FIPR Hydrologic Model

Part II:

HydroGIS:
ARC/INFO Utilities

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CHAPTER 1. OVERVIEW

Function and Utility

HydroGIS performs hydrologic spatial analysis operations which are specific to the data requirements and assumptions of the integrated FIPR Hydrologic Model (see Part I) and its component models MODFLOW (McDonald and Harbaugh 1988) and HSPF (Bicknell et al. 1993). Within the FIPR Hydrologic Model (FHM) interface, the capability exists to perform ground water only simulations with MODFLOW, surface water only simulations with HSPF and integrated hydrologic simulations.

The data requirements for these models can be completely satisfied by the user through manual data entry in the appropriate FHM pre-processor(s). Alternatively, approximately 80% of the data requirements (spatial data) can be fulfilled through automated GIS spatial analysis with the remaining portion (mostly temporal data) satisfied through manual entry in the pre-processor(s). The automated spatial analysis provided through HydroGIS yield many benefits: repeatable results, accurate data manipulation, significantly more detail, and time savings. The relationship between HydroGIS and FHM, from data requirements to feedback loop, is illustrated in Figure 1.1. Application of a centralized GIS and temporal data base to all model projects is a key concept to the most effective use of HydroGIS.

HydroGIS is a collection of Arc macro language (AML) and FORTRAN codes which perform spatial analysis operations and produce files that contain supporting hydrologic data for FHM and its component models. The free-format, comma delimited data files produced by HydroGIS are read by FHM pre-processors. GIS derived data are combined with manually entered information to create formatted files for FHM.

The graphical user interface of HydroGIS guides the user through four functions which include workspace management, coverage and data base management, spatial analysis, and map displays. Data preparation utilities, for surface water and ground water spatial data, are also available within the HydroGIS interface. The structure of the interface is illustrated in Figure 1.2.

Benefits and Liabilities

To fully utilize the capabilities of HydroGIS, a centralized spatial data base must be created, maintained and made available to a well-trained user community. Tremendous efforts must be made to build and maintain the spatial data base required for hydrologic modeling. The creation of the data base, in itself, provides for more efficient water resources management. Furthermore, the HydroGIS utilities (spatial analysis operations) provide significant assessment capabilities even without model simulations with FHM. One consequence of setting out to apply FHM using HydroGIS will be to identify significant data gaps in landform spatial data and hydrogeologic information. A unique aspect of the combination of the HydroGIS utilities and a comprehensive hydrologic model such as FHM is the capacity to pull model calibration datasets back into the GIS datasets to be archived and applied in subsequent model simulations or newly created model domains. This is a key feature for combined regional and local model domains.

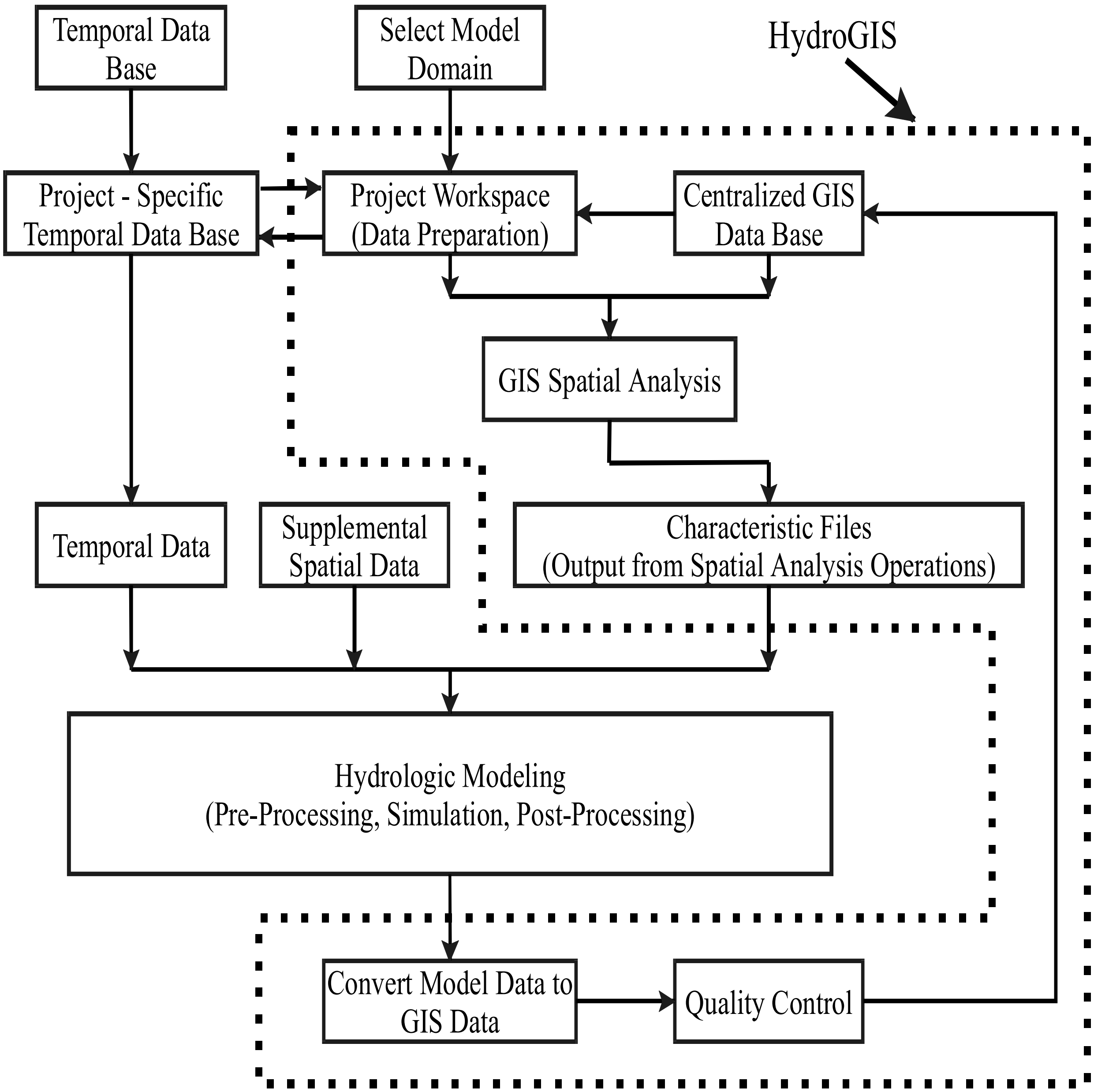


Figure 1.1 Relationship Between HydroGIS and FHM.

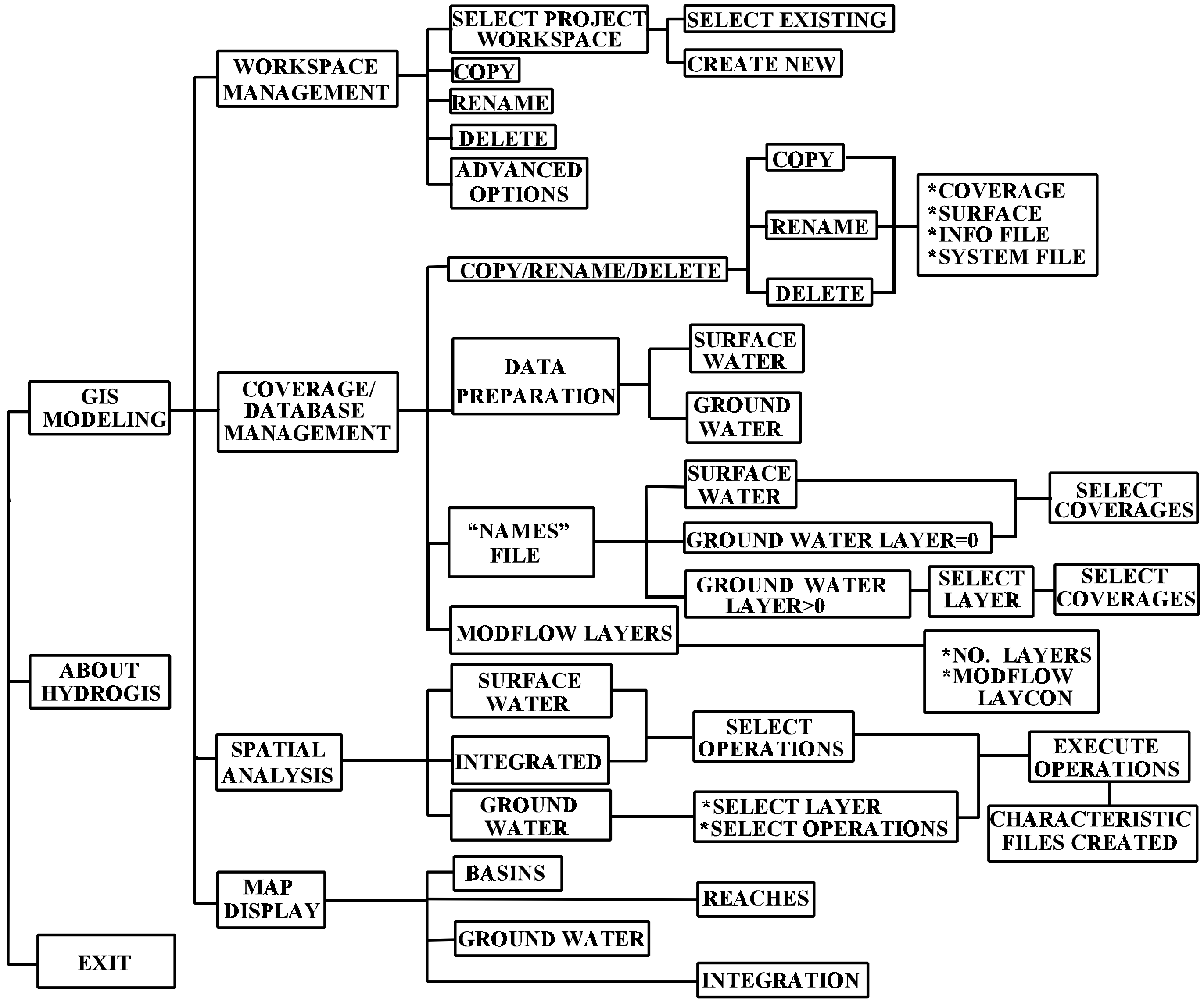


Figure 1.2 Structure of the HydroGIS Interface.

It is the opinion of the authors that the GIS is in fact what makes integrated modeling feasible, at least at the level of FHM. The data requirements and complexity would simply be intractable to provide manually for any appreciable domain. There are significant costs, however, in building the prerequisite GIS data base. In fact, costs are probably prohibitively high for a single application.

However, where a data base has been created, repetition in use will result in continued supplementation and increased quality assurance. Model application could inevitably become faster and comparable to even the simplest hydrologic models and, ultimately, much more reliable.

The GIS greatly facilitates the multi-scale modeling features of FHM that are so desirable. Near-field detailed (e.g., permitting) models rely on the same data base that is used in the regional (e.g., management) models. Boundary conditions are properly addressed and cumulative effects are inherently accounted for. The GIS provides the necessary linkages between the model scales. Hydrologic influences surrounding the near-field (refined) domain are properly included. With the GIS feature of FHM, local data generated to refine the near field models can be readily incorporated into the regional data base and, ultimately, the regional models. Overall data base improvement is an expected consequence.

The considerable benefits of this overall data base driven modeling strategy are not without costs. First, FHM requires a high level of user expertise because it encompasses both the hydrogeologic and surface water hydraulic systems. Furthermore, the GIS used for HydroGIS is a commercial software package that is generally <u>not</u> user friendly. ARC/INFO takes considerable training to become a proficient user, even more training to manage a system, and still more abilities to perform the required data base management. There are sufficient automated utilities (AMLs) provided in HydroGIS which develop datasets to "drive" FHM and the component models. However, development of the data base to a sufficient condition and maintenance of the data base are the predominant costs of applying the HydroGIS utilities. There is a ready supply of GIS data, however, much of this data is insufficient for hydrologic model applications. GIS technicians cannot develop the data base for hydrologic modeling without supervision and input from the end product users (water resource modelers). It may be equally unlikely that the periodic model users can stay proficient with the data base. For this reason a team approach should be expected to apply FHM and the component models, especially utilizing the GIS data base.

What is more likely and perhaps most desirable is that regional calibrated models (with associated GIS data sets and GIS resultant files) will be developed, distributed and supported for a much wider user community. This community will ideally include government agencies, consultants and corporate professionals who would benefit greatly from the technology for the day-to-day management and permitting requirements of the industry. The concept of using a common accepted data base and modeling tool would contribute to conflict avoidance.

The hardware requirements for HydroGIS are a UNIX workstation running ESRI ARC/INFO version 6.1 or better. Hard disk requirements vary with the data base used and level of detail (e.g., 1-10 Gb may be ultimately required). FHM and the component models, model data sets and GIS resultant files require a very modest platform readily available to any potential user. At the time of this printing, a desktop PC (e.g., 586) running windows or DOS with 16 Mb of RAM and greater than 200 Mb of hard disk would be adequate.

CHAPTER 2. DATA BASE STRUCTURE

HydroGIS is capable of accessing spatial data in ARC/INFO format from four different source areas at any time. The four source areas include two ARC/INFO workspaces, the ARC/INFO map library data base, and the hydrologic attribute data base. A typical data base structure is shown in Figure 2.1. Three of the four data sources are conceptually part of the centralized spatial data base. The project workspaces are not included in the centralized data base.

Data in ARC/INFO formats must be stored in an ARC/INFO workspace which is a system directory with an INFO subdirectory. HydroGIS accesses three different types of workspaces which include a project/user workspace, a protected/shared workspace, and a set of hydrologic attribute workspaces. The user has full read and write access to a project workspace, while there may be read-only access to protected and attribute workspaces. Typically, there is more than one workspace for either the project or the protected workspace categories. However, only one workspace from each category can be accessed during data preparation or spatial analysis processing while using HydroGIS.

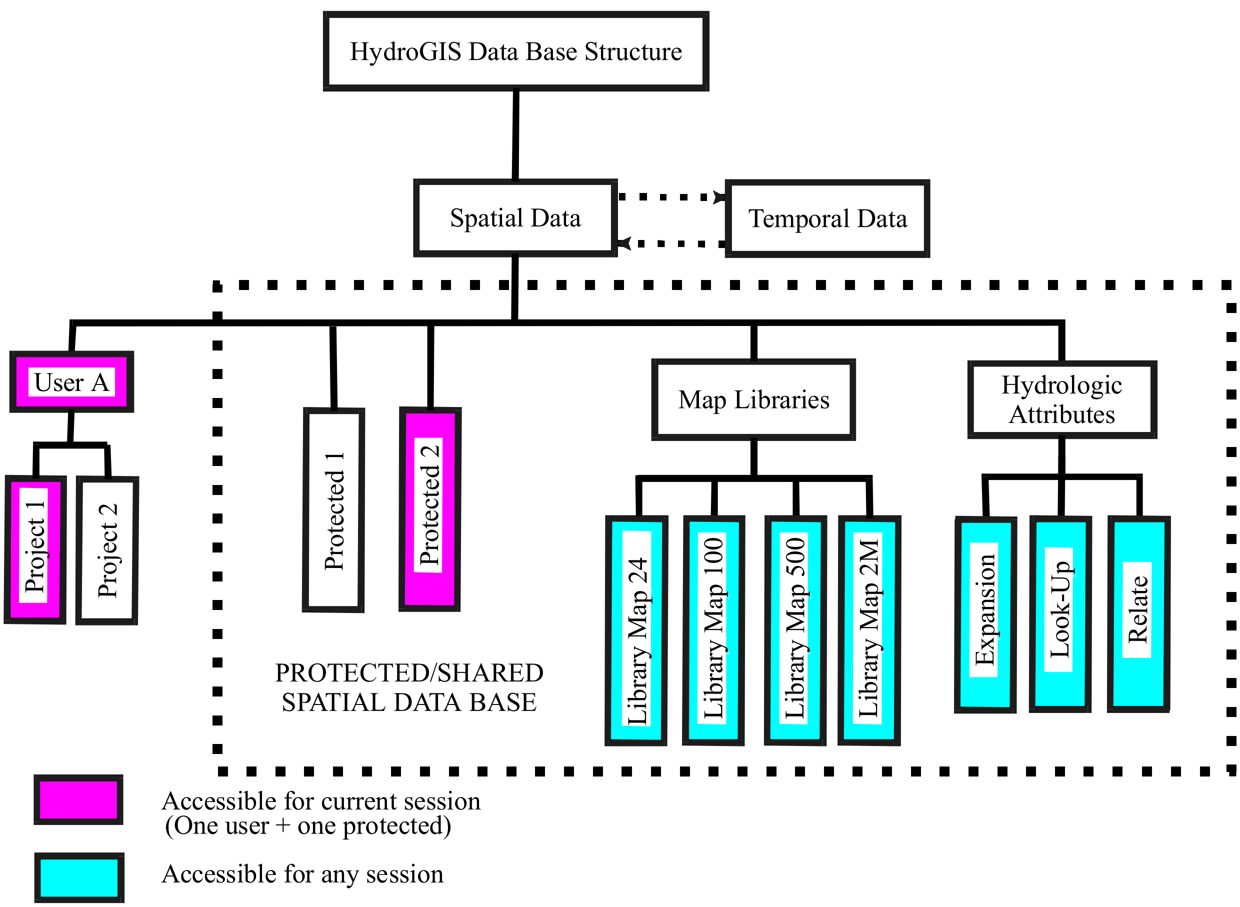


Figure 2.1 Example of the Four Data Source Areas Available to HydroGIS During a Session

Within the map library data base, there usually exists multiple libraries. Each map library is a special category of an ARC/INFO workspace which could be referred to as a "super" workspace. HydroGIS can access any and all map libraries which have been made available to the users by the ARC/INFO administrator. A map library is an efficient means of storing small-scale spatial data or data which require great amounts of disk space. A map library is also an efficient means for storing spatial data which must be shared among many users in a centralized data base concept.

The hydrologic attribute data base consists of three workspaces, which are typically assigned read-only access. Each workspace contains INFO tables that store hydrologic characteristics of physical features. The physical features include land use, streams, wetlands, lakes, pumping wells, etc. The attributes of the physical features include interception storage for the land use, stream cross-section geometry, bed leakance for streams and lakes, and cased and total depths for wells.

HydroGIS utilizes four data types to define the data base that is used for data preparation and spatial analysis processing. The four types are: (1) coverages, (2) continuous surfaces (TIN or lattice), (3) INFO tables, and (4) ASCII system files. HydroGIS can read from and write to each of the four data types. Other data element types can be used by ARC/INFO. However, the data requirements were designed to limit the types to those listed.

It is essential to maintain a system of unique identification (ID) with which spatial and temporal data base elements can be linked. The output data produced by HydroGIS is spatial data. Hydrologic model development requires linkage between spatial and temporal data. HydroGIS does a limited amount of temporal data processing. Most of the spatial/temporal linkage must be performed outside the HydroGIS interface. Examples include rainfall, potential or pan ET, and well pumping rates. Without a unique ID system, the full benefit and advantage of automated spatial analysis processing cannot be realized.

Workspace Environment

Two of the four HydroGIS functions handle issues related to the workspace environment. Through the workspace management and coverage and data base management functions of the HydroGIS interface, the project and protected workspaces are selected and the project data base is established and indexed. In addition, coverage and file manipulation tools are available within the interface to facilitate the tasks.

Before the first two functions of the HydroGIS interface are specifically discussed, a general description of a workspace and how workspaces are used within HydroGIS will be presented. In addition, the four data types used by HydroGIS will be defined and application examples provided. A workspace is a system directory within which all ARC/INFO processing is conducted. Recall that a workspace contains an INFO subdirectory, as well other directories and files, including:

1. An INFO directory where all INFO tables are stored
2. A directory for each coverage and continuous surface
3. A directory for each map composition (ARC/INFO graphical display format)
4. ASCII format files for various purposes (e.g., graphical files, projection files, contents of INFO tables, HydroGIS characteristic files)

Three categories of workspaces are used within HydroGIS: project/user, protected/shared, and attribute. Within HydroGIS, all data preparation and spatial analysis processing are performed within the selected project/user workspace. A protected/shared workspace is considered a read-only data base where thematic map data (coverages and continuous surfaces) are stored. The thematic map data stored in protected workspaces are applicable to all projects within a region (i.e., the data is not project specific) and are centrally accessible to all users. Three attribute workspaces are utilized by HydroGIS which are also considered read-only data bases and centrally-accessible. The attribute workspaces contain INFO tables which store hydrologic attributes. The tables can be associated with coverages stored either in the selected project workspace, selected protected workspace, or map library data base. The coverages provide the spatial position of physical features (e.g., land use or stream segment) while the attribute tables provide the hydrologic characteristics (e.g., interception storage or stream bottom width, respectively) of the physical feature.

Coverages and continuous surfaces contain topologic data. Topologic data provide the spatial relationships between connected or adjacent coverage features such as arcs, polygons, points, and nodes. Coverage data are a set of thematically associated data which form a digital analog of a map consisting of vectors, points, and associated attributes. ARC/INFO organizes the digital data into feature classes which include: polygons, arcs, points, nodes, routes, sections, and annotations ("ARC/INFO" 1991). The surfaces represent topographic elevation (land surface), aquifer top or bottom elevation, aquifer thickness, or confining bed thickness.

Each coverage and INFO table contain items, the name given to the data columns in feature attribute tables of coverages and in ARC/INFO tables. Each item of a coverage or INFO table is defined by a name, an input width, an output width, a data type (e.g., real, integer, character), and the number of decimal places.

The first three types of data used by HydroGIS are discussed above. The fourth type of data are ASCII system files. HydroGIS employs ASCII files in a variety of ways. This data type is used to index the data used for the project, to provide input for spatial analysis, to temporarily store spatial analysis results for subsequent additional processing, and to store the final results of spatial analysis in characteristic files.

The workspace management function of the HydroGIS interface is used to select the current project workspace and the current protected workspace. It is also used to move to a different directory (possibly to a different physical disk) to obtain a list of workspaces from which a selection can be made. Workspaces can be copied, renamed, or deleted with this HydroGIS interface function.

Before any data preparation or spatial analysis can be performed, the project workspace must be selected. As shown in Figure 2, an existing project workspace can be selected or a new project workspace can be created. The name of the new project workspace must be provided. A workspace is considered a project workspace by HydroGIS when two of the three project index files are available in a workspace. The two files are the "names" file (*.NAM) and the "paths" file (*.PTH). **When used with a file name in this document, the asterisk (*) refers to the name of the selected project workspace.** The project index files are ASCII, system files which are discussed in more detail in a subsequent section.

Upon initial execution of the HydroGIS interface, HydroGIS attempts to automatically select the project workspace. If HydroGIS is launched within a project workspace, as defined above, the project workspace is automatically selected as the workspace from which the interface was launched. However, if the directory from which HydroGIS is launched is not a project workspace, the interface displays a list of login IDs and project names. Each of the IDs and projects are associated with a path to a directory under which there are one or more workspaces from which the project workspace can be selected. After the appropriate login ID or project name is selected, the interface displays a list of workspaces from which the project workspace is selected.

When a new project workspace is created, the names and paths files are copied from a workspace which already contains these files. The files can be copied from a default set which is stored in the startup workspace or from another project workspace that is specified by the user. In either case, the paths contained in the "paths" file that are related to the project workspace are automatically altered to be compatible with the selected project workspace. The "names" file is not altered at this time.

The workspace management function permits a workspace to be copied to another name, renamed, or deleted. Full read/write/delete/execute privileges must be available to the user for the workspace to be renamed or deleted. The copy/rename/delete functions for a workspace do not require that the project workspace be selected.

Multiple project workspaces may be in production at any time. HydroGIS allows work to be performed within any project workspace. However, only the selected project workspace is active and is permitted to be used for data preparation and spatial analysis.

Through the coverage and data base management function, the project data base is established and indexed for utilization within the spatial analysis function. In addition, all four data types including coverages, surfaces, INFO tables, and system files can be copied, renamed, and deleted within the interface. The project workspace must be selected before any of the coverage and data base management functions are made available. All operations performed within this function of the interface are performed for the project workspace only.

Establishing the project data base refers to making all necessary input data available for spatial analysis. Establishing the project data base will typically entail using existing thematic map data (coverages and surfaces) to satisfy some input requirements and modifying existing or creating new thematic map data to satisfy the remaining input requirements. Recall that there are four data sources which can be accessed to satisfy input data requirements. Three of the sources (selected project and protected workspaces, and map libraries) can be accessed for coverages.

Only two of the sources (selected project and protected workspaces) can be accessed for continuous surfaces. Surfaces cannot be stored in map libraries.

It is necessary to index only the existing thematic map data which will not be altered. Thematic map data are indexed in the names file which is discussed later. The existing thematic map data that does not need to be altered is applicable to all model projects regardless of domain location or scale.

In addition to the existing, unaltered data, the remaining elements of the project data base are established through the data preparation process by modifying existing and creating new thematic maps. Many thematic maps, mostly coverages, require some form of modification to be applicable to the current project. Data preparation is competed through data preparation utilities within the interface and through user-defined methods outside the interface. Data preparation utilities are available for many facets of the thematic map modification and creation process. Utilities are available for data preparation of surface water and ground water thematic maps. The format specifications of coverages created or modified with the utilities meet the input requirements of the spatial analysis operations of HydroGIS. The utilities provide the capability to update the names file (automated indexing) with the names of any new thematic maps that are created with the utilities. Examples of coverages which are typically altered for a project include surface basins, hydrography, and rainfall and potential ET station locations. New thematic maps must be created for other coverages such as the ground water grid and general head boundaries for ground water spatial analysis. Refer to the Data Preparation Utilities sections in Chapter 3 for documentation of the data preparation utilities that are available within HydroGIS.

As the data base is being established and prior to initiation of spatial analysis processing, the project data base must be indexed. Data base indexing refers to providing the location of all required input data and to defining how ground water hydraulics data are to be used. Recall that there are three project index files which include the paths" file (*.PTH), the "names" file (*.NAM), and the ground water layer configuration file (LAYCHAR.DAT). The project index files are used for data preparation utilities and spatial analysis operations. Additional details on the project index files are available in a subsequent section.

Through the coverage and data base management function, all four data types including coverages, surfaces, INFO tables, and system files can be copied, renamed, and deleted within the interface. Each type of data can be copied from another workspace or directory only to the selected project workspace. All four types of data can also be renamed and deleted. However, these options are only available to data within the selected project workspace. These limitations are imposed due to system permission issues. It is assumed that the user has full permissions to read/write/delete/execute within the selected project workspace.

Once the entire project data base is established and indexed, processing can proceed to the spatial analysis operations. Refer to Spatial Analysis and Control in Chapter 3 for documentation of each spatial analysis operation and the associated data requirements.

Project/User Workspace

All data processing within the HydroGIS interface is performed within the selected project/user (project) workspace. By default, the selected project workspace is one of the four data source areas for spatial analysis operations. All coverages which were modified from the original content, to be applicable for the project, are stored in this workspace. All project index files for the project are also stored in this workspace. The results of the spatial analysis operations include characteristic files which are stored in the project workspace. An example listing of the contents of a project workspace is provided in Appendix A after the Project Index Files section. The workspace listing includes coverages, continuous surfaces, INFO tables, and ASCII files. The coverages and surfaces in the listing correspond to the contents of the names file example provided in Appendix A.

Protected/Shared Data Base

The protected/shared data base consists of all protected workspaces which contain thematic map data (coverages and continuous surfaces). The protected workspaces and their contents are read-only (protected) for all but authorized personnel who can modify the data, but accessible to all users (shared) through a network system. The protected/shared system maintains the integrity of the data and promotes efficiency in disk storage and accessibility. As stated earlier, only one protected/shared workspace can be accessed for HydroGIS data preparation and spatial analysis processing.

As limited by ARC/INFO, all continuous surfaces must be stored in a workspace. Continuous surfaces include Triangular Irregular Networks (TINs) and lattices. ARC/INFO does not include provisions for storage of TINs and lattices within a map library. Thus, all centrally-accessible surfaces must be stored in a protected/shared workspace. Surfaces which are specific to a project can be stored in the project workspace where they can be accessed for spatial analysis operations. The project index files must reflect the location of all required surfaces.

Map Library Data Base

The map library structure of ARC/INFO permits small-scale, typically disk-intensive coverages to be stored as one virtual "super" coverage. The library data base can consist of multiple map libraries which are all protected and shared. A map library is a special category of an ARC/INFO workspace and could be referred to as a "super" workspace. The hierarchy of a map library data base is fully explained in ARC/INFO documentation ("ARC/INFO" 1991 and "Using" 1991) and is summarized below:

1. Map library: "super" workspace, the virtual joining of all tiles (workspaces) within the library
    2. Library layer(s): "super" coverage, the virtual joining of a specific coverage from all tiles which contain the specific coverage
        3. Library tile(s): regular workspace with multiple coverages called library layers (contains a portion of the entire layer)

Within each map library "super" workspace, there exists multiple regular workspaces which are called tiles. Each tile workspace can contain multiple coverages. If, for a specific coverage stored in the tile(s) of a map library, the coverage parts from each tile could be physically joined into one coverage, a "super" coverage would be created. However, due to ARC/INFO limitations, disk space, and time efficiency this is not usually possible or desired. Thus, ARC/INFO "virtually" joins the parts of the coverages to permit graphical displays and limited analysis processing on the entire "super" coverage or library layer. A layer of a map library is the equivalent of a coverage in a regular workspace. GIS overlays cannot be performed on layers of a map library which requires special processing for HydroGIS spatial analysis operations which access map library layers.

In many cases, map library layers cannot be converted to a regular coverage due to ARC/INFO or disk space limitations. In summary, HydroGIS processes library layer data in parts. For example, an overlay must be performed between a library layer and another coverage. The layer consists of 100 tiles which are equivalent to 100 separate coverages that form one "super" coverage. This library contains small-scale, data intensive layers. Therefore, the ARC/INFO administrator for your system has specified for that library that only two (2) tiles can be joined together at any one time. HydroGIS copies two tiles (coverages), for the desired layer, from the library to the project workspace and joins them into one coverage. This is called the extraction process. The overlay is performed between the "two-tile" coverage and the other coverage. The results of the overlay are stored in a temporary "append" file. The "append" file contains the overlay results for only the area common to both coverages of the overlay. For the example, the extraction, overlay, and append processes are performed 50 times. After the 50th append, the "append" file contains all of the necessary overlay information. The summary process is used to generate the desired output. The summary process is identical for coverages stored in workspaces or map libraries.

Coverages which require topologic modifications that are stored in a map library must be copied (extracted) to the project workspace. The map libraries are a protected data base. Within the project directory, the coverage can be edited freely to meet the needs of the project. The modified coverage is then accessed from the project workspace instead of the map library. If the layer exceeds the limits of ARC/INFO or disk space, the ARC/INFO administrator must be consulted for a solution. Refer to Spatial Analysis and Control in Chapter 3 for more details on processing of map library data.

Attribute Data Base

The hydrologic attribute tables used by HydroGIS are stored in the hydrologic attribute data base which has protected and shared status. This data base is divided into three workspaces which include:

1. Expansion tables
2. Look-up tables
3. Relate tables

The attribute workspaces and their contents are read-only (protected) for all but authorized personnel who can modify the data, but accessible to all users (shared) through a network system. The protected/shared system maintains the integrity of the data and promotes efficiency in disk storage and accessibility. All three workspaces are accessible by HydroGIS for data preparation or spatial analysis processing. The tables which contain the hydrologic attributes are related to selected coverages including layers of map libraries.

Expansion tables are used for coverages which use a unique ID to form the relationship between coverage element and attribute table record. There is usually a one-to-one or one-to-many relationship between the coverage and the attribute table. An example coverage is stream hydrography.

Look-up tables are used for coverages which use a classification index to form the relationship between coverage element and attribute table record. There is usually a many-to-one relationship between the coverage and the attribute table. An example coverage is land use.

Relate tables are used when it is desired to "virtually" link an expansion or look-up table with a coverage. Relate tables do not contain attribute data. Alternatively, ARC/INFO commands are available to physically link the table to the coverage.

The attribute tables in the attribute workspaces are stored in INFO format. INFO is a relational data base which is used by ARC/INFO to manipulate feature attribute tables of a coverage and other tables such as the attribute tables. Although other relational data base formats are supported by ARC/INFO, the INFO data base system is packaged with the ARC/INFO system and is therefore available to all ARC/INFO users. By storing the hydrologic attributes in INFO tables which are separate from the coverages to which the data are associated, the data can be associated to multiple forms of the original coverage.

The original coverage is typically stored in a protected workspace or in the map library data base. The data elements of the coverage are attributed with a unique ID or classification index. For hydrologic modeling, the data elements are classified into groups. An example of this is the classification of streams into routing reaches. The unique ID of the stream arcs are preserved in the modified coverage but a new classification item (data column) which represents the reach number is added to the coverage. The modified coverage resides in the project workspace and is a copy of the original coverage. For the example, the hydrologic attributes can be related to the original coverage or to the modified coverage using the unique ID of the stream arc.

Project Index

As the data base is being established and prior to initiation of spatial analysis processing, the project data base must be indexed. Data base indexing refers to providing the location of all required input data and to defining how ground water hydraulics data are to be used. There are three project index files which include the "paths" file (*.PTH), the "names" file (*.NAM), and the ground water layer configuration file (LAYCHAR.DAT). All data preparation utilities and spatial analysis operations use the "paths" and "names" files. Some data preparation utilities and spatial analysis operations require input from all three of the project index files. Those that require all three index files are related to ground water operations.

The ground water layer configuration file contains MODFLOW "laycon" data which is necessary for operations related only to ground water. The MODFLOW "laycon" data provide an index of how thematic map data, which represent ground water hydraulics, are to be used to create compatible data sets for MODFLOW.

The "paths" file is also used to determine whether a workspace is a project workspace. This is important in the workspace management function when the project workspace is being selected.

The index files are ASCII, system files which can be created within the HydroGIS interface or with an ASCII editor appropriate to the operating system. Format specifications and examples for the "paths", "names", and ground water layer configuration files are contained in Appendix A.

Paths File

The "paths" file contains the full paths to four directories. The first two records after the headers indicate the paths to the directories which contain the selected project and protected workspaces. The first two directory paths are used for various coverage and data base management functions. The last two records contain the full paths to the selected project and protected workspaces. For data preparation utilities and spatial analysis operations, the workspace paths are concatenated to the names of coverages and surfaces contained in the names file to create full path names for indexed coverages and surfaces.

Names File

The "names" file is the second part of the project index. This file contains the names of coverages and surfaces that are used for data preparation and spatial analysis processing for surface water, ground water, or integration operations. At the top of the file, the number of GIS ground water layers and the x-y units (feet or meters) for coverages and surfaces are specified. For each coverage or surface, the following information is specified on one record in the "names" file:

1. *Layer number*, which is zero for coverages and surfaces not related to ground water operations for ground water layers and is equal to the number of the ground water layer if used for an operation related to a ground water layer.
2. *Coverage/Surface code*, which is repeated for layers greater than zero.
3. *Library name*, enter NONE if stored in a workspace.
4. *Layer/Coverage/Surface name* (not full path), enter NONE if there is no coverage or surface for the code.
5. *Analysis item name* for selected coverages and surfaces. Enter NONE if there is no coverage or surface for the code or if the item name is not required.
6. *x-y units* (feet or meters) of coverage or surface, must match the x-y units specified at the top of the file. Enter NONE if there is no coverage or surface for the code.
7. *z units* (feet or meters) are the units used for elevations in the continuous surfaces, must match the units specified at the top of the file. Enter NONE if there is no surface for the code.
8. *Storage location code*, which indicates where the coverage or surface is stored including project workspace (PR), protected workspace (PT), map library (LI), or no coverage (NO).

Ground Water Layer Configuration File

The ground water layer configuration file summarizes the conceptualization of the aquifer system. The number of ground water layers are provided along with the MODFLOW "laycon" value for each layer. The "laycon" value indicates the conceptualization of each ground water layer used in MODFLOW (McDonald and Harbaugh 1988).

CHAPTER 3. SPATIAL ANALYSIS OPERATIONS AND CONTROL

The third function of HydroGIS controls and executes the spatial analysis operations which create input files for the integrated FHM and FHM component models HSPF and MODFLOW. The bulk of the objectives for creating HydroGIS are fulfilled by this function. Within the context of HydroGIS, spatial analysis refers to the characterization of spatially-dependent data into representative values for the spatial descriptor (irregular polygon or grid) which is appropriate to the hydrologic model. The characterization process includes the methods utilized to summarize a continuously varying (in space) set of data, such as the soil infiltration rate or the aquifer hydraulic conductivity, into one representative value for each unique spatial descriptor zone. The spatial analysis operations are divided into three categories which are surface water, ground water, and FHM integrated. Documented for each operation category are the objectives, data requirements and preparation, data preparation utilities, and the individual operations. For each operation, documentation includes a description of the operation and the characterization process for hydrologic model data, a detailed accounting of the input data specifications, data preparation requirements and assumptions, and the output specifications. Following the discussion of the three categories of operations, documentation is provided for the controlling procedures that are used during spatial analysis. The AML codes which control the processing sequence for the individual operations are documented. In addition, the special processing requirements associated with map library data are provided.

Overview

As used within the context of HydroGIS, a spatial analysis operation characterizes spatially-dependent data to support the development of a hydrologic model. The HydroGIS operations provide input data for the integrated FHM and FHM component models: HSPF for surface water and MODFLOW for ground water. Each hydrologic model maintains a set of assumptions which places model-specific conditions upon the input data. Therefore, the data produced by the HydroGIS operations are applicable to only the models listed above. However, specific components of the hydrologic system may be simulated in the same manner by other hydrologic models. The data associated with those components of the hydrologic system would only then be applicable to other models.

The graphical user interface of HydroGIS guides the use of the spatial analysis function which consists of surface water, ground water, and integration operations. The spatial analysis operations are performed with modular computer codes written predominantly in AML language, with supplemental codes written in FORTRAN. There are 12 surface water operations, 22 ground water operations, and three (3) additional operations which support integrated FHM modeling. There are a total of 37 spatial analysis operations within HydroGIS.

Data requirements for the operations include 31 map themes including coverages and continuous surfaces. In addition, 14 INFO attribute and relate tables, three ASCII project index files, and the ASCII operation control file are necessary. Within each operation category, the data requirements are further refined. Most of the coverages and surfaces are used only for surface water or ground water operations, while the remaining are shared by surface water, ground water, and integration operations. There are no thematic data requirements which are unique to the integration operations. Required data for the operations are accessible from four storage locations which include the selected project workspace, the selected protected workspace, the map library data base, and the attribute data base.

Prior to initiating operations for spatial analysis, there are essential data preparation issues which must be resolved. There are data preparation requirements for both surface water and ground water operations. Data preparation utility codes, written in AML and FORTRAN languages, are provided within HydroGIS to facilitate the resolution of these issues.

Any combination of the 37 operations can be executed during a single run within HydroGIS. Within the interface, spatial analysis operations are executed with either an interactive mode (immediate execution) or a batch mode (scheduled execution at a later time). The selected operations are stored in the operations control file.

The result of any HydroGIS spatial analysis operation is an INFO characteristic file(s) and an ASCII, free-format characteristic file(s) which contain characterized hydrologic data in support of the integrated FHM and FHM component models. The results of the 37 operations are stored in at least 13 characteristic files. The number of files varies for ground water operations. Surface water characteristic files account for five of the files. There are at least seven characteristic files containing ground water model data and one file which is shared between the ground water and integrated FHM models. The seven ground water characteristic files are based on one aquifer layer and 20 or fewer stress periods. If there is either greater than one aquifer layer or greater than 20 stress periods, the number of ground water characteristic files becomes larger.

The ASCII characteristic files are read by FHM pre-processors which create formatted model input data files for the integrated FHM and/or the component models. The formatted files produced by FHM pre-processor for the HSPF and MODFLOW models conform to standard input formats of the respective models.

An error file, log file, and performance timer file are also produced as a result of executing spatial analysis operations. These files provide a means to ascertain the source of data errors, to document the operations which were processed, and to evaluate the performance efficiency and processing time requirements of each spatial analysis operation.

Surface Water

The spatial analysis operations for surface water are documented below. Documentation for each operation includes a description of the data characterization process, specifications for input and output data, requirements and assumptions for data preparation, derivation of spatial analysis algorithms where necessary, and other code documentation.

Objectives

The objective of the HydroGIS spatial analysis operations for surface water is to support the data requirements of FHM surface water component model HSPF. The 12 surface water operations in HydroGIS satisfy approximately 70% of the data requirements of HSPF that are necessary for FHM. HSPF provides pervious and impervious surface basin simulation and routing reach simulation. The data requirements for surface basins are supported by seven operations. The routing reaches account for the remaining five operations. The 12 surface water operations are summarized in Table 3.1.

