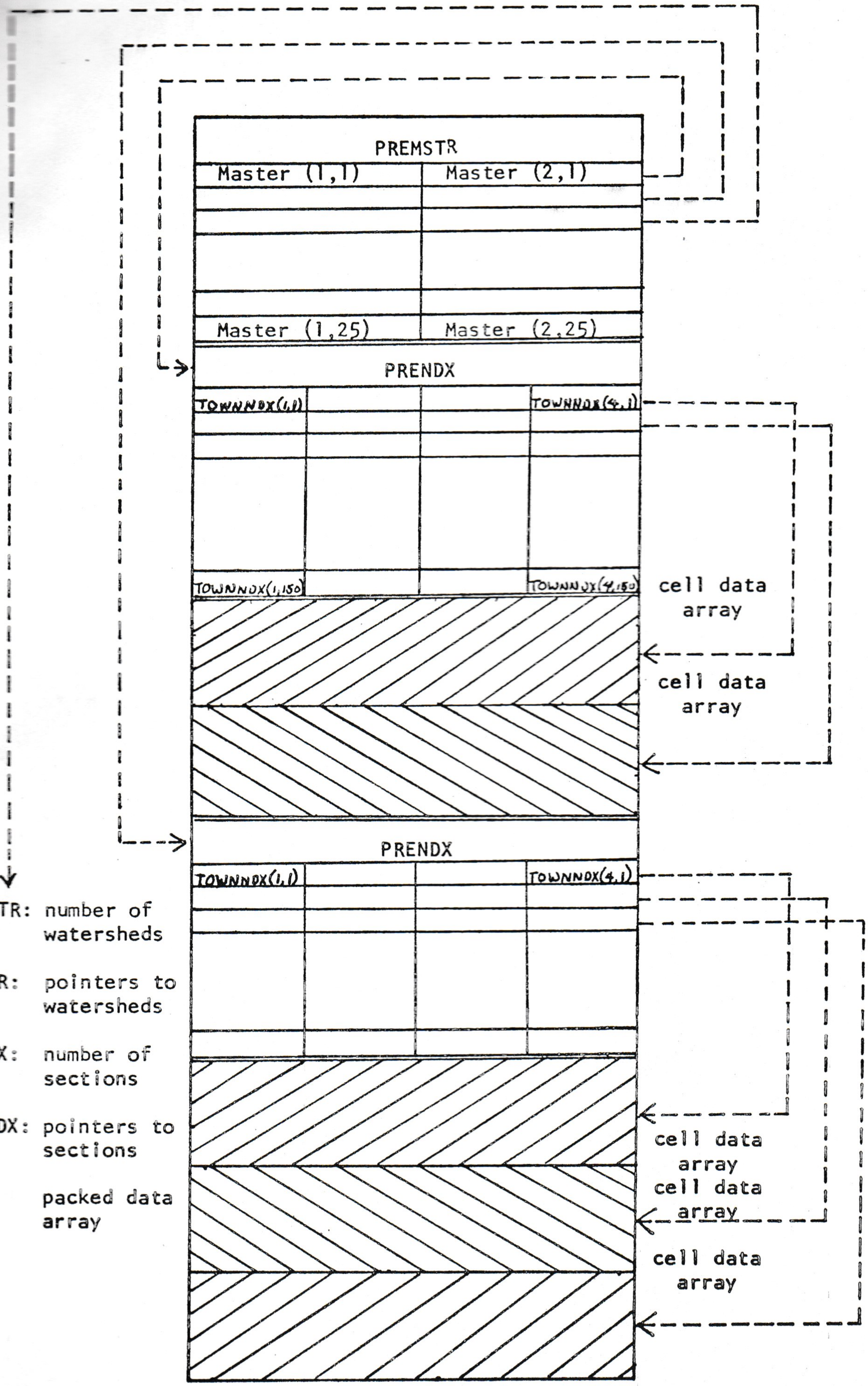


Figure 2. Cell File Structure



PREMSTR: number of watersheds

MASTER: pointers to watersheds

PRENDX: number of sections

TOWNNDX: pointers to sections

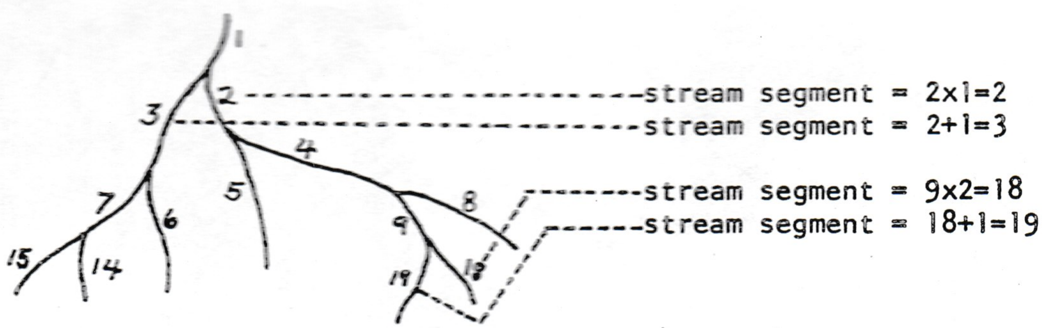
CELL: packed data array

the indices necessary to relate them to the stream numbers and watersheds make up the stream file.

As mentioned above, within a watershed each stream segment is given a unique number. This numbering process is initiated by assigning the number one to the stream segment located at the outflow of the watershed. Moving upstream to a junction one segment is given a number equal to twice the lower segments number. The second segment is given a number equal to the first plus one. This continues upstream until all stream segments have been numbered. This numbering process is more easily understood in Figure 3.

FIGURE 3

Stream Segment Numbering



The purpose for this numbering scheme is to provide a simple mechanism for routing streamflow through a watershed. Dividing any stream number by two and truncating the result to an integer will yield the number for the stream segment into which it flows. Conversly, multiplying any stream number by two and adding one to the result yields the two segments which join to form the original.

The major drawback of this numbering scheme is the fact that the numbers become large quite rapidly. It is not uncommon in a large watershed for these numbers to reach sixteen to eighteen digits. Obviously, interpretation and manipulation of these numbers by a user would be extremely time consuming and a very likely source of error. The solution to this problem lies in the fact that these large numbers are stored in order in an array called STRMNUM. All stream file manipulation routines have been written to accept the location of the stream number within this array as the actual stream number. This makes these large double-precision numbers invisible to the user allowing him to use much more manageable numbers.

The data block for a stream segment is made up of two types of cells. These are cells through which the stream passes and cells which drain into the stream. The basic data record for a cell is made up of twelve elements of information packed into one computer word for storage. These elements are a flag bit used in search routines, the four word cell identifier, a code denoting permanent or temporary streams, a code indicating cells not containing a stream and finally the stream location within the cell. In cells through which no stream flows the stream location is replaced by a pointer to the cell into which it drains.

The cells and pointer locations of a stream segment are ordered in the data block progressing upstream from the junction of the segment to the end of the segment. All cells and coordinate points through which the stream passes are stored first followed by the cells not containing a stream. Any cell through which more than one stream passes are stored in the data block for each stream.

The stream information for all cells within a watershed is stored in packed form in an array called MEMORY. Each position in MEMORY contains data for one cell. These cells are grouped into stream segment data blocks by the indices stored in the STRMNUM and MASTER arrays.

STRMNUM contains the double precision stream numbers as defined earlier. MASTER contains, for each stream, the positions in MEMORY at which the data block begins and the number of positions used by that data block. Thus, in this manner a particular stream is associated with the correct cell data. Figure 4 illustrates the structure of these arrays and the format of the cell data.

One STRMNUM, MASTER and MEMORY array exists for each of the twenty watersheds in the Snohomish River Basin. These, along with counters of the number of stream segments and the number of cells for each watershed are stored on a random access disk file. Figure 5 illustrates the structure of the stream file.

The data for the specified watershed are located through the use of an index to the watersheds. This index includes a list of the watershed identifiers and pointers to the relative disk sectors where their data begins. When a watershed is requested the index is searched, the starting disk sector located and all data for that watershed loaded. The entire block of information remains in core until a new watershed is requested.