Data Requirements and Preparation

Data requirements for the 12 surface water operations include 10 thematic maps in the form of nine coverages and 1 continuous surface, seven INFO attribute tables, and three ASCII files. One of the coverages (Modified Basins) is created by an operation and it is not required to be explicitly specified in the "names" file. Three of the INFO attribute tables also require an INFO relate table for a total of 10 INFO tables. The INFO attribute tables contain hydrologic attributes which are associated with classifications or unique IDs. The unique IDs are used to relate the elements (e.g., land use polygon, stream segment, lake in a coverage) to hydrologic attributes. As stated above, some of the attribute tables require an additional table (relate) to form the relationship between elements of a coverage and attributes in the INFO attribute. The coverages most often used are the surface basins and the line and polygon hydrography. A summary of the input requirements for each operation is provided in Table 3.2.

The surface water operations require two categories of spatial descriptors for which the spatial data are characterized for model applications. The categories include surface basins and routing reaches. The surface basins provide the spatial descriptor for all pervious and impervious land surface processes that are simulated by HSPF. The routing reaches provide the spatial descriptor for the reservoir routing processes that are simulated by HSPF. A surface basin typically forms an irregularly-shaped polygon which courses along topographic divides. In some instances, streams are also used to form basin lines.

Within HSPF, water which does not infiltrate the soil becomes runoff that is routed to a reach. Also, ground water which discharges into a water feature is routed to a reach. The water within a reach is routed downstream to adjoining reaches. Routing reaches are comprised of line and polygon hydrography features. Streams are represented by line hydrography while lakes, wetlands, reservoirs, and wide rivers are represented by the polygons. Polygons are created for the line hydrography features through a buffering process (i.e., the line is given width). The routing reach spatial descriptor is comprised of the combined features from the buffered lines and polygons for hydrography.

In the following sections, detailed specifications are provided about each of the coverages, the continuous surface, the INFO tables, and ASCII files. As with any model, there are specific data formatting requirements. However, the formatting requirements are provided in terms which are consistent with those used in ARC/INFO documentation. Although it is not required, familiarity with ARC/INFO terms will facilitate the understanding of the format specifications ("ARC/INFO" 1991).

Table 3.1 Descriptions of HydroGIS Surface Water Operations.

Operation	Operation Description	Operation Code
Modify Basins	The original classified basins coverage is modified by classifying regions associated with routing hydrography to a basin number equal to zero. The modified basin area is used for pervious and impervious land simulations. The basin areas in the modified basins coverage are equal to the areas in the original classified basin coverage less the routing reach area.	BASN
Slope	An area weighted mean slope is calculated for each basin.	SLPE
Soils Basins	An area weighted mean value of infiltration rate is calculated for each basin.	SOILSW
Land Use Basins	Area weighted mean values of overland flow Manning n, interception storage, and depression storage are calculated for each basin.	LANDSW
Hydraulic Length	A mean hydraulic length is calculated for each basin. Three methods are used to calculate the hydraulic length. If data are not available to calculate the hydraulic length with the primary method for a basin, an attempt is made to utilize the secondary method. If data are not available for either the primary or secondary methods, a minimum hydraulic length is assigned for the basin.	HYDL
Reach Length	The length of each reach is calculated. The reach length includes the length of all stream arcs added to the square root of the area of polygon hydrography elements.	LENGTH
Invert Elevation	The invert elevation for each reach is determined from the most downstream hydrography element of the reach.	STCOR
Depth/Area/Volume	The depth/surface area/volume relationship is determined for each reach. The algorithms compensate for reaches with multiple Strahler orders.	DAVD
Rainfall Basin	The point source rainfall data are spatially distributed over the basins using Thiessen polygons. The percentage contribution of each rainfall station to each basin is calculated.	RNFBASIN
Rainfall Reach	The point source rainfall data are spatially distributed over the reaches using Thiessen polygons. The percentage contribution of each rainfall station to each reach is calculated.	RNFREACH
PET Basin	The point source PET (potential evapotranspiration) data are spatially distributed over the basins using Thiessen polygons. The percentage contribution of each PET station to each basin is calculated.	EVTBASIN
PET Reach	The point source PET data are spatially distributed over the reaches using Thiessen polygons. The percentage contribution of each PET station to each reach is calculated.	EVTREACH

Table 3.2 Input Data Requirements for HydroGIS Surface Water Operations.

NOTES:

[1] T/L represents a tin or lattice surface.

[2] Modified basin area is used in the hydrologic model. The modified basin area is equal to the original basin coverage area less the routing reach area.

[3] Routing hydrography features, including buffered streams and hydrography polygons, are contained in the coverage with a basin number (for the item class) equal to zero.

[4] For topographic surface in lattice format.

		THEMATIC MAP and (FEATURE CLASS [1])										ATTRIBUTE TABLES (INFO FORMAT)						
OPERATION	CHARACTERISTIC	Classified Basins (Poly)	Modified Basins [3] (Poly)	Topographic Slope (Poly)	Land Use (Poly)	Soils (Poly)	Classified Line Hydrography (Line)	Classified Polygon Hydrography (Poly)	Topography (T/L)	Rainfall Thiessen (Poly)	PET Thiessen (Poly)	Land Use Hydrologic & RELATE	Soils Hydrologic & RELATE	Line Hydrography Connectivity	Line Hydrography Hydrologic	Polygon Hydrography Hydrologic	Lattice Slope LOOK-UP & RELATE [4]	Reach Water Depths LOOK-UP
Modify Basins	Modified Basin Area [2]	X					X	X							X			
Slope	Basin Slope		X	X														
Soils Basins	Infiltration Rate		X			X							X					
Land Use Basins	Overland Manning n		X		X							X						
Land Use Basins	Interception Storage		X		X							X						
Land Use Basins	Depression Storage		X		X							X						
Hydraulic Length	Basin Hydraulic Length	X					X	X	X					X		X	X	
Reach Length	Reach Length						X	X										
Invert Elevation	Reach Invert Elevation						X	X							X	X		
Depth/Area/Vol.	Reach Depth/Area/Volume						X	X						X	X	X		X
Rainfall Basin	Rainfall Station % by Basin		X							X								
Rainfall Reach	Rainfall Station % by Reach						X	X		X					X			
PET Basin	PET Station % by Basin		X								X							
PET Reach	PET Station % by Reach						X	X			X				X			

In addition to the format specifications there are data preparation issues which must be resolved prior to execution of spatial analysis operations. Data preparation within HydroGIS refers to the preparation of thematic maps, INFO tables, and ASCII files to conform to required specifications and assumptions for the data. Within HydroGIS, data preparation utilities are provided which facilitate the preparation of selected coverages and INFO attribute tables. Data preparation pertains to both the protected/shared and to the project-specific data bases. As stated earlier, the protected/shared data base elements include all coverages, surfaces and INFO attribute tables which are protected and shared through a centrally-accessible network. All of the attribute tables listed in Table 3.2 are typically a part of the protected/shared data base. The protected/shared data base elements should be updated as new data become available. The purpose for data preparation for project-specific coverages is usually to meet the objectives of the project and may include incorporation of new data. All project-specific data are stored in the project workspace.

Data preparation and specifications for coverages and surfaces for surface water operations are provided in the following section. Data preparation and specifications for INFO tables and ASCII files are provided in the section which follows coverages and surfaces. The data preparation utilities for surface water operations are documented in the section which follows ASCII files.

Coverages and Continuous Surfaces

As summarized in Table 3.2, surface water operations require nine coverages and one surface which are listed below (with the feature class). These data are defined briefly in this section. Detailed format specifications for each coverage and the surface are provided in Appendix A. The specifications pertain to naming conventions, names file requirements, feature classes, required items, prohibited items, coverage building, projections, elevation (z) units for surfaces, and special requirements for each coverage or surface. Typically, data preparation issues must be addressed for the coverages which are **highlighted** to make them applicable to the objectives of the current project. The highlighted coverages may originate from a protected/shared data base but the spatial detail of the data is not appropriate for the current project. The highlighted coverages are most likely to be stored in the project workspace, applicable only to the current project. Data collected subsequent to the last time a coverage or surface was updated could warrant a data preparation step for the remaining coverages and surface which are not highlighted. Of the coverages listed below, only the Modified Basins coverage is not explicitly contained in the “names” file.

- **Classified Basins** (polygon)
- **Modified Basins** (polygon)
- Mean Basin Slope (polygon)
- Land Use (polygon)
- Soils (polygon)
- **Classified Line Hydrography** (line)
- **Classified Polygon Hydrography** (polygon)
- **Rainfall Thiessen** (polygon)
- **PET Thiessen** (polygon)
- Topographic Elevation (TIN or lattice)

In the following paragraphs, each of the coverages and the surface are briefly defined. Following the definitions, a summary of data preparation steps for each are provided.

Typically, the **classified basins** coverage is only applicable to the current project. The classification system for basins follows a sequential numbering system (no skips) starting with basin number 1. There is a maximum limit of 50 basins which is imposed by FHM V3.0. Where necessary, basin divides are added to the original basins coverage (i.e., stored in a protected/shared data base) at calibration points such as streamflow or stream stage recording stations. It may be necessary to add other basin divides or to aggregate basins to meet the objectives of the current project. Any new basin divides should be added to the original basins coverage. Subsequent modeling projects benefit from including all new basin divides in the original basins coverage. The classified basins coverage is used as the spatial descriptor for the hydraulic length operation.

The **modified basins** coverage is the spatial descriptor for all but one surface water operation for surface basins. As stated above, only the hydraulic length operation uses the classified basins coverage. The modified basins coverage is created by one of the surface water operations (Modify Basins) through automated re-classification of basin zones where routing reaches are located. Wherever a routing reach exists, the surface area associated with it is removed from the basin area. The area for each basin in the modified basin coverage will be either equal to or less than the area for the same basin in the classified basins coverage. This coverage must be stored in the project workspace and is given the same name as the classified basins coverage concatenated with the prefix letter "m" representing modified.

With a continuous surface of topographic elevation in either TIN or lattice format, a **mean basin slope** coverage is created. The basin slope coverage is created for the smallest surface basins available or it can remain in its original polygon form with no averaging of slopes. The mean slope for each basin is added as an attribute to a basins coverage to create the basin slope coverage. The basin slope coverage should be updated whenever smaller basins have been delineated or topographic elevations have been revised. A protected/shared data base is the typical storage location for this coverage.

The **land use**/land cover coverage is likely to be very detailed and could require storage in a map library, a unique form of a protected/shared data base for large coverages. The coverage contains polygons which represent a homogenous classification of land use or land cover. Hydrologic attributes are assigned to each unique classification. The attributes are stored in INFO tables, which are discussed in the next section.

The **soils** coverage is likely to be very detailed and could require storage in a map library, a unique form of a protected/shared data base for large coverages. The coverage contains polygons which represent a homogenous classification of soil series or soil association. Hydrologic attributes are assigned to each unique classification. The attributes are stored in INFO tables, which are discussed in the next section.

For surface water operations, water features or hydrography are stored in two forms which include the **classified line hydrography** and the **classified polygon hydrography** coverages. The combination of these two coverages form the spatial descriptor for surface water operations for routing reaches. The original line and polygon hydrography coverages (i.e., stored in a protected/shared data base) may contain hydrography features which are located outside the model area for the project. To increase processing efficiency, it is recommended that unnecessary data be removed from the classified coverages.

The hydrography features are classified (i.e., grouped and numbered) into routing reaches for surface water modeling applications with HSPF and for integrated modeling. The reach classification (i.e., numbering) is used by the surface water and the ground water component models for integrated modeling. The classification system for reaches follows a sequential numbering system (no skips) starting with reach number 1. Similar to the limitation on the number of basins, there is a maximum limit of 50 reaches which is imposed by FHM V3.0. FHM requires smaller numbered reaches to be routed to larger numbered reaches, an issue to be aware of during hydrography classification.

A second classification system for hydrography is employed only for simulation with the integrated FHM. Each line and polygon hydrography element that has been assigned a reach number for routing is further classified as dynamic or static. The significance of dynamic/static classification is explained later in this definition. Dynamic elements maintain a positive reach number while static elements are given a negative reach number. A reach can be comprised of both dynamic and static elements or can be classified as only dynamic. A special case of static-only classification is explained later in this definition.

The dynamic/static classification is significant for integrated FHM simulations (see Part I). One component of the integration process includes the modification of stream stage with time in the ground water component model, MODFLOW. For each integration time step, the water depth in each reach that is simulated by HSPF is transferred to the river package of MODFLOW. Based on the new water depths, the stream stages in the river package are updated which affects the baseflow flux. However, the stage is updated for only the dynamic elements of each reach. Because the water depth decreases with decreasing stream order (Strahler method), a significantly greater water depth is applied to the lower order streams if the dynamic elements of a reach include a mixed set of stream orders. The water depth simulated by HSPF represents the most downstream cross-section which is associated with the highest-ordered stream. For the above reasons it is recommended to classify as dynamic only those elements that represent the highest stream order for each reach. The remaining elements of the reach are classified as static.

The special case of static-only reach classification is used when the hydrography elements are not included as part of a routing reach, but are significant enough to be included in the ground water model component of FHM. Ground water only reaches are classified as completely static and are given the highest reach classification values. This means that all reach numbers that are greater than a static-only reach are either also static-only or do not exist.

A static reach element has constant stage in the ground water component model (river package) throughout the simulation. Only the first stress period data for stage from the MODFLOW river package are used.

The line hydrography coverage must be in the EPA RF3-Alpha format ("EPA" 1994). The polygon coverage was created from the RF3-Alpha line coverage and has specifications provided in Appendix A.

The **rainfall Thiessen** and **PET Thiessen** coverages are created from the station locations (point) of hourly rainfall and daily pan or potential ET respectively. As the name implies, the coverages consist of Thiessen polygons. The temporal data associated with each station (point) is spatially distributed across surface basins and routing reaches with these Thiessen polygon coverages. Therefore, to avoid inadequate rainfall and/or PET distribution, it is important that the temporal data for each station included in the Thiessen polygon coverages meet the specifications of the project for missing or erroneous data. Only verified stations should be included in the Thiessen coverages. These coverages are likely to be project-specific.

The **topographic elevation surface** can be a TIN or a lattice. However, due to ARC/INFO limits, a lattice may be the only option for large regional project areas. This surface is typically stored in a protected/shared data base.

Before embarking upon spatial analysis using the surface water operations, ten project-specific operations for data preparation must be completed. These operations include:

1. Modify Basin Delineation - To meet project objectives, add additional basin delineations, especially at streamflow or stream stage recording stations. Again, any new basin divides should be added to the original basins coverage. Subsequent modeling projects benefit from including all new basin divides in the original basins coverage.
2. Basin Selection - From the original basins coverage stored in a protected/shared data base, select the surface basins to include in the model. This process removes basins which are located outside the model extent. If an integrated model is being developed, the active region of the ground water grid will place additional constraints on basin selection. For the integrated FHM model, all active cells of the ground water grid must be covered by a surface basin. To meet this requirement, surface basins outside the area of immediate interest may need to be included.
3. Classify Surface Basins - Using FHM V3.0 specifications, classify (group) the basins to meet project objectives. Classification values (i.e., basin numbers) are contained in item "class" of the polygon attribute table of the classified basins coverage.
4. Hydrography Selection - From the original line and polygon coverages stored in a protected/shared data base, select the hydrography elements to include in the model. This process removes hydrography elements which are located outside the model extent and unnecessary elements. Saltwater features are considered unnecessary.
5. Classify Hydrography - Using FHM V3.0 specifications, classify (group) the line and polygon hydrography elements into reaches to meet project objectives. Classification values (i.e., reach numbers) are contained in item "rchclass" of the arc and polygon attribute tables of the classified line and polygon coverages respectively. Also classify each hydrography element used for routing in HSPF as dynamic or static. Ground water only reaches are classified as completely static and are given the highest reach classification values. Dynamic reaches have a positive reach classification while static reaches have a negative reach classification.

6. Reach Water Depths - For only the Depth/Area/Volume operation, an INFO table must be created which contains the depth intervals for each reach. FHM V3.0 limits the number of depth intervals to 11.
7. Select Rainfall Stations - Select verified hourly point source rainfall stations. The rainfall data are verified to be acceptable for simulation over the simulation period.
8. Rainfall Thiessen - Create a Thiessen polygon coverage from the locations of verified hourly point source rainfall stations.
9. Select PET Stations - Select verified daily point source potential or pan evapotranspiration (ET) stations. The potential or pan ET data are verified to be acceptable for simulation over the simulation period.
10. PET Thiessen - Create a Thiessen polygon coverage from the locations of verified daily point source potential or pan ET stations.

INFO Tables

As summarized in Table 3.2, surface water operations require seven INFO attribute tables which contain hydrologic attributes. The INFO attribute tables are divided into two categories which include expansion tables and look-up tables. Three of the INFO attribute tables also require an INFO relate table (a third category) for a total of 10 INFO tables. The INFO attribute tables contain hydrologic attributes which are associated with classifications or unique IDs. The unique IDs are used to relate the elements (e.g., land use polygon, a stream segment, a lake) in a coverage to hydrologic attributes. As stated above, some of the attribute tables require an additional table (relate) to form the relationship between elements of a coverage and attributes in the INFO attribute table. Of the 10 tables, nine tables are typically stored in a protected/shared data base. The look-up table for reach water depths contains project-specific data and is stored only in the project workspace. The system administrator of ARC/INFO establishes the locations (workspaces) for the tables and specifies the paths to the INFO tables in the administrator variable AML (HGISVAR.AML). Each of the three INFO file categories require separate workspaces for storage in the protected/shared data base. The location of the INFO tables is transparent to the user. The expansion, look-up, and relate INFO tables required for surface water operations are defined in Appendix A. Detailed format specifications for each INFO table are also provided in Appendix A. The specifications pertain to naming conventions, storage location, sort item(s), required items, prohibited items, and special requirements for each table. Data collected subsequent to the last time an attribute table was updated could warrant a data preparation step for the affected tables. A list of the INFO tables is provided below. The **highlighted** table must be prepared for each model project.

- Land Use Hydrologic (look-up)
- Land Use Hydrologic (relate)
- Soils Hydrologic (look-up)
- Soils Hydrologic (relate)
- Line Hydrography Connectivity (expansion)
- Line Hydrography Hydrologic (expansion)
- Polygon Hydrography Hydrologic (expansion)
- **Reach Water Depths** (look-up)
- Lattice Slope (look-up)
- Lattice Slope (relate)

In the following paragraphs, each of the INFO tables listed above are briefly defined. Following the definitions, a discussion of data preparation for the INFO tables is provided.

The **look-up** table which contains **land use hydrologic attributes** includes a land use/land cover classification code and five hydrologic attributes. The classification codes used in the look-up table match those used in the land use coverage. There is a many-to-one relationship between the land use coverage and the look-up table.

The **relate** table for **land use hydrologic attributes** provides a virtual link (i.e., the tables are not physically joined) between the look-up table and the coverage for land use. The relate table contains the full path to the look-up table, and contains the items (data columns) in the look-up table and in the coverage which are used to produce record matches.

The **look-up** table which contains **soils hydrologic attributes** includes a soil series or soil association classification code and five hydrologic attributes. The classification codes used in the look-up table match those used in the soils coverage. There is a many-to-one relationship between the soils coverage and the look-up table.

The **relate** table for **soils hydrologic attributes** provides a virtual link (i.e., the tables are not physically joined) between the look-up table and the coverage for soils. The relate table contains the full path to the look-up table, and contains the items (data columns) in the look-up table and in the coverage which are used to produce record matches.

The EPA RF3-Alpha coverage includes a **line hydrography connectivity** expansion table. This table establishes the upstream and downstream connections between stream arcs. Beyond the standard items (data columns) which are provided by the EPA in this table, one additional item is added which is the Strahler stream order. There is a one-to-one relationship between the line hydrography coverage and the expansion table.

Hydrologic attributes for the line hydrography coverage are provided in two expansion tables which are the **line hydrography hydrologic** and the line hydrography hydrologic layer tables. The line hydrography hydrologic table contains attributes that are applicable to surface water modeling and to ground water modeling which are not related to aquifer layers. The second table contains attributes related to aquifer layers that is only applicable to ground water modeling. The second table is discussed under ground water operations. The expansion table for line hydrography hydrologic attributes has a one-to-one relationship with all stream arcs in the line hydrography coverage for which hydrologic attributes are desired.

Hydrologic attributes for the polygon hydrography coverage are provided in two expansion tables which are the **polygon hydrography hydrologic** and the polygon hydrography hydrologic layer tables. The polygon hydrography hydrologic table contains attributes that are applicable to surface water modeling and to ground water modeling which are not related to aquifer layers. The second table contains attributes related to aquifer layers that is only applicable to ground water modeling. The second table is discussed under ground water operations. The expansion table for polygon hydrography hydrologic attributes has a one-to-one relationship with all hydrography polygons in the polygon hydrography coverage for which hydrologic attributes are desired.

The **look-up** table for **reach water depths** includes all reach classifications (numbers) which are used as routing reaches in HSPF. For each reach classification included in the look-up table, there are up to 11 water depths with a range which varies from reach to reach depending upon the expected range in water depth over the simulation period. The limit of 11 water depths is imposed by FHM V3.0. There is a many-to-one relationship between the line and polygon hydrography coverages and the look-up table. This table is project-specific and is stored only in the project workspace. The table is used only with the spatial analysis operation Depth/Area/Volume. Each routing reach must contain at least one dynamic hydrography element (at least one positive reach number). For HSPF, a rating table is established for each routing reach by determining the surface area, storage volume, and discharge rate for each water depth specified in the look-up table.

The **look-up** table for **lattice slope** contains a slope code with an associated upper limit of slope and a slope value which is used for calculations. The table is used to reduce the number of polygons created when converting a lattice surface to a temporary slope coverage during the hydraulic length operation. There is a many-to-one relationship between the temporary slope coverage and the look-up table.

The **relate** table for **lattice slope** provides a virtual link (i.e., the tables are not physically joined) between the look-up table and the temporary coverage for slope. The relate table contains the full path to the look-up table, and contains the items (data columns) in the look-up table and in the coverage which are used to produce record matches.

Unless new data are available, data preparation for the expansion, look-up, and related tables is not necessary for a new modeling project. The look-up table for reach water depths is an exception to this general procedure. As stated above, the expansion, look-up, and relate tables are typically stored in the protected/shared data base. However, an expansion, look-up, and relate table stored in the project workspace takes precedence over the same table which is stored in the protected/shared data base. The look-up table for reach water depths is always stored in the project workspace. The ability to store attribute tables in the project workspace is useful when new data are being incorporated into the attribute tables. The integrity of the established data base remains intact for other users to access while the new data are being tested. Once it is confirmed that the new attribute tables are acceptable, the existing attribute tables are replaced by the new tables. Storing the attribute tables in the project workspace is also useful for projects that require changes to the attribute values that are only applicable to that project.

ASCII Files

Three ASCII format files are required for surface water operations. These files include the HydroGIS operations control file (*.INP) and the project index files for surface water which are the “names” file (*.NAM) and the “paths” file (*.PTH). **When used with a file name in this document, the asterisk (*) refers to the name of the selected project workspace.** These three files are the “standard set” of ASCII input files for all surface water operations. Format specifications for the files are provided in Appendix A.

Data Preparation Utilities

The following data preparation utilities are available within the HydroGIS interface under surface water data preparation. The hydrography utilities may be applicable for ground water only model applications also. Appendix A contains coverage specifications. Appendix B contains the specifications for INFO tables and ASCII files that are referenced in this section.

- **Basin Selection:** From the original basins coverage, the basins which are required for the model domain are graphically selected. Before basin selection is initiated, the original basins coverage should contain any additional basin delineations that are required for the model project. Two supplemental basin coverages are created with the Basin Selection utility. The first supplemental coverage (basin preparation #1) is a copy of the original basins coverage with the addition of the basin selected status. The second supplemental coverage (basin preparation #2) includes only the selected basins. All data columns (items) in the polygon attribute table (<cover>.pat) of the original basins coverage are maintained in both of the supplemental coverages. Errors or omissions in the classified basins coverage can be the result of errors which were made during basin selection or later during basin classification. Error correction is facilitated with the use of the two supplemental coverages. The basin selection utility automatically retrieves the basin preparation #1 coverage for modifications. If all required basins have been selected, basin preparation #2 coverage is created.

- **Basin Classification:** Basin numbers (sequential) are assigned to each of the selected basins contained in the basin preparation #2 coverage. The Basin Classification utility automatically retrieves the basin preparation #2 coverage for the classification process. Basins which are to be aggregated (i.e., form one basin from many) are assigned the same basin number. As much as possible, number the basins from upstream to downstream. When the basins are used for modeling with the integrated FHM, the active region of the ground water grid is used to assist the classification process. The entire active region of the grid must be covered by the basins coverage. In relation to the grid, the entire area of an inward discharging basin must be maintained. Alternatively, the runoff and baseflow rates attributed to the area outside the grid, for an inward discharging basin, can be provided to FHM by an external time series file. Basins which have an outward discharge in relation to the grid are clipped at the edge of the active domain of the grid. The basin classification utility creates an aggregated basins coverage which is the classified basins coverage. The basin classification values are maintained in both of the supplemental coverages for basins.

- Hydrography Selection: The hydrography elements that are required for the model project are selected with the Hydrography Selection utility. Hydrography selection is divided into two parts, one for line hydrography and one for polygon hydrography. Selection is completed through a combination of automated and manual methods. Selection begins with the automated process which removes unnecessary hydrography elements from the original hydrography coverage. The elements which are removed are either located outside the classified basins coverage or are saltwater features. Because there is a separate coverage for line and polygon hydrography, any lines in the line hydrography coverage which are associated with a polygon are also removed. The manual selection process is typically used for polygon hydrography only. Many polygon hydrography features are isolated from the surface routing system of the basin. Only the hydrography polygons which are considered as contributors to the surface routing system should be selected. The isolated hydrography features (i.e., those not selected) must be incorporated into the macro depressional storage term of the basin. The Hydrography Selection utility creates a supplemental coverage for each type of hydrography. The utility automatically retrieves the supplemental coverage for modifications.

- **Hydrography Classification:** HSPF reach numbers (sequential) are assigned to each of the selected hydrography elements contained in the supplemental coverage. It is recommended to classify line hydrography elements first, followed by polygon hydrography elements. The Hydrography Classification utility automatically retrieves the supplemental coverage for the classification process. To conform to FHM requirements, hydrography elements are assigned reach numbers from upstream to downstream. The reach numbering must allow smaller numbered (absolute value) reaches to be routed to larger numbered reaches but not vice versa. (Routing is performed in the pre-processor of FHM.) Dynamic/static status is also assigned to each reach. Dynamic is represented by positive reach numbers and static is represented by negative reach numbers. The line hydrography elements with the highest stream order (Strahler) <u>within a reach</u> are assigned dynamic status. All other elements with lower stream order should be assigned static status. If all selected hydrography elements have been classified, the Hydrography Classification utility creates a classified hydrography coverage for the current hydrography type. The classified coverages are copies of the supplemental coverages but include only the essential data columns (items).

- Reach Water Depths: Through a series of menus, this utility provides the opportunity to assign the minimum and maximum water depth for each reach. FHM allows up to 11 water depths for each HSPF reach. The water depths are used in the reach flow table (F-Table) of HSPF. The range in water depth is divided into 10 equal increments to develop the 11 water depths for each reach. Alternatively, the water depths can be explicitly determined (instead of linearly interpolated) by using an ASCII, free-format file RCHDEPTH.LUT as input to the utility. Each record of the ASCII file contains a reach number followed by 11 water depth values. The water depths for each reach are written to the reach water depths table (INFO) called RCHDEPTH.LUT.

- **Select Stations:** Temporal data stations (points) are graphically selected with this utility. The selection is followed by the creation of an ASCII file which contains a list of the selected stations and/or the creation of a coverage of the selected stations. The utility supports selection of various stations types which include: rainfall, potential/pan ET, stream flow, diversions (stream flow, spring flow, surface water pumping), surface water stage, and ground water levels. The list of stations is contained in the ASCII station characteristic file called STACHAR.DAT. The file can contain a list of selected stations for each station type. An INFO version of the station characteristic file is also created. See Appendix B for file specifications. The station characteristic file is used to select temporal data, within the period provided in the file, for the stations listed in the file. The executable code for temporal data retrieval is user-supplied. The coverage created by the utility can be used for map displays in reports or for spatial analysis. The format of the station coverage is ready for use in the Thiessen Polygons utility which is convenient for rainfall and potential/pan ET stations.

- **Thiessen Polygons:** From the point coverage provided and the extents of the basins coverage (classified or modified), a Thiessen polygon coverage is created. By using the extents of the basins coverage, the Thiessen polygon coverage will extend over the entire basins coverage. The point coverage format that is accepted by the utility is the same as that produced by the Station Selection utility.

Operations

Each operation uses topologic data from coverages and/or continuous surfaces, and related hydrologic attribute data to produce hydrologic model data. The model data represent one or more characteristics of the hydrologic system. There are two spatial descriptors for the characteristics data of a surface water model such as HSPF, which are both defined by irregularly-shaped polygons that represent basins and routing reaches. A summary description of each of the surface water operations is provided in Table 3.1. Data requirements are summarized in Table 3.2.

The operations are executed through a combination of AML and FORTRAN language codes. The coding is modular which permits sharing of specific codes among various operations. Each operation is controlled by one AML which is referred to as the main AML for the operation. In some cases, one AML is used by multiple operations as the main AML. The main AML for the operation controls processing in supplemental codes which are written in AML and FORTRAN.

Each operation follows a three-part processing sequence which is carried out by the main AML. By utilizing the three-part processing sequence, map library data are accessible without extracting the library data into the project workspace prior to execution of the operation. The three parts of the processing sequence generally include: (1) cleaning the workspace and gathering attribute data, (2) performing spatial overlays and saving the results into temporary append files, and (3) summarizing the data contained in the append files to produce characteristic data which is saved in the characteristic file(s).

For each of the 12 surface water operations (seven for basins and five for reaches), the following documentation elements are provided:

1. Operation description
2. Data characterization process description
3. Input data list
4. Summary of data preparation requirements and assumptions
5. Execution instructions
6. Output data list
7. Derivation of model algorithms or spatial analysis, where needed
8. Code documentation

Provided in Appendix C for each operation is a processing flowchart under the name of the main AML for the operation. Documentation of arguments, variables, coverages and surfaces used, INFO and ASCII files used, and assumptions are available for each AML and FORTRAN code in electronic format only. The documentation is provided in the header of the source code listing under the name of the code as provided.

Modify Basins (BASN)

The Modify Basins operation contributes to one characteristic file and creates the modified basins coverage. This operation provides the basin area characteristic which is contained in the characteristic file SUBCHAR.DAT. The modified basins coverage is used as the spatial descriptor for all but one (Hydraulic Length) basin related surface water operation. The modified basin area is used in the simulation of all pervious and impervious land processes.

This operation reduces the original area associated with each basin classification (i.e., basin number) by an amount equal to the surface area associated with routing reaches. The original area for each basin is taken from the classified basins coverage. Overlays (intersect) between the classified basins coverage and the line and polygon hydrography coverages are employed to remove the reach routing area from the basin area. A separate overlay for each type of hydrography is necessary. Before the overlay, the elements of the line hydrography coverage are buffered by half of the stream width to create a polygon coverage for streams. The stream width is stored in the hydrologic attribute table for line hydrography (HYDROARC_EXP).

The basin area is reduced by changing the basin number for selected polygons to zero in the overlay resultant coverage, which is the modified basins coverage. The polygons which contain a reach number which is non-zero (i.e., rchclass NE 0) are part of the reach routing area. The basin number of these polygons are reclassified automatically to a value of zero (i.e., class = 0). Since basin classification is required to begin with a value of 1, all polygons with a basin classification equal to zero are no longer included in the basin. The areas are then summed by basin classification and the new area for each basin is stored in the characteristic file subchar.dat.

In addition, the modified basins coverage is created and given the same name as the classified basins coverage concatenated with the prefix letter “m” representing modified. Area weighted characteristics for each basin are determined with the spatial description for the basins provided in the modified basins coverage. The remaining basin characteristics are calculated through other surface water operations.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Classified Basins	Line Hydrography Hydrologic	standard set
Classified Line Hydrography		
Classified Polygon Hydrog.		

Data preparation operations numbered 1 to 5 for coverages and surfaces, under spatial analysis operations for surface water, must be completed prior to execution of operation Modify Basins. The INFO table is assumed to exist and to meet required specifications.

This operation can be executed by selecting the Basin Area menu item under Spatial Analysis for Surface Water. The operation code BASN is placed in the operations control file for layer number 0.

Output from the Modify Basins operation includes one coverage and one characteristic, which is contained in one INFO characteristic file as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
Modified Basins	SUBCHAR.DAT	none

Slope (SLPE)

The Slope operation contributes to one characteristic file. For each surface basin this operation provides the mean topographic slope which is contained in the characteristic file SUBCHAR.DAT. The modified basins coverage is used as the spatial descriptor for this operation.

An overlay (intersect) between the slope coverage and the modified basins coverage is employed to gather varying slope values across each basin. Each polygon of the slope coverage represents an area of homogeneous slope or average slope over a small-scale basin. The product of area and slope are summed by basin classification and then divided by the modified basin area. The mean value for the topographic slope characteristic of each basin is determined with an area weighted, arithmetic mean.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Modified Basins	none	standard set
Topographic Slope		

Data preparation operations numbered 1 to 3 for coverages and surfaces, under spatial analysis operations for surface water, must be completed prior to execution of operation Slope.

This operation can be executed by selecting the Basin Average Slope menu item under Spatial Analysis for Surface Water. The operation code SLPE is placed in the operations control file for layer number 0.

Output from the Slope operation includes one characteristic which is contained in one INFO characteristic file as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	SUBCHAR.DAT	none

Soils Basins (SOILSW)

The Soils Basins operation contributes to one characteristic file. For each surface basin this operation provides a mean value for the soil infiltration rate which is contained in the characteristic file SUBCHAR.DAT. The modified basins coverage is used as the spatial descriptor for this operation.

An overlay (intersect) between the soils coverage and the modified basins coverage is used to gather varying classifications of soil series or soil associations across each basin. Each polygon of the soils coverage is classified into a homogeneous unit of soil series or association. The soils coverage and the soils hydrologic attribute table contain the same classification system. Associated with the classification codes in the attribute table is the hydrologic attribute for infiltration rate. The soils relate table is used to virtually (i.e., the tables are not physically joined) join the coverage and the attribute table. The product of area and attribute value are summed by basin classification and then divided by the modified basin area. The mean value for the infiltration rate characteristic of each basin is determined with an area weighted, arithmetic mean.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Modified Basins	Soils Hydrologic	standard set
Soils	Soils Relate	

Data preparation operations numbered 1 to 3 for coverages and surfaces, under spatial analysis operations for surface water, must be completed prior to execution of operation Soils Basins.

This operation can be executed by selecting the Soils menu item under Spatial Analysis for Surface Water. The operation code SOILSW is placed in the operations control file for layer number 0.

Output from the Soils Basins operation includes one characteristic which is contained in one INFO characteristic file as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	SUBCHAR.DAT	none

Land Use Basins (LANDSW)

The Land Use Basins operation contributes to one characteristic file. For each surface basin this operation provides mean values for the Manning n friction factor for overland flow, interception storage, and depression storage which are contained in the characteristic file SUBCHAR.DAT. The modified basins coverage is used as the spatial descriptor for this operation.

An overlay (intersect) between the land use coverage and the modified basins coverage is used to gather varying classifications of land use/land cover across each basin. Each polygon of the land use coverage is classified into a homogeneous unit of land use/land cover. The land use coverage and the land use hydrologic attribute table contain the same classification system. Associated with the classification codes in the attribute table are hydrologic attributes for overland flow Manning n, interception storage, and depression storage. The land use relate table is used to virtually (i.e., the tables are not physically joined) join the coverage and the attribute table. The product of area and attribute value are summed by basin classification and then divided by the modified basin area. The mean values for the three land use characteristics of each basin are determined with an area weighted, arithmetic mean.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Modified Basins	Land Use Hydrologic	standard set
Land Use	Land Use Relate	

Data preparation operations numbered 1 to 3 for coverages and surfaces, under spatial analysis operations for surface water, must be completed prior to execution of operation Land Use Basins.

This operation can be executed by selecting the Land Use menu item under Spatial Analysis for Surface Water. The operation code LANDSW is placed in the operations control file for layer number 0.

Output from the Land Use Basins operation includes three characteristics which are contained in one INFO characteristic file as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	SUBCHAR.DAT	none

Hydraulic Length (HYDL)

The Hydraulic Length operation contributes to one characteristic file. For each surface basin this operation provides a mean value for the hydraulic length which is contained in the characteristic file SUBCHAR.DAT. The classified basins coverage is used as the spatial descriptor for this operation. This operation is the only surface water operation for basins which uses the classified basins instead of the modified basins coverage. This change is necessary because the region surrounding the hydrography elements within the modified basin coverage is classified to basin zero. The basin number cannot be associated to the hydrography elements with an overlay between the hydrography and the modified basins coverages.

The kinematic hydraulic length of a basin is determined by one of three methods in a hierarchical manner. If all required data are not available to calculate the hydraulic length using the Primary Method, the code attempts to calculate the hydraulic length using the Secondary Method. If the attempt to use the Secondary Method also fails, the basin is assigned a default value of hydraulic length (i.e., the third method). The default value is controlled by the user. The Primary and Secondary methods are documented below.

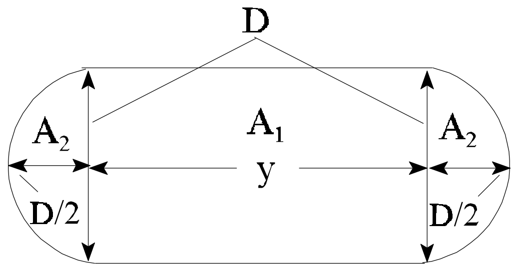
Primary Method for Hydraulic Length

The methodology employed to determine the hydraulic length for each basin assumes that the contributing area for each hydrography element can be represented by a rectangle. A hydrography element is an individual stream arc or a lake/wetland polygon. Furthermore, the summation of the areas of all "contributing" rectangles within a basin equals the total area of the basin.

In support of the methodology used to determine the mean hydraulic length for each basin, the following derivation is presented. The kinematic hydraulic length represents the mean flow path of all overland flow planes within the basin. Through representative sampling of the overland flow planes within a basin, an estimate for the kinematic hydraulic length is obtained.

One GIS approach to determining the kinematic hydraulic length requires a determination of the overland flow areas in the form of rectangles which contribute to each GIS hydrography element. The total area of overland flow plane for each basin is determined by removing the area associated with routing hydrography and with macro depressional storage. Isolated hydrography elements which do not contribute flow to the surface conveyance system of the basin are considered macro depressional storage zones. As stated earlier, the “contributing” areas surrounding each hydrography element are represented by rectangles. The two dimensions of the overland flow plane for each rectangle are provided by the mean hydraulic length of the basin and the arc length or the equivalent arc length for polygon hydrography. Both the arc and equivalent arc lengths can be readily determined from a GIS data set of hydrography. The solution to basin hydraulic length is iterative on the mean hydraulic length.

The equivalent arc length for hydrography polygons is determined by using the area and perimeter of each polygon. The figure below indicates that the equivalent length for polygons is equal to: $\mathbf{L_P = y + D}$. The following derivation provides the basis for determining the **y** and **D** dimensions for each polygon.



The total area and perimeter of each hydrography polygon are represented by the terms **y** and **D** in the following manner:

$$A_{poly} = A_1 + 2A_2 = yD + \frac{\pi D^2}{4}$$

$$P_{poly} = 2y + \pi D \textit{ which yields } D = \frac{P - 2y}{\pi}$$

Substitution of **D** into the polygon area equation yields:

$$A_{poly} = y\left(\frac{P - 2y}{\pi}\right) + \frac{\pi}{4}\frac{(P - 2y)^2}{\pi^2} = y\left(\frac{P - 2y}{\pi}\right) + \frac{(P - 2y)^2}{4\pi}$$

$$A_{poly} = \frac{P^2 - 4y^2}{4\pi}$$

Rearranging the terms provides an equation for dimension **y**:

$$y = \left(\frac{P^2}{4} - \pi A_{poly} \right)^{\frac{1}{2}}$$

With equations for the hydrography polygon dimensions **y** and **D** in terms of hydrography polygon area and perimeter, the equivalent polygon length ($\mathbf{L_P}$) is determined for each hydrography polygon.