History File:

Since the system simulation model acts directly on the resource data base, possibly destroying last cycle information, an additional file was required in which to record vital historical information. This history file contains two general types of information. These are: a) historical data for which time trend charts are required and b) previous cycle information and summaries which are required by current cycle submodels.

Figure 4. Stream File Array Structure

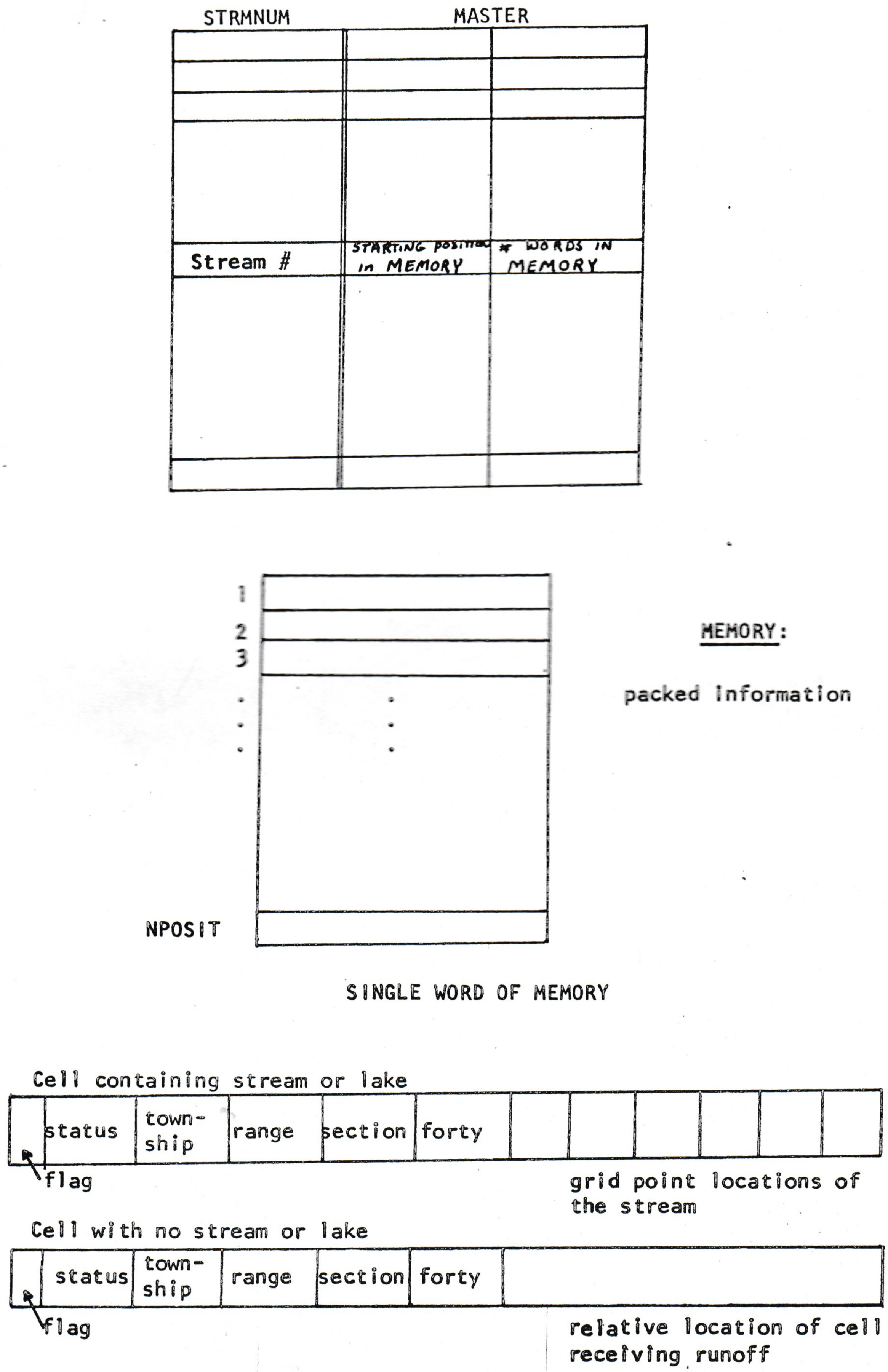
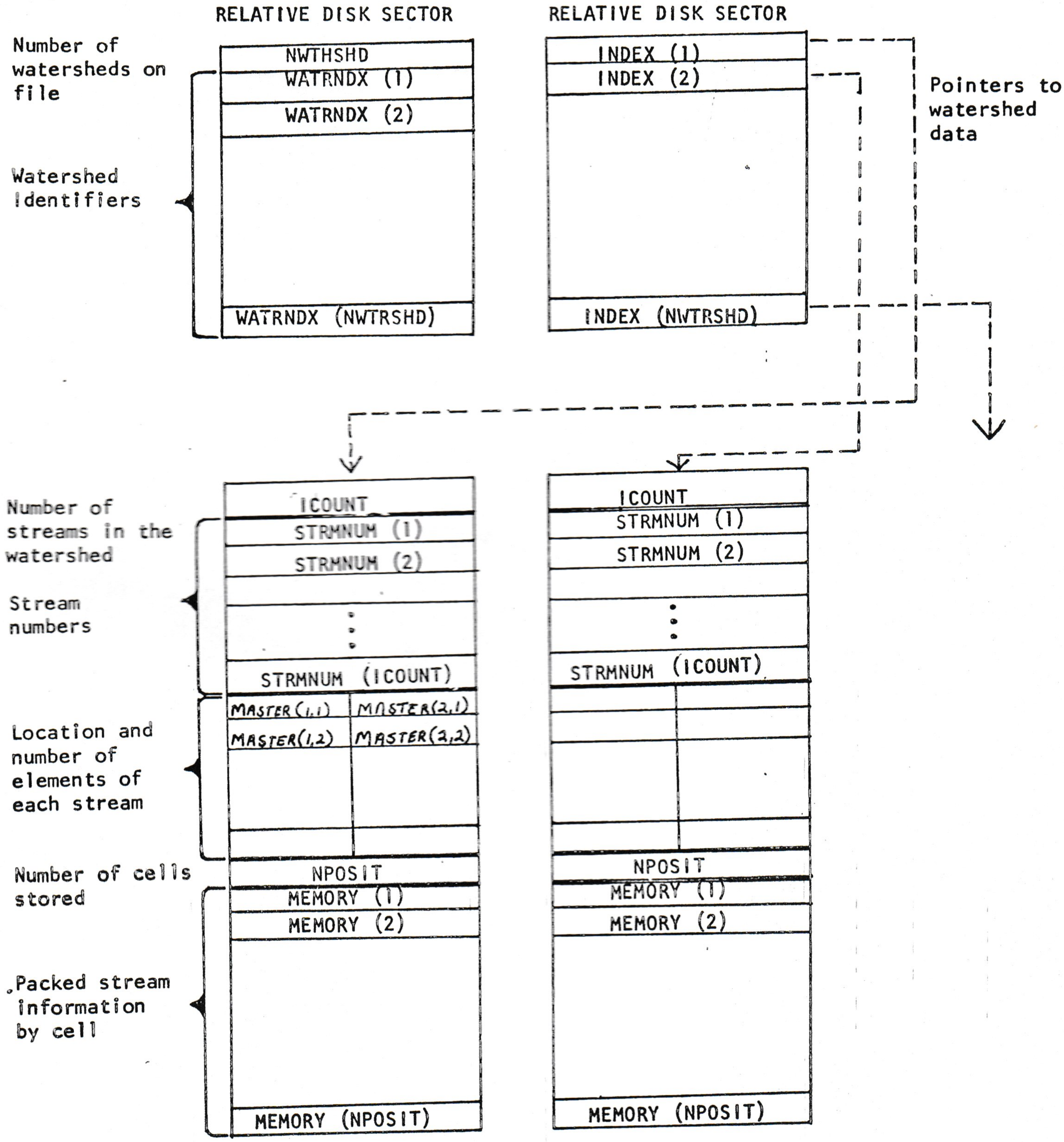


Figure 5. Stream File Structure



Information placed in the history file is keyed on year, watershed and a user definable trait name which describes the nature of the data being recorded. Certain information regarding the form of the data is also required. Data stored on the file are retrieved by specifying the year, watershed, and trait name. Figure 6 illustrates the history file structure.

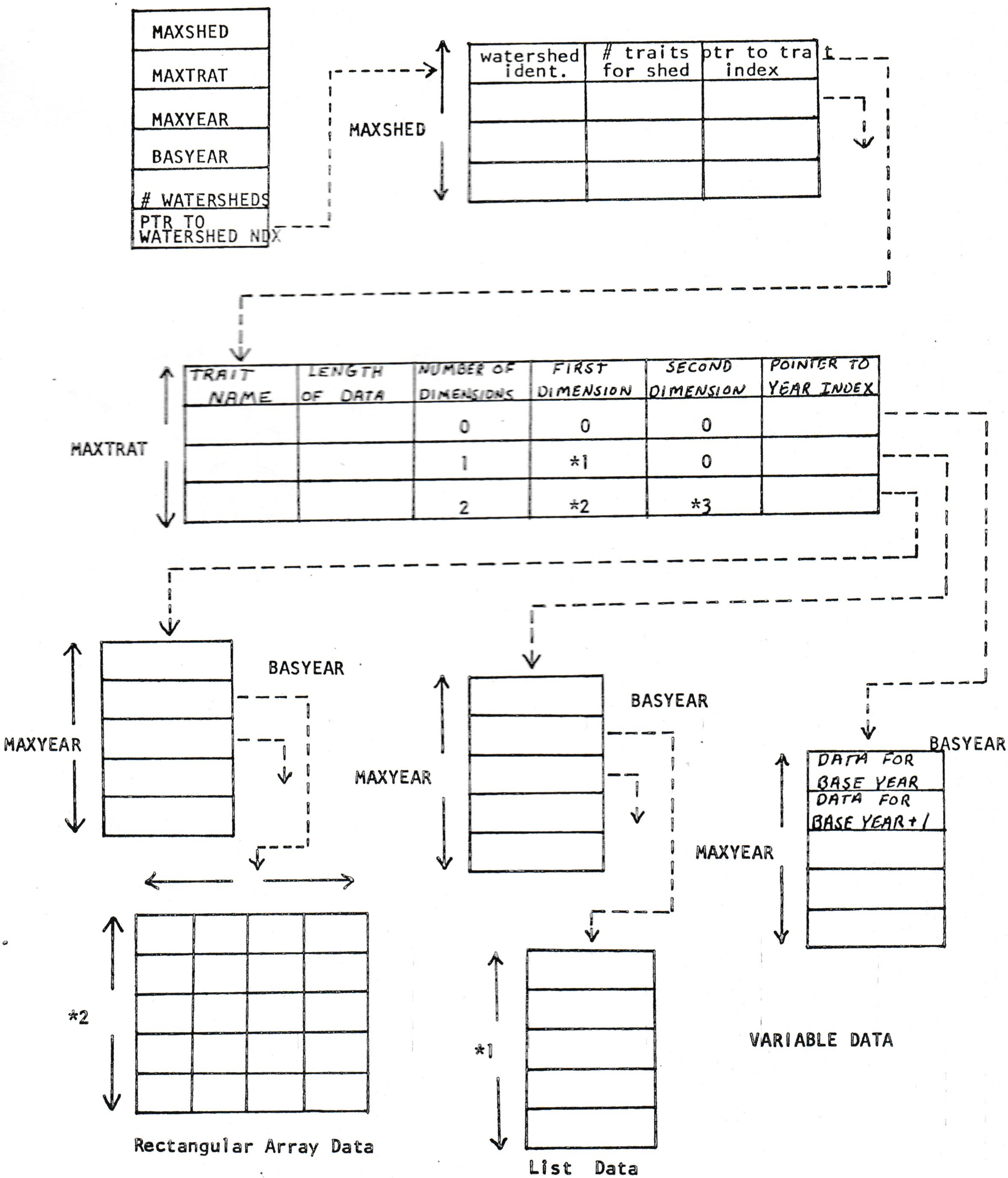
The flexibility of the history file allows for its use in many ways other than simple storage of historical data. The file is used for communication between submodels as well as storage of hydrologic and watershed summaries, fish and wildlife populations and results of individual submodel calculations.