Up to this point, the overland flow areas which are located upgradient of the order 1 (Strahler method) stream arcs and on the "ends" of the polygons have been neglected in the formulation. The total area within the basin which is located upgradient of order 1 stream arcs is estimated by the product of the hydraulic length and the number of order 1 stream arcs which are also starting arcs. The overland flow area associated with the "end" areas of hydrography polygons is estimated by the product of mean end segments, the number of polygons, and the hydraulic length for the basin within which the polygon is located. The number of end segments (**k**) for a polygon are determined by whether there is stream inflow and stream outflow (**k**=0), only inflow or only outflow (**k**=1), or neither inflow nor outflow (**k**=2).

The sum of the individual stream arc lengths and the equivalent polygon lengths, and the polygon end segment data combined with the number of order 1 stream arcs for a basin are used in the following <u>iterative</u> equation to determine the basin kinematic hydraulic length. A full derivation of the following equation is provided after the definition of terms.

$$\overline{L}_H = \frac{A_B - A_I}{2\ [\ \sum_{i=1}^{m} L_A + \sum_{j=1}^{n} L_P + \overline{L}_H * (\overline{k} N_P + N_{O1})\ ]}$$

where:

L_H = kinematic hydraulic length for the basin, feet

A_B = modified basin area, original basin area with routing hydrography area removed, square feet

A_I = isolated hydrography area, macro depressional storage that is not included in the routing hydrography area, square feet

L_A = total length of hydrography stream arcs within the basin, feet

L_P = equivalent total length for hydrography polygons within the basin, feet

$\overline{k}$ = mean number of end segments for hydrography polygons within the basin

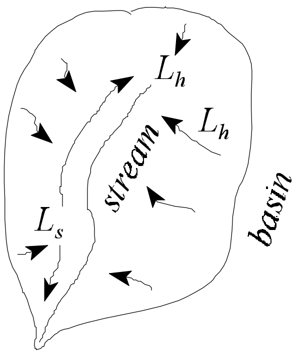
N_P = number of hydrography polygons within the basin

N_{O1} = number of hydrography order 1 stream arcs that are starting arcs within the basin

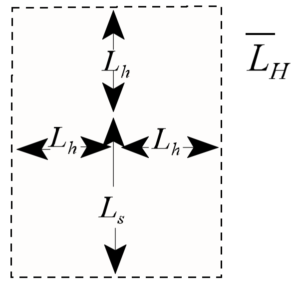
Full Derivation of Primary Method

Consider Receiving Streams as Arcs (Lines)

Simplistic "real" basin



"model" basin



a) Square basin approx.

$$A_{basin} = L_s * 2\,\overline{L}_h$$

then $\overline{L}_h = \dfrac{A_{basin}}{2\,L_s}$

A_{basin} = basin area

$\overline{L}_h$ = kinematic hydraulic length

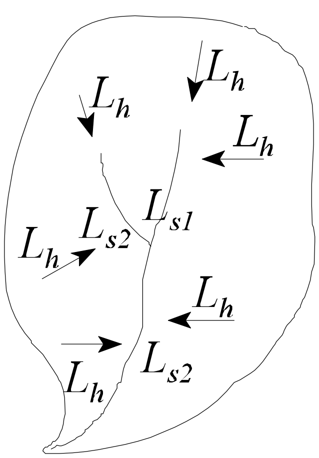
L_s = stream length

b) Extended stream length

$$A_{basin} = (L_s + \overline{L}_h) * 2\overline{L}_h)$$

$$\overline{L}_h = \frac{A_{basin}}{2\left(L_s + \overline{L}_h\right)}$$

Iterative, or use quadratic solution



c) Complex arc system

$$L_{s_T} = \sum_{i=1}^{n} L_{s_i} \qquad n = \text{no. of arcs}$$

N_{01} = no. of 1st order arcs (2) (end segments)

$$A_{basin} = 2\overline{L}_h \cdot \left(L_{S_T} + N_{01}\overline{L}_h\right)$$

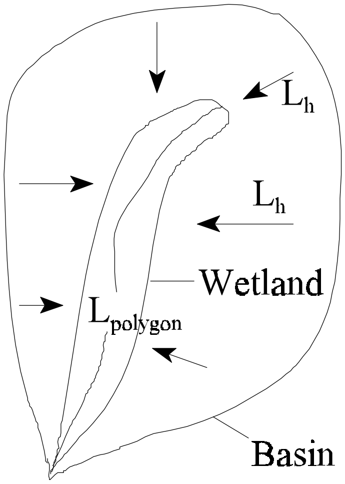
or in general for arcs:

$$\overline{L}_h = \frac{A_{basin} - A_{stream}}{2\left(L_{S_T} + N_{01}\,\overline{L}_h\right)}$$

A_{basin}, A_{stream}, L_{ST} and N_{01} derived from GIS data.

A_{stream} = surface area for contributing and isolated hydrography for streams

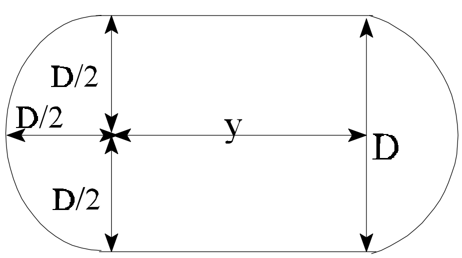
Consider Wetland (Stream) Polygons



Problem:
$L_h = f\,([A_{basin} - A_{wetland}],\ L_{polygon})$
as before,
A_{basin}, $A_{polygon}$ from GIS
need to find equivalent length of polygon, $L_{polygon}$

Solution: find equivalent oval
from GIS 6 $A_{polygon}$, $Perimeter_{polygon}$

Consider Polygon as a Racetrack (Oval-like)



$$A_{poly} = y \cdot D + \frac{\pi D^2}{4}$$

$$P_{poly} = 2y + 2\frac{\pi D}{2}$$

Solving for D:

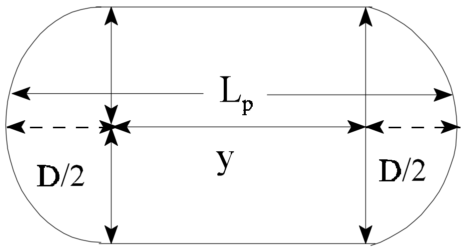
$$\boxed{D = \frac{P - 2y}{\pi}}$$

Substituting:

$$A_{poly} = y\left(\frac{P-2y}{\pi}\right) + \frac{\pi}{4}\left(\frac{P-2y}{\pi}\right)^2 = y\left(\frac{P-2y}{\pi}\right) + \frac{(P-2y)^2}{4\pi}$$

$$= \frac{P^2 - 4yP + 4y^2}{4\pi} + \frac{4yP - 8y^2}{4\pi} = \frac{P^2 - 4y^2}{4\pi}$$

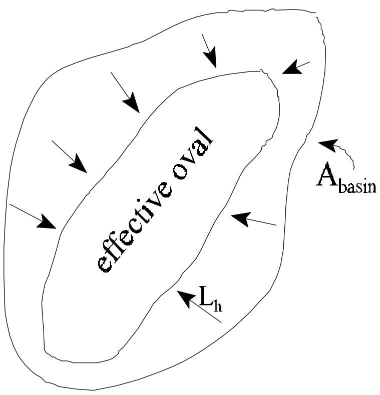
And thus: $$\boxed{y = \left(\frac{P^2}{4} - \pi A\right)^{\frac{1}{2}}}$$



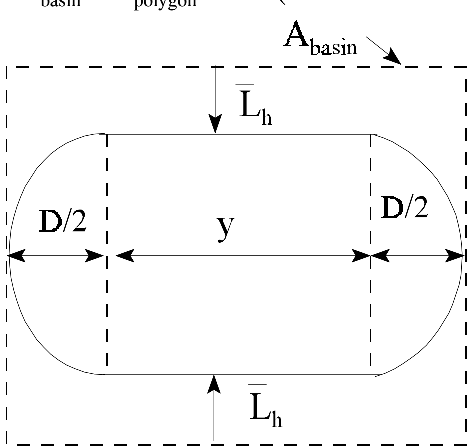
equivalent length for polygons:

$$L_{poly} = y + 2\,\frac{D}{2} \Rightarrow \boxed{L_p = y + D}$$

for <u>instream</u> polygons



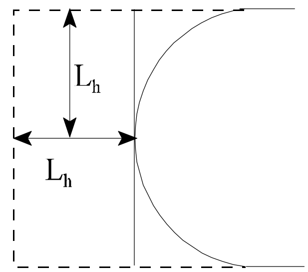
$A_{O.F.P.} = A_{basin} - A_{polygon}$ (O.F.P. = overland flow plane)



simplest approach:

$A_{O.F.P.} = 2\,\overline{L}_h \cdot L_P$ (Slightly too long because it does not account for inflow on the "ends")

<u>Polygon End Segments: Correction for Inflow on "Ends"</u>

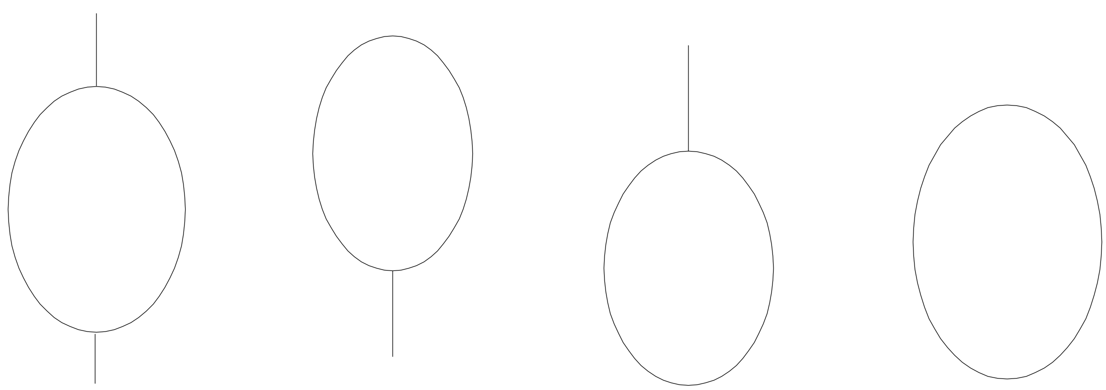


Overland flow area $= 2\,L_h\,L_h = 2\,L_h^2$
per end segment (k)
(simple square segments)

Total end segment area per polygon: $2\,k\,(L_h)^2$, k = number of end segments

Total end segment areas for <u>polygons</u> per basin $= 2\,\bar{k}\,N_p\,(L_h)^2$

where:
$\bar{k}$ = mean number of polygon end segments in basin
N_p = number of polygons in basin



k = 0		k = 1		k = 2
in stream	headwater		receiving	isolated

Grand total overland flow area for all hydrography polygons (contributing and isolated)

$$\sum A_{\substack{O.F.P.\\ \text{polygons}}} = 2\,L_h \sum_i^{N_p} L_{Pi} + 2\,\bar{k}\,N_p\,(L_h)^2$$

To provide the necessary data to support the hydraulic length methodology as presented, two overlays are necessary. The first overlay (intersect) occurs between the line hydrography and classified basins coverages. For each basin, the resultant overlay coverage provides the total arc length for streams and the number of order 1 (Strahler method) stream arcs which are starting arcs (i.e., stream arcs are absent upgradient of the starting arc). The stream order values are retrieved from the connectivity table for line hydrography.

The second overlay (intersect) occurs between the polygon hydrography and classified basins coverages. For each basin, the resultant overlay coverage provides the area and perimeter for each hydrography polygon (routed and unrouted), the isolated hydrography area (unrouted only) which represents macro depressional storage, the number of hydrography polygons (routed and unrouted), and the number of end segments for hydrography polygons (routed and unrouted).

A hydrography polygon is determined to be isolated by the value of the attribute item "depthtobs". The item "depthtobs" indicates the depth to top of bank for the stream which is connected to the hydrography polygon on the downstream end. If the value of "depthtobs" is zero, this indicates that the hydrography polygon is isolated. The data for the depth to top of bank for the downstream connecting stream is contained in the hydrologic attributes table for hydrography polygons. The reach type for the hydrography polygon is available in the polygon attribute table of the polygon hydrography coverage.

With the above data, the kinematic hydraulic length for each basin can be determined with the iterative approach presented earlier. If the required data are not available for a basin the secondary method is attempted.

Secondary Method for Hydraulic Length

The Secondary Method is used for only the basins which failed to meet the data needs of the Primary Method. In short, these basins contain no hydrography according to the GIS line and polygon hydrography coverages. If the arc length and the equivalent arc length for polygons are both equal to zero for a basin, there is no hydrography.

The Secondary Method employs the maximum difference in topographic elevation and the average slope of the basin to determine the average hydraulic length. The equation takes the form:

$$L_h = \frac{\left(Z_{\max} - Z_{\min}\right)}{2 * \bar{s}}$$

where:

L_h	=	kinematic hydraulic length for the basin, feet
Z_{max}	=	maximum topographic elevation for the basin, feet
Z_{min}	=	minimum topographic elevation for the basin, feet
$\bar{s}$	=	average slope for the basin

The maximum and minimum topographic elevations are assumed to occur along the basin boundary. A densified set of points are created along the basin boundary. At each of the points along the basin boundary, a value of topographic elevation is retrieved from the topography surface with a spot operation (tinspot or latticespot). The minimum and maximum values from the spot operations are used in the hydraulic length equation.

The basin average slope is determined by execution of the slope operation prior to execution of the Hydraulic Length operation. The slope values are retrieved from the INFO characteristic file SUBCHAR.DAT. In the event that a basin does not have a slope value available, the basin slope is calculated by using the topography surface. If the surface is a lattice, the lattice slope look-up and relate INFO tables are also used.

The input data required for operation Hydraulic Length include the data elements listed below. The hydrography coverages and INFO tables are used for the Primary Method. The topography surface and slope look-up and relate "tables" are used for the Secondary Method. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Classified Basins	Line Hydrography Connectivity	standard set
Classified Line Hydrography	Polygon Hydrography Hydrologic	
Classified Polygon Hydrog.	Lattice Slope Look-up	
Topography Surface	Lattice Slope Relate	

Data preparation operations numbered 1 to 5 for coverages and surfaces, under spatial analysis operations for surface water, must be completed prior to execution of operation Hydraulic Length.

This operation can be executed by selecting the Basin Average Hydraulic Length menu item under Spatial Analysis for Surface Water. The operation code HYDL is placed in the operations control file for layer number 0.

Output from the Hydraulic Length operation includes one characteristic which is contained in one INFO characteristic file as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	SUBCHAR.DAT	none

Reach Length (LENGTH)

The Reach Length operation contributes to one characteristic file. The total length of each reach is determined by this operation. The reach length is contained in the characteristic file RIVCHAR.DAT. The combination of the classified line and classified polygon hydrography coverages are used as the spatial descriptor for this operation.

A summation procedure is all that is necessary for this operation. No overlays are required. The reach length is comprised of two components which are the length of stream arcs and the square root of the area of lakes, wetlands, and wide rivers. From the lengths of the individual arcs in the classified line hydrography coverage, the reach length contributed by streams is calculated. From the square root of the area of the individual polygons in the classified polygon hydrography coverage, the reach length contributed by lakes, wetlands, and wide rivers is calculated. The total length of each reach is calculated from the sum of the line and polygon contributions. Only the lengths of hydrography elements which are classified or assigned a reach number (i.e., rchclass NE 0) are included in the reach length.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Classified Line Hydrography	none	standard set
Classified Polygon Hydrog.		

Data preparation operations numbered 4 and 5 for coverages and surfaces, under spatial analysis operations for surface water, must be completed prior to execution of operation Reach Length.

This operation can be executed by selecting the Reach Length menu item under Spatial Analysis for Surface Water. The operation code LENGTH is placed in the operations control file for layer number 0.

Output from the Reach Length operation includes one characteristic which is contained in one INFO characteristic file as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	RIVCHAR.DAT	none

Invert Elevation (STCOR)

The Invert Elevation operation contributes to one characteristic file. The invert elevation of each reach is determined by this operation. The invert elevation is the elevation at the bed bottom for the most downstream hydrography element of the reach. The invert elevation is contained in the characteristic file RIVCHAR.DAT. The combination of the classified line and classified polygon hydrography coverages are used as the spatial descriptor for this operation.

A query process is used to determine the invert elevation for each reach. No overlays are required. Both hydrography coverages and two hydrography attribute tables are employed for this operation. The invert elevation is determined for each reach by accounting for both line and polygon hydrography elements which are classified with a dynamic (positive integer) reach number. Refer to the hydrography coverage definition under the definition of coverages and surfaces section for details on dynamic reach elements. By being classified with a reach number, the hydrography element is assumed to contribute to the outfall of the reach.

For line hydrography, it is assumed that the invert elevation is taken from the stream arc with the minimum bed bottom elevation of the highest-ordered stream arcs of the reach. For polygon hydrography, it is assumed that the invert elevation is taken from the polygon with the minimum bed bottom elevation of all polygons for the reach classification. The invert elevation of the reach is then determined to be the minimum bed bottom elevation of the line and polygon minimum bed bottom elevations for each reach. The bed bottom elevation data is retrieved from the hydrologic attribute tables of both line and polygon hydrography.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Classified Line Hydrography	Line Hydrography Hydrologic	standard set
Classified Polygon Hydrog.	Polygon Hydrography Hydrologic	

Data preparation operations numbered 4 and 5 for coverages and surfaces, under spatial analysis operations for surface water, must be completed prior to execution of operation Invert Elevation.

This operation can be executed by selecting the Reach Invert Elevation menu item under Spatial Analysis for Surface Water. The operation code STCOR is placed in the operations control file under layer number 0.

Output from the Invert Elevation operation includes one characteristic which is contained in one INFO characteristic file as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	RIVCHAR.DAT	none

Depth/Area/Volume (DAVD)

The Depth/Area/Volume operation creates one complete characteristic file. For each water depth, the surface area and storage volume of each reach are determined. A reach represents the surface conveyance system for routing within a basin. The data are used to develop rating tables for HSPF which are used to perform reach (reservoir) routing. The rating tables are called flow tables (F-TABLES). The depth, surface area, and storage volume are contained in the characteristic file DAVDCHAR.DAT. The combination of the classified line and classified polygon hydrography coverages are used as the spatial descriptor for this operation.

Streams are represented by the line hydrography coverage and the associated attribute tables. Lakes, wetlands, reservoirs, and wide rivers are represented by the polygon hydrography coverage and the associated attribute tables. All of these types of water features contribute to the surface area and storage volume of the surface conveyance system that collect and attenuate rainfall, runoff, and ground water baseflow. The conveyance characteristics of the various types of water features vary greatly from the upper extent of the watershed to the ultimate discharge point at the outlet of the watershed. The simulated conveyance system represented in the F-TABLES is developed by aggregation. The conveyance characteristics of the individual hydrography elements are aggregated on a reach basis.

As stated above, this operation supports the development of flow tables for the routing process as simulated by HSPF. To develop the characteristics of surface area and storage volume for each routing reach, it is important to account for the diversity in the characteristics which influence surface area and storage volume at the level of the individual line and polygon hydrology elements in the coverage. The attribute tables for the hydrography coverages provide the means to account for the diversity in water feature characteristics throughout the watershed.

The attributes which are applicable to the development of surface area and storage volume data are those which define the cross-section characteristics of the hydrography element. The following attributes are retrieved from the attribute tables. The item (data column) name is provided within brackets []. For line hydrography, the connectivity table provides the stream order (Strahler method) [order] and the hydrologic table provides the channel side slope below top of bank [sidslope], the channel bottom width [width], and the flood plain side slope for the region above the top of bank [sidslopeb]. For polygon hydrography all applicable attributes are retrieved from the hydrologic table. This table provides the maximum defined depth [depthmax], the factor for maximum defined surface area at the maximum defined depth [samax], the factor for minimum surface area at the bed bottom elevation [samin], depth to top of bank [depthtob], and depth to top of bank of the downstream connecting stream [depthtobs]. The maximum and minimum surface areas are calculated for each polygon with the product of the area of the polygon and either the samax factor or the samin factor respectively. Applicable to both hydrography coverages is the look-up table for reach water depths. Developed for each project, this look-up table defines for each reach the water depth intervals for which surface area and storage volume data (flow table data) are developed.

The water depths which are specified for each depth interval in the look-up table of reach water depths are applicable to the most downstream hydrography element (i.e., outfall) of a reach. The cross-section and other factors which define the conveyance characteristics of the outfall define the discharge conditions. These water depths are also applicable to hydrography elements upstream of the outfall which have similar conveyance characteristics to that of the outfall. The water depths that are specified in the look-up table are not applicable to hydrography features with significantly different conveyance characteristics from the outfall. Within HydroGIS, streams which have the same stream order are assumed to have similar conveyance characteristics. However, multiple stream orders and various types of hydrography polygons (i.e., lakes, wetlands, wide rivers) are typically present within a single reach. Generally, the conveyance magnitude of lower-ordered streams and polygon elements that are located upstream of the outfall is smaller. A relative measure of conveyance characteristics is established to form a relationship between the outfall and all other elements assigned to the routing reach.

Within HydroGIS, the depth to top of bank is utilized as the relative measure of conveyance characteristics. As stated earlier, the reach water depths in the look-up table are assumed to be the water depth in the outfall element. All hydrography elements are assigned a depth to top of bank [depthtob] value from the hydrologic attribute tables. The depth of water in all hydrography elements (line and polygon) is determined from the product of the water depth from the look-up table and a conveyance factor. The conveyance factor is equal to the [depthtob] of the element divided by the [depthtob] of the reach outfall. This procedure reduces the depth of water in all hydrography elements located upstream of the outfall to produce a smaller conveyance magnitude.

Within HydroGIS, calculations for flow table data employ an index number or depth interval because relative depths are used. The depth interval index starts at the bed and increases as the depth of water increases. For each new depth interval index, a reach water depth is retrieved from the reach water depth look-up table. The new reach water depth is used to calculate the new relative water depth for all hydrography elements assigned to the reach.

To calculate the flow table data for each depth interval index of each reach, the calculation procedure is divided into multiple cross-section zones. For line hydrography elements, the flow table data are developed within three cross-section zones which are: channel, flood plain, and undefined. For polygon hydrography elements, the flow table data are developed within two cross-section zones which are: channel and undefined. The flow table data are cumulative with increasing water depth. The change in surface area and storage volume that is attributable to the change in water depths between the current depth interval index and the previous depth interval index is referred to as the incremental flow table data. The flow table data from the previous depth interval index are added to the incremental flow table data for the current depth interval index to calculate the total values for the flow table data at the current depth interval index. The flow table data are defined in this manner for each water depth for each reach as defined in the look-up table containing reach water depths.

As stated above three zones are used to develop flow table data from line hydrography elements. The channel zone includes water depths from the bed bottom to and including the depth to top of bank. Within the channel zone the channel side slope and the change in depth from the previous water depth interval are used to calculate values for flow table data. The second zone is referred to as the flood plain zone which begins above the depth to top of bank and extends to and including the maximum defined depth as specified by the extrapolation factor for the flood plain. The maximum defined depth for a line hydrography element is determined with the product of the depth to top of bank for the element and the extrapolation factor for the flood plain. The extrapolation factor applies globally to all line hydrography elements. Within the flood plain zone the flood plain side slope and the change in depth from the previous water depth interval are used to calculate values for rating table data. Within the first two zones, both surface area and storage volume become larger with increasing water depth. However, neither surface area nor storage volume increase for relative water depths within the undefined zone. For depth interval indexes where the relative water depth for the element exceeds the maximum defined depth, the surface area and storage volume are set equal to the surface area and storage volume associated with the maximum defined depth.

Flow table data from polygon elements are developed using two zones. The channel zone includes water depths from the bed bottom to and including the maximum defined depth as specified in the attribute table. Within the channel zone the minimum and maximum surface areas and the change in depth from the previous water depth interval are used to calculate values for flow table data. Within the channel zone, both surface area and storage volume become larger with increasing depth interval index. The undefined zone is processed in the same way as described for line hydrography.

The total surface area and storage volume for a reach is the aggregate of all hydrography elements assigned to the reach. The flow table data from the individual elements are aggregated on a depth interval index basis and not on an absolute water depth basis due to conveyance differences. For each depth interval index, the surface area and volume are summed for all elements.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Classified Line Hydrography	Line Hydrography Connectivity	standard set
Classified Polygon Hydrog.	Line Hydrography Hydrologic	
	Polygon Hydrography Hydrologic	
	Reach Water Depths Look-Up	

Data preparation operations numbered 4 to 6 for coverages and surfaces, under spatial analysis operations for surface water, must be completed prior to execution of operation Depth/Area/Volume.

This operation can be executed by selecting the Reach Depth/Area/Volume menu item under Spatial Analysis for Surface Water. The operation code DAVD is placed in the operations control file for layer number 0.

Output from the Depth/Area/Volume operation includes three characteristics which are contained in one INFO characteristic file as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	DAVDCHAR.DAT	none

Rainfall Basin (RNFBASIN)

The Rainfall Basin operation contributes to one characteristic file. The spatial distribution of rainfall for basins is determined by this operation. The basin classification value (i.e., basin number) with up to 10 (FHM V3.0 limit) rainfall station factors are produced by this operation and are contained in the characteristic file RNFCHAR.DAT. The station factors indicate the percentage (out of 100) contribution of each rainfall station to each basin using an area basis. The hydrologic model simulation (with HSPF or FHM) uses a composite temporal distribution for rainfall based on the station factors. The modified basins coverage is used as the spatial descriptor for this operation.

Overlays (intersect) between the rainfall Thiessen coverage and the modified basins coverage is used to gather the rainfall stations which contribute to each basin. A rainfall station is assumed to contribute to the composite rainfall distribution for a basin whenever the station factor is five percent or greater. The station factor is equivalent to the percentage of the modified basin area. Station factors which are less than five percent for a basin are set equal to zero. The deficit (out of 100 percent) in station factor magnitude created by this procedure is divided evenly among the remaining stations which are assigned to the basin.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Modified Basins	none	standard set
Rainfall Thiessen		

Data preparation operations numbered 1, 2, 3, 7, and 8 for coverages and surfaces, under spatial analysis operations for surface water, must be completed prior to execution of operation Rainfall Basin.

This operation can be executed by selecting the Rainfall Distribution Over Basins menu item under Spatial Analysis for Surface Water. The operation code RNFBASIN is placed in the operations control file for layer number 0.

Output from the Rainfall Basin operation includes the basin number and up to 10 station factors which are contained in one INFO characteristic file as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	RNFCHAR.DAT	none

Rainfall Reach (RNFREACH)

The Rainfall Reach operation contributes to one characteristic file. The spatial distribution of rainfall for reaches is determined by this operation. The reach classification value (i.e., reach number) with up to 10 (FHM V3.0 limit) rainfall station factors are produced by this operation and are contained in the characteristic file RNFCHAR.DAT. The station factors indicate the percentage (out of 100) contribution of each rainfall station to each reach using an area basis. The hydrologic model simulation (with HSPF or FHM) uses a composite temporal distribution for rainfall based on the station factors. The combination of the classified line and classified polygon hydrography coverages are used as the spatial descriptor for this operation.

Overlays (intersect) between the rainfall Thiessen coverage and the line and polygon hydrography coverages are employed to gather the rainfall stations which contribute to each reach. A separate overlay for each type of hydrography is necessary. Following the overlay, the line hydrography elements are given an attribute of area which is equal to the product of arc length and width of stream at top of bank. The hydrologic attribute table for line hydrography (HYDROARC_EXP) contains the width of stream at top of bank (item=widthtob) which is unique for each stream arc. The overlays determine which stations contribute to the reach and the area determines the magnitude of the contribution.

Following the overlay with polygon hydrography, the hydrography areas are grouped by reach. For each reach, the areas for each station are summed from the line and polygon hydrography elements.

A rainfall station is assumed to contribute to the composite rainfall distribution for a reach whenever the station factor is five percent or greater. The station factor is equivalent to the percentage of the surface area of the reach. Station factors which are less than five percent for a reach are set equal to zero. The deficit (out of 100 percent) in station factor magnitude created by this procedure is divided evenly among the remaining stations which are assigned to the reach.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Classified Line Hydrography	Line Hydrography Hydrologic	standard set
Classified Polygon Hydrog.		
Rainfall Thiessen		

Data preparation operations numbered 1 to 5, 7, and 8 for coverages and surfaces, under spatial analysis operations for surface water, must be completed prior to execution of operation Rainfall Reach.

This operation can be executed by selecting the Rainfall Distribution Over Reaches menu item under Spatial Analysis for Surface Water. The operation code RNFREACH is placed in the operations control file for layer number 0.

Output from the Rainfall Reach operation includes the reach number and up to 10 station factors which are contained in one INFO characteristic file as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	RNFCHAR.DAT	none

Potential ET Basin (EVTBASIN)

The Potential or Pan ET (PET) Basin operation contributes to one characteristic file. The spatial distribution of PET for basins is determined by this operation. The basin classification value (i.e., basin number) with up to 10 (FHM V3.0 limit) PET station factors are produced by this operation and are contained in the characteristic file EVTCHAR.DAT. The station factors indicate the percentage (out of 100) contribution of each PET station to each basin using an area basis. The hydrologic model simulation (with HSPF or FHM) uses a composite temporal distribution for PET based on the station factors. The modified basins coverage is used as the spatial descriptor for this operation.

An overlay (intersect) between the PET Thiessen coverage and the modified basins coverage is used to gather the PET stations which contribute to each basin. A PET station is assumed to contribute to the composite PET distribution for a basin whenever the station factor is five percent or greater. The station factor is equivalent to the percentage of the modified basin area. Station factors which are less than five percent for a basin are set equal to zero. The deficit (out of 100 percent) in station factor magnitude created by this procedure is divided evenly among the remaining stations which are assigned to the basin.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Modified Basins	none	standard set
Potential or Pan ET Thiessen		

Data preparation operations numbered 1, 2, 3, 9, and 10 for coverages and surfaces, under spatial analysis operations for surface water, must be completed prior to execution of operation PET Basin.

This operation can be executed by selecting the Potential ET Distribution Over Basins menu item under Spatial Analysis for Surface Water. The operation code EVTBASIN is placed in the operations control file for layer number 0.

Output from the PET Basin operation includes the basin number and up to 10 station factors which are contained in one INFO characteristic file as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	EVTCHAR.DAT	none

Potential ET Reach (EVTREACH)

The Potential or Pan (PET) Reach operation contributes to one characteristic file. The spatial distribution of PET for reaches is determined by this operation. The reach classification value (i.e., reach number) with up to 10 (FHM V3.0 limit) PET station factors are produced by this operation and are contained in the characteristic file EVTCHAR.DAT. The station factors indicate the percentage (out of 100) contribution of each PET station to each reach using an area basis. The hydrologic model simulation (with HSPF or FHM) uses a composite temporal distribution for PET based on the station factors. The combination of the classified line and classified polygon hydrography coverages are used as the spatial descriptor for this operation.

Overlays (intersect) between the PET Thiessen coverage and the line and polygon hydrography coverages are employed to gather the PET stations which contribute to each reach. A separate overlay for each type of hydrography is necessary. Following the overlay, the line hydrography elements are given an attribute of area which is equal to the product of arc length and width of stream at top of bank. The hydrologic attribute table for line hydrography (HYDROARC_EXP) contains the width of stream at top of bank (item=widthtob) which is unique for each stream arc. The overlays determine which stations contribute to the reach and the area determines the magnitude of the contribution.

Following the overlay with polygon hydrography, the hydrography areas are grouped by reach. For each reach, the areas for each station are summed from the line and polygon hydrography elements.

A PET station is assumed to contribute to the composite PET distribution for a reach whenever the station factor is five percent or greater. The station factor is equivalent to the percentage of the surface area of the reach. Station factors which are less than five percent for a reach are set equal to zero. The deficit (out of 100 percent) in station factor magnitude created by this procedure is divided evenly among the remaining stations which are assigned to the reach.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Classified Line Hydrography	Line Hydrography Hydrologic	standard set
Classified Polygon Hydrog.		
Potential or Pan ET Thiessen		

Data preparation operations numbered 1 to 5, 9, and 10 for coverages and surfaces, under spatial analysis operations for surface water, must be completed prior to execution of operation PET Reach.

This operation can be executed by selecting the Potential ET Distribution over Reaches menu item under Spatial Analysis for Surface Water. The operation code EVTREACH is placed in the operations control file for layer number 0.

Output from the PET Reach operation includes the reach number and up to 10 station factors which are contained in one INFO characteristic file as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	EVTCHAR.DAT	none

Results

The surface water operations create or contribute to five characteristic file pairs (INFO and ASCII). The ASCII characteristic files contain free-format, comma-delimited, hydrologic data that are read by FHM surface water or integrated pre-processor. Formatted files which are compatible with HSPF and the integrated FHM are created from the characteristic files by the pre-processor. The INFO characteristic files contain all of the data contained in the ASCII characteristic files plus additional data which may be necessary to produce graphical displays of the data or to perform advanced record selection for model calibration.

As stated under each of the operations, the INFO characteristic files are created during the processing of each operation. Following the completion of processing for all surface water and integrated operations, the ASCII characteristic files are created sequentially by the AML code CHARFILE.AML based on the operations which were successfully completed. The ASCII characteristic files are summarized in Table 3.3. Detailed descriptions of the contents of the INFO and ASCII characteristic files are provided in Appendix B.

Table 3.3 Characteristic Files Created by the HydroGIS Surface Water Operations for FHM Surface Water Component Model HSPF.

Characteristic File	File Description	Contributing Operations	Operation Type [1]
subchar.dat	mean value model characteristics by surface basin	Modify Basins	S
		Slope	S
		Soils Basins	S
		Land Use Basins	S
		Hydraulic Length	S
		Basin to Grid	I
rivchar.dat	routing reach characteristics	Reach Length	S
		Invert Elevation	S
davdchar.dat	routing reach depth/surface area/volume relationship	Depth/Area/Volume	S
rnfchar.dat	rainfall station spatial distribution over surface basins and reaches	Rainfall Basin	S
		Rainfall Reach	S
evtchar.dat	potential or pan ET station spatial distribution over surface basins and reaches	PET Basin	S
		PET Reach	S

[1] S = surface water, I = integrated

Ground Water

The spatial analysis operations for ground water are documented below. Documentation for each operation includes a description of the data characterization process, specifications for input and output data, requirements and assumptions for data preparation, derivation of spatial analysis algorithms where necessary, and other code documentation.

Objectives

The objective of the HydroGIS spatial analysis operations for ground water is to support the data requirements of FHM ground water component model MODFLOW. The 22 ground water operations in HydroGIS satisfy approximately 90% of the data requirements of MODFLOW for ground water flow simulation that are necessary for FHM. Thirteen of the operations provide data support for ground water hydraulics and boundary conditions and are summarized in Table 3.4. The remaining nine operations are summarized in Table 3.5 and provide data support for anthropogenic and natural ground water stresses.

Data Requirements and Preparation

Data requirements for the 22 ground water operations include 30 thematic maps, nine INFO tables, and four ASCII files. Two categories of thematic maps are used which include those that are related to specific layers of the ground water system as conceptualized for a ground water model and those which are not related to a specific ground water layer.

The thematic maps are stored in the form of coverages and continuous surfaces. The required thematic maps include 18 coverages and one continuous surface which are not related to a specific ground water layer. For each layer of the ground water system, 11 additional thematic maps are required to characterize the ground water hydraulics through six coverages and five continuous surfaces.

The ground water operations require eight INFO attribute tables. One of the INFO attribute tables also requires an INFO relate table for a total of nine INFO tables. The INFO attribute tables contain hydrologic attributes which are associated with classifications or unique IDs. The unique IDs are used to relate the elements (e.g., land use polygon, a stream segment, a lake) in a coverage to hydrologic attributes. Relate tables form a "virtual" relationship between elements of a coverage and attributes in the INFO attribute table.

The most often used coverages are the processing grid and the processing spot/overlay. A summary of the input requirements for each operation is provided in Tables 3.6 to 3.9.

Table 3.4 Descriptions of HydroGIS Ground Water Operations Which Create Characteristic Files for Anthropogenic and Natural Ground Water Stresses.

Operation	Operation Description	Operation Code
Hydraulic Conductivity	An area weighted mean for hydraulic conductivity is calculated for each grid cell within the processing ground water grid.	HYC
Transmissivity	An area weighted mean for transmissivity is calculated for each grid cell within the ground water processing grid.	TRN
Specific Yield	An area weighted mean for specific yield is calculated for each grid cell within the ground water processing grid.	SPY
Storage Coefficient	An area weighted mean for the confined storage coefficient is calculated for each grid cell within the ground water processing grid.	STC
Leakance	An area weighted mean for leakance is calculated for each grid cell within the ground water processing grid. Leakance is not calculated for the lower-most layer.	LEK
Aquifer Top	An area weighted mean for aquifer top elevation is calculated for each grid cell within the ground water processing grid.	TOP
Aquifer Bottom	An area weighted mean for aquifer bottom elevation is calculated for each grid cell within the ground water processing grid.	BOT
Initial Aquifer Head	An area weighted mean for initial aquifer head elevation is calculated for each grid cell within the ground water processing grid.	EWL
IBOUND	The MODFLOW IBOUND values are retrieved for each cell of the ground water grid.	IBD
Boundary Flux	The position and layer for boundary fluxes, represented by “wells” in MODFLOW, are retrieved.	FLX
General Head Boundary	Characteristics for general head boundaries (GHB) are calculated for GHBs which are classified as “calculated”, and retrieved for GHBs which are classified as “user-defined”.	GHB
Multi-Scale GHB	The inverse distance is calculated between the GHBs classified as “calculated” and the location of grid cell centers for the nearest large-scale grid cells. This operation is used for multi-scale modeling only.	MSCALE
Top-Most Active Layer	The top-most active layer for all grid cells of the ground water grid is determined.	TACT

Table 3.5 Descriptions of HydroGIS Ground Water Operations Which Create Characteristic Files for Anthropogenic and Natural Ground Water Stresses.

Operation	Operation Description	Operation Code
Line Hydrography	Hydrography characteristics for ground water modeling are calculated for line hydrography elements (i.e., streams). The characteristics include bed conductance and elevations for surface water stage and bed bottom.	STRM
Polygon Hydrography	Hydrography characteristics for ground water modeling are calculated for polygon hydrography elements (i.e., lakes, wetlands, wide rivers). The characteristics include bed conductance and elevations for surface water stage and bed bottom.	LAKE
Springs	Characteristics for ground water modeling are calculated or retrieved for ground water springs. The characteristics include spring conductance and surface water stage.	SPR
Existing Pumping Well	This operation determines the grid cell position for each existing well and the aquifer layer(s) which contributes water to each well. For each well, the relative magnitude (out of 100%) of contribution from each layer is determined.	WELL
Proposed Pumping Well	This operation determines the grid cell position for each proposed well and the aquifer layer(s) which contributes water to each well. For each well, the relative magnitude (out of 100%) of contribution from each layer is determined.	PWEL
Recharge	An area weighted mean for annual recharge is calculated for each grid cell within the processing grid.	REC
Ground Water ET Rate	An area weighted mean for annual maximum ground water ET rate is calculated for each grid cell within the processing grid.	GWET
Ground Water ET Surface	An area weighted mean for the ground water ET surface at which maximum ground water ET occurs is calculated for each grid cell within the processing grid.	ESRF
Ground Water ET Extinction Depth	An area weighted mean for the ground water ET extinction depth is calculated for each grid cell within the processing grid. The extinction depth is represented by the rhizosphere depth in the land use hydrologic attribute table.	EDEP

Table 3.6 Input Data Requirements for HydroGIS Ground Water Operations Which Create Data Sets for Ground Water Hydraulics and Boundary Conditions.

NOTES:

[1] T/L represents a tin or a lattice surface.
[2] LC represents MODFLOW laycon (McDonald and Harbaugh 1988).
[3] Used only for well layer assignment for existing and proposed wells.
[4] Processed for LC = 3 when aquifer is at land surface (map TOP = map TOPO). STC is set to 1 in all cells.
[5] Processing for the lower-most layer is not required. The layer for map TOP is below the layer for map CTHK. The layer for map BOT is the same as the layer for map CTHK.

P refers to a primary data element. If permitted, secondary (S) data element(s) can be substituted. Except where noted, S data elements are taken from the same layer as P elements.

GW refers to ground water.
GHB refers to general head boundary.