Computer Requirements

The SVEN information system is currently operational on the CDC 6400 computer system at the University of Washington Computer Center. This system provides the memory and disk capacity required by the resource data base and processing programs. Most operations performed on the resource data base can be done with less than $(40,000)_8$ words of core. The disk space required for the files is the major restriction. The cell file uses approximately 500,000 words of disk storage and the stream file 200,000 words.

Despite its size, interaction with the data base does not consume large amounts of computer time. Sequential access of the cell file can be accomplished at a rate of approximately 2,000 cells per second. This includes disk access and unpacking. Random access takes slightly longer since the indices must be searched during each access of a new section.

Figure 6. History File Structure



The stream file uses very little time in accessing the disk since this is done only when a new watershed is needed. The time spent manipulating the stream file is usually small as all the information is in core.

The majority of the programming for the information system was done in FORTRAN. However, certain utilities, the most notable of which are the data packing and random file access routines, are written in COMPASS, the CDC assembly language. This was done because the expected frequency of their use demanded that they be as efficient as possible. No large problems should be encountered in transferring the system to other CDC 6400 systems. However, the COMPASS routines require re-coding if the system should be transferred to other computer systems. To date approximately five man-years have been devoted to the design and implementation of the information system.

Capabilities of the System

The three major purposes of the SVEN information system are to: a) provide for efficient storage, retrieval and updating of information during running of the system simulation model, b) provide information to support model development and c) respond to queries requesting information in the form of maps, summaries or listings.

Cell data may be retrieved or updated in either random or sequential fashion. In random access operations the order in which the cells are accessed makes no difference to the system. In sequential access operations the user specifies the area in which he is interested, such as a particular watershed or section, and the cells are returned one at a time when requested. In either case a specific subset of the attributes describing the contents of a cell or all of the attributes may be retrieved.

A user can request output from the system in the form of summaries, listings or maps. A specific group of attributes can be summarized over a given area. These summaries reveal the total acreage in each area by attribute. For example, acreage in each timber type may be retrieved for a watershed. Line printer maps may be produced for any attribute in a watershed and an English language dump describing the contents of cells in a specified area may be obtained.

A series of search routines have been written to allow a user to enter a set of constraints and retrieve data on cells meeting these constraints. Summaries, maps or listings may be obtained from this data as well as using it for input into the submodels.

The results of each year of simulated results may be stored on the history file. From this file a tabular listing or plot of values can be obtained. Both line printer and CALCOMP plotter graphs may be generated.

The stream file provides one of the most unique features of this system. This file allows a user to trace water flows both upstream and downstream and to define the watershed for any point within the basin. Interaction between the cell and stream files allows models to determine the factors affecting the hydrology of any point in the basin. For example, if certain fish spawning areas are known the watersheds for these points can be determined and activities within this area related to effects on the fish. We see this to be a valuable tool for modeling these types of activities.

Summary

As part of a study dealing with the environmental impacts associated with alternative forest land uses and practices, an information storage and retrieval system has been developed. This information system consists of a resource data base and a variety of support programs which facilitate file creation, maintenance, editing, and updating. In addition, summaries, listings, and maps can be generated in response to user queries. Approximately 190 programs (inclusive of the 50 used primarily for mapping) have been developed and are operational on a CDC 6400 computer system.

The resource data base consists of a set of files which describe the land, soils, vegetation, water, fish, and wildlife resources of the study area. After reviewing the advantages and disadvantages of both the polygon and cell approaches to computer information systems, a variable-size cell approach was adopted.

The information system was primarily designed to support the mathematical modeling of nonpoint sources of pollution arising from forest management activities. Further, the information system was designed to interface directly with the system simulation model, thus permitting rapid and efficient updating of the resource data base over time. Experience to date suggests that the system is satisfying both objectives extremely well.

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