		THEMATIC MAP and (FEATURE CLASS[1])																			
OPERATION	CHARACTERISTIC	Ground Water Grid (Poly)	IBOUND for each model layer (Poly)	Processing Ground Water Grid (Poly)	Spot/Overlay (Point)	Processing/Spot Overlay (Point)	Hydraulic Conductivity (Poly)	Specific Yield (Poly)	Specific Storage (Poly)	Confining Bed Hydraulic Conductivity (Poly)	Boundary Flux (Point)	General Head Boundary (Point)	Large-Scale Ground Water Grid (Poly)	Large-Scale Point Ground Water Grid (Point)	Large-Scale IBOUND for each model layer (Poly)	Aquifer Top (T/L)	Aquifer Thickness (T/L)	Aquifer Bottom (T/L)	Confining Bed Thickness (T/L)	Initial Aquifer Head (T/L)	Topography (T/L)
Processing Grid Coverage	N/A	X	X																		
Processing Spot/Overlay Coverage	N/A			X	X																
Hydraulic Conductivity	Hydraulic Conductivity					X	X														
Transmissivity	Transmissivity (LC = 0 or 2) [2]					X	X									S	P	S			
Transmissivity	Transmissivity (LC= 1 or 3) [2, 3]					X	X									P	S	P		X	
Specific Yield	Specific Yield					X		X													
Storage Coefficient	Storage Coefficient (STC)					X			X							S	P	S			
Storage Coefficient	Above Land STC [4]															X					X
Leakance	Leakance [5]					X				X						S	S	S	P		

Table 3.7 Input Data Requirements for HydroGIS Ground Water Operations Which Create Data Sets for Ground Water Hydraulics and Boundary Conditions (continued).

NOTES:

[1] T/L represents a tin or a lattice surface.
[2] LC represents MODFLOW laycon (McDonald and Harbaugh 1988).
[3] Used only for well layer assignment for existing and proposed wells.
[4] Processed for LC = 3 when aquifer is at land surface (map TOP = map TOPO). STC is set to 1 in all cells.
[5] Processing for the lower-most layer is not required. The layer for map TOP is below the layer for map CTHK. The layer for map BOT is the same as the layer for map CTHK.

P refers to a primary data element. If permitted, secondary (S) data element(s) can be substituted. Except where noted, S data elements are taken from the same layer as P elements.

GW refers to ground water.
GHB refers to general head boundary.

		THEMATIC MAP and (FEATURE CLASS[1])																			
OPERATION	CHARACTERISTIC	Ground Water Grid (Poly)	IBOUND for each model layer (Poly)	Processing Ground Water Grid (Poly)	Spot/Overlay (Point)	Processing/Spot Overlay (Point)	Hydraulic Conductivity (Poly)	Specific Yield (Poly)	Specific Storage (Poly)	Confining Bed Hydraulic Conductivity (Poly)	Boundary Flux (Point)	General Head Boundary (Point)	Large-Scale Ground Water Grid (Poly)	Large-Scale Point Ground Water Grid (Point)	Large-Scale IBOUND for each model layer (Poly)	Aquifer Top (T/L)	Aquifer Thickness (T/L)	Aquifer Bottom (T/L)	Confining Bed Thickness (T/L)	Initial Aquifer Head (T/L)	Topography (T/L)
Aquifer Top	Aquifer Top					X										P	S	S			
Aquifer Bottom	Aquifer Bottom					X										S	S	P			
Initial Aquifer Head	Initial Aquifer Head					X														X	
IBOUND	IBOUND		X																		
Boundary Flux	Layer Coefficient										X										
General Head Boundary	GHB Conductance (LC = 0 or 2) [2]						X					X				S	P	S			
General Head Boundary	GHB Conductance (LC = 1 or 3) [2]						X					X				P	S	P		X	
General Head Boundary	GHB Head											X								X	
Multi-Scale GHB	GHB to Large-Scale Grid Inverse Distance											X	X	X	X						
Top-Most Active Layer	Top-Most Active Layer	X	X																		

Table 3.8 Input Data Requirements for HydroGIS Ground Water Operations Which Create Data Sets for Anthropogenic and Natural Ground Water Stresses.

NOTES:
[1] T/L represents a tin or a lattice surface.
[2] The bottom elevation for springs is set to -9998.
[3] LC represents MODFLOW laycon (McDonald and Harbaugh 1988).
[4] Required for pumping rate distribution to layers.
[5] Required for well layer assignment when the casing and total depth values are not elevations.
[6] A series of ASCII, formatted, pumping rate files are required for input. File naming uses puYYchar.inp, where YY = a two digit sequential number starting with 01.

P refers to a primary data element. If permitted, secondary (S) data element(s) can be substituted. Except where noted, S data elements are taken from the same layer as P elements.

GW refers to ground water.

		THEMATIC MAP and (FEATURE CLASS[1])																	ATTRIBUTE TABLES (INFO FORMAT)							
OPERATION	CHARACTERISTIC	Processing Ground Water Grid (Poly)	Processing Spot/Overlay (Point)	Classified Line Hydrography (Line)	Classified Polygon Hydrography (Poly)	Classified Springs (Point)	Existing Pumping Wells (Point)	Proposed Pumping Wells (Point)	Recharge Rate (Poly)	Ground Water ET Rate (Poly)	Land Use (Poly)	Hydraulic Conductivity (Poly)	Aquifer Top (T/L)	Aquifer Thickness (T/L)	Aquifer Bottom (T/L)	Initial Aquifer Head (T/L)	Ground Water ET Surface (T/L)	Topography (T/L)	Line Hydrography Connectivity	Line Hydrography Hydrologic	Line Hydrography Layer Hydrologic	Polygon Hydrography Hydrologic	Polygon Hydrography Layer Hydrologic	Springs Layer Hydrologic	Existing Well Characteristics	Land Use Hydrologic & RELATE
Line Hydrography	Conductance	X		X															X	X	X					
Line Hydrography	Bottom Elevation	X	X	X														X	X	X						
Line Hydrography	Stage Elevation	X	X	X														X	X	X						
Polygon Hydrography	Conductance	X			X																	X	X			
Polygon Hydrography	Bottom Elevation	X	X		X													X				X				
Polygon Hydrography	Stage Elevation	X	X		X													X				X				
Springs	Conductance	X				X																		X		
Springs	Bottom Elevation[2]	X	X			X																				
Springs	Stage Elevation	X	X			X												X						X		
Existing Well	Layer Coefficient (LC= 0 or 2)[3]	X	X				X					X^4	S^4	P^4	S^4			X^5							X	
Existing Well	Layer Coefficient (LC= 1 or 3)[3]	X	X				X					X^4	P^4	S^4	P^4	X^4		X^5							X	
Existing Well	Pumping Rates[6]						X																			

Table 3.9 Input Data Requirements for HydroGIS Ground Water Operations Which Create Data Sets for Anthropogenic and Natural Ground Water Stresses (continued).

NOTES:
[1] T/L represents a tin or a lattice surface.
[2] The bottom elevation for springs is set to -9998.
[3] LC represents MODFLOW laycon (McDonald and Harbaugh 1988).
[4] Required for pumping rate distribution to layers.
[5] Required for well layer assignment when the casing and total depth values are not elevations.
[6] A series of ASCII, formatted, pumping rate files are required for input. File naming uses puYYchar.inp, where YY = a two digit sequential number starting with 01.
P refers to a primary data element. If permitted, secondary (S) data element(s) can be substituted. Except where noted, S data elements are taken from the same layer as P elements.
GW refers to ground water.

		THEMATIC MAP and (FEATURE CLASS[1])																	ATTRIBUTE TABLES (INFO FORMAT)							
OPERATION	CHARACTERISTIC	Processing Ground Water Grid (Poly)	Processing Spot/Overlay (Point)	Classified Line Hydrography (Line)	Classified Polygon Hydrography (Poly)	Classified Springs (Point)	Existing Pumping Wells (Point)	Proposed Pumping Wells (Point)	Recharge Rate (Poly)	Ground Water ET Rate (Poly)	Land Use (Poly)	Hydraulic Conductivity (Poly)	Aquifer Top (T/L)	Aquifer Thickness (T/L)	Aquifer Bottom (T/L)	Initial Aquifer Head (T/L)	Ground Water ET Surface (T/L)	Topography (T/L)	Line Hydrography Connectivity	Line Hydrography Hydrologic	Line Hydrography Layer Hydrologic	Polygon Hydrography Hydrologic	Polygon Hydrography Layer Hydrologic	Springs Layer Hydrologic	Existing Well Characteristics	Land Use Hydrologic & RELATE
Proposed Well	Layer Coefficient (LC= 0 or 2)[3]	X	X					X				X[4]	S[4]	P[4]	S[4]			X[5]								
Proposed Well	Layer Coefficient (LC= 1 or 3)[3]	X	X					X				X[4]	P[4]	S[4]	P[4]	X[4]		X[5]								
Recharge	Recharge Rate	X							X																	
GW ET Rate	Max GW ET Rate	X								X																
GW ET Surface	GW ET Surface		X														X									
GW ET Ext. Depth	GW ET Ext. Depth	X									X															X

Four of the 18 coverages which are not related to a specific ground water layer are not explicitly referenced in the "names" file. These coverages include the ground water point grid for both small and large-scale, the processing spot/overlay, and the processing ground water grid. The point grids are created by the utility which creates the ground water grid (polygon). A "pt" suffix at the end of the name which is used for the polygon grid designates the name for the point grid. The processing spot/overlay and processing grid are created after execution of the selected operations has been launched but before any single operation is executed. A prefix letter "g" is added to the spot/overlay coverage name to designate the processing spot/overlay coverage. The processing grid is given the name PROCGRID. The point grids are permanent while the processing coverages are temporary (i.e., deleted from workspace following operation processing for ground water).

The spatial descriptor for all ground water operations is the ground water grid or the processing ground water grid which is a subset (i.e., inactive regions removed) of the original grid. In final form, all data produced by the ground water operations are spatially described in terms of a grid cell or a row and column location. The vertical description of the data are provided by the layer number. The data are valid for the assumptions used in the ground water model MODFLOW. The data are generated for a grid cell which is block-centered (i.e., the cell node is located in the center of a grid cell). Node-centered models place the cell node at the point of intersection of the cell faces.

In the following sections, detailed specifications are provided about each of the coverages, continuous surfaces, INFO tables, and ASCII files. As with any model, there are specific data formatting requirements. However, the formatting requirements are provided in terms which are consistent with those used in ARC/INFO documentation. Although it is not required, familiarity with ARC/INFO terms will facilitate the understanding of the format specifications ("ARC/INFO" 1991).

In addition to the format specifications there are data preparation issues which must be resolved prior to execution of spatial analysis operations. Data preparation within HydroGIS refers to the preparation of thematic maps, INFO tables, and ASCII files to conform to required specifications and assumptions for the data. Within HydroGIS, data preparation utilities are provided which facilitate the preparation of selected coverages and INFO attribute tables. Data preparation pertains to both the protected/shared and to the project-specific data bases. As stated earlier, the protected/shared data base elements include all coverages, surfaces and INFO attribute tables which are protected and shared through a centrally-accessible network. All of the attribute tables listed in Tables 3.8 and 3.9 are typically a part of the protected/shared data base. The protected/shared data base elements should be updated as new data become available. The purpose for data preparation for project-specific coverages is usually to meet the objectives of the project and may include incorporation of new data. All project-specific data are stored in the project workspace.

Data preparation and specifications for coverages and surfaces for ground water operations are provided in the following section. Data preparation and specifications for INFO tables and ASCII files are provided in the section which follows coverages and surfaces. The data preparation utilities for ground water operations are documented in the section which follows ASCII files.

Coverages and Continuous Surfaces

As summarized in Tables 3.6 to 3.9, ground water operations require 25 coverages and six continuous surfaces which are listed below (with the feature class). These data are defined briefly in this section. Detailed format specifications for each coverage and surface are provided in Appendix A. The specifications pertain to naming conventions, names file requirements, feature classes, required items, prohibited items, coverage building, projections, elevation (z) units for surfaces, and special requirements for each coverage or surface. Typically, data preparation issues must be addressed for the coverages which are highlighted to make them applicable to the objectives of the current project. However, some **highlighted** coverages originate with the current project. The **highlighted** coverages may originate from a protected/shared data base but the spatial detail of the data is not appropriate for the current project. The highlighted coverages are most likely to be stored in the project workspace, applicable only to the current project. Data collected subsequent to the last time a coverage or surface was updated could warrant a data preparation step for the remaining coverages and surface which are not highlighted. Of the thematic maps listed below, the point grid coverages for small and large-scale models and the processing coverages for the polygon grid and the spot/overlay are not explicitly contained in the "names" file. The thematic maps used for ground water operations are listed below in two groups which include those that are not related to a single ground water layer and those that are related to a single ground water layer.

thematic maps not related to a single ground water layer

- **Ground Water (GW) Grid** (polygon)
- Processing Ground Water Grid (polygon)
- **Ground Water Point Grid** (point)
- **Spot/Overlay** (point)
- Processing Spot/Overlay (point)
- Large-Scale GW Grid (polygon)
- Large-Scale GW Point Grid (point)
- **Classified Line Hydrography** (line)
- **Classified Polygon Hydrography** (poly)
- **Classified Springs** (point)
- Land Use (polygon)
- Topographic Elevation (TIN or lattice)
- **General Head Boundary** (point)
- **Boundary Flux** (point)
- Existing Pumping Wells (point)
- **Proposed Pumping Wells** (point)
- **Recharge Rate** (polygon)
- **Ground Water ET Rate** (polygon)
- Ground Water ET Surface (polygon)

thematic maps related to a single ground water layer

- **IBOUND** (polygon)
- **Large-Scale IBOUND** (polygon)
- Hydraulic Conductivity (polygon)
- Specific Yield (polygon)
- Specific Storage (polygon)
- Conf. Bed Hydraulic Conduct. (polygon)
- Aquifer Top Elevation (TIN or lattice)
- Aquifer Thickness (TIN or lattice)
- Aquifer Bottom Elevation (TIN or lattice)
- Confining Bed Thickness (TIN or lattice)
- Initial Aquifer Head Elev. (TIN or lattice)

In the following paragraphs, each of the coverages and surfaces are briefly defined. Unless stated otherwise, the names for the thematic maps are specified in the "names" file. Following the definitions, a summary of the data preparation steps is provided.

The thematic maps which are defined in the following group are not related to a single ground water layer.

The cells of the **ground water grid** form the basis for the spatial description of data in a finite-difference model such as MODFLOW, the ground water component model of FHM. The ground water grid is the spatial descriptor for the ground water operations of the small-scale domain. When ground water model data are desired for a smaller-scale domain located within the ground water grid of the current project, then the current grid becomes the large-scale ground water grid. The grid coverage is created by a data preparation utility called "Ground Water Grid". This coverage is a project-specific coverage unless it is subsequently used as a large-scale coverage.

A subset of the ground water grid is the **processing ground water grid**. The processing grid is automatically created each time that ground water operations are executed. At each cell (i.e., row and column) of the ground water grid, the vertical profile of IBOUND values are reviewed. If the IBOUND value of any layer at a given cell is classified as active or constant head, then the cell is included in the processing grid coverage. The processing grid is used for most ground water operations which require a grid overlay. With the inactive cells removed, the processing time is reduced for those operations which require the grid overlay. This coverage is given the name "procgrid". The coverage is not listed in the "names" file and is a project-specific coverage.

The points in the **ground water point grid** represent the grid cell centers of the ground water grid coverage. This coverage is created by the utility which creates the ground water grid and at the same time that the grid is created. The letters "pt" are added as a suffix to the name given to the ground water grid coverage to specify the name for the point coverage. This coverage is not listed in the "names" file. This coverage is a project-specific coverage unless it is subsequently used as a large-scale coverage.

The **spot/overlay** coverage is defined by a dense set of evenly-spaced points which is used to retrieve elevation and thickness data from continuous surfaces and to retrieve hydraulic data from ground water coverages. This coverage is created by the "Ground Water Grid" utility. The point coverage, that is created along with the polygon coverage by the utility, is used as the spot/overlay coverage. This is a project-specific coverage.

The **processing spot/overlay coverage** is automatically created each time that it is necessary to execute ground water operations. The processing spot/overlay coverage is created by an overlay (intersect) between the spot/overlay and processing ground water grid coverages. The letter "g" is added as a prefix to the name given to the spot/overlay coverage to specify the name for the processing spot/overlay coverage. This coverage is not listed in the "names" file and is a project-specific coverage.

The **large-scale ground water grid** is defined in the same way as the ground water grid (small-scale) coverage. However, the grid cell dimensions (i.e., MODFLOW delr and delc) for the large-scale grid are larger than those in the ground water grid. It is used to develop the data set for a multi-scale ground water model. The large-scale grid and point grid can be applied to any sub-scale project within the large-scale domain.

The points in the **large-scale ground water point grid** represent the grid cell centers of the large-scale ground water grid coverage. This coverage is created by the utility which creates the large-scale ground water grid and at the same time that the grid is created. The letters "pt" are added as a suffix to the name given to the large-scale ground water grid coverage to specify the name for the point coverage. This coverage is not listed in the "names" file. The large-scale grid and point grid can be applied to any sub-scale project within the large-scale domain.

Refer to the section which documents data requirements for surface water operations for the definitions for **classified line** and **polygon hydrography** coverages.

Ground water springs are represented by the **classified springs** coverage. The original springs coverage is typically stored in the protected/shared data base. The original coverage may contain springs which are located outside the model area for the project. However, because the springs coverage is not very data intensive, it is not necessary to remove springs from the original coverage when creating the classified springs coverage. Refer to the section which documents data requirements for surface water operations, under classified line and polygon hydrography coverages, for an explanation of hydrography element classification.

Each spring is classified into a routing reach for ground water only applications with MODFLOW and for integrated modeling. The ground water discharge (baseflow) which is simulated by the ground water model can be totaled by reach to assess calibration to observed baseflow. This is a project-specific coverage.

Refer to the section which documents data requirements for surface water operations for the definition for the **land use** coverage.

Refer to the section which documents data requirements for surface water operations for the definition for the **topographic elevation** surface.

All ground water layers are represented in the **general head boundary** (GHB) coverage by a separate set of points which represent the location of the external GHB point. The GHB coverage is created by the utility "General Head Boundary". The utility starts with the ground water point grid for the interior points of the GHB coverage. An external GHB point is added along the face which adjoins active and inactive cells for all layers. The external GHB points can be designated as inactive or active. Active GHB points are further classified as user-defined or calculated. The GHB head and conductance are supplied by the user for GHB points classified as user-defined. The GHB head and conductance are calculated with the General Head Boundary operation for GHB points classified as calculated. The GHB coverage is an essential component of the multi-scale ground water modeling concept of HydroGIS and FHM. This is a project-specific coverage.

The **boundary flux** coverage provides the location (cells and layers) for specified flux boundary conditions. The coverage is created by the "Boundary Flux" utility which uses the points from the ground water point grid to represent the location of boundary flux conditions. Each layer is represented by a separate set of points. Each point is classified as active or inactive. This is a project-specific coverage.

The coverage which contains the location of **existing pumping wells** is stored in the protected/ shared data base. The physical characteristics of the wells are contained in an INFO attribute table (see next section).

The location of **proposed pumping wells** can be stored in this coverage which can be created by the "Proposed Pumping Well" utility. The physical characteristics of the wells are contained in the polygon attribute table (PAT) of the coverage. This is a project-specific coverage.

The **recharge rate** coverage is applicable to ground water only models. The recharge rate is not an input for an integrated FHM model because recharge is explicitly determined throughout the simulation. This is a project-specific coverage.

The **ground water ET rate** coverage is applicable to ground water only models. The ground water ET rate is not an input for an integrated FHM model because the ET rate is explicitly determined throughout the simulation. This is a project-specific coverage.

The **ground water ET surface** is an elevation surface that is typically the same as the topographic elevation surface. The data are used for both ground water only and integrated FHM applications.

The thematic maps which are defined in the following group are required for each layer of the ground water system, unless stated otherwise.

The **IBOUND** coverage is used to classify each grid cell of the ground water grid coverage into one of three categories that are used by MODFLOW. Each layer of the ground water system is classified separately. The three categories include active, constant head, and inactive. The IBOUND coverage retains the original grid cells (polygons) of the ground water grid. Cells classified with the same value are not dissolved together. The utility "MODFLOW IBOUND" is used to create this coverage. This coverage is a project-specific coverage unless it is subsequently used as a large-scale coverage. Classification values for all layers are contained in one coverage.

The **Large-Scale IBOUND** coverage is used to classify each grid cell of the large-scale ground water grid coverage into one of three categories that are used by MODFLOW. Each layer of the ground water system is classified separately. The three categories include active, constant head, and inactive. The large-scale IBOUND coverage retains the original grid cells (polygons) of the large-scale ground water grid. Cells classified with the same value are not dissolved together. The large-scale IBOUND can be applied to any sub-scale project within the large-scale domain. The utility "MODFLOW IBOUND" was used to create this coverage when it was a small-scale IBOUND. Classification values for all layers are contained in one coverage.

Zones of hydraulic conductivity magnitude are stored in the **hydraulic conductivity** coverage. This coverage is typically stored in the protected/shared data base.

Zones of specific yield magnitude are stored in the **specific yield** coverage. Specific yield is required for ground water layers classified as MODFLOW "laycon" 1, 2, or 3. This coverage is typically stored in the protected/shared data base.

Zones of specific storage magnitude are stored in the **specific storage** coverage. Specific storage is required for ground water layers classified as MODFLOW "laycon" 0 or 2. This coverage is typically stored in the protected/shared data base.

Zones which indicate the magnitude of vertical hydraulic conductivity for the confining bed are stored in the **confining bed hydraulic conductivity** coverage. Confining bed hydraulic conductivity is required for all ground water layers except the lower-most (i.e., highest-numbered) layer. This coverage is typically stored in the protected/shared data base.

The **aquifer top** continuous surface provides the elevations for the aquifer top. Aquifer top is explicitly required for ground water layers classified as MODFLOW "laycon" 2 or 3. If aquifer thickness, aquifer bottom elevation, or confining bed thickness, is required but is missing, then aquifer top may be necessary as a secondary coverage to calculate the missing surface. This surface is typically stored in the protected/shared data base.

The **aquifer thickness** continuous surface provides the physical thickness for the aquifer. Aquifer thickness is required for ground water layers classified as MODFLOW "laycon" 0, 2 or 3, but may also be necessary for laycon 1 to calculate aquifer bottom elevation if that surface is missing. If the confining bed thickness is missing, the aquifer thickness may be necessary to calculate the confining bed thickness. This surface is typically stored in the protected/shared data base.

The **aquifer bottom** continuous surface provides the elevations for the aquifer bottom. Aquifer bottom is explicitly required for ground water layers classified as MODFLOW "laycon" 1 or 3. If aquifer thickness, aquifer top elevation, or confining bed thickness is required but is missing, then aquifer bottom may be necessary as a secondary coverage to calculate the missing surface. This surface is typically stored in the protected/shared data base.

The **confining bed thickness** continuous surface provides the physical thickness for the confining bed. Confining bed thickness is required for all ground water layers except the lower-most (i.e., highest-numbered) layer. This surface is typically stored in the protected/shared data base.

The **initial aquifer head** continuous surface provides the elevations of the aquifer head which are used as initial conditions for the ground water model. This surface is typically stored in the protected/shared data base or in the project workspace.

Before embarking upon spatial analysis using the ground water operations, 10 project-specific operations for data preparation must be reviewed and/or completed. These operations include:

1. Create Grid and Point Grid - This thematic map is a required coverage. The ground water grid is the first project-specific thematic map that is created. It is recommended that the "Ground Water Grid" utility within HydroGIS be used to create the grid. This utility also creates the point grid (cell center locations) at the same time. For each grid created by the utility, three INFO attribute tables (<cover>.rc, <cover>.del and <cover>.dat) and two ASCII characteristic files are also created. The information contained in these tables and files provides

characteristics of the grid. The utility attributes each grid cell with a unique ID which is determined by: (row number) * 1000 + (column number).

2. Create Spot/Overlay - This thematic map is a required coverage. The spot/overlay coverage is created by the "Ground Water Grid" utility. The point grid created by the utility is used as the spot/overlay coverage. The number of points in this coverage is usually greater than the number of points in the point grid. The number of points in the spot/overlay coverage must be sufficient to capture the variability in the data that is sampled by the coverage with the operations of HydroGIS.
3. Create IBOUND - This thematic map is a required coverage. All cells of all layers must be classified with a MODFLOW IBOUND integer which include: positive (active), negative (constant head), zero (inactive). IBOUND classifications for each of the layers are stored in one coverage. The IBOUND coverage must maintain the original grid cells of the ground water grid (i.e., cells cannot be dissolved). The "MODFLOW IBOUND" utility within HydroGIS can be used to facilitate the development of the IBOUND coverage.
4. Create General Head Boundary - If general head boundaries are to be processed with HydroGIS, this coverage is required input for operation General Head Boundary. The general head boundary (GHB) coverage is also required input for multi-scale ground water or integrated model applications for operation Multi-Scale GHB of HydroGIS. The utility "General Head Boundary" is used to create this coverage. Initially, the utility adds GHB points around the entire perimeter of the active region of the grid for each layer. Where other boundary conditions are desired for a model application which will not use multi-scale boundaries, the GHB points can be classified as inactive.
5. Classify Springs - In the same way that line and polygon hydrography were classified into reaches, ground water springs are also classified. The springs are classified with a reach number and as dynamic or static. Refer to the Data Requirements and Preparation section of the surface water operations for more information on hydrography classification.
6. Prepare Pumping Rate Files for Existing Wells - If existing pumping wells are to be processed with HydroGIS, a series of ASCII files are required input for operation Existing Pumping Well. The pumping rate files are formatted, ASCII with a limit of 20 stress periods per file. The file naming convention is PUYYCHAR.DAT, where YY represents the sequential file number starting with one. File numbers less than 10 have a preceding zero. A utility is not provided within HydroGIS to create this file series. See Appendix A for format specifications.
7. Create Proposed Wells - If proposed pumping wells are to be processed with HydroGIS, this coverage is required input for operation Proposed Pumping Well. The x-y position of the wells are specified with the utility "Proposed Pumping Wells". In addition, the proposed casing and total depths are provided in the same units that are used for existing pumping wells. The units include feet or meters and

depth or elevation. The rates for the proposed wells are entered in FHM pre-processor.

8. Create Boundary Flux - If boundary flux are to be processed with HydroGIS, this coverage is required input for operation Boundary Flux. The location of boundary flux is specified at the grid cell center. The utility "Boundary Flux" uses the point grid and an active/inactive classification to designate the position of boundary flux. The position is specified by cell and by layer.
9. Create Recharge Rate - If the distribution of recharge rate is to be processed with HydroGIS, this coverage is required input for operation Recharge Rate. A utility is not provided within HydroGIS to create this coverage.
10. Create Ground Water ET Rate - If the distribution of ground water ET rate (potential for ground water) is to be processed with HydroGIS, this coverage is required input for operation Ground Water ET Rate. A utility is not provided within HydroGIS to create this coverage.

INFO Tables

As summarized in Tables 3.8 and 3.9, ground water operations require eight INFO attribute tables which contain hydrologic attributes. The INFO attribute tables are divided into two categories which include expansion tables and look-up tables. One of the INFO attribute tables also requires an INFO relate table (a third category) for a total of nine INFO tables. The INFO attribute tables contain hydrologic attributes which are associated with classifications or unique IDs. The unique IDs are used to relate the elements (e.g., land use polygon, a stream segment, a lake) in a coverage to hydrologic attributes. All of the INFO tables are typically stored in a protected/shared data base. The system administrator of ARC/INFO establishes the locations (workspaces) for the tables and specifies the paths to the INFO tables in the administrator variable AML (HGISVAR.AML). Each of the three INFO file categories require separate workspaces for storage in the protected/shared data base. The location of the INFO tables is transparent to the user. The expansion, look-up, and relate tables required for ground water operations are defined in Appendix A. Detailed format specifications for each INFO table are also provided in Appendix A. The specifications pertain to naming conventions, storage location, sort item(s), required items, prohibited items, and special requirements for each table. Data collected subsequent to the last time an attribute table was updated could warrant a data preparation step for the affected tables. A list of the INFO tables is provided below.

- Line Hydrography Connectivity (expansion)
- Line Hydrography Hydrologic (expansion)
- Line Hydrography Layer Hydrologic (expansion)
- Polygon Hydrography Hydrologic (expansion)
- Poly. Hydrography Layer Hydrologic (expansion)
- Springs Layer Hydrologic(expansion)
- Existing Well Characteristics (expansion)
- Land Use Hydrologic (look-up)
- Land Use Hydrologic (relate)

In the following paragraphs, definitions are provided for the three layer hydrologic tables for hydrography and for the well characteristics table. Definitions for the other tables are provided in the section which describes surface water operations. Following the definitions, a discussion of data preparation for the INFO tables is provided.

The **line hydrography layer hydrologic** table contains hydrologic attributes for line hydrography elements which are "connected" to the ground water system. For each layer of the ground water system to which the hydrography element is "connected", there exists one record in this expansion table.

The **polygon hydrography layer hydrologic** table contains hydrologic attributes for polygon hydrography elements which are "connected" to the ground water system. For each layer of the ground water system to which the hydrography element is "connected", there exists one record in this expansion table.

The **springs layer hydrologic** table contains hydrologic attributes for ground water springs elements which are "connected" to the ground water system. For each layer of the ground water system to which the spring element is "connected", there exists one record in this expansion table.

The **existing wells characteristics** table contains physical attributes for existing wells which includes casing and total depths, diameter, and possibly others. There is a one-to-one relationship between the existing pumping wells coverage and this table.

Unless new data are available, data preparation for the expansion, look-up, and related tables is not necessary for a new modeling project. As stated above, the expansion, look-up, and relate tables are typically stored in the protected/shared data base. However, an expansion, look-up, and relate table stored in the project workspace takes precedence over the same table which is stored in the protected/shared data base. The ability to store attribute tables in the project workspace is useful when new data are being incorporated into the attribute tables. The integrity of the established data base remains intact for other users to access while the new data are being tested. Once it is confirmed that the new attribute tables are acceptable, the existing attribute tables are replaced by the new tables. Storing the attribute tables in the project workspace is also useful for projects that require changes to the attribute values that are only applicable to that project.

ASCII Files

Four ASCII format files are required for ground water operations. These files include the HydroGIS operations control file (*.INP) and the project index files for ground water operations which are the "names" file (*.NAM), the "paths" file (*.PTH), and the ground water layer configuration file (LAYCHAR.DAT). **When used with a file name in this document, the asterisk (*) refers to the name of the selected project workspace.** About half of the ground water operations do not require the file LAYCHAR.DAT. The other three files are the "standard set" of ASCII input files for ground water operations. Whenever the file LAYCHAR.DAT is required for an operation, it will be listed individually within the operation description. Format specifications for the files are provided in Appendix A.

Data Preparation Utilities

The following data preparation utilities are available within the HydroGIS interface under ground water data preparation. Appendix A contains coverage specifications.

- **Ground Water Grid**: A block-centered, ground water grid is created with this utility. The grid is created for MODFLOW applications. The utility is currently limited to square grid cells (DELR=DELC). The following input must be provided:

  - number of rows and columns
  - DELR and DELC spacing (DELR = DELC)
  - rotation angle between 90 and -90 degrees (counter-clockwise rotation is positive)
  - origin coordinates (grid corner of grid cell where row = last and column = 1)

  The origin coordinates are provided by one of three methods:

  - menu entry of x and y coordinates in the projection x-y units for the project
  - graphically select a point off an existing grid where the cell face lines intersect
  - graphically select any point within the model domain

  Two coverages, three INFO tables, and two ASCII files are created by the utility. A full description of all output data produced by the grid utilities is available in Appendices A and B and summarized below. A polygon and a point coverage are created for the grid. The polygon coverage contains label points at the centroid of each polygon (cell). The point coverage represents the grid cell centers. The three INFO tables are associated with the polygon coverage and include (refer to Appendix A):

  <GRID_COVER>.RC - general characteristics of the grid
  <GRID_COVER>.DEL - DELR and DELC values of the grid
  <GRID_COVER>.DAT - unique ID for each grid cell

  The two ASCII files include (refer to Appendix B):

  GRD2CHAR.DAT - characteristics of the grid
  GRD3CHAR.DAT - x and y coordinates for the grid cell centers

  An opportunity is provided to update the “names” file with the name of the grid.

- **Spot/Overlay**: The spot/overlay coverage is created with the “Ground Water Grid” utility. The point coverage created with the utility is used as the spot/overlay coverage. This point coverage should contain a higher density of points per cell than are available in the point coverage of the grid (only one point). The input requirements are the same as those needed to create the grid. An opportunity is provided to update the "names" file with the name of the spot/overlay coverage. To create the desired point density per grid cell, the distances along the rows and columns are reduced (e.g., for four points per cell, the row and column of distances for the spot/overlay coverages are one-half that of the grid).

- **MODFLOW IBOUND:** The IBOUND coverage contains MODFLOW boundary condition classifications for each grid cell of all layers. For each ground water layer, one data column (item) is added to represent IBOUND classification. Each cell is classified as active, constant head, or inactive. The coverage is a copy of the grid polygon coverage. All of the grid cells remain in the coverage (a dissolve is not used to delete inactive cells). All cells are initially classified as active without user input. Through menus and graphical selection, an individual or a block of cells are classified as constant head or inactive. All ground water layers are classified in this way. An opportunity is provided to update the "names" file with the name of the IBOUND coverage.

- **Boundary Flux:** The boundary flux coverage is created to provide the ability to add specified boundary flux at selected cells of selected layers. The grid and IBOUND coverages must be completed before this utility is executed. The coverage is created from a copy of the grid point coverage. For each ground water layer, one data column (item) is added to represent an active or inactive boundary flux at each cell. Through menus and graphical selection, an individual or a block of cells are classified as active boundary flux locations. An opportunity is provided to update the "names" file with the name of the boundary flux coverage.

- **General Head Boundary:** The general head boundary (GHB) coverage is created to permit the use of head-dependent flux boundaries. The grid and IBOUND coverages must be completed before this utility is executed. The GHB coverage is essential for multi-scale applications using the concepts presented in this document. The coverage is created from the grid point coverage but modified on a layer-by-layer basis in accordance with IBOUND classifications. The coverage includes a set of points for each layer. The points represent internal points (grid cell centers) which are associated with external points (GHB external head location). In addition, the points for grid cell centers for constant head cells are maintained as internal points. All inactive points and active points which are located in a cell that does not share a face with an inactive cell are deleted for a layer. Points that represent constant head cells are maintained only for display purposes. The active cell, internal points can be (especially at corners) associated with multiple external points. Each of the external points must be classified as active GHB or inactive GHB. Furthermore, active GHB cells are classified as calculated or user-defined. For GHB calculated classifications, the GHB conductance and external head are calculated/determined through the General Head Boundary operation. For GHB user-defined classifications, the GHB conductance and head are provided by the user through the utility menus and are stored in the GHB coverage. Initially, all external points are classified as active/calculated.

Through menus and graphical selection, an individual or a block of cells are classified as inactive or active/user-defined. The line formed between the external point and the associated internal point is always orthogonal to the cell face. The external point can be moved from the default location to a user-defined position. However, the utility subjects the new location to the orthogonality requirements. An opportunity is provided to update the "names" file with the name of the GHB coverage. Again, classification is performed on a layer-by-layer basis.

- **Proposed Pumping Wells:** This utility creates a proposed pumping well coverage. Within the grid area, proposed wells are graphically located and added to the coverage. Through menus, the casing and total depths and casing diameter are provided and are added to the point attribute table of the coverage. Subsequent to the initial creation of the proposed well coverage, wells can be added, deleted, or moved and the physical attributes can be altered. An opportunity is provided to update the "names" file with the name of the proposed pumping wells coverage.

- **Assign Layers to Pumping Wells:** With this utility, aquifer layers are assigned to existing or proposed pumping wells. A start and stop layer are assigned to each well on the basis of the open interval between cased and total depths and the elevations of the top and bottom of aquifer layers. The physical attributes (e.g., cased and total depths and diameter) of wells are stored in an INFO file PUMPWELL_EXP for existing wells or in the point attribute table (PAT) of the proposed pumping well coverage. If the values of cased and total depths are depths and not elevations, the utility determines the corresponding elevations for casing depth and total depth. A land surface elevation reference is established at each well by spotting the wells onto the topography surface. For each ground water layer, the top and bottom surface elevation are determined at each well through a spot operation onto the respective surface. If either the top or bottom surface for a layer is missing, the layer thickness surface is used to derive the missing surface elevations at each well. After surface elevations are established for all layers, the upper-most (laystart) and lower-most (laystop) contributing layers are determined for each well. In many cases, either or both the cased and total depth values are missing. Using alternate data, an attempt is made to assign contributing layers through a user-customized AML called TDCDMISS.AML. This AML should incorporate the standard practices that are used in the region to assign contributing layers to wells with missing data. All data referenced in TDCDMISS.AML must be in the correct table as referenced above. There must also be compatibility between the calling AML code (WELLLAYR.AML) and TDCDMISS.AML. The output from this utility is an INFO table called WELLLAYR.DAT that is sorted by the data column (item) called welluid. It is recommended that the contents of WELLLAYR.DAT be joined to the table which contains physical attributes (PUMPWELL_EXP or the proposed well PAT) based on the type of wells that were processed. Appendix A contains specifications for the PUMPWELL_EXP INFO table. Appendix B contains specifications for the WELLLAYR.DAT INFO table.

Operations

Each operation uses topologic data from coverages and/or continuous surfaces, and related hydrologic attribute data to produce hydrologic model data. The model data represent one or more characteristics of the hydrologic system. There is one spatial descriptor for the characteristics data of a ground water model such as MODFLOW, which is defined by a square or rectangular grid cell. A summary description of each of the ground water operations is provided in Tables 3.4 and 3.5. Data requirements are summarized in Tables 3.6 to 3.9.

The operations are executed through a combination of AML and FORTRAN language codes. The coding is modular which permits sharing of specific codes among various operations. Each operation is controlled by one AML which is referred to as the main AML for the operation. In some cases, one AML is used by multiple operations as the main AML. The main AML for the operation controls processing in supplemental codes which are written in AML and FORTRAN.

Each operation follows a three-part processing sequence which is carried out by the main AML. By utilizing the three-part processing sequence, map library data are accessible without extracting the library data prior to execution of the operation. The three parts of the processing sequence generally include: (1) cleaning the workspace and gathering attribute data, (2) performing spatial overlays and saving the results into temporary append files, and (3) summarizing the data contained in the append files to produce characteristic data which is saved in the characteristic file(s).

For each of the 22 ground water operations, the following documentation elements are provided:

- Operation description
- Data characterization process description
- Input data list
- Summary of data preparation requirements and assumptions
- Execution instructions
- Output data list
- Derivation of model algorithms or spatial analysis, where needed
- Code documentation

Provided in Appendix C for each operation is a processing flowchart under the name of the main AML for the operation. Documentation of arguments, variables, coverages and surfaces used, INFO and ASCII files used, and assumptions are available for each AML and FORTRAN code in electronic format only. The documentation is provided in the header of the source code listing under the name of the code as provided.

Hydraulic Conductivity (HYC)

The Hydraulic Conductivity operation contributes to the characteristic file for the current ground water layer. For each cell of the ground water grid this operation provides a mean value for the aquifer hydraulic conductivity of the current ground water layer. The hydraulic conductivity values are contained in the characteristic file LYXXCHAR.DAT. The letters XX represent a two-digit aquifer layer number where a preceding zero is used for layers less than 10. Through the use of the processing spot/overlay coverage, the processing ground water grid (processing grid) coverage is used as the spatial descriptor for this operation. Grid cells which are located outside the processing grid (i.e., inactive cells) are given the no data value (-9999.) for the characteristic processed with this operation. This operation is valid for layers which are assigned a MODFLOW "laycon" value of 1 or 3 only.

At each point contained in the processing spot/overlay coverage, a value of hydraulic conductivity is retrieved from the hydraulic conductivity coverage with an overlay (intersect) operation. The points in the spot/overlay coverage are evenly-spaced in all directions. With a dense set of points, a representative sampling of the hydraulic conductivity distribution is obtained. After the distribution is sampled, an area weighted, arithmetic mean value of hydraulic conductivity is calculated within each grid cell. Because the sampling points are evenly-spaced, each sampling point is given equal weight. The mean value of hydraulic conductivity within a grid cell is equal to the sum of all hydraulic conductivity values within the grid cell divided by the number of sampling points within the grid cell.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Processing Spot/Overlay	none	standard set
Hydraulic Conductivity (layer XX)		LAYCHAR.DAT

Data preparation operations numbered 1 to 3 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation Hydraulic Conductivity.

This operation can be executed by selecting the Aquifer Hydraulic Conductivity menu item for layer number XX under Spatial Analysis for Ground Water. The operation code HYC is placed in the operations control file for layer number XX.

Output from the Hydraulic Conductivity operation includes one characteristic which is contained in the INFO characteristic file for the current layer (XX) as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	LYXXCHAR.DAT	none

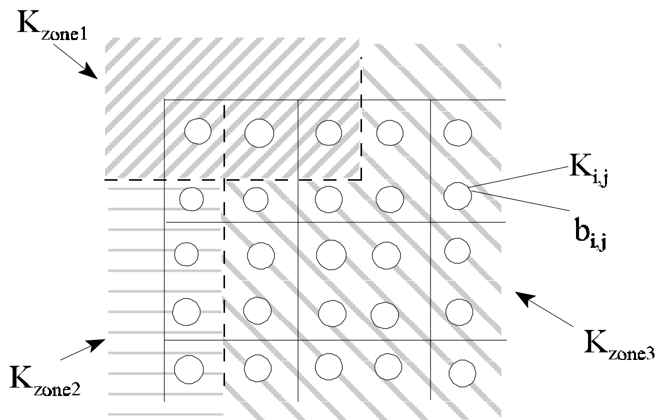
Transmissivity (TRN)

The Transmissivity operation contributes to the characteristic file for the current ground water layer. For each cell of the ground water grid this operation provides mean values for selected characteristics of the aquifer which can include transmissivity, hydraulic conductivity, and physical or saturated thickness for the current ground water layer. The list of characteristics for which mean values are determined depends upon the MODFLOW "laycon" value. The values of the characteristics are contained in the characteristic file LYXXCHAR.DAT. The letters XX represent a two-digit aquifer layer number where a preceding zero is used for layers less than 10. Through the use of the processing spot/overlay coverage, the processing ground water grid (processing grid) coverage is used as the spatial descriptor for this operation. Grid cells which are located outside the processing grid (i.e., inactive cells) are given the no data value (-9999.) for the characteristics processed with this operation.

The Transmissivity operation is used for two purposes. The typical purpose for the Transmissivity operation is to calculate the spatial distribution of transmissivity for the current aquifer layer for confined (MODFLOW "laycon" = 0) or partially-convertible (MODFLOW "laycon" = 2) aquifers as defined by MODFLOW. The physical thickness of the aquifer is used with the hydraulic conductivity to calculate transmissivity for these aquifer conceptualizations. The Transmissivity operation is also used to support the Existing Wells (WELL) and Proposed Wells (PWEL) operations which is the second purpose. Transmissivity values are used to assign layer(s) to pumping wells to vertically apportion total pumping rates by well. Refer to the operation descriptions for Existing Wells and Proposed Wells for more information on pumping rate apportionment. The Transmissivity operation must precede the Existing Wells and Proposed Wells operations whenever either are selected to be executed. When either the Existing Wells or Proposed Wells operation is selected, the Transmissivity operation is invoked for all aquifer layers including unconfined (MODFLOW "laycon" = 1) and fully-convertible (MODFLOW "laycon" = 3) aquifers as defined by MODFLOW. The saturated thickness of the aquifer is used with the hydraulic conductivity to calculate transmissivity for these aquifer configurations. Calculation of transmissivity with the physical and saturated thickness are presented below.

Transmissivity for Confined or Partially-Convertible (MODFLOW) Aquifers

At each point contained in the processing spot/overlay coverage, a value of hydraulic conductivity is retrieved from the hydraulic conductivity coverage with an overlay (intersect) operation. In addition, at each point contained in the processing spot/overlay coverage, a value of physical aquifer thickness is retrieved from the continuous surface for aquifer thickness with a surface spot (tinspot or latticespot) operation. The points in the spot/overlay coverage are evenly-spaced in all directions. The relationship between the processing spot/overlay, ground water grid, hydraulic conductivity, and aquifer thickness coverages/surfaces is shown in Figure 3.1. With a dense set of points, a representative sampling of the hydraulic conductivity and physical aquifer thickness distribution are obtained.



each square represents a grid cell

○	=	a point in the processing spot/overlay coverage
i	=	point in cell
j	=	cell number
n	=	number of points in cell
K	=	hydraulic conductivity
b	=	physical or saturated thickness of aquifer

If directional, Harmonic Mean

$$T_j = \frac{n}{\frac{1}{K_{i,j}\, b_{i,j}} + \frac{1}{K_{i+1,j}\, b_{i+1,j}} + \frac{1}{K_{i+2,j}\, b_{i+2,j}} + \ldots + \frac{1}{K_{n,j}\, b_{n,j}}}$$

otherwise, Arithmetic Mean

$$T_j = \frac{K_{i,j}\, b_{i,j} + K_{i+1,j}\, b_{i+1,j} + K_{i+2,j}\, b_{i+2,j} + \ldots + K_{n,j}\, b_{n,j}}{n}$$

Figure 3.1 Grid Cell Transmissivity Formulation With HydroGIS.

After the distributions are sampled, a value of transmissivity is calculated at each point in the processing spot/overlay coverage. The transmissivity at each point is calculated from the product of hydraulic conductivity and physical aquifer thickness. Because the sampling points are evenly-spaced, each sampling point is given equal weight. The area weighted, arithmetic mean value of transmissivity within a grid cell is equal to the sum of all transmissivity values within the grid cell divided by the number of sampling points within the grid cell.

After the mean values of transmissivity are calculated, area weighted, arithmetic mean values of hydraulic conductivity and physical aquifer thickness are calculated within each grid cell. The mean value of hydraulic conductivity or aquifer thickness within a grid cell is equal to the sum of all hydraulic conductivity or aquifer thickness values within the grid cell divided by the number of sampling points within the grid cell.

If the continuous surface for physical aquifer thickness is missing, an attempt is made to utilize the secondary method to calculate the value of aquifer thickness at each point in the spot/overlay coverage. Using the aquifer top and aquifer bottom surfaces for the current layer (XX), the aquifer thickness is determined. At each point contained in the processing spot/overlay coverage, a surface value is retrieved from both the aquifer top and aquifer bottom surfaces with a spot (tinspot or latticespot) operation. After the surfaces are sampled, the aquifer bottom is subtracted from the aquifer top elevation at each sampling point to derive a physical aquifer thickness at each sampling point. Once the thickness is known, the processing proceeds in the same way as described above.

The input data required for *confined or partially-convertible* aquifers for operation Transmissivity include the data elements listed below. The **highlighted** data elements are used in the secondary calculation procedure only, under the condition that the surface for aquifer thickness is missing. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Processing Spot/Overlay	none	standard set
Hydraulic Conductivity (layer XX)		LAYCHAR.DAT
Aquifer Thickness (layer XX)		
Aquifer Top (layer XX)		
Aquifer Bottom (layer XX)		

Data preparation operations numbered 1 to 3 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation Transmissivity.

This operation can be executed by selecting the Transmissivity menu item for layer number XX under Spatial Analysis for Ground Water. The operation code TRN is placed in the operations control file for layer number XX.

If either the Existing Wells or Proposed Wells operation is selected under Spatial Analysis for Ground Water, the Transmissivity operation will be selected automatically regardless of any explicit selection by the user. In this case, the operation code TRN is placed in the operations control file for all layers.

Output from the Transmissivity operation for *confined or partially-convertible aquifers* includes three characteristics which are contained in the INFO characteristic file for the current layer (XX) as listed below. The three characteristics include transmissivity, hydraulic conductivity, and physical aquifer thickness. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	LYXXCHAR.DAT	none

Transmissivity for Unconfined or Fully-Convertible (MODFLOW) Aquifers

At each point contained in the processing spot/overlay coverage, a value of hydraulic conductivity is retrieved from the hydraulic conductivity coverage with an overlay (intersect) operation. In addition, at each point contained in the processing spot/overlay coverage, values of aquifer top, aquifer bottom, and initial aquifer head are retrieved from the respective continuous surfaces with a surface spot (tinspot or latticespot) operation. The points in the spot/overlay coverage are evenly-spaced in all directions. The overlay and spot operations are similar to the visual depiction in Figure 3.1. With a dense set of points, a representative sampling of the distributions for hydraulic conductivity and the referenced surfaces are obtained.

After the distributions are sampled, the saturated aquifer thickness is calculated at each point in the spot/overlay coverage. The initial aquifer head elevation is compared to the aquifer top elevation at each point. For the condition where the initial aquifer head is less than or equal to the aquifer top, the saturated thickness is equal to the aquifer bottom elevation subtracted from the initial aquifer head elevation. For the condition where the initial aquifer head is greater than the aquifer top, the saturated thickness is equal to the aquifer bottom elevation subtracted from the aquifer top elevation.

Following the determination of saturated aquifer thickness, a value of transmissivity is calculated at each point in the processing spot/overlay coverage. The transmissivity at each point is calculated from the product of hydraulic conductivity and saturated aquifer thickness. Because the sampling points are evenly-spaced, each sampling point is given equal weight. The area weighted, arithmetic mean value of transmissivity within a grid cell is equal to the sum of all transmissivity values within the grid cell divided by the number of sampling points within the grid cell.

After the mean values of transmissivity are calculated, area weighted, arithmetic mean values of hydraulic conductivity and saturated aquifer thickness are calculated within each grid cell. The mean value of hydraulic conductivity or saturated aquifer thickness within a grid cell is equal to the sum of all hydraulic conductivity or saturated aquifer thickness values within the grid cell divided by the number of sampling points within the grid cell.

If the continuous surface for either aquifer top or aquifer bottom elevation is missing, an attempt is made to utilize the secondary method to calculate the value of aquifer top or bottom at each point in the spot/overlay coverage. There must be at least two of the three surfaces (i.e., top, physical thickness, bottom) to determine aquifer top and bottom for the current layer. Refer to the Aquifer Top and Aquifer Bottom operations for information on determining the respective elevation using the secondary method. Once the missing surface is determined with the secondary method, the processing proceeds in the same way as described above.

The input data required for *unconfined or fully-convertible aquifers* for operation Transmissivity include the data elements listed below. The **highlighted** data element is used in the secondary calculation procedure only, under the condition that the surface for aquifer top or bottom elevation is missing. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Processing Spot/Overlay	none	standard set
Hydraulic Conductivity (layer XX)		LAYCHAR.DAT
Aquifer Top (layer XX)		
Aquifer Bottom (layer XX)		
Initial Aquifer Head (layer XX)		
Aquifer Thickness (layer XX)		

Data preparation operations numbered 1 to 3 and 6 (existing wells) or 7 (proposed wells) for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation Existing Wells or Proposed Wells.

If either the Existing Pumping Wells or Proposed Pumping Wells menu item is selected under Spatial Analysis for Ground Water, the Transmissivity operation will be selected automatically regardless of any explicit selection by the user. The operation code TRN is placed in the operations control file for all layers. For unconfined aquifers, the Trasmissivity operation is invoked only to support operations for Existing Pumping Wells, Proposed Pumping Wells, and General Head Boundaries (conductance).

Output from the Transmissivity operation for *unconfined or fully-convertible aquifers* includes three characteristics which are contained in the INFO characteristic file for layer XX as listed below. The three characteristics include transmissivity, hydraulic conductivity, and saturated aquifer thickness. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	LYXXCHAR.DAT	none

Specific Yield (SPY)

The Specific Yield operation contributes to the characteristic file for the current ground water layer. For each cell of the ground water grid this operation provides a mean value for the aquifer specific yield of the current ground water layer. The specific yield values are contained in the characteristic file LYXXCHAR.DAT. The letters XX represent a two-digit aquifer layer number where a preceding zero is used for layers less than 10. Through the use of the processing spot/overlay coverage, the processing ground water grid (processing grid) coverage is used as the spatial descriptor for this operation. Grid cells which are located outside the processing grid (i.e., inactive cells) are given the no data value (-9999.) for the characteristic processed with this operation. This operation is valid for layers which are assigned a MODFLOW “laycon” value of 1, 2, or 3 only.

At each point contained in the processing spot/overlay coverage, a value of specific yield is retrieved from the specific yield coverage with an overlay (intersect) operation. The points in the spot/overlay coverage are evenly-spaced in all directions. With a dense set of points, a representative sampling of the specific yield distribution is obtained. After the distribution is sampled, an area weighted, arithmetic mean value of specific yield is calculated within each grid cell. Because the sampling points are evenly-spaced, each sampling point is given equal weight. The mean value of specific yield within a grid cell is equal to the sum of all specific yield values within the grid cell divided by the number of sampling points within the grid cell.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Processing Spot/Overlay	none	standard set
Specific Yield (layer XX)		LAYCHAR.DAT

Data preparation operations numbered 1 to 3 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation Specific Yield.

This operation can be executed by selecting the Specific Yield menu item for layer number XX under Spatial Analysis for Ground Water. The operation code SPY is placed in the operations control file for layer number XX.

Output from the Specific Yield operation includes one characteristic which is contained in the INFO characteristic file for the current layer (XX) as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	LYXXCHAR.DAT	none

Storage Coefficient (STC)

The Storage Coefficient operation contributes to the characteristic file for the current ground water layer. For each cell of the ground water grid this operation provides mean values for aquifer characteristics which can include storage coefficient, specific storage, and physical aquifer thickness for the current ground water layer. The calculated characteristics are dependent upon the MODFLOW “laycon” value combined with the vertical position of the layer. The values of the characteristics are contained in the characteristic file LYXXCHAR.DAT. The letters XX represent a two-digit aquifer layer number where a preceding zero is used for layers less than 10. Through the use of the processing spot/overlay coverage, the processing ground water grid (processing grid) coverage is used as the spatial descriptor for this operation. Grid cells which are located outside the processing grid (i.e., inactive cells) are given the no data value (-9999.) for the characteristics processed with this operation. This operation is valid for layers which are assigned a MODFLOW “laycon” value of 0, 2, or 3 only.

At each point contained in the processing spot/overlay coverage, a value of specific storage is retrieved from the specific storage coverage with an overlay (intersect) operation. In addition, at each point contained in the processing spot/overlay coverage, a value of physical aquifer thickness is retrieved from the continuous surface for aquifer thickness with a surface spot (tinspot or latticespot) operation. The points in the spot/overlay coverage are evenly-spaced in all directions. With a dense set of points, a representative sampling of the distributions for specific storage and physical aquifer thickness are obtained.

After the distributions are sampled, a value of storage coefficient is calculated at each point in the processing spot/overlay coverage. The storage coefficient at each point is calculated from the product of specific storage and physical aquifer thickness. Because the sampling points are evenly-spaced, each sampling point is given equal weight. The area weighted, arithmetic mean value of storage coefficient within a grid cell is equal to the sum of all storage coefficient values within the grid cell divided by the number of sampling points within the grid cell. As displayed in Figure 3.1, the same approach that is used to calculate transmissivity is used to calculate storage coefficient.

After the mean values of storage coefficient are calculated, area weighted, arithmetic mean values of specific storage and physical aquifer thickness are calculated within each grid cell. The mean value of specific storage or aquifer thickness within a grid cell is equal to the sum of all specific storage or aquifer thickness values within the grid cell divided by the number of sampling points within the grid cell.

If the continuous surface for physical aquifer thickness is missing, an attempt is made to utilize the secondary method to calculate the value of aquifer thickness at each point in the spot/overlay coverage. Using the aquifer top and aquifer bottom surfaces for the current layer (XX), the aquifer thickness is determined. At each point contained in the processing spot/overlay coverage, a surface value is retrieved from both the aquifer top and aquifer bottom surfaces with a spot (tinspot or latticespot) operation. After the surfaces are sampled, the aquifer bottom is subtracted from the aquifer top elevation at each sampling point to derive a physical aquifer thickness at each sampling point. Once the thickness is known, the processing proceeds in the same way as described above.

The input data required for the Storage Coefficient operation include the data elements listed below. The **highlighted** data elements are used in the secondary calculation procedure only, under the condition that the surface for aquifer thickness is missing. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Processing Spot/Overlay	none	standard set
Specific Storage (layer XX)		LAYCHAR.DAT
Aquifer Thickness (layer XX)		
Aquifer Top (layer XX)		
Aquifer Bottom (layer XX)		

Data preparation operations numbered 1 to 3 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation Storage Coefficient.

This operation can be executed by selecting the Storage Coefficient menu item for layer number XX under Spatial Analysis for Ground Water. The operation code STC is placed in the operations control file for layer number XX.

Output from the Storage Coefficient operation includes three characteristics which are contained in the INFO characteristic file for the current layer (XX) as listed below. The three characteristics include storage coefficient, specific storage, and physical aquifer thickness. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	LYXXCHAR.DAT	none

Storage Coefficient and Water Above Land

A special case exists for the MODFLOW "laycon" equal to 3 for an aquifer layer which is at land surface. This condition allows *water to pond above land* on a cell-by-cell basis. The storage coefficient is set to 1.0 for this condition. No other aquifer characteristics are affected. The names of the elevation surfaces for aquifer top and topography are used to determine whether the current layer is at land surface. No processing is performed with these surfaces for the water above land condition for operation Storage Coefficient.

The input data required for the Storage Coefficient operation for the *water above land condition* include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Processing Grid	none	standard set
Aquifer Top (layer XX)		LAYCHAR.DAT
Topography		

Data preparation operations numbered 1 and 3 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation Storage Coefficient for the *water above land condition*.

This special case of operation Storage Coefficient can be executed by selecting the Storage Coefficient menu item for layer number 01 (the layer must be at land surface with a MODFLOW "laycon" equal to 3) under Spatial Analysis for Ground Water. The operation code STC is placed in the operations control file for layer number 01.

Output from the Storage Coefficient operation for the *water above land condition* includes one characteristic (storage coefficient) which is contained in the INFO characteristic file for layer 01 as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	LY01CHAR.DAT	none

Leakance (LEK)

The Leakance operation contributes to the characteristic file for the current ground water layer. For each cell of the ground water grid this operation provides mean values for aquifer characteristics which include leakance, confining bed hydraulic conductivity, and confining bed thickness for the current ground water layer. The values of the characteristics are contained in the characteristic file LYXXCHAR.DAT. The letters XX represent a two-digit aquifer layer number where a preceding zero is used for layers less than 10. Through the use of the processing spot/overlay coverage, the processing ground water grid (processing grid) coverage is used as the spatial descriptor for this operation. Grid cells which are located outside the processing grid (i.e., inactive cells) are given the no data value (-9999.) for the characteristics processed with this operation. This operation is valid for all MODFLOW laycon values. MODFLOW assumes a no-flow boundary condition at the bottom of the lower-most layer. Thus, leakance data are not required for the lower-most layer which is the layer with the highest layer number.

At each point contained in the processing spot/overlay coverage, a value of confining bed hydraulic conductivity is retrieved from the confining bed hydraulic conductivity coverage with an overlay (intersect) operation. In addition, at each point contained in the processing spot/overlay coverage, a value of confining bed thickness is retrieved from the continuous surface for confining bed thickness with a surface spot (tinspot or latticespot) operation. The points in the spot/overlay coverage are evenly-spaced in all directions. With a dense set of points, a representative sampling of the distributions for confining bed hydraulic conductivity and confining bed thickness are obtained.

After the distributions are sampled, a value of leakance is calculated at each point in the processing spot/overlay coverage. The leakance at each point is calculated from the confining bed hydraulic conductivity divided by the confining bed thickness. Because the sampling points are evenly-spaced, each sampling point is given equal weight. The area weighted, arithmetic mean value of leakance within a grid cell is equal to the leakance values within the grid cell divided by the number of sampling points within the grid cell.

After the mean values of leakance are calculated, area weighted, arithmetic mean values of confining bed hydraulic conductivity and confining bed thickness are calculated within each grid cell. The mean value of confining bed hydraulic conductivity or confining bed thickness within a grid cell is equal to the sum of all confining bed hydraulic conductivity or confining bed thickness values within the grid cell divided by the number of sampling points within the grid cell.

If the continuous surface for confining bed thickness is missing, an attempt is made to utilize the secondary method to calculate the value of confining bed thickness at each point in the spot/overlay coverage. Using the aquifer top elevation for the layer below (XX=1) the current layer and the aquifer bottom elevation for the current layer (XX), the confining bed thickness is determined. At each point contained in the processing spot/overlay coverage, a surface value is retrieved from both the aquifer top (layer XX + 1) and aquifer bottom (layer XX) surfaces with a spot (tinspot or latticespot) operation. After the surfaces are sampled, the aquifer top is subtracted from the aquifer bottom elevation at each sampling point to derive a confining bed thickness at each sampling point. Once the confining bed thickness is known, the processing proceeds in the same way as described above.

If the surfaces for aquifer bottom (layer XX) and/or aquifer top (layer XX + 1) are missing, then the secondary surfaces for aquifer bottom (layer XX) and/or aquifer top (layer XX + 1) are used to determine the elevation(s). Refer to the operations Aquifer Top and Aquifer Bottom for more information about secondary coverages. Once elevations are known for the missing surface(s), the processing proceeds in the same way as described above.

The input data required for the Leakance operation include the data elements listed below. The **highlighted** data elements are used in the secondary calculation procedure only, under the condition that the surface for confining bed thickness is missing. The ***highlighted and italicized*** data elements are secondary surfaces for aquifer bottom (layer XX) and/or aquifer top (layer XX + 1). Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Processing Spot/Overlay	none	standard set
Conf. Bed Hydr. Cond. (layer XX)		
Conf. Bed Thickness (layer XX)		
Aquifer Bottom (layer XX)		
Aquifer Top (layer XX)		
Aquifer Thickness (layer XX)		
Aquifer Top (layer XX + 1)		
Aquifer Thickness (layer XX + 1)		
Aquifer Bottom (layer XX + 1)		

Data preparation operations numbered 1 to 3 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation Leakance.

This operation can be executed by selecting the Leakance menu item for layer number XX under Spatial Analysis for Ground Water. The operation code LEK is placed in the operations control file for layer number XX.

Output from the Leakance operation includes three characteristics which are contained in the INFO characteristic file for the current layer (XX) as listed below. The three characteristics include leakance, confining bed hydraulic conductivity, and confining bed thickness. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	LYXXCHAR.DAT	none

Aquifer Top (TOP)

The Aquifer Top operation contributes to the characteristic file for the current ground water layer. For each cell of the ground water grid this operation provides a mean value for the aquifer top surface (elevation) of the current ground water layer. The elevation values for the aquifer top surface are contained in the characteristic file LYXXCHAR.DAT. The letters XX represent a two-digit aquifer layer number where a preceding zero is used for layers less than 10. Through the use of the processing spot/overlay coverage, the processing ground water grid (processing grid) coverage is used as the spatial descriptor for this operation. Grid cells which are located outside the processing grid (i.e., inactive cells) are given the no data value (-9999.) for the characteristic processed with this operation. This operation is valid for layers which are assigned a MODFLOW “laycon” value of 2 or 3 only.

At each point contained in the processing spot/overlay coverage, an elevation value is retrieved from the aquifer top surface with a spot operation (tinspot or latticespot). The points in the spot/overlay coverage are evenly-spaced in all directions. With a dense set of points, a representative sampling of the surface is obtained. After the surface is sampled, an area weighted, arithmetic mean value of elevation for the aquifer top surface is calculated within each grid cell. Because the sampling points are evenly-spaced, each sampling point is given equal weight. The mean value of elevation within a grid cell is equal to the sum of all elevations within the grid cell divided by the number of sampling points within the grid cell.

If the aquifer top surface is missing, an attempt is made to utilize the secondary method to calculate the mean value of elevation for aquifer top. Using the aquifer thickness and aquifer bottom surfaces for the current layer (XX), the aquifer top is determined. At each point contained in the processing spot/overlay coverage, a surface value is retrieved from both the aquifer thickness and aquifer bottom surfaces with a spot operation. After the surfaces are sampled, the aquifer thickness is added to the aquifer bottom elevation at each sampling point to derive an aquifer top elevation at each sampling point. Then the mean value of aquifer top elevation within each grid cell is determined in the same way as described above.

The input data required for this operation include the data elements listed below. The **highlighted** data elements are used in the secondary calculation procedure only, under the condition that the aquifer top surface is missing. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Processing Spot/Overlay	none	standard set
Aquifer Top (layer XX)		LAYCHAR.DAT
Aquifer Thickness (layer XX)		
Aquifer Bottom (layer XX)		

Data preparation operations numbered 1 to 3 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation Aquifer Top.

This operation can be executed by selecting the Aquifer Top Elevation menu item for layer number XX under Spatial Analysis for Ground Water. The operation code TOP is placed in the operations control file for layer number XX.

Output from the Aquifer Top operation includes one characteristic which is contained in the INFO characteristic file for the current layer (XX) as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	LYXXCHAR.DAT	none

Aquifer Bottom (BOT)

The Aquifer Bottom operation contributes to the characteristic file for the current ground water layer. For each cell of the ground water grid this operation provides a mean value for the aquifer bottom surface (elevation) of the current ground water layer. The elevation values for the aquifer bottom surface are contained in the characteristic file LYXXCHAR.DAT. The letters XX represent a two-digit aquifer layer number where a preceding zero is used for layers less than 10. Through the use of the processing spot/overlay coverage, the processing ground water grid (processing grid) coverage is used as the spatial descriptor for this operation. Grid cells which are located outside the processing grid (i.e., inactive cells) are given the no data value (-9999.) for the characteristic processed with this operation. This operation is valid for layers which are assigned a MODFLOW "laycon" value of 1 or 3 only.

At each point contained in the processing spot/overlay coverage, an elevation value is retrieved from the aquifer bottom surface with a spot operation (tinspot or latticespot). The points in the spot/overlay coverage are evenly-spaced in all directions. With a dense set of points, a representative sampling of the surface is obtained. After the surface is sampled, an area weighted, arithmetic mean value of elevation for the aquifer bottom surface is calculated within each grid cell. Because the sampling points are evenly-spaced, each sampling point is given equal weight. The mean value of elevation within a grid cell is equal to the sum of all elevations within the grid cell divided by the number of sampling points within the grid cell.

If the aquifer bottom surface is missing, an attempt is made to utilize the secondary method to calculate the mean value of elevation for aquifer bottom. Using the aquifer thickness and aquifer top surfaces for the current layer (XX), the aquifer bottom is determined. At each point contained in the processing spot/overlay coverage, a surface value is retrieved from both the aquifer thickness and aquifer top surfaces with a spot operation. After the surfaces are sampled, the aquifer thickness is subtracted from the aquifer top elevation at each sampling point to derive an aquifer bottom elevation at each sampling point. Then the mean value of aquifer bottom elevation within each grid cell is determined in the same way as described above.

The input data required for this operation include the data elements listed below. The **highlighted** data elements are used in the secondary calculation procedure only, under the condition that the aquifer bottom surface is missing. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Processing Spot/Overlay	none	standard set
Aquifer Bottom (layer XX)		LAYCHAR.DAT
Aquifer Top (layer XX)		
Aquifer Thickness (layer XX)		

Data preparation operations numbered 1 to 3 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation Aquifer Bottom.

This operation can be executed by selecting the Aquifer Bottom Elevation menu item for layer number XX under Spatial Analysis for Ground Water. The operation code BOT is placed in the operations control file for layer number XX.

Output from the Aquifer Bottom operation includes one characteristic which is contained in the INFO characteristic file for the current layer (XX) as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	LYXXCHAR.DAT	none

Initial Aquifer Head (EWL)

The Initial Aquifer Head operation contributes to the characteristic file for the current ground water layer. For each cell of the ground water grid this operation provides a mean value for the initial aquifer head surface (elevation) of the current ground water layer. The elevation values for the initial aquifer head surface are contained in the characteristic file LYXXCHAR.DAT. The letters XX represent a two-digit aquifer layer number where a preceding zero is used for layers less than 10. Through the use of the processing spot/overlay coverage, the processing ground water grid (processing grid) coverage is used as the spatial descriptor for this operation. Grid cells which are located outside the processing grid (i.e., inactive cells) are given the no data value (-9999.) for the characteristic processed with this operation. This operation is valid for all MODFLOW laycon values.

At each point contained in the processing spot/overlay coverage, an elevation value is retrieved from the initial aquifer head surface with a spot operation (tinspot or latticespot). The points in the spot/overlay coverage are evenly-spaced in all directions. With a dense set of points, a representative sampling of the surface is obtained. After the surface is sampled, an area weighted, arithmetic mean value of elevation for the initial aquifer head surface is calculated within each grid cell. Because the sampling points are evenly-spaced, each sampling point is given equal weight. The mean value of elevation within a grid cell is equal to the sum of all elevations within the grid cell divided by the number of sampling points within the grid cell.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Processing Spot/Overlay	none	standard set
Initial Aquifer Head Surface (layer XX)		

Data preparation operations numbered 1 to 3 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation Initial Aquifer Head.

This operation can be executed by selecting the Initial Aquifer Head menu item for layer number XX under Spatial Analysis for Ground Water. The operation code EWL is placed in the operations control file for layer number XX.

Output from the Initial Aquifer Head operation includes one characteristic which is contained in the INFO characteristic file for the current layer (XX) as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	LYXXCHAR.DAT	none

IBOUND (IBD)

The IBOUND operation contributes to the characteristic file for the current ground water layer. For each cell of the ground water grid this operation retrieves the MODFLOW IBOUND values for the current ground water layer. Following execution of the IBOUND operation, the IBOUND values are contained in the characteristic file LYXXCHAR.DAT. The letters XX represent a two-digit aquifer layer number where a preceding zero is used for layers less than 10. Through the use of the IBOUND coverage, the ground water grid coverage (grid coverage) is used as the spatial descriptor for this operation. This operation is valid for all MODFLOW "laycon" values.

MODFLOW IBOUND data indicate whether a grid cell is active, constant head, or inactive. The IBOUND coverage can be created by a HydroGIS ground water utility. Values for IBOUND are specified for each layer and the values can vary from layer to layer for a given cell. The IBOUND data are stored in one IBOUND coverage. The topology of the IBOUND coverage matches exactly with the topology of the grid coverage.

The IBOUND data are retrieved from the IBOUND coverage for the current layer by first creating a temporary INFO file. Contained within the INFO file are only the unique grid cell ID and the IBOUND data for the current layer for all grid cells. The temporary INFO file is then physically joined to the INFO characteristic file for the current layer (LYXXCHAR.DAT).

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
IBOUND	none	standard set

Data preparation operations numbered 1 and 3 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation IBOUND.

This operation can be executed by selecting the IBOUND Boundary Conditions menu item for layer number XX under Spatial Analysis for Ground Water. The operation code IBD is placed in the operations control file for layer number XX.

Output from the IBOUND operation includes one characteristic which is contained in the INFO characteristic file for the current layer (XX) as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	LYXXCHAR.DAT	none

Boundary Flux (FLX)

The Boundary Flux operation contributes to one characteristic file. In MODFLOW, specified boundary flux are represented by point stresses in the well package. For each boundary flux “well”, this operation provides the spatial location (i.e., row and column), vertical connection (i.e., layer number(s)), and the layer coefficient (i.e., the degree of vertical connection). These four characteristics are gathered for each boundary flux “well”. The values of the characteristics for each boundary flux “well” are contained in the characteristic file WELLCHAR.DAT. Through the unique grid cell ID contained in the boundary flux coverage, the processing ground water grid (processing grid) coverage is used as the spatial descriptor for this operation.

The boundary flux coverage is a copy of the grid point coverage with an additional data column (item) for each layer to indicate the cells with boundary flux. Each cell is classified as active or inactive with respect to boundary flux. All cells of all layers must be classified which can be completed by a HydroGIS ground water utility.

Because the elements of the boundary flux coverage contain the unique grid cell ID, an overlay with the processing grid is not necessary. The boundary flux coverage is copied to a temporary coverage on which the remaining processing is performed. Boundary flux “wells” which are classified as inactive are removed from the data set. Each boundary flux “well” is assigned to one and only one grid cell which provides the grid cell row and column for each flux “well”.

The vertical connections (layer value) for each well are provided in the point attribute table (<cover>.pat) of the boundary flux coverage. All of the layer coefficients in the well characteristic file are equal to 1 for boundary flux.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Boundary Flux	none	standard set

Data preparation operations numbered 1, 3, and 8 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation Boundary Flux.

This operation can be executed by selecting the Boundary Flux menu item for layer 0 under Spatial Analysis for Ground Water. The operation code FLX is placed in the operations control file for layer number 0.

Output from the Boundary Flux operation includes four characteristics which are contained in the INFO characteristic file WELLCHAR.DAT. The four characteristics include row, column, layer, and layer coefficient which is always equal to one for Boundary Flux. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	WELLCHAR.DAT	none

General Head Boundary (GHB)

The General Head Boundary (GHB) operation creates one characteristic file. The general head boundary condition in MODFLOW is a head-dependent flux that is typically applied at the edges of the model grid to simulate temporal flux changes along the model domain boundary at specified cells of specified layers. For each cell of the ground water grid which contains general head boundary elements, this operation provides boundary conductance and external boundary elevation of aquifer head. GHB elements are unique within a cell, between cells, and between layers. Within one cell for a layer, multiple GHB elements can exist. The row, column, layer, boundary conductance, and external head characteristics are determined for each unique GHB element. The values of the characteristics for all layers are contained in the characteristic file GHBCHAR.DAT. Through the unique grid cell ID contained in the GHB coverage, the processing ground water grid (processing grid) coverage is used as the spatial descriptor for this operation.

Because the elements of the GHB coverage contain the unique grid cell ID, an overlay with the processing grid is not necessary. It is recommended that the GHB coverage be created with the ground water utility which creates GHB coverages. By using the utility, the coverage format and specifications will conform to the input requirements of the GHB operation. Refer to the GHB utility documentation under Data Preparation Utilities for ground water.

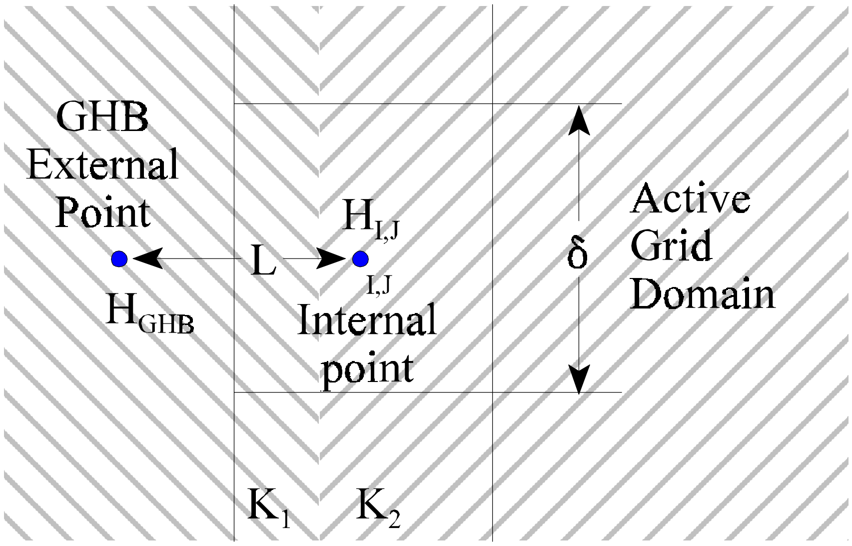
The GHB coverage can contain active and inactive GHB elements. In addition, the active elements are classified as calculated or user-defined. Only the GHB elements which are classified as calculated are processed under the GHB operation which is used to calculate the boundary conductance and external head. The boundary conductance and external head for the GHB elements that are classified as user-defined are copied from the GHB coverage to the GHB characteristic file. The conductance and head for user-defined GHB elements must be available in the GHB coverage prior to execution of the GHB operation. The data preparation utility for GHB provides the opportunity to establish user-defined values.

With the GHB operation, the boundary conductance and external head are calculated for each active GHB element that is classified as calculated. Processing is completed one layer at a time starting with layer 1. The components of the boundary conductance include mean aquifer transmissivity along the GHB flow path, the cell dimension orthogonal to the GHB flow path, and the GHB flow path distance. The GHB flow path is defined by a line located between the external GHB point and the active grid cell center to which the GHB is associated. The latter two components of boundary conductance are attributes of each GHB element. The attributes are stored in the point attribute table of the GHB coverage (<cover>.pat). The values for the orthogonal dimension and the flow path are determined by the utility which creates GHB coverages.

The mean aquifer transmissivity along the GHB flow path is calculated with the GHB operation from aquifer hydraulic conductivity and aquifer thickness. The same coverages (data) that are used to calculate the mean aquifer transmissivity for each grid cell are used for the GHB boundary conductance. However, the procedure used to calculate the mean transmissivity for the boundary conductance is different in two ways. First, a **harmonic** mean transmissivity is calculated for the GHB boundary conductance because the direction of flow is known (an **arithmetic** mean is used for grid cell transmissivity). Second, a **line-length weighted** mean is used for the transmissivity calculation of the GHB boundary conductance (an **area weighted** mean is used for grid cell transmissivity). The GHB flow path is divided into multiple segments as defined by the default value ($\geq$ 4) or as defined by the user. It is assumed that conductance properties along the flow path line are representative of the conductance properties in the direction of the boundary flux at all points along the cell face. In Figure 3.2 the data requirements for a GHB of MODFLOW are illustrated. The formulation of GHB conductance with HydroGIS is shown in Figure 3.3.

The transmissivity and GHB operations use two methods to calculate transmissivity. Recall that the GHB transmissivity is a component of GHB boundary conductance. The aquifer type dictates the method to use to calculate the boundary conductance. For aquifer layers classified as confined (MODFLOW "laycon" = 0) or partially-convertible (MODFLOW "laycon" = 2), the physical thickness of the aquifer is used with the hydraulic conductivity of the aquifer to calculate the transmissivity component of the boundary conductance. For aquifers classified as unconfined (MODFLOW "laycon" = 1) and fully-convertible (MODFLOW "laycon" = 3), the saturated thickness of the aquifer is used with the hydraulic conductivity of the aquifer to calculate the transmissivity component of the boundary conductance. Calculation of transmissivity with the physical and saturated thickness are presented below. In addition, the procedure used to determine the external aquifer head for GHB elements is provided.

MODFLOW GHB REQUIREMENTS



MODFLOW Input:
H_{GHB}, C_{GHB}

$$Q = -KA\frac{\Delta H}{L} \qquad \textit{Darcy}$$

define:

$$C_{GHB} = \frac{+KA}{L}$$

where:
C_{GHB} = GHB conductance
K = aquifer hydraulic conductivity
L = flow distance from GHB to internal point
A = face x-sectional flow area $(\delta \cdot b)$
δ = orthogonal cell dimension
b = thickness of aquifer

or, more precisely:

$$C_{GHB} = +\overline{Kb}\left(\frac{\delta}{L}\right)$$

$\overline{Kb}$ = Harmonic mean transmissivity over distance, L

then,

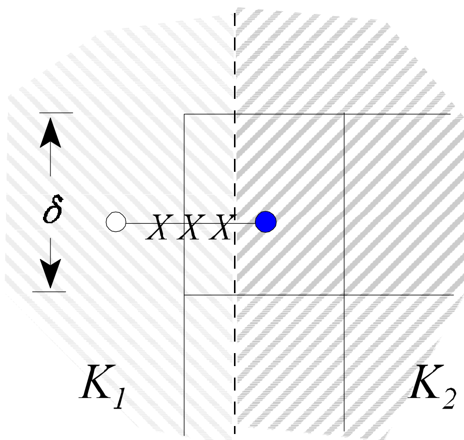
$$Q = C_{GHB}\left(H_{GHB} - H_{I,J}\right)$$

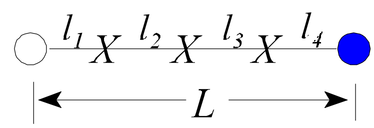
Figure 3.2 MODFLOW Requirements for General Head Boundaries.

GHB Conductance Formulation with HydroGIS

$$C_{ghb} = \frac{KA}{L} = \frac{Kb\delta}{L}$$

$$= T_{ghb}\left(\frac{\delta}{L}\right)$$





$$T_{ghb} = \frac{L}{\frac{l_1}{T_1} + \frac{l_2}{T_2} + \frac{l_3}{T_3} + \ldots + \frac{l_n}{T_n}}$$

Harmonic Mean

○ GHB external point and ARC/INFO line node

● Cell internal point and ARC/INFO line node

X ARC/INFO line node

l_i length of segment i of GHB flow path, L

Figure 3.3 Formulation of General Head Boundary Conductance with HydroGIS.

GHB Conductance for Confined or Partially-Convertible (MODFLOW) Aquifers

Aquifer hydraulic conductivity and physical aquifer thickness are used to determine the transmissivity component of the boundary conductance. An overlay (intersect) between the segmented GHB flow path and the aquifer hydraulic conductivity coverage is used to gather hydraulic conductivity values along the total length of the flow path. The nodes at the ends of each of the flow path segments are used to retrieve the physical thickness of the aquifer from the continuous surface for aquifer thickness with a surface spot (tinspot or latticespot) operation. The arithmetic mean value of aquifer thickness for each flow path segment is determined from the values at the ends (nodes) of each segment. A value of transmissivity is calculated for each flow path segment from the product of hydraulic conductivity and the mean value of physical aquifer thickness. Then, a line, length-weighted, harmonic mean value of transmissivity is calculated for each flow path of the current layer. Figure 3.3 illustrates the components of the GHB flow path.

If the continuous surface for physical aquifer thickness is missing, an attempt is made to utilize the secondary method to calculate the value of aquifer thickness at each node of the segmented flow path. Using the aquifer top and aquifer bottom surfaces for the current layer (XX), the aquifer thickness is determined. At each node of the segmented flow path, a surface value is retrieved from both the aquifer top and aquifer bottom surfaces with a spot (tinspot or latticespot) operation. After the surfaces are sampled, the aquifer bottom is subtracted from the aquifer top elevation at each sampling point to derive a physical aquifer thickness at each sampling point. Once the thickness is known, the processing proceeds in the same way as described above.

The GHB external head is determined with a surface spot (tinspot or latticespot) operation. The external GHB points are used to retrieve a value of initial aquifer head from the continuous surface for initial aquifer head. The head value at the point is stored in the characteristic file.

The input data required for *confined or partially-convertible* aquifers for operation GHB include the data elements listed below. The **highlighted** data elements are used in the secondary calculation procedure only, under the condition that the surface for aquifer thickness is missing. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
General Head Boundary	none	standard set
Hydraulic Conductivity (layer XX)		LAYCHAR.DAT
Aquifer Thickness (layer XX)		
Aquifer Top (layer XX)		
Aquifer Bottom (layer XX)		
Initial Aquifer Head (layer XX)		

Data preparation operations numbered 1 to 4 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation GHB for *confined or partially-convertible aquifers*.

This operation can be executed by selecting the General Head Boundary Flux menu item for layer 0 under Spatial Analysis for Ground Water. The operation code GHB is placed in the operations control file for layer number 0.

Output from the GHB operation for *confined or partially-convertible aquifers* includes five characteristics which are contained in the INFO characteristic file as listed below. The five characteristics include layer, row, column, boundary conductance, and external aquifer head. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	GHBCHAR.DAT	none

GHB Conductance for Unconfined or Fully-Convertible (MODFLOW) Aquifers

Aquifer hydraulic conductivity and saturated aquifer thickness are used to determine the transmissivity component of the boundary conductance. An overlay (intersect) between the segmented GHB flow path and the aquifer hydraulic conductivity coverage is used to gather hydraulic conductivity values along the total length of the flow path. The nodes at the ends of each of the flow path segments are used to retrieve elevation values for aquifer top, aquifer bottom, and initial aquifer head from the respective continuous surfaces with a surface spot (tinspot or latticespot) operation. These elevation values are used to calculate the saturated aquifer thickness. Figure 3.3 illustrates the components of the GHB flow path.

After the elevation surfaces are sampled, the saturated aquifer thickness at each segment node is calculated. The initial aquifer head elevation is compared to the aquifer top elevation at each node. For the condition where the initial aquifer head is less than or equal to the aquifer top, the saturated thickness is equal to the aquifer bottom elevation subtracted from the initial aquifer head elevation. For the condition where the initial aquifer head is greater than the aquifer top, the saturated thickness is equal to the aquifer bottom elevation subtracted from the aquifer top elevation.

The arithmetic mean value of saturated aquifer thickness for each flow path segment is determined from the values at the ends (nodes) of each segment. A value of transmissivity is calculated for each flow path segment from the product of hydraulic conductivity and the mean value of saturated aquifer thickness. Then a line, length-weighted, harmonic mean value of transmissivity is calculated for each flow path of the current layer.

If the continuous surface for either aquifer top or aquifer bottom elevation is missing, an attempt is made to utilize the secondary method to calculate the value of aquifer top or bottom at each node of the segmented flow path. There must be at least two of the three surfaces (i.e., top, physical thickness, bottom) to determine aquifer top and bottom for the current layer. Refer to the Aquifer Top and Aquifer Bottom operations for information on determining the respective elevation using the secondary method. Once the missing surface is determined with the secondary method, the processing proceeds in the same way as described above.

The GHB external head is determined with a surface spot (tinspot or latticespot) operation. The external GHB points are used to retrieve a value of initial aquifer head from the continuous surface for initial aquifer head. The head value at the point is stored in the characteristic file.

The input data required for *unconfined or fully-convertible aquifers* for operation GHB include the data elements listed below. The **highlighted** data element is used in the secondary calculation procedure only, under the condition that the surface for aquifer top or bottom elevation is missing. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
General Head Boundary	none	standard set
Hydraulic Conductivity (layer XX)		LAYCHAR.DAT
Aquifer Top (layer XX)		
Aquifer Bottom (layer XX)		
Initial Aquifer Head (layer XX)		
Aquifer Thickness (layer XX)		

Data preparation operations numbered 1 to 4 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation GHB.

This operation can be executed by selecting the General Head Boundary Flux menu item for layer 0 under Spatial Analysis for Ground Water. The operation code GHB is placed in the operations control file for layer number 0.

Output from the GHB operation for *unconfined or fully-convertible aquifers* includes five characteristics which are contained in the INFO characteristic file as listed below. The five characteristics include layer, row, column, boundary conductance, and external aquifer head. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	GHBCHAR.DAT	none

Multi-Scale GHB (MSCALE)

The Multi-Scale GHB operation creates one characteristic file. This operation provides data to establish spatial and temporal boundary conditions for a small-scale model from the simulated head results of a large-scale model. The data supplied by operation Multi-Scale GHB include the inverse distance from the location of the external head for the small-scale GHB to the location of the four nearest grid cell centers of the large-scale grid. In addition, the unique ID of the small-scale GHB element and the grid row and column for the four nearest grid cells of the large-scale grid are provided.

The pre-processor of FHM and simulation codes utilize the inverse distance data to create head-dependent boundary conditions for a small-scale ground water model domain which are spatially and temporally varying. The head data are retrieved from a previously completed, and independent large-scale simulation.

The Multi-Scale GHB operation selects only the GHB elements which are classified as active and calculated for processing. For the selected small-scale GHB elements, the grid cell unique ID and inverse distances for the four nearest large-scale grid cells are determined and stored in the characteristic file GHBDCHAR.DAT. Through the unique grid cell ID contained in the GHB coverage, the processing ground water grid (processing grid) coverage is used as the spatial descriptor for this operation.

A processing grid for the large-scale domain is created to determine the four nearest large-scale cells for each small-scale GHB external point. A processing grid in HydroGIS contains the largest extent of active and constant head cells when accounting for all layers of the model. A processing grid also contains the MODFLOW IBOUND data and border cell data for all layers. For each layer, border cell data indicate the cells which are next to an inactive cell on the model boundary. The IBOUND and border cell data are used to indicate whether an external point for a small-scale GHB is located in an inactive or border cell region of the large-scale model domain. Small-scale GHB external points which are classified as calculated are not permitted to be located in the inactive or border cell region of the large-scale grid. If this condition occurs, the Multi-Scale GHB processing is terminated and an error message is written to the error file.

On a layer by layer basis, each of the small-scale GHB external points are evaluated to determine the associated large-scale cells. An overlay (identity) between a temporary coverage of external GHB points for the current layer and the large-scale processing grid for the current layer is used to retrieve the first large-scale grid cell for each external GHB point. Then the remaining three large-scale grid cells are determined. Selection of the remaining three large-scale cells depends upon the relative rotation angle between the small-scale and large-scale grids and the position of the small-scale, external GHB point relative to the first large-scale grid. The relationship between small-scale and large-scale grid cell centers and the formulation of the inverse distance interpolation of head are illustrated in Figure 3.4. The inverse distance and grid row and column for each large-scale grid cell that is retrieved are written to the characteristic file.

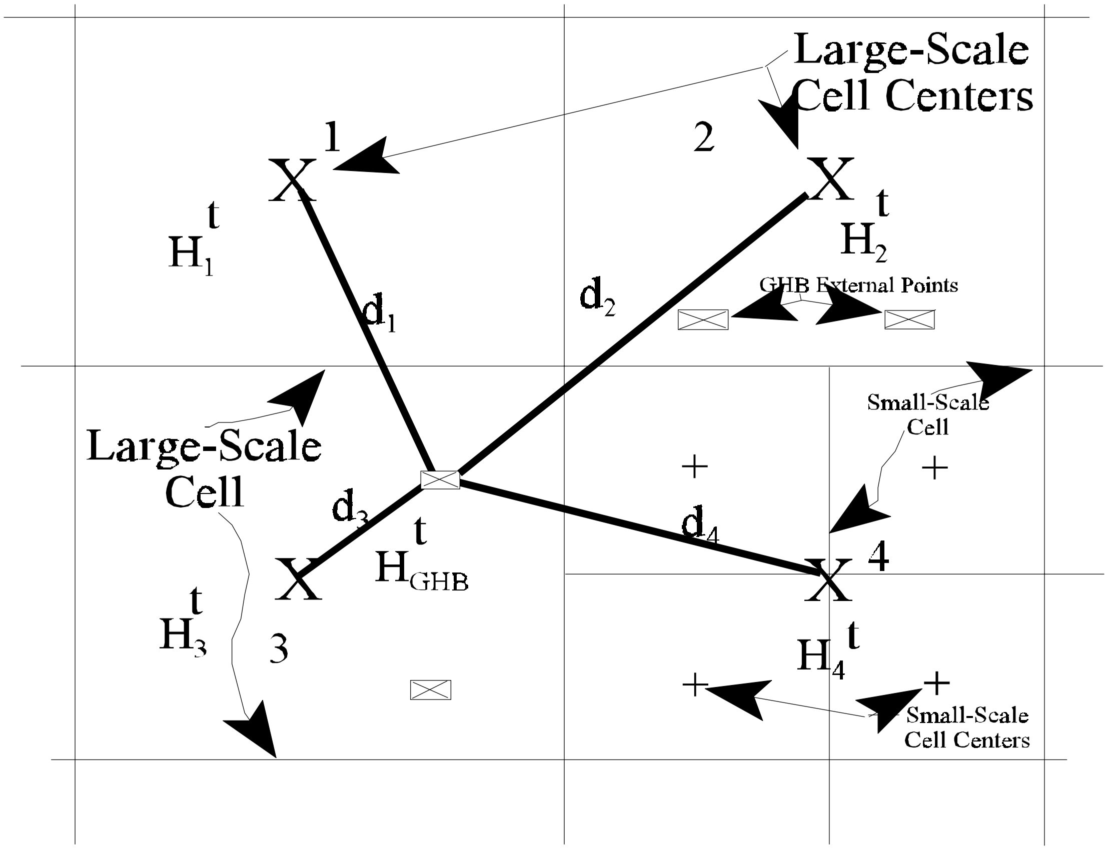
The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
General Head Boundary	none	standard set
Large-Scale Grid		
Large-Scale Point		
Large-Scale IBOUND		

Data preparation operations numbered 1 to 4 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation Multi-Scale GHB.

This operation can be executed by selecting the Multi-Scale GHB menu item for layer 0 under Spatial Analysis for Ground Water. The operation code MSCALE is placed in the operations control file for layer number 0.

Formulation of Multi-Scale GHB Head



Interpolated GHB Head Using Inverse Distance:

$$H_{GHB}^t = \frac{\sum H_i^t \left(\frac{1}{d_i}\right)}{\sum \left(\frac{1}{d_i}\right)} = \frac{H_1^t\left(\frac{1}{d_1}\right) + H_2^t\left(\frac{1}{d_2}\right) + H_3^t\left(\frac{1}{d_3}\right) + H_4^t\left(\frac{1}{d_4}\right)}{\left(\frac{1}{d_1}\right) + \left(\frac{1}{d_2}\right) + \left(\frac{1}{d_3}\right) + \left(\frac{1}{d_4}\right)}$$

Figure 3.4 Relationship of the Small-Scale GHB External Point to the Cell Centers of the Large-Scale Grid.

Output from the Multi-Scale GHB operation includes four characteristics for each small-scale GHB external point that is classified as calculated. The data for each layer are contained in the INFO characteristic file as listed below. The four characteristics include large-scale grid row and column, the inverse distance, and the unique ID of the small-scale GHB element. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	GHBDCHAR.DAT	none

Line Hydrography (STRM)

The Line Hydrography operation contributes to one characteristic file. For each cell of the ground water grid which contains line hydrography elements (i.e., streams), this operation provides grid row and column, layer, HSPF reach number, code for hydrography type, bed conductance, and model elevations for bed bottom and surface water stage. The data which is provided accounts for all aquifer layers to which the hydrography elements are "connected". These eight characteristics are determined for each unique line hydrography element. Based on the intended model application and user preference, the individual hydrography elements can be aggregated by one of three methods. The default aggregation method is set to none. Depending on the cell dimensions of the ground water grid, there are usually multiple hydrography elements within the grid cells which contain hydrography. The values of the characteristics for all layers are contained in the characteristic file RIV2CHAR.DAT. The processing ground water grid (processing grid) coverage is used as the spatial descriptor for this operation.

An overlay (intersect) between the classified line hydrography coverage and the processing grid coverage is used to assign the line hydrography arcs to grid cells. The coverage that is created by the overlay (overlay coverage) contains more unique arcs which represent streams (overlay arcs) than the number contained in the classified line hydrography coverage. This is caused by the intersection of grid cells with the arcs that represent hydrography. Each overlay arc in the overlay coverage is assigned to one grid cell which provides the spatial location (i.e., row and column) for each overlay arc in the model.

The classified line hydrography coverage contains a unique ID for each arc. The overlay coverage also contains the unique ID. However, the overlay coverage contains multiple arcs with the same unique ID which is caused by the overlay process.

The hydrologic data for line hydrography are contained in three INFO attribute tables. Each of the hydrologic attribute tables also contain the same unique ID that was discussed earlier for the coverage. Associated with the unique ID in each of the attribute tables are attribute values which are unique to each arc. The tables include connectivity, hydrologic, and layer hydrologic data. The tables include data such as stream order (Strahler method, Viessman et al. 1996), bottom width, and upstream and downstream elevations for mean annual stage, bed bottom, and proxy datum. Also available are streambed thickness and vertical hydraulic conductivity for each layer to which the hydrography element is "connected". The complete set of attributes which are contained within each table are listed and described in Appendix A.

During processing for the Line Hydrography operation, selected attributes from the three attribute tables for line hydrography are physically joined to the overlay arcs in the overlay coverage. The attribute data for each overlay arc can now be summarized into stream characteristics that are required for the hydrologic model. As stated above, upstream and downstream elevations are available for the line hydrography elements. Because the overlay creates new arcs, the upstream and downstream elevations for these overlay arcs are determined by using a linear interpolation of the upstream and downstream elevations from the attribute table. Following the determination of upstream and downstream elevations for each overlay arc, the arithmetic mean values for mean annual stage, bed bottom, and proxy datum elevations are determined for each overlay arc. The interpolated values of upstream and downstream elevations are used to calculate the arithmetic mean. The mean elevations and the bed values for vertical hydraulic conductivity and thickness by layer for each overlay arc are carried forward to complete the characteristics table.

In the physical system, hydrography elements are associated with gradients in surface water stage and bed bottom elevations. Within a finite-difference hydrologic model, gradients exist from cell to cell but gradients are removed within each cell. The head difference between surface water stage and aquifer head is conceptualized as the driving mechanism for flow direction and magnitude between hydrography and the ground water system. In a hydrologic model, it is necessary to maintain this head difference. Because the hydrologic model removes the gradients in hydrography and aquifer head elevations within each cell, physical elevations for surface water stage and bed bottom of hydrography cannot be used. Instead, relative elevations are prepared for the hydrologic model.

The relative elevations are derived from the mean proxy datum elevation for each overlay arc and the mean topographic elevation for the grid cell. The proxy datum represents approximately the top of bank elevation at the stream. For each overlay arc, the mean elevations for the physical surface water stage and bed bottom are shifted to a relative elevation. The magnitude of the shift is equal to the mean proxy datum of the overlay arc subtracted from the mean topographic elevation for the grid cell. The elevation shift (positive or negative) for the overlay arc is added to the mean surface water stage and mean bed bottom elevations. The relative or shifted elevations are stored in the characteristics file for ground water hydrography.

In addition to the elevations, bed conductance is determined by operation Line Hydrography for each overlay arc. The bed conductance is equal to the product of conductance area and bed leakance. Conductance area is equal to the product of arc length and the width attribute from the hydrologic attribute table. Bed leakance is layer specific and is equal to the vertical hydraulic conductivity of the bed divided by the bed thickness which are both contained in the layer hydrologic attribute table. Following the determination of elevations and conductance, the hydrography is aggregated within each grid cell.

Three aggregation methods are available to combine overlay arcs within the grid cell. In order of increasing aggregation, the methods include no aggregation (default), aggregation by reach classification and stream order, and aggregation by grid cell and stream order. The no aggregation method preserves all overlay arcs in the characteristics file. The reach classification method is the highest level of aggregation that can be used for an integrated FHM model application. Within a grid cell, the overlay arcs are grouped by the same stream order within each reach classification. The grid cell aggregation method groups overlay arcs within the grid cell by stream order. This aggregation method can be used for a ground water only model application. For an aggregated group of overlay arcs, the resultant conductance is equal to the sum of the individual conductances, and the elevations are equal to the conductance-weighted mean of the individual elevations.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Processing Grid	Line Hydrography Connectivity	standard set
Processing Spot/Overlay	Line Hydrography Hydrologic	
Line Hydrography	Line Hydrog. Layer Hydrologic	
Topography		

Data preparation operations for coverages and surfaces, under spatial analysis operations for ground water and surface water, must be completed prior to execution of operation Line Hydrography. Data preparation includes operations numbered 1 to 3 for ground water and operations numbered 4 and 5 for surface water.

This operation can be executed by selecting the Line Hydrography menu item for layer 0 under Spatial Analysis for Ground Water. The operation code STRM is placed in the operations control file for layer number 0.

Output from the Line Hydrography operation includes eight characteristics which are contained in the INFO characteristic file as listed below. The eight characteristics include grid row and column, layer, HSPF reach number, code for hydrography type, hydrography conductance, and surface water stage and bed bottom elevations. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	RIV2CHAR.DAT	none

Polygon Hydrography (LAKE)

The Polygon Hydrography operation contributes to one characteristic file. For each cell of the ground water grid which contains polygon hydrography elements (i.e., lakes, wetlands, wide rivers), this operation provides grid row and column, layer, HSPF reach number, code for hydrography type, bed conductance, and model elevations for bed bottom and surface water stage. The data which is provided accounts for all aquifer layers to which the hydrography elements are "connected". These eight characteristics are determined for each unique polygon hydrography element. Based on the intended model application and user preference, the individual hydrography elements can be aggregated by one of three methods. The default aggregation method is set to none. Depending on the cell dimensions of the ground water grid, there are usually multiple hydrography elements within the grid cells which contain hydrography. The values of the characteristics for all layers are contained in the characteristic file RIV2CHAR.DAT. The processing ground water grid (processing grid) coverage is used as the spatial descriptor for this operation.

An overlay (intersect) between the classified polygon hydrography coverage and the processing grid coverage is used to assign the polygon hydrography to grid cells. The coverage that is created by the overlay (overlay coverage) contains more unique polygons representing hydrography (overlay polygons) than the number contained in the classified polygon hydrography coverage. This is caused by the intersection of grid cells with the polygons that represent hydrography. Each overlay polygon in the overlay coverage is assigned to one grid cell which provides the spatial location (i.e., row and column) for each overlay polygon in the model.

The classified polygon hydrography coverage contains a unique ID for each polygon. The overlay coverage also contains the unique ID. However, the overlay coverage contains multiple polygons with the same unique ID which is caused by the overlay process.

The hydrologic data for polygon hydrography are contained in two INFO attribute tables. Each of the hydrologic attribute tables also contain the same unique ID that was discussed earlier for the coverage. Associated with the unique ID in each of the attribute tables are attribute values which are unique to each polygon. The tables include hydrologic and layer hydrologic data. The tables include data such as the maximum water surface area factor, and elevations for mean annual stage, bed bottom, and proxy datum. Also available are streambed thickness and vertical hydraulic conductivity for each layer to which the hydrography element is "connected". The product of the maximum water surface area factor and the polygon area from the coverage provide the maximum defined surface area for the polygon. The complete set of attributes which are contained within each table are listed and described in Appendix A.

During processing for the Polygon Hydrography operation, selected attributes from the two attribute tables for polygon hydrography are physically joined to the overlay polygons in the overlay coverage. The attribute data for each overlay polygon can now be summarized into hydrography characteristics that are required for the hydrologic model. The surface water stage and bed bottom elevations and the bed values for vertical hydraulic conductivity and thickness by layer for each overlay polygon are carried forward to complete the characteristics table.

In the physical system, hydrography elements are associated with gradients in surface water stage and bed bottom elevations. Within a finite-difference hydrologic model, gradients exist from cell to cell but gradients are removed within each cell. The head difference between surface water stage and aquifer head is conceptualized as the driving mechanism for flow direction and magnitude between hydrography and the ground water system. In a hydrologic model, it is necessary to maintain this head difference. Because the hydrologic model removes the gradients in hydrography and aquifer head elevations within each cell, physical elevations for surface water stage and bed bottom of hydrography cannot be used. Instead, relative elevations are prepared for the hydrologic model.

The relative elevations are derived from the proxy datum elevation for each overlay polygon and the mean topographic elevation for the grid cell. The proxy datum represents approximately the top of bank elevation at the lake, wetland, wide river, etc. For each overlay polygon, the elevations for the physical surface water stage and bed bottom are shifted to a relative elevation. The magnitude of the shift is equal to the proxy datum of the overlay polygon subtracted from the mean topographic elevation for the grid cell. The elevation shift (positive or negative) for the overlay polygon is added to the surface water stage and bed bottom elevations. The relative or shifted elevations are stored in the characteristics file for ground water hydrography.

In addition to the elevations, bed conductance is determined by operation Polygon Hydrography for each overlay polygon. The bed conductance is equal to the product of conductance area and bed leakance. Conductance area is equal to the product of the maximum defined surface area as defined above and the polygon area factor which defines the fraction of the area of the hydrography polygon which conducts water through the bed. Bed leakance is layer specific and is equal to the vertical hydraulic conductivity of the bed divided by the bed thickness which are both contained in the layer hydrologic attribute table. Following the determination of elevations and conductance, the hydrography is aggregated within each grid cell.

Three aggregation methods are available to combine overlay polygons within the grid cell. In order of increasing aggregation, the methods include no aggregation (default), aggregation by reach classification and stream order, and aggregation by grid cell and stream order. For hydrography polygons, the value of stream order is set to zero. The no aggregation method preserves all overlay polygons in the characteristics file. The reach classification method is the highest level of aggregation that can be used for an integrated FHM model application. Within a grid cell, the overlay polygons are grouped for order equal to zero by reach classification. The grid cell aggregation method groups overlay arcs within the grid cell by order equal to zero. This aggregation method can be used for a ground water only model application. For an aggregated group of overlay polygons, the resultant conductance is equal to the sum of the individual conductances, and the elevations are equal to the conductance-weighted mean of the individual elevations.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Processing Grid	Poly. Hydrog. Hydrologic	standard set
Processing Spot/Overlay	Poly. Hydrog. Layer Hydrologic	
Polygon Hydrography		
Topography		

Data preparation operations for coverages and surfaces, under spatial analysis operations for ground water and surface water, must be completed prior to execution of operation Polygon Hydrography. Data preparation includes operations numbered 1 to 3 for ground water and operations numbered 4 and 5 for surface water.

This operation can be executed by selecting the Polygon Hydrography menu item for layer 0 under Spatial Analysis for Ground Water. The operation code LAKE is placed in the operations control file for layer number 0.

Output from the Polygon Hydrography operation includes eight characteristics which are contained in the INFO characteristic file as listed below. The eight characteristics include grid row and column, layer, HSPF reach number, code for hydrography type, hydrography conductance, and surface water stage and bed bottom elevations. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	RIV2CHAR.DAT	none

Springs (SPR)

The Springs operation contributes to one characteristic file. For each cell of the ground water grid which contains springs, this operation provides grid row and column layer, HSPF reach number, code for hydrography type, spring conductance, and model elevations for bed bottom and surface water stage. The data which is provided accounts for all aquifer layers to which the hydrography elements are "connected". The bed elevation is set to a flag value of -9998. These eight characteristics are determined for each unique spring element. Due to the conductance magnitude, spring elements are not permitted to be aggregated with line and polygon hydrography elements. The values of the characteristics for all layers are contained in the characteristic file RIV2CHAR.DAT. The processing ground water grid (processing grid) coverage is used as the spatial descriptor for this operation.

An overlay (intersect) between the classified springs coverage and the processing grid coverage is used to assign the springs to grid cells. The coverage that is created by the overlay (overlay coverage) contains the same number of springs as were stored in the classified springs coverage unless a spring is located outside the processing grid. Each spring in the overlay coverage is assigned to one grid cell which provides the spatial location (i.e., row and column) for each spring in the model.

The classified springs coverage contains a unique ID for each spring. The overlay coverage also contains the unique ID.

The hydrologic data for springs are contained in one INFO attribute table. The hydrologic attribute table also contains the same unique ID that was discussed earlier for the coverage. Associated with the unique ID in the attribute table are attribute values which are unique to each spring. The table includes layer hydrologic data such as elevations for mean annual stage and proxy datum, and spring conductance for each layer to which the hydrography element is "connected". The complete set of attributes which are contained within each table are listed and described in Appendix A.

During processing for the Springs operation, selected attributes from the attribute table for springs are physically joined to the points (springs) in the overlay coverage. The attribute data for each point can now be summarized into hydrography characteristics that are required for the hydrologic model. The surface water stage elevation and the spring conductance by layer for each point are carried forward to complete the characteristics table.

In the physical system, spring elements are associated with gradients in surface water stage and bed bottom elevations. Within a finite-difference hydrologic model, gradients exist from cell to cell but gradients are removed within each cell. In the physical system, the head difference between surface water stage for a spring and aquifer head is conceptualized as the driving mechanism for flow magnitude out of the ground water system. In a hydrologic model, it is necessary to maintain this head difference. Because the hydrologic model alters the gradient between the spring stage and the aquifer head due to the removal of the aquifer head gradient within the cell, physical elevations for spring stage cannot be used. Instead, a relative stage elevation is prepared for the hydrologic model.

The relative stage elevation is derived from the proxy datum elevation for each spring and the mean topographic elevation for the grid cell. The proxy datum represents approximately the top of bank elevation at the spring vent. For each overlay point, the physical spring stage elevation is shifted to a relative elevation. The magnitude of the shift is equal to the proxy datum of the overlay point subtracted from the mean topographic elevation for the grid cell. The elevation shift (positive or negative) for the overlay point is added to the surface water stage elevation. The relative or shifted surface water stage elevation is stored in the characteristics file for ground water hydrography.

In addition to the surface water stage elevation, spring conductance is provided by operation Springs for each spring. The spring conductance is stored in the attribute table for springs. The conductance value is transferred to the characteristics file.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Processing Grid	Springs Layer Hydrologic	standard set
Processing Spot/Overlay		
Springs		
Topography		

Data preparation operations numbered 1 to 3 and 5 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation Springs.

This operation can be executed by selecting the Springs menu item for layer 0 under Spatial Analysis for Ground Water. The operation code SPR is placed in the operations control file for layer number 0.

Output from the Springs operation includes eight characteristics which are contained in the INFO characteristic file as listed below. The eight characteristics include grid row and column, HSPF reach number, code for hydrography type, spring conductance, and surface water stage and bed bottom elevations. The bed bottom elevation is set to a flag value of -9998. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	RIV2CHAR.DAT	none

Existing Pumping Well (WELL)

The Existing Pumping Well operation contributes to one characteristic file. For each existing pumping well located within the ground water grid, this operation provides the spatial location (i.e., row and column), vertical connection (i.e., layer number(s)), and the layer coefficient (i.e., the fraction out of one). These four characteristics are determined for each existing pumping well. The values of the characteristics for each well are contained in the characteristic file WELLCHAR.DAT, which also includes a unique well ID and a code for the type of well. The processing ground water grid (processing grid) coverage is used as the spatial descriptor for this operation.

An overlay (intersect) between the existing pumping well coverage and the processing grid coverage is used to assign the wells to grid cells. Each well is assigned to one and only one grid cell which provides the grid cell row and column for each well.

The vertical connections for each well are determined with the contents of the physical characteristics attribute table for existing pumping wells called PUMPWELL_EXP or through a layer assignment procedure. If the layer connections have been established for the wells prior to execution of the operation, the items laystart and laystop will be present in the physical attributes table. The Existing Pumping Well operation retrieves the start and stop layer connection data from the attribute table. Layer connections to existing pumping wells, which are established prior to execution of the Existing Pumping Well operation, can be determined with the utility for layer assignment for wells that is described in the Data Preparation section for ground water or by some other means. By whatever means the vertical connections are pre-determined, the beginning (item laystart) and ending layer (laystop) number for existing pumping wells are stored in the physical attributes table for pumping wells.

If the vertical connection(s) for existing pumping wells have not been determined before execution of the Existing Pumping Well operation, the utility for layer assignment for pumping wells will be used. If either of the items laystart or laystop are missing from the physical attribute table, the layer assignment utility will be executed. The results of the well layer assignment are contained in a temporary file called WELLLAYR.DAT. However, to permanently store the vertical connections, the contents of WELLLAYR.DAT must be joined manually to the physical attributes table. Following the assignment of each well to the appropriate layer(s), the relative magnitude of contribution from each layer to the total pumping rate of the well is determined.

The vertical distribution of transmissivity is used to determine the relative magnitude of contribution from each layer to the total pumping rate of the well. The relative magnitude of contribution is called the layer coefficient. The mean transmissivity of the grid cell is assumed be representative for each well located within the cell. The transmissivity data are retrieved from the aquifer layer characteristic file (INFO) series LYXXCHAR.DAT. Each well has n layers open to the well. For a specific layer, k, the layer coefficient is calculated as the transmissivity of layer k divided by the sum of the transmissivities for all n layers open to the well.

The mean transmissivity data is pre-determined by operation Transmissivity. Any time the Existing Pumping Well operation is selected, the Transmissivity operation is selected automatically. The Transmissivity operation is executed prior to the Existing Pumping Wells operation. Refer to operation Transmissivity for details on the methods used to calculate transmissivity using physical and saturated thicknesses.

For existing pumping wells only, a series of pumping rate files (puYYchar.inp) in ASCII format are evaluated. Each well contained in the characteristic file for wells must be matched one-to one with a well record in each file of the series puYYchar.inp. The letters YY represent a two digit file number where files 1 to nine have a leading zero. If a one-to-one match does not exist, for any one of the files in the series, the processing is terminated and an error messages is written to the error file. If all pumping rate files are acceptable, a pumping rate characteristic file (PUYYCHAR.DAT) is created for each file in the series.

The input data required for this operation include the data elements listed below and in the documentation for operation Transmissivity. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Processing Grid	Physical Well Characteristics	standard set
Existing Pumping Wells		LAYCHAR.DAT
Topography		PUYYCHAR.INP
Input for Transmissivity Operation		

Data preparation operations numbered 1 to 3 and 6 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation Existing Pumping Wells.

This operation can be executed by selecting the Existing Pumping Wells menu item for layer 0 under Spatial Analysis for Ground Water. The operation code WELL is placed in the operations control file for layer number 0.

Output from the Existing Pumping Wells operation includes six characteristics which are contained in the INFO characteristic file WELLCHAR.DAT, well layer assignment data contained in WELLLAYR.DAT (if the attribute table did not contain the data), and pumping rate data contained in the file series PUYYCHAR.DAT. The six characteristics include grid row, column, layer, unique well ID, code for well type, and layer coefficient. The ASCII characteristic file is created by the AML code and CHARFILE.AML. The YY in the

PUYYCHAR.DAT file series represents a two digit file number. Files numbered 1 to 9 have a leading zero. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	WELLCHAR.DAT	PUYYCHAR.DAT
	WELLLAYR.DAT	

Proposed Pumping Well (PWEL)

The Proposed Pumping Well operation contributes to one characteristic file. For each proposed pumping well located within the ground water grid, this operation provides the spatial location (i.e., row and column), vertical connection (i.e., layer number(s)), and the layer coefficient (i.e., the fraction out of one). These four characteristics are determined for each proposed pumping well. The values of the characteristics for each well are contained in the characteristic file WELLCHAR.DAT, which also includes a unique ID and a code for the type of well. The processing ground water grid (processing grid) coverage is used as the spatial descriptor for this operation.

An overlay (intersect) between the proposed pumping well coverage and the processing grid coverage is used to assign the wells to grid cells. Each well is assigned to one and only one grid cell which provides the grid cell row and column for each well.

The vertical connections for each well are determined with the contents of the point attribute table (<cover>.pat) for the proposed pumping wells coverage or through a layer assignment procedure. If the layer connections have been established for the wells prior to execution of the operation, the items laystart and laystop will be present in the feature attribute table for proposed wells. The Proposed Pumping Well operation retrieves the start and stop layer connection data from the feature attribute table. Layer connections to proposed pumping wells, which are established prior to execution of the Proposed Pumping Well operation, can be determined with the utility for layer assignment for wells that is described in the Data Preparation section for ground water or by some other means. By whatever means the vertical connections are pre-determined, the beginning (item laystart) and ending layer (laystop) number for proposed pumping wells are stored in the point attribute table of the proposed pumping wells coverage.

If the vertical connection(s) for existing pumping wells have not been determined before execution of the Proposed Pumping Well operation, the utility for layer assignment for pumping wells will be used. If either of the items laystart or laystop are missing from the feature attribute table, the layer assignment utility will be executed. The results of the well layer assignment are contained in a temporary file called WELLLAYR.DAT. However, to permanently store the vertical connections, the contents of WELLLAYR.DAT must be joined manually to the point attribute table. Following the assignment of each well to the appropriate layer(s), the relative magnitude of contribution from each layer to the total pumping rate of the well is determined.

The vertical distribution of transmissivity is used to determine the relative magnitude of contribution from each layer to the total pumping rate of the well. The relative magnitude of contribution is called the layer coefficient. The mean transmissivity of the grid cell is assumed be representative for each well located within the cell. The transmissivity data are retrieved from the aquifer layer characteristic file (INFO) series LYXXCHAR.DAT. Each well has n layers open to the well. For a specific layer, k, the layer coefficient is calculated as the transmissivity of layer k divided by the sum of the transmissivities for all n layers open to the well.

The mean transmissivity data is pre-determined by operation Transmissivity. Any time the Proposed Pumping Well operation is selected, the Transmissivity operation is selected automatically. The Transmissivity operation is executed prior to the Proposed Pumping Wells operation. Refer to operation Transmissivity for details on the methods used to calculate transmissivity using physical and saturated thicknesses.

The input data required for this operation include the data elements listed below and in the documentation for operation Transmissivity. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Processing Grid	none	standard set
Proposed Pumping Wells		LAYCHAR.DAT
Topography		
Input for Transmissivity Operation		

Data preparation operations numbered 1 to 3 and 7 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation Proposed Pumping Wells.

This operation can be executed by selecting the Proposed Pumping Wells menu item for layer 0 under Spatial Analysis for Ground Water. The operation code PWEL is placed in the operations control file for layer number 0.

Output from the Proposed Pumping Wells operation includes six characteristics which are contained in the INFO characteristic file WELLCHAR.DAT and well layer assignment data contained in WELLLAYR.DAT (if the point attribute table did not contain the data). The six characteristics include grid row and column, layer, unique well ID, code for well type and layer coefficient. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	WELLCHAR.DAT	none
	WELLLAYR.DAT	

Recharge Rate (REC)

The Recharge Rate operation contributes to one characteristic file. For each cell of the ground water grid this operation provides an annual value for the recharge rate which is contained in the characteristic file RCETCHAR.DAT. To derive temporally varying recharge (i.e., other than annual), it is suggested to use an FHM integrated simulation. The processing ground water grid (processing grid) coverage is used as the spatial descriptor for this operation. Grid cells which are located outside the processing grid (i.e., inactive cells) are given the no data value (-9999.) for the characteristic processed with this operation.

An overlay (intersect) between the recharge rate coverage and the processing grid coverage is used to gather varying zones of recharge rate across each grid cell. Each polygon of the recharge rate coverage represents a homogeneous zone of recharge rate. The product of area and attribute value are summed by the unique ID of the grid cell and then divided by the area of the grid cell. The annual values for the recharge rate characteristic of each grid cell are determined with an area weighted, arithmetic mean.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Proc. Ground Water Grid	none	standard set
Recharge Rate		

Data preparation operations numbered 1, 3, and 9 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation Recharge Rate.

This operation can be executed by selecting the Annual Recharge Rate menu item for layer 0 under Spatial Analysis for Ground Water. The operation code REC is placed in the operations control file for layer number 0.

Output from the Recharge Rate operation includes one characteristic which is contained in one INFO characteristic file as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	RCETCHAR.DAT	none

Ground Water ET Rate (GWET)

The Ground Water ET Rate operation contributes to one characteristic file. For each cell of the ground water grid this operation provides an annual value for the maximum rate (potential) of ground water ET which is contained in the characteristic file RCETCHAR.DAT. To derive temporally varying ground water ET (i.e., other than annual), it is suggested to use an FHM integrated simulation. The processing ground water grid (processing grid) coverage is used as the spatial descriptor for this operation. Grid cells which are located outside the processing grid (i.e., inactive cells) are given the no data value (-9999.) for the characteristic processed with this operation.

An overlay (intersect) between the ground water ET rate coverage and the processing grid coverage is used to gather varying zones of the potential ET rate for ground water across each grid cell. Each polygon of the ground water ET rate coverage represents a homogeneous zone of the potential ET rate for ground water. The product of area and attribute value are summed by the unique ID of the grid cell and then divided by the area of the grid cell. The annual values for the ground water ET rate characteristic of each grid cell are determined with an area weighted, arithmetic mean.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Proc. Ground Water Grid	none	standard set
Ground Water ET Rate		

Data preparation operations numbered 1, 3, and 10 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation Ground Water ET Rate.

This operation can be executed by selecting the Annual Ground Water ET Rate menu item for layer 0 under Spatial Analysis for Ground Water. The operation code GWET is placed in the operations control file for layer number 0.

Output from the Ground Water ET Rate operation includes one characteristic which is contained in one INFO characteristic file as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	RCETCHAR.DAT	none

Ground Water ET Surface (ESRF)

The Ground Water ET Surface operation contributes to one characteristic file. For each cell of the ground water grid this operation provides a mean value for the surface (elevation) at which ground water ET is at the maximum rate (potential). The elevation values for the ground water ET surface are contained in the characteristic file RCETCHAR.DAT. Through the use of the processing spot/overlay coverage, the processing ground water grid (processing grid) coverage is used as the spatial descriptor for this operation. Grid cells which are located outside the processing grid (i.e., inactive cells) are given the no data value (-9999.) for the characteristic processed with this operation.

At each point contained in the processing spot/overlay coverage, an elevation value is retrieved from the ground water ET surface with a spot operation (tinspot or latticespot). The points in the spot/overlay coverage are evenly-spaced in all directions. With a dense set of points, a representative sampling of the surface is obtained. After the surface is sampled, an area weighted, arithmetic mean value of elevation for the ground water ET surface is calculated within each grid cell. Because the sampling points are evenly-spaced, each sampling point is given equal weight. The mean value of elevation within a grid cell is equal to the sum of all elevations within the grid cell divided by the number of sampling points within the grid cell.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Processing Spot/Overlay	none	standard set
Ground Water ET Surface		

Data preparation operations numbered 1 to 3 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation Ground Water ET Surface.

This operation can be executed by selecting the Ground Water ET Surface Elevation menu item for layer 0 under Spatial Analysis for Ground Water. The operation code ESRF is placed in the operations control file for layer number 0.

Output from the Ground Water ET Surface operation includes one characteristic which is contained in one INFO characteristic file as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	RCETCHAR.DAT	none

Ground Water ET Extinction Depth (EDEP)

The Ground Water ET Extinction Depth operation is a subset of the Land Use ET operation under the integrated operations which is where this operation is fully documented. The ground water ET extinction depth is represented by the rhizosphere depth.

This operation can be executed by selecting the Ground Water ET Extinction Depth menu item for layer 0 under Spatial Analysis for Ground Water. The operation code EDEP is activated.

However, this code is replaced by the operation code LANDET which is placed in the operations control file for layer number 0.

Output from the LANDET operation is contained in one INFO characteristic file as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Refer to operation Land Use ET under integrated operations for more information. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	RCETCHAR.DAT	none

Top-Most Active Layer (TACT)

The Top-Most Active Layer operation contributes to one characteristic file. For each cell of the ground water grid this operation provides the top-most active layer which is contained in the characteristic file RCETCHAR.DAT (INFO only). The ground water grid coverage is used as the spatial descriptor for this operation. Grid cells which are located outside the processing grid (i.e., inactive cells) are given the no data value (-9999.) for the characteristic processed with this operation.

The IBOUND data of MODFLOW designates each cell as active, constant head, or inactive on a layer-by-layer basis. All layers of the IBOUND data are added to the ground water grid coverage to determine the top-most active layer. Starting with the lower-most layer (i.e., highest layer number), each grid cell which is either active or constant head is designated as "active" for the purposes of this operation. All grid cells are then queried for "active" status in the next layer upward (i.e., toward land surface). Processing progresses to layers closer to land surface until all layers have been processed. For each layer, all grid cells are queried for "active" status and are assigned the current layer number if determined to be "active" in that layer. Any grid cells which have not been designated as "active" after the top-most layer has been processed will have a layer number of zero because the cell was designated as inactive through all layers. Grid cells are designated as "active" by assigning the top-most active layer number to the cell. Layer numbers which are negative indicate that the cell was designated as "active" by a constant head.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Ground Water Grid	none	standard set
IBOUND - one for each layer		

Data preparation operations numbered 1 and 3 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation Top-Most Active Layer.

This operation can be executed by selecting the Top-Most Active Layer menu item under Spatial Analysis for Ground Water. The operation code TACT is placed in the operations control file.

Output from the Top-Most Active Layer operation includes one characteristic which is contained in one INFO characteristic file as listed below. The top-most active layer data is NOT passed to the ASCII characteristic file. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	RCETCHAR.DAT	none

Results

The ground water operations create or contribute to at least eight characteristic file pairs (INFO and ASCII). The number of characteristic files for ground water operations varies based on the number of aquifer layers and the number of stress periods used in the ground water model. One additional characteristic file pair is added for each aquifer layer greater than one. For every set of 20 stress periods greater than 20 stress periods, one additional file pair is required. The ASCII characteristic files contain free-format, comma-delimited, hydrologic data that are read by the ground water or integrated pre-processor of FHM. Formatted files which are compatible with standard MODFLOW and the integrated FHM are created from the characteristic files by the pre-processor. The INFO characteristic files contain all of the data contained in the ASCII characteristic files plus additional data which may be necessary to produce graphical displays of the data or to perform advanced record selection for model calibration.

As stated under each of the operations, the INFO characteristic files are created during the processing of each operation. Following the completion of processing for all ground water operations for a layer, the ASCII characteristic files are created sequentially by the AML code CHARFILE.AML based on the operations which were successfully completed. The ASCII characteristic files are summarized in Tables 3.10 and 3.11. Detailed descriptions of the contents of the INFO and ASCII characteristic files are provided in Appendix B.

Table 3.10 Characteristic Files Created by the HydroGIS Ground Water Operations for FHM Ground Water Component Model MODFLOW.

Characteristic File	File Description	Contributing Operations	Operation Type [1]
lyXXchar.dat	hydraulic characteristics for one aquifer layer; XX denotes layer number	Hydraulic Conductivity	G
		Transmissivity	G
		Specific Yield	G
		Storage Coefficient	G
		Leakance	G
		Aquifer Top	G
		Aquifer Bottom	G
		Initial Aquifer Head	G
		IBOUND	G
		Existing Pumping Wells	G
		Proposed Pumping Wells	G
riv2char.dat	hydrography characteristics for the MODFLOW river package; streams, lakes, wetlands and springs are represented	Line Hydrography	G
		Polygon Hydrography	G
		Springs	G
ghbchar.dat	characteristics for the MODFLOW GHB package	General Head Boundary	G
ghbdchar.dat[2]	inverse distance between the GHB external head location and the grid center of the large-scale grid; used to interpolate head at the GHB external head location from a large-scale simulation	Multi-Scale GHB	G
drnchar.dat	required data for the MODFLOW drain package, not available	Drains	G
strchar.dat	required data for the MODFLOW stream package, not available	Streams	G
wellchar.dat	characteristics for the MODFLOW well package; existing and proposed pumping wells and boundary flux wells are represented	Existing Pumping Well	G
		Proposed Pumping Well	G
		Boundary Flux	G
puYYchar.dat	a series of files containing temporal pumping records for all existing wells in the wellchar.dat file; a one-to-one relationship must exist between existing wells in wellchar.dat and puYYchar.dat; each file holds up to 20 stress periods; YY denotes a two-digit sequential number starting with 01	Existing Pumping Well	G

[1] G = ground water, I = integrated

[2] Used for multi-scale simulations only.

Table 3.11 Characteristic Files Created by the HydroGIS Ground Water Operations for FHM Ground Water Component Model MODFLOW (continued).

Characteristic File	File Description	Contributing Operations	Operation [1] Type
rcetchar.dat	ground water recharge and ground water ET characteristics, and integrated FHM characteristics	Recharge (GW only)	G
		GW ET Rate (GW only)	G
		ET Surface	G
		Ext. Depth/Land Use ET	G/I
		Soils ET	I
		Basin to Grid	I
pnumchar.dat	the total number of records stored in each of the following characteristic files: riv2char.dat, ghbchar.dat, drnchar.dat, strchar.dat, and wellchar.dat; used to define the maximum number of entries in the packages of MODFLOW	Line Hydrography	G
		Polygon Hydrography	G
		Springs	G
		General Head Boundary	G
		Existing Pumping Well	G
		Proposed Pumping Well	G
		Boundary Flux	G
grd2char.dat	grid characteristics including number of rows and columns, rotation angle, x and y origin coordinates, and MODFLOW DELR and DELC values	gridmaker utility	N/A
grd3char.dat	griduid, row, column, x-coordinate and y-coordinate of grid cell center	gridmaker utility	N/A

[1] G = ground water, I = integrated

Integrated

The spatial analysis operations for the integrated FHM are documented below. Documentation for each operation includes a description of the data characterization process, specifications for input and output data, requirements and assumptions for data preparation, derivation of spatial analysis algorithms where necessary, and other code documentation.

Objectives

The objective of the HydroGIS spatial analysis operations for the integrated FHM is to support the data requirements of FHM integration codes. The integration codes are used for unsaturated zone water budget simulation and flux transfer between the surface basins and the ground water grid cells and between the routing reaches and the ground water grid cells. The three integrated operations in HydroGIS satisfy 100% of the data requirements of the integration codes of FHM. The three integrated operations are summarized in Table 3.12.

Table 3.12 Descriptions of HydroGIS Integrated FHM Operations.

Operation	Operation Description	Operation Code
Soils ET	Area weighted mean values of soil porosity and field capacity are calculated for each grid cell.	SOILET
Land Use ET	Area weighted mean values of ground water ET extinction depth and plant ET coefficient are calculated for each grid cell.	LANDET
Basin to Grid	Based on a majority area process, each grid cell is assigned a basin number. Also, basin area located in the inactive region of the grid is determined by basin.	BASIN2GRD

Data Requirements and Preparation

Data requirements for the three integrated operations include six thematic maps (add one additional map for each aquifer layer greater than one) in the form of coverages, two INFO attribute tables, and two ASCII files. Both of the INFO attribute tables also require an INFO relate table for a total of four INFO tables. All data required for the integrated operations are also required by either or both the ground water and the surface water operations. A summary of the input requirements for each operation is provided in 3.13. Refer to the Data Requirements and Preparation section of the surface water and ground water operations for more information about the coverages, tables, and files required for the integrated operations.

Table 3.13 Input Data Requirements for HydroGIS Integrated FHM Operations.

NOTES:
[1] T/L represents a tin or lattice surface.
[2] Only the active and constant head cells of the original grid are contained in the processing grid coverage. This operation is required for ground water and integrated operation types.
[3] Routing hydrography features, including buffered streams and hydrography polygons, are contained in the coverage with a basin number (for the item class) equal to zero.

		THEMATIC MAP and (FEATURE CLASS [1])						ATTRIBUTE TABLES (INFO FORMAT)	
OPERATION	CHARACTERISTIC	Modified Basins [3] (Poly)	Ground Water Grid (Poly)	Processing Ground Water Grid (Poly)	IBOUND for each model layer (Poly)	Land Use (Poly)	Soils (Poly)	Land Use Hydrologic & RELATE	Soils Hydrologic & RELATE
Processing Grid Coverage [2]	N/A		X		X				
Soils ET	Soil Porosity			X			X		X
Soils ET	Soil Field Capacity			X			X		X
Land Use ET	Ground Water ET Extinction Depth			X		X		X	
Land Use ET	Plant ET Coefficient			X		X		X	
Basin to Grid	Basin Number Assignment to Grid Cell	X	X						
Basin to Grid	Basin Area in Inactive Region of Grid	X		X					

Coverages and Continuous Surfaces

The integrated operations require six thematic maps which are listed below (with the feature class). The highlighted maps require data preparation for the model project. Refer to the Data Requirements and Preparation section of the surface water and ground water operations for more information.

- **Modified Basins** (polygon)
- **Ground Water Grid** (polygon)
- Proc. Ground Water Grid (polygon)
- **IBOUND** - one per layer (polygon)
- Land Use (polygon)
- Soils (polygon)

INFO Tables

The integrated operations require two INFO attribute tables and two additional relate tables which are listed below. Refer to the Data Requirements and Preparation section of the surface water operations for more information.

- Land Use Hydrologic (look-up)
- Land Use Hydrologic (relate)
- Soils Hydrologic (look-up)
- Soils Hydrologic (relate)

ASCII Files

Three ASCII format files are required for integrated operations. These files include the HydroGIS operations control file (*.INP) and the project index files for integrated operations which are the "names" file (*.NAM) and the "paths" file (*.PTH). **The asterisk (*) refers to the name of the selected project workspace.** These three files are the "standard set" of ASCII input files for all integrated operations. Format specifications for the files are provided in Appendix A.

Data Preparation Utilities

Refer to the Data Preparation Utilities section of the surface water and ground water operations for information about the utilities available to prepare the required data for the integrated operations.

Operations

Each operation uses topologic data from coverages and/or continuous surfaces, and related hydrologic attribute data to produce hydrologic model data. The model data represent one or more characteristics of the hydrologic system. There are two spatial descriptors used for the characteristics data of the integrated FHM. Operations Soils ET and Land Use ET use only a square or rectangular grid cell. Operation Basin to Grid uses both a square or rectangular grid cell and an irregularly-shaped set of polygons to represent surface basins. A summary description of each of the integrated operations is provided in Table 3.12. Data requirements are summarized in Table 3.13.

The operations are executed through a combination of AML and FORTRAN language codes. The coding is modular which permits sharing of specific codes among various operations. Each operation is controlled by one AML which is referred to as the main AML for the operation. In some cases, one AML is used by multiple operations as the main AML. The main AML for the operation controls processing in supplemental codes which are written in AML and FORTRAN.

Each operation follows a three-part processing sequence which is carried out by the main AML. By utilizing the three-part processing sequence, map library data are accessible without extracting the library data prior to execution of the operation. The three parts of the processing sequence generally include: (1) cleaning the workspace and gathering attribute data, (2) performing spatial overlays and saving the results into temporary append files, and (3) summarizing the data contained in the append files to produce characteristic data which is saved in the characteristic file(s).

For each of the three integrated operations, the following documentation elements are provided:

1. Operation description
2. Data characterization process description
3. Input data list
4. Summary of data preparation requirements and assumptions
5. Execution instructions
6. Output data list
7. Derivation of model algorithms or spatial analysis, where needed
8. Code documentation

Provided in Appendix C for each operation is a processing flowchart under the name of the main AML for the operation. Documentation of arguments, variables, coverages and surfaces used, INFO and ASCII files used, and assumptions are available for each AML and FORTRAN code in electronic format only. The documentation is provided in the header of the source code listing under the name of the code as provided.

Soils ET (SOILET)

The Soils ET operation contributes to one characteristic file. For each cell of the ground water grid this operation provides mean values for soil porosity and soil field capacity which are contained in the characteristic file RCETCHAR.DAT. The processing ground water grid (processing grid) coverage is used as the spatial descriptor for this operation. Grid cells which are located outside the processing grid (i.e., inactive cells) are given the no data value (-9999.) for the characteristics processed with this operation.

An overlay (intersect) between the soils coverage and the processing grid coverage is used to gather varying classifications of soil series or soil associations across each grid cell. Each polygon of the soils coverage is classified into a homogeneous unit of soil series or association. The soils coverage and the soils hydrologic attribute table contain the same classification system for soil porosity and field capacity. Associated with the classification codes in the attribute table are the hydrologic attributes for soil porosity and field capacity. The soils relate table is used to virtually (i.e., the tables are not physically joined) join the coverage and the attribute table. The product of area and attribute value are summed by the unique ID of the grid cell and then divided by the area of the grid cell. The mean values for the soil porosity and soil field capacity characteristics of each grid cell are determined with an area weighted, arithmetic mean.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Proc. Ground Water Grid	Soils Hydrologic	standard set
Soils	Soils Relate	

Data preparation operations numbered 1 and 3 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation Soils ET.

This operation can be executed by selecting the Soils menu item under Spatial Analysis for Integrated FHM. The operation code SOILET is placed in the operations control file for layer number 0.

Output from the Soils ET operation includes two characteristics which are contained in one INFO characteristic file as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	RCETCHAR.DAT	none

Land Use ET (LANDET)

The Land Use ET operation contributes to one characteristic file. For each cell of the ground water grid this operation provides a mean value of the maximum rhizosphere depth byland use category to produce the ground water ET extinction depth and a mean value for the plant ET coefficient. The characteristics are contained in the characteristic file RCETCHAR.DAT. The processing ground water grid (processing grid) coverage is used as the spatial descriptor for this operation. Grid cells which are located outside the processing grid (i.e., inactive cells) are given the no data value (-9999.) for the characteristics processed with this operation.

An overlay (intersect) between the land use coverage and the processing grid coverage is used to gather varying classifications of land use/land cover across each grid cell. Each polygon of the land use coverage is classified into a homogeneous unit of land use/land cover. The land use coverage and the land use hydrologic attribute table contain the same classification system. Associated with the classification codes in the attribute table are hydrologic attributes for the representative maximum rhizosphere depth and average plant ET coefficient. The land use relate table is used to virtually (i.e., the tables are not physically joined) join the coverage and the attribute table.

To calculate mean values, the product of area and attribute value are summed by the unique ID of the grid cell and then divided by the area of the grid cell. The mean values for the ground water ET extinction depth and the plant ET coefficient characteristics are determined with an area weighted, arithmetic mean.

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Proc. Ground Water Grid	Land Use Hydrologic	standard set
Land Use	Land Use Relate	

Data preparation operations numbered 1 and 3 for coverages and surfaces, under spatial analysis operations for ground water, must be completed prior to execution of operation Land Use ET.

This operation can be executed by selecting the Land Use menu item under Spatial Analysis for Integrated FHM. The operation code LANDET is placed in the operations control file for layer number 0.

Output from the Land Use ET operation includes two characteristics which are contained in one INFO characteristic file as listed below. The ASCII characteristic file is created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	RCETCHAR.DAT	none

Basin to Grid (BASIN2GRD)

The Basin to Grid operation contributes to two characteristic files. This operation assigns a surface basin number to each cell of the ground water grid. The basin number assignment is contained in the characteristic file RCETCHAR.DAT. This operation also determines the area of each surface basin which is located in the inactive region of the ground water grid. The inactive zone area is contained in the characteristic file SUBCHAR.DAT. For the basin number assignment, the original ground water grid coverage is used as the spatial descriptor. For the basin area located outside the grid, the modified basins coverage is used as the spatial descriptor.

To assign basin classifications (numbers) to each grid cell, an overlay (identity) between the original ground water grid and the modified basins coverage is used to gather all of the basin and routing reaches which intersect each grid cell. A majority area basis is used for basin number or reach number assignment to a grid cell. The basin or reach which covers the most area of a grid cell is assigned to the cell. If a basin is assigned to the cell, the grid cell is attributed with the basin number that is used in the surface water model. If a reach is assigned to the cell, the grid cell is attributed with a basin number equal to zero.

A special overlay (erase) is used to determine the area of each basin which extends into the inactive region of the ground water grid. The processing ground water grid is comprised of cells which are either active or constant head. All regions which are located outside the processing grid are inactive ground water regions for the present model domain. The erase overlay between the modified basins coverage and the processing grid removes all basin area that is contained within the active and constant head region of the ground water grid. Any basin area which remains is located in the inactive region. The remaining area is summed by basin classification (number).

The input data required for this operation include the data elements listed below. Format specifications and assumptions for each data element are provided in Appendix A.

Input Coverages and Surfaces	Input INFO Tables	Input ASCII Files
Modified Basins	none	standard set
Ground Water Grid		
Proc. Ground Water Grid		

Data preparation operations for coverages and surfaces, under spatial analysis operations for ground water and surface water, must be completed prior to execution of operation Basin to Grid. Data preparation includes operations numbered 1 and 3 for ground water and operations numbered 1 to 5 for surface water.

This operation can be executed by selecting the Basin to Grid Conversion menu item under Spatial Analysis for Integrated FHM. The operation code BASIN2GRD is placed in the operations control file for layer number 0.

Output from the Basin to Grid operation includes two characteristics which are contained in two INFO characteristic files as listed below. The ASCII characteristic files are created by the AML code CHARFILE.AML. Additional details for the output are provided in Appendix B.

Output Coverages and Surfaces	Output INFO Tables	Output ASCII Files
none	RCETCHAR.DAT	none
	SUBCHAR.DAT	

Results

The integrated operations contribute to two characteristic file pairs (INFO and ASCII) called RCETCHAR.DAT and SUBCHAR.DAT. The ASCII characteristic files contain free-format, comma-delimited, hydrologic data that are read by FHM surface water, ground water, and integrated pre-processors. Formatted files which are compatible with HSPF, standard MODFLOW, and the integrated FHM are created from the characteristic files by the pre-processor. The INFO characteristic files contain all of the data contained in the ASCII characteristic files plus additional data which may be necessary to produce graphical displays of the data or to perform advanced record selection for model calibration.

As stated under each of the operations, the INFO characteristic files are created during the processing of each operation. Following the completion of processing for all surface water and integrated operations, the ASCII characteristic files are created sequentially by the AML code CHARFILE.AML based on the operations which were successfully completed. The ASCII characteristic files are summarized in Table 3.14. Detailed descriptions of the contents of the INFO and ASCII characteristic files are provided in Appendix B.

Table 3.14 Characteristic Files Created by Operations of HydroGIS to Support the Integrated FHM and the Component Models for Surface Water and Ground Water Simulation.

Characteristic File	File Description	Contributing Operations	Operation[1] Type
rcetchar.dat	ground water recharge and ground water ET characteristics, and integrated FHM characteristics	Recharge (GW only)	G
		GW ET Rate (GW only)	G
		ET Surface	G
		Ext. Depth/Land Use ET	G/I
		Soils ET	I
		Basin to Grid	I
subchar.dat	mean value model characteristics by surface water basin	Modify Basins	S
		Slope	S
		Soils Basins	S
		Land Use Basins	S
		Hydraulic Length	S
		Basin to Grid	I

[1] S = surface water, G = ground water, I = integrated

Spatial Analysis Management

During execution of the selected spatial analysis operations, two AMLs are used to manage the operation processing, data retrieval from libraries, error trapping, log and performance timer files, and AML code debugging. The AML called HGISSWIN.AML controls the surface water and integrated operations and the AML called HGISGW.AML controls all ground water operations. Operations which are selected for processing are stored in a fixed-format, ASCII file called *.INP which is the operations control file. **When used with a file name in this document, the asterisk (*) refers to the name of the selected project workspace**. Any combination of the 37 operations available within HydroGIS can be processed during a single execution of the HydroGIS AMLs which provide spatial analysis management. The spatial analysis management AMLs are executed through one of two modes. The interactive mode provides the capability for immediate processing of spatial analysis operations. The batch mode provides the capability for the selected operations to be processed at a later time as scheduled by the operating system administrator. The batch mode creates a system-specific batch file which calls the spatial analysis management AMLs as needed. The batch file is created by the AML called MKBATCH.AML which is customized for the operating system which executes ARC/INFO.

Verification and Initialization

Before either of the spatial analysis management AMLs are executed, verification and initialization processing is completed. This automated "pre-processing" is performed for interactive and batch mode by two AMLs which are HGISPRE.AML and HGISPROC.AML. Spatial analysis operations are selected for execution from the surface water, ground water, or integrated menu items. Figure 3.5 displays the selection and verification steps.

First, the selected operations are verified for subsequent processing. Verification includes removal of duplicate and invalid operations and error checking for input data. If the operations to be processed were selected through the HydroGIS interface, invalid or duplicate operations cannot be entered into the operations control file. However, since the operations control file is in ASCII format, it can be easily edited outside the interface with a text editor which could introduce errors. The input data are determined from the project index files which include the "paths" and "names" files (*.PTH and *.NAM) for all operations and the ground water layer configuration file (LAYCHAR.DAT) for about half of the ground water operations. Each thematic map is checked for the following characteristics: (1) does it exist, (2) correct feature class, (3) required items, and (4) prohibited items. If an error exists for any of the queried characteristics of a thematic map, all operations which require that thematic map are removed from the operations control file. Messages in the error file (HYDROGIS.ERR) are provided to indicate the specific errors in the thematic map and the affected operations. For both interactive and batch processing modes, an opportunity is provided to correct the errors in the input data before executing the AMLs which perform spatial analysis management. Only the verified operations are written to the operations control file following the verification process.

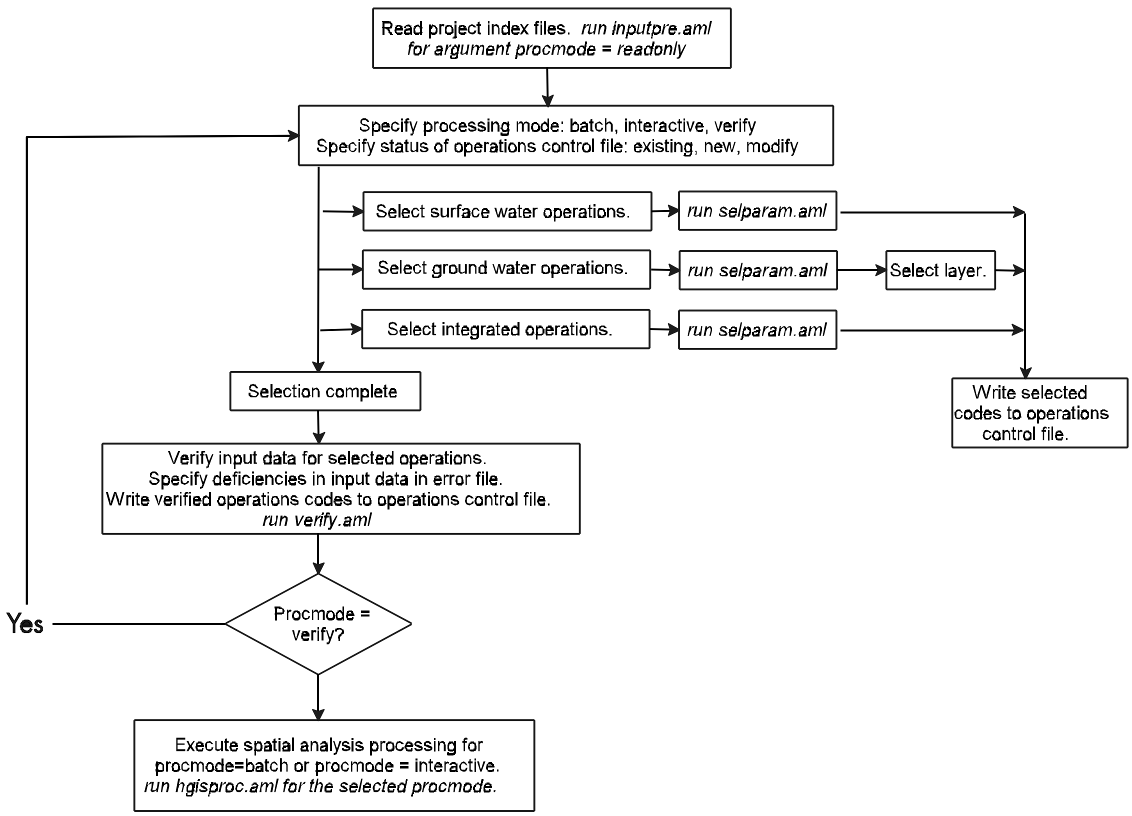


Figure 3.5 Selection and Verification of Spatial Analysis Operations Within HydroGIS.

The contents of the three project index files are written to a temporary AML called VARTEMP.AML. This AML contains global variables which are referenced in the spatial analysis management AMLs. In addition, the system administrator AML called HGISVAR.AML is read before the project index files are read. The system administrator AML adds global variables for paths to FORTRAN executable codes and for default values that are used as input data to spatial analysis operations. An example of the system administrator AML is provided in Appendix C.

Initialization processing affects the order in which operations are processed and creates new error and performance timer files. The top portion of Figure 3.6, which shows the spatial analysis processing sequence, also summarizes the initialization “pre-processing”. The order of operation processing is affected by order critical operations and by efficiency issues. Many operations require one or more other operations to be processed first. In addition, utilizing data from map libraries stimulates efficiency issues. Whenever, more than one operation requires an overlay with the same coverage (e.g., overlay the processing grid and the modified basins coverages with land use), a “combined” operation code is substituted for the two individual codes. In the example, the overlay between the modified basins and land use is immediately followed by the overlay between the processing grid and land use.

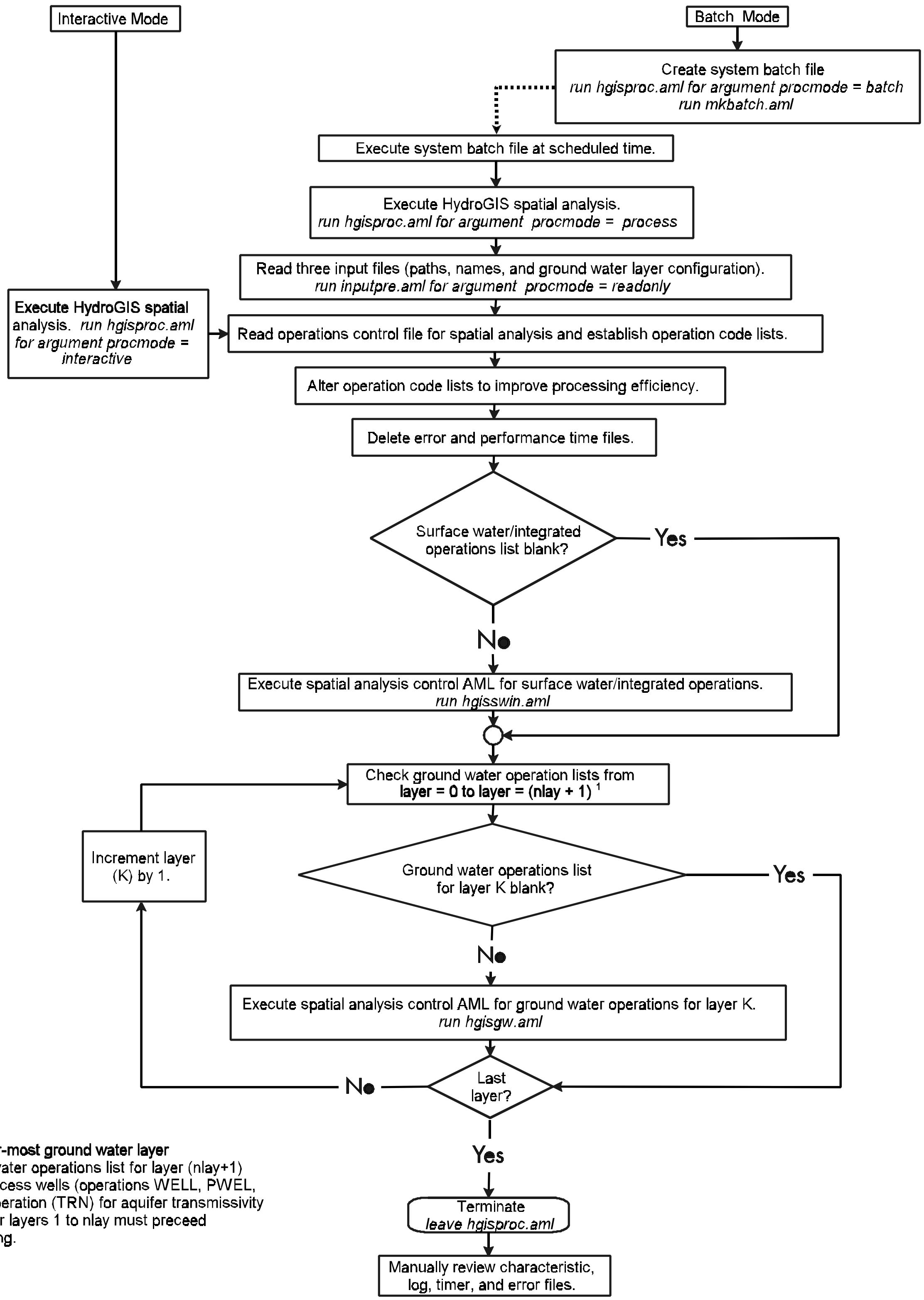
Initialization affects the error and performance timer files. Whenever an error or performance timer file exists before operations are processed, the file is deleted. A new empty file is created to permit information to be appended throughout the processing of verified spatial analysis operations. Errors which occur during operation processing are documented in the error file (HYDROGIS.ERR) which can be used to determine the source of the error. The performance timer file (HYDROGIS.TIM) can be used to ascertain processing time requirements for specific operations. This may be helpful when deciding whether the selected operations, due to limits imposed by a system administrator, are to be executed with interactive or batch mode. Examples of the error and performance timer files are provided in Appendix B.

The verified operations are divided into the following groups. The groups are processed in the order shown. The processing sequence for these groups, for interactive or batch mode, is displayed in Figure 3.6.

1. surface water and integrated
2. ground water, layer = 0
3. ground water, layer > 0 (a separate group for each layer, starts with layer = 1)

Processing Sequence

The two AMLs which provide spatial analysis management have a very similar structure. Both AMLs employ a five-part processing sequence for most operations. The sequence includes: (1) initialization for the operation group, (2) initialization for the operation, (3) overlay and append data to temporary file(s) for the operation, (4) summarize data and create INFO characteristic table(s) for the operation, and (5) create ASCII characteristic file(s) for the operation group. The group initialization process is completed for all operations at once. The operations are processed sequentially for steps two to four in the sequence. For each operation, steps two



[1] **nlay = lower-most ground water layer**
The ground water operations list for layer (nlay+1) is used to process wells (operations WELL, PWEL, FLX). The operation (TRN) for aquifer transmissivity processing for layers 1 to nlay must preceed well processing.

Figure 3.6 Interactive and Batch Mode Processing of Spatial Analysis Operations Within HydroGIS.

to four are completed before the next operation is processed. The final step in the sequence begins after all operations have been processed through steps two, three, and four. A summary of the spatial analysis sequence is provided in Figure 3.7.

The group initialization step includes file initialization, copying thematic map data from map libraries where necessary, and performing a limited degree of spatial analysis. Headers which are appropriate to the current group of operations are appended to the error and performance timer files during initialization. The processing completed in this step is generally applicable to all operations within the group.

Coverages which are required to be available within the selected project workspace must be copied from map libraries (extracted), if stored there, before any operations are processed. These coverages include: classified and modified basins, ground water grid and point grid, IBOUND for all layers, spot/overlay, large-scale ground water grid and point grid, and large-scale IBOUND for all layers. The spatial analysis component of group initialization is performed only in the AML for spatial analysis management of ground water operations which is discussed below.

Processing steps two to four are completed for one operation before processing for the next operation begins. For operations which require overlay processing, steps two to four are executed sequentially with separate calls for each step to the main AML which directs processing for the current operation. For map library data, the main AML may be called multiple times to complete step three. The operations which do not require overlay processing combine steps two to four into one processing step. For these operations, the main AML which directs processing is called only once to complete steps two to four. In Figures 3.8 and 3.9, the main AML is inside the box to the right of the associated spatial analysis operation. The processing sequence for the operations which require overlay processing are discussed next and followed by the remaining operations.

Initialization for individual operations is completed by the main AML within step two for those operations which require overlay processing. Initialization for operations includes cleaning the project workspace, gathering data from attribute tables, and initializing files. The workspace is cleaned of any existing temporary coverages, tables, and files that are generated by the processing for the operation.

During the overlay step, spatial overlays are completed by the main AML between the spatial descriptor coverage and the overlay coverage for the operation. The resultant data from the overlay are appended to a temporary INFO table or ASCII file until all overlays or data gathering are completed for the current operation. It is during this step that data which are stored in map libraries are temporarily copied from the library into the project workspace (extracted) for the purpose of executing overlay procedures. All library tiles for the current layer (coverage) which are contained within the model domain are extracted and overlay processed. The resultant data are stored in the temporary append table(s) and/or file(s). The extraction, overlay, and append process for map library data may require multiple calls to the main AML which controls processing for the current operation. The number of tiles which can be extracted in one pass is specified for each library by the ARC/INFO administrator in the administrator AML (HGISVAR.AML).

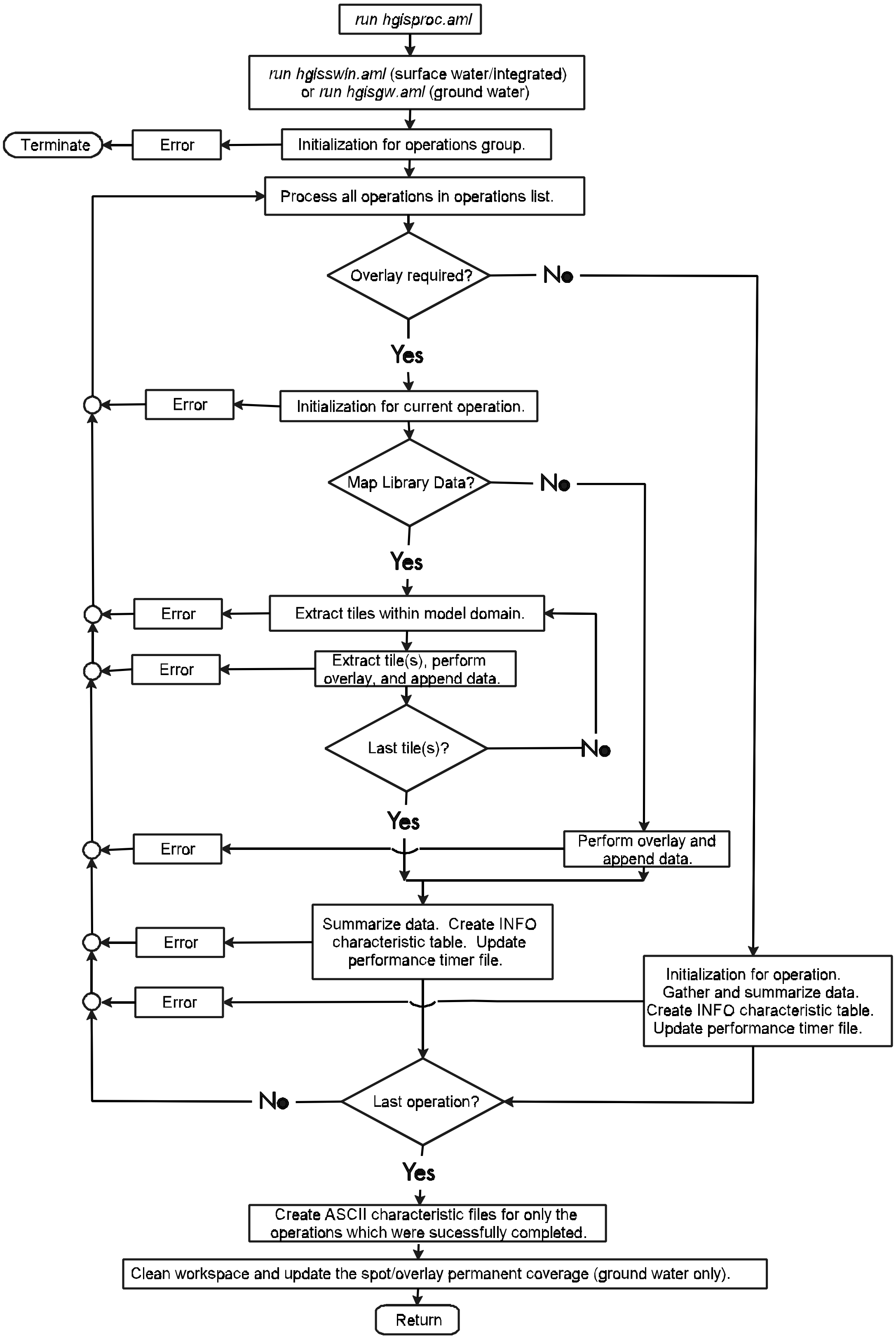


Figure 3.7 Management of Spatial Analysis Operations Within HydroGIS.

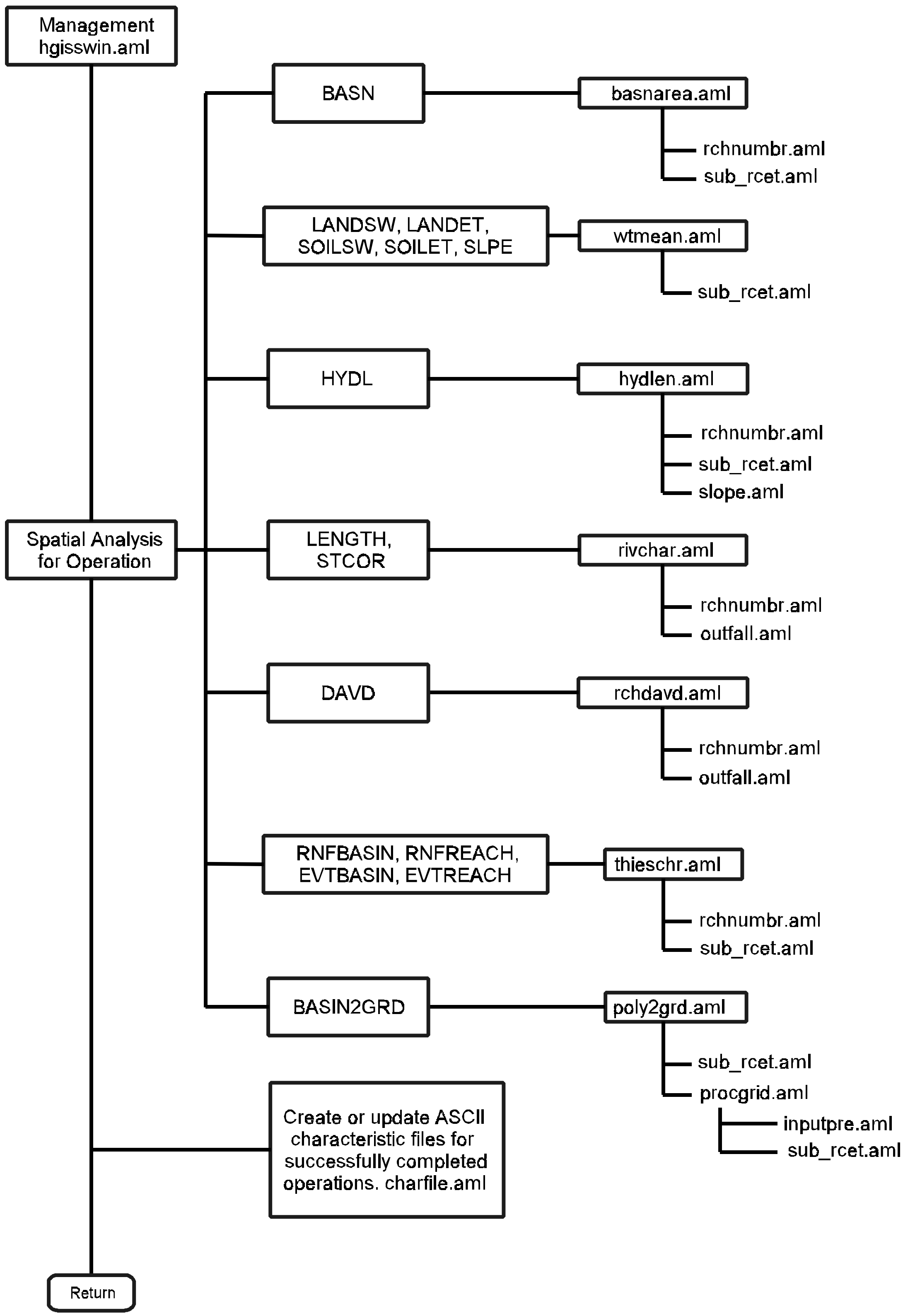


Figure 3.8 Executable Codes Used for Management and Spatial Analysis for Surface Water and Integrated Operations.

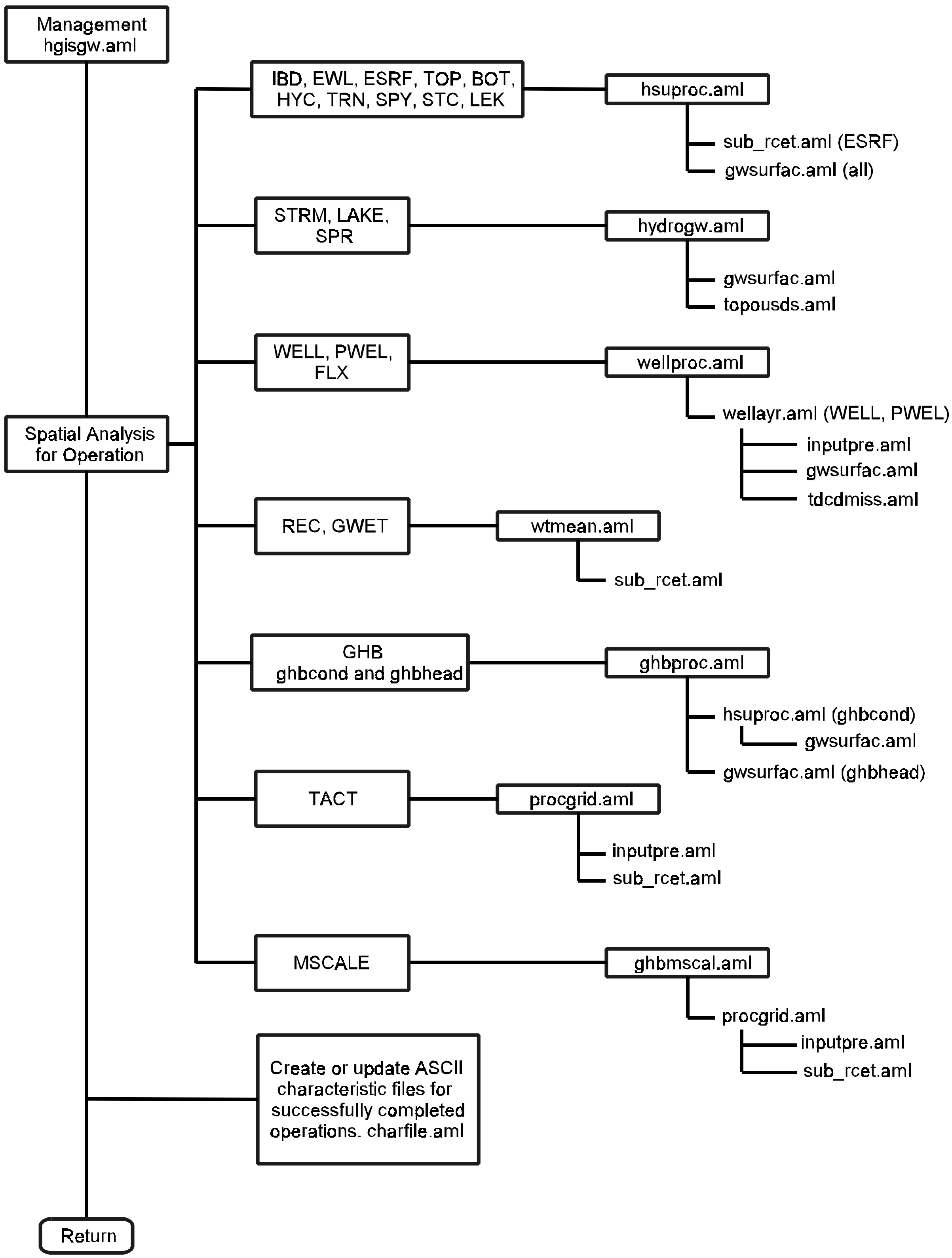


Figure 3.9 Executable Codes Used for Management and Spatial Analysis for Ground Water Operations.

During the fourth step in the processing sequence the data are summarized into a form which is stored in the INFO characteristic tables. The append tables and files are gathered and summarized for the spatial descriptor (e.g., basins, reaches, or grid) of the operation. The final results are stored in the INFO characteristic table(s) assigned to the operation. The main AML for the operation cleans the workspace which deletes all temporary coverages, tables, and files that were generated for the operation. Control is then passed back to the management AML where the performance timer file is updated with information for the current operation before control is passed to the next operation. As stated above, when step four is completed for an operation, processing begins for the next operation at step two.

For the operations which do not require overlay processing, steps two to four are combined. Processing control is passed to the main AML for the operation to complete steps two to four. The workspace is cleaned and the required data are gathered from thematic maps and attribute tables as completed by steps two and three. Data may be retrieved from a continuous surface through a spot operation. Recall that continuous surfaces are not permitted to be stored in a map library structure. Also, the required data may be gathered through a statistical procedure which can be performed on thematic map data stored in a workspace or in a map library. As with operations which require overlay processing the data are summarized and the INFO characteristic table(s) is created to complete step four. The workspace is cleaned, then control is passed back to the management AML where the performance timer file is updated. The next operation is subsequently processed.

The ASCII characteristic files are created during the final step in the processing sequence. This step begins following the completion of steps two, three, and four for all operations. Only the operations which were successfully completed are processed in the final step. Each characteristic file that is affected by operations that are controlled by the management AML is created or updated as necessary using the AML CHARFILE.AML.

The ASCII characteristic files are read by FHM pre-processors which create formatted model input data files for the integrated FHM and/or the component models which are HSPF and MODFLOW. The pre-processors of FHM create standard file formats for the public domain models.

An exception to the procedure used in step five is necessary to create the ASCII characteristic file RIV2CHAR.DAT and the ASCII characteristic file series PU**YY**CHAR.DAT (**YY** is the table number with leading zero for numbers less than 10). The file RIV2CHAR.DAT contains ground water hydrography data. The file series PU**YY**CHAR.DAT contain pumping rates by stress period for existing wells. These characteristic files are created during step four of the associated operations.

Error checking is a vital part of spatial analysis processing with HydroGIS. Any errors that are encountered are documented in two files which are the error and log files.

Any time an error occurs during the processing sequence for an operation, a message is written to the error file. Any further attempts to continue processing for the current operation are terminated and processing proceeds to the next operation. The modular design and error checking of HydroGIS permit processing to continue for all unaffected operations.

Each time that an operation is processed, a summary of the steps taken to complete the operation is documented in the log file. A new log file is created each day that an operation is processed. A summary of processing steps are appended to the log file for multiple calls of the spatial analysis management AMLs during a single day . The naming convention for the log file uses a date and time stamp concatenated to the prefix “log”. A more detailed source of information is invoked by using the “debug mode” which allows each line that is executed to be echoed to the screen and to the log file. The “debug mode” is invoked by adding the keyword “debug” as the first argument when starting HydroGIS.

The differences between the two AMLs which provide spatial analysis management are provided in the following two sections.

Surface Water and Integrated Operations

Processing management for the surface water and integrated operations is provided by HGISSWIN.AML. The processing sequence is the same as is summarized in the preceding paragraphs. There is no spatial analysis processing in the initialization step. The processing management AML is displayed in Figure 3.10.

Ground Water Operations

Processing management for all ground water operations, including “layer zero” operations, is provided by HGISGW.AML. This AML is called one time for each layer starting with layer equals zero to the lower-most layer. If there are no verified operations for a layer, then the layer is skipped. In general, the processing sequence is the same as is summarized in the preceding paragraphs. The processing management AML is displayed in Figure 3.11.

Significant differences exist in the group initialization step when compared to the surface water/integrated management of operations. The group initialization step contains two spatial analysis processing procedures. Each time the AML is called, the processing ground water grid is created. The supplemental AML called PROCGRID.AML is called to create the processing ground water grid. While the processing grid is created, the top-most active (TACT) operation is also completed. The top-most active operation is completed under step one of the processing sequence, but the ASCII characteristic file which stores the data is created or updated with the others under step five. The processing spot/overlay coverage is created by the second spatial analysis procedure of the group initialization step. This coverage is created one time unless it is inadvertently deleted. A temporary spot/overlay coverage is created each time the AML is called. The temporary coverage is a modified copy of the processing spot/overlay coverage. The temporary spot/overlay coverage is used as the processing spot/overlay coverage for all operations where it is required.

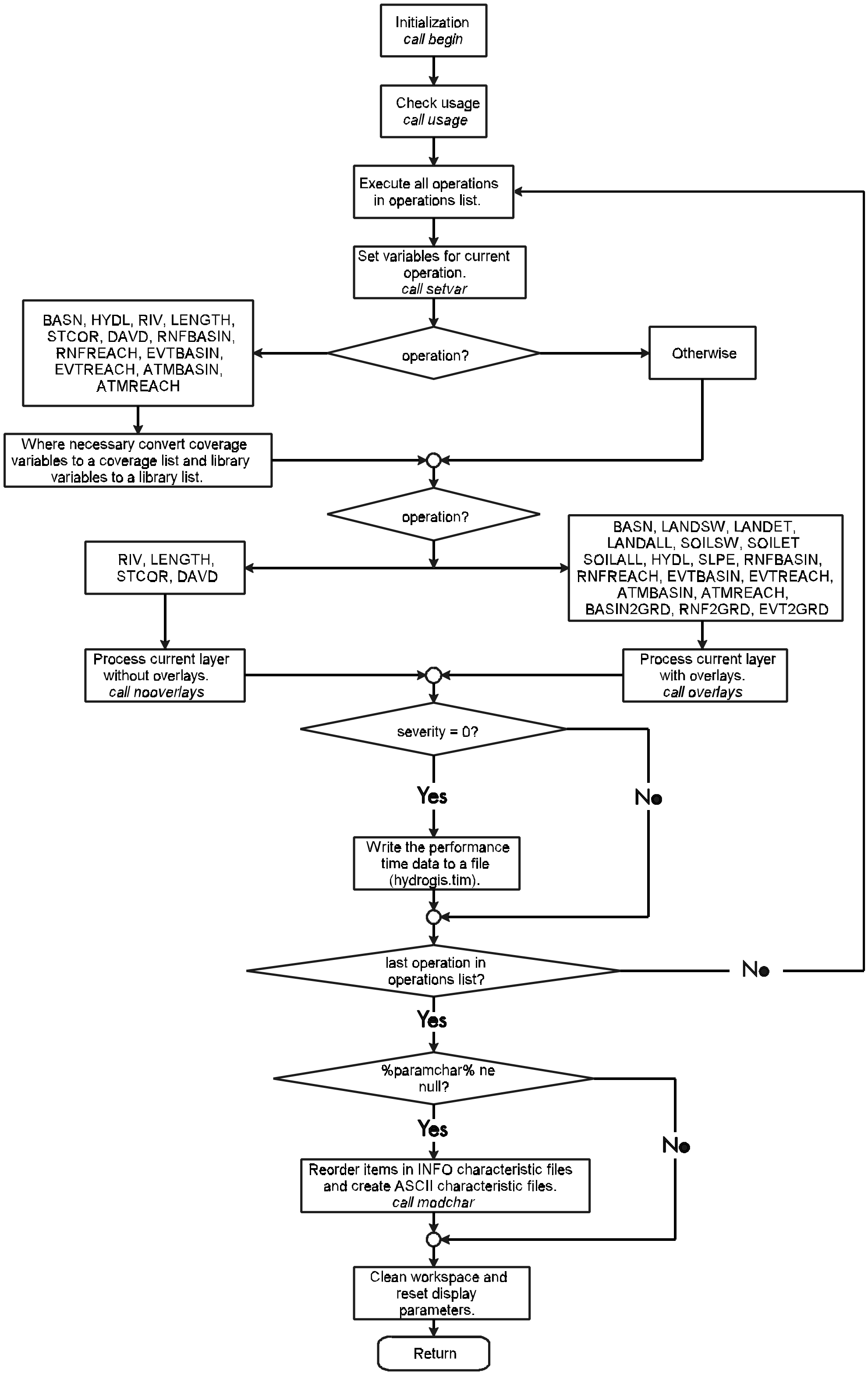


Figure 3.10 Processing Sequence for Surface Water and Integrated Spatial Analysis Operations as Provided by the Management AML (HGISSWIN.AML).

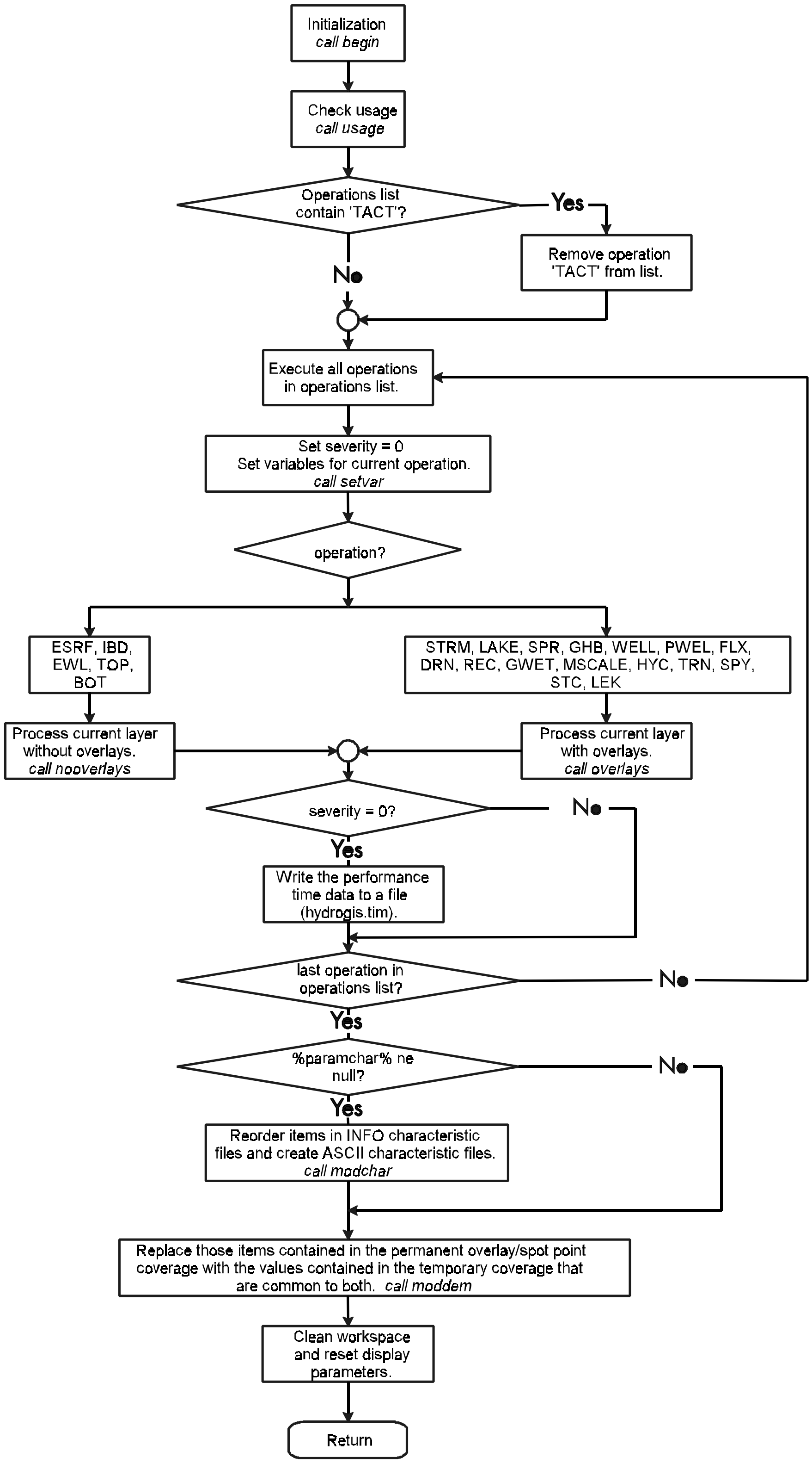


Figure 3.11 Processing Sequence for Ground Water Spatial Analysis Operations as Provided by the Management AML (HGISGW.AML).

Interactive Processing Mode

Interactive mode permits processing of spatial analysis operations to commence immediately following the verification and initialization "pre-processing". Some operations may take a significant amount of time to complete the processing sequence. If the ARC/INFO or system administrator of the platform on which ARC/INFO resides has specified guidelines for sharing the computer resources, it is recommended that the batch mode be employed initially. The contents of the performance timer file can be used to assess the computer resources required to complete each of the operations. However, the size of the model domain and the resolution of the data being processed have a significant impact on processing time. The performance timer results must be used on a relative scale to estimate requirements for computer resources from one project to another. After enough information has been gathered on each operation, the administrator may allow specific operations to be executed with the interactive mode.

The processing sequence for interactive and batch modes are very similar. Figure 3.6 provides the processing sequence for both modes.

Batch Processing Mode

With batch mode, the processing of spatial analysis operations are scheduled to commence at a later time as specified by the administrator. Following the verification and initialization "pre-processing", the verified operations are read from the operations control file. The operations are grouped as stated earlier and the AML MKBATCH.AML creates a system batch file which will execute HGISSWIN.AML for surface water and integrated operations which are verified, followed by HGISGW.AML for each ground water layer which has verified operations. The AML MKBATCH.AML is customized by the administrator to create a system batch file which properly interfaces with the platform on which ARC/INFO resides. The processing sequence for batch mode is provided in Figure 3.6. An example of MKBATCH.AML is provided in Appendix C.

Graphic Displays

Graphic display of spatial data is useful for finding errors in model data and for interpretation of simulation results from a model. Within HydroGIS, a utility (MAPMAKER.AML) is provided to review model data prior to using the data in a simulation. A utility to review simulation results is not yet available.

Versatility is provided within the graphic display utility through various options. Display options include black and white or color, and portrait or landscape views. As a means to provide spatial reference, up to ten supplemental or background thematic maps can be displayed with the model parameter data. Where necessary, up to ten intervals can be specified to show the distribution of the data. Ground water data which are layer-dependent are viewed on a layer-by-layer basis. While the data are displayed on the screen, the data can be reviewed with alternate views using pan, zoom, and new windows.

Each graphic display of model data viewed on the screen is stored in a map composition. Each map composition is stored in the GRAPHICS subdirectory within the project workspace. Although an automated utility is not available within HydroGIS, a hardcopy map can be created from a map composition after it is converted to a graphic file format compatible with the printer device. Map composition names are hard-wired and are a self-explanatory representation of the model parameter.

Inspection of model data by means of a picture is an efficient means of finding errors. The spatially-dependent data which support HSPF, MODFLOW, and/or FHM integration might be reviewed following one of two data development paths. The first path follows the development of the thematic maps which define the spatial descriptors (e.g., basins, reaches, grid) or the ground water boundary conditions. The second path follows the execution of one or more spatial analysis operations as defined in Chapter 3.

Spatial descriptors for a hydrologic model are the spatial entities for which model parameter values are developed. For HSPF, the spatial descriptors are basins and reaches. The surface water processes of each basin are defined by a set of homogeneous model parameter values. The routing processes of each reach are also defined by a set of homogeneous model parameter values. The spatial descriptor for MODFLOW and FHM integration data is a grid comprised of rectangular cells. A set of homogeneous model parameter values for each cell define the ground water and integration processes. Ground water boundary conditions supply additional constraints to the ground water model.

Following the creation of the thematic map for a spatial descriptor, the thematic map can be displayed with the graphic display utility. Recall that the thematic maps for basins, reaches (including lines, polygons, and points), and the grid can be created within the data development utility of HydroGIS. Thematic maps for ground water boundary conditions are also created within the data development utility section. It is recommended that the thematic maps representing spatial descriptors and ground water boundary conditions be reviewed with the graphic display utility prior to execution of spatial analysis operations.

After the thematic maps representing spatial descriptors and ground water boundary conditions have been reviewed and are considered satisfactory, the spatial analysis operations are then executed as needed. Following completion of a spatial analysis operation, the model data contained in the characteristic file or files should be reviewed with the graphic display utility. This data review should be conducted prior to FHM pre-processing of the model data.

Within the graphic display utility, the viewing of thematic maps and model data is organized into four data categories (level 1). The data categories include:

1. surface basins
2. reaches
3. ground water
4. FHM integration

With the exception of FHM integration, each category includes multiple sub-categories (level 2). The third tier of the organizational structure is model parameters (level 3). Displayed in Figures 4.1 to 4.4 is the three level structure for each category. Menus are employed within the utility to guide users through the three levels.

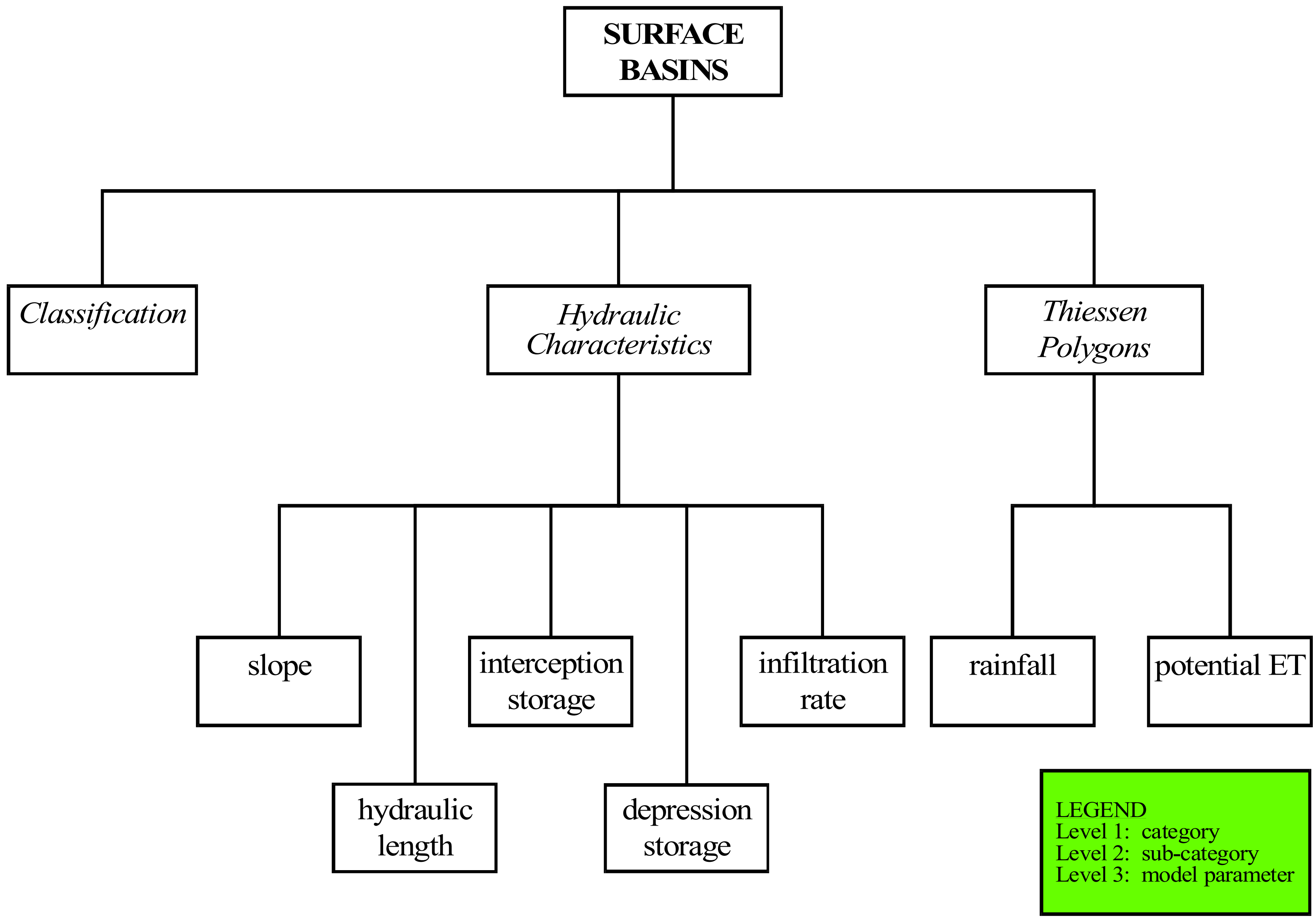


Figure 3.12 Graphic Display Options for the Surface Basins Category

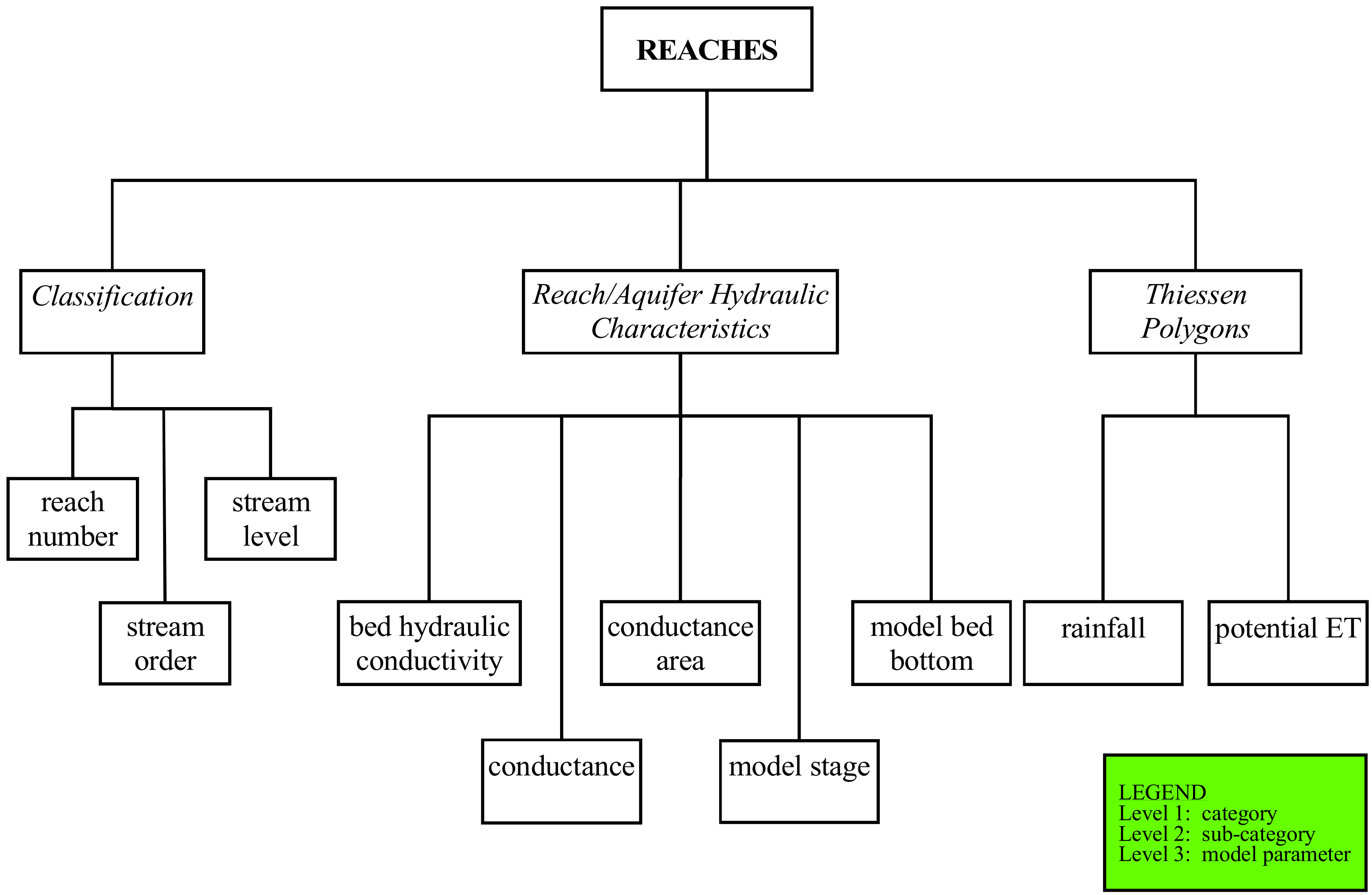


Figure 3.13 Graphic Display Options for the Reaches Category

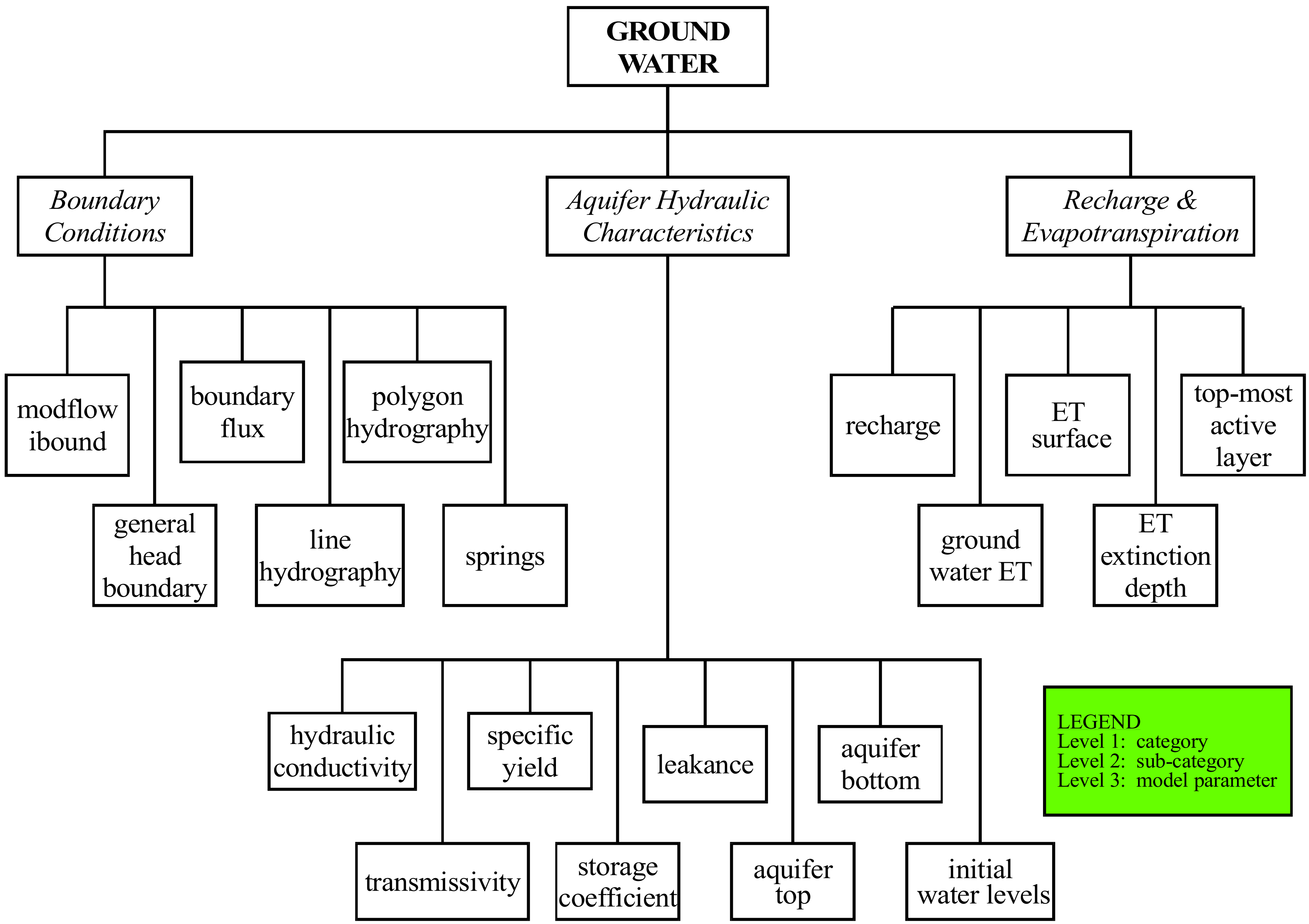


Figure 3.14 Graphic Display Options for the Ground Water Category

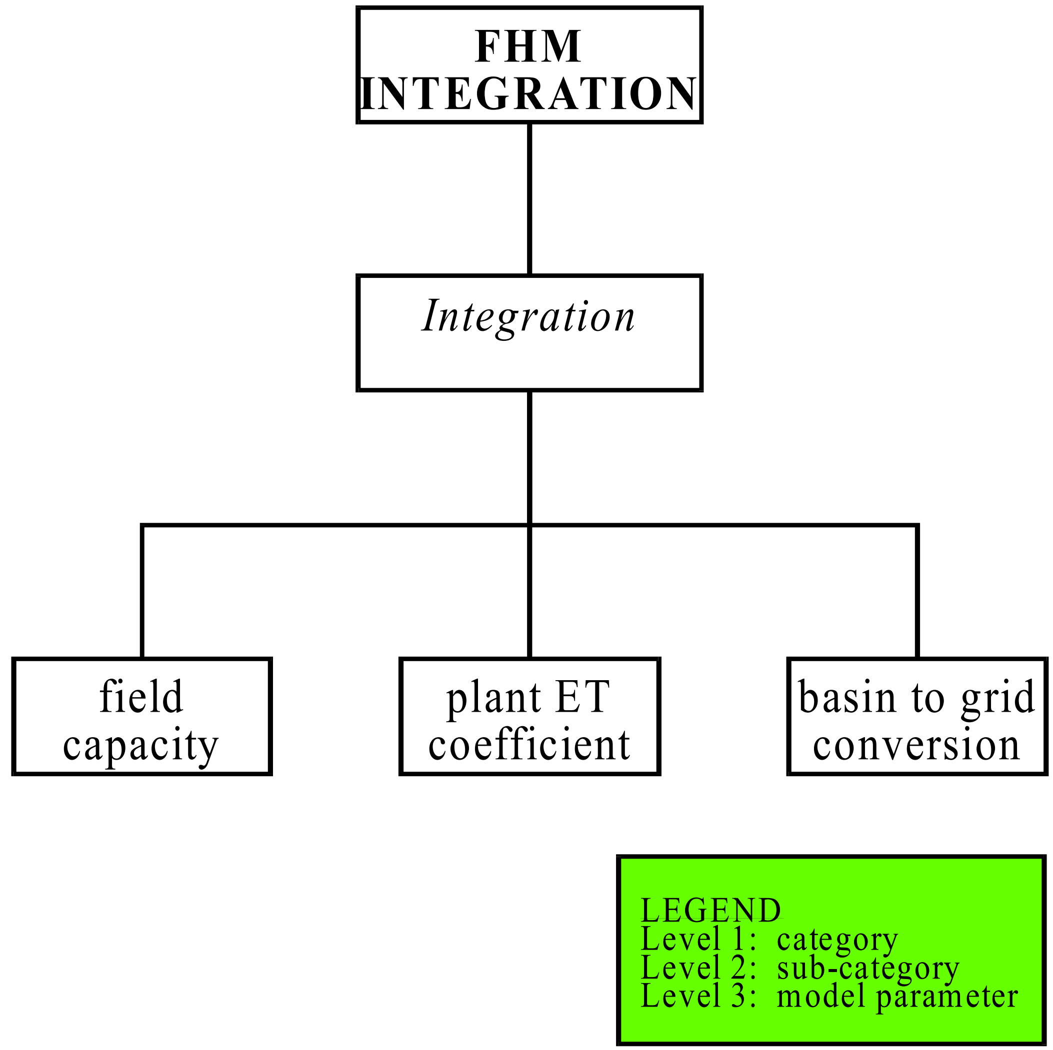


Figure 3.15 Graphic Display Options for the FHM Integration Category

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APPENDIX A. INPUT DATA SPECIFICATIONS

Input data requirements for HydroGIS include coverages, continuous surfaces, INFO tables, and ASCII files. Various types of INFO tables are required which include expansion, look-up, and relate. The specifications for each unique set of data are provided in this Appendix.

Coverages

Coverage data are a set of thematically associated data which form a digital analog of a map consisting of vectors, points, and associated attributes. ARC/INFO organizes the digital data into feature classes which include: polygons, arcs, points, nodes, routes, sections, and annotations ("ARC/INFO" 1991).

HydroGIS utilizes three different data base storage areas for coverages which include a project/user workspace, a protected/shared workspace, and map libraries. Details of the data base structure utilized by HydroGIS are found in the Data Base Structure chapter.

HydroGIS imposes general and unique specifications upon input coverage data. The general specifications include:

1. ARC/INFO allows coverage names to contain up to 13 characters. HydroGIS allows only 11 characters due to additional letters added to the beginning or end of the coverage name during data preparation or spatial analysis processing.

2. Input coverages are divided into two categories which include primary and supplemental.

3. All primary input coverages are specified in the HydroGIS "names" file with an associated coverage code. The codes are found in the specifications summary for primary coverages which immediately follows these general specifications. Refer to the Data Base Structure chapter and to a subsequent section in this appendix for a complete description of specifications for the HydroGIS "names" file.

4. Supplemental coverages are not specified in the "names" file and a coverage code is not assigned to these coverages. Each supplemental coverage is associated with one primary coverage. In many cases, the supplemental coverage has the same coverage name as the primary coverage with a prefix or suffix added to the name. Specifications for supplemental coverages are provided in the section which follows primary coverages.

5. The coverages must be properly built for the required feature class. The coverages must be properly projected into the projection used for the project.

Primary Coverages

The specifications which are unique to each primary coverage are provided below. Standard ARC/INFO items (e.g., area and perimeter for polygons) are assumed and not explicitly provided in the following specifications. The names of all primary coverages must be specified in the HydroGIS "names" file.

There are two groups of primary coverages. The first group contains coverages for which only one coverage is needed for each coverage specification. The second group contains coverages for which a separate coverage for each ground water layer is necessary for each coverage specification. Within each group, the coverages are arranged in alphabetic order using the coverage code which is **highlighted**.

Names File Coverage Code: **BASN**
Coverage Description: Surface basins classified for hydrologic modeling with HSPF
Feature Class: polygon
Required for Operation(s): Modify Basins (BASN), Hydraulic Length (HYDL), indirectly used for the following: Basin Slope (SLOPE), Soils Basins (SOILSW), Land Use Basins (LANDSW), Rainfall Basin (RNFBASIN), Potential ET Basin (EVTBASIN), Basin to Grid (BASIN2GRD)
Prohibited Items: griduid, row, col, rchclass, mrchclass
Other Specifications: HydroGIS data preparation utilities (Basin Selection and Basin Classification) can be used to create this coverage. The modified basins coverage is a supplemental coverage that is associated with this coverage. Other supplemental coverages include original surface basins, basin preparation #1, and basin preparation #2. Specifications for supplemental coverages are provided in the next section.
Required Items: The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
HSPF basin classification	class [1]	6	6	I	--

[1] The classification values start at 1 and must be numbered consecutively with no values skipped from lowest to highest.

Names File Coverage Code: **DEM**

Coverage Description: Spot/overlay coverage of regularly-spaced points

Feature Class: point

Required for Operation(s): Create processing spot/overlay coverage, indirectly used for the following: Hydraulic Conductivity (HYC), Transmissivity (TRN), Specific Yield (SPY), Storage Coefficient (STC), Leakance (LEK), Aquifer Top (TOP), Aquifer Bottom (BOT), Initial Aquifer Head (EWL), Line Hydrography (STRM), Polygon Hydrography (LAKE), Springs (SPR), Existing Pumping Well (WELL), Proposed Pumping Well (PWEL), Ground Water ET Surface (ESRF)

Prohibited Items: griduid, row, col, class, rchclass

Other Specifications: At least one point must be located within the boundaries of each small-scale, grid cell polygon referenced by coverage code GRID. The HydroGIS data preparation utility which creates the ground water grid is used to create this coverage. The processing spot/overlay coverage is a supplemental coverage that is associated with this coverage. Specifications for supplemental coverages are provided in the next section.

Required Items: The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
dem point unique ID	demuid [1]	8	8	I	--

[1] demuid = value of ARC/INFO <cover>#

Names File Coverage Code: **EVT**

Coverage Description: Potential or pan Thiessen

Feature Class: polygon

Required for Operation(s): Potential ET Basin (EVTBASIN), Potential ET Reach (EVTREACH)

Prohibited Items: class, rchclass, mrchclass

Other Specifications: The potential or pan Thiessen coverage is created by a HydroGIS data preparation utility from a point coverage of the locations of verified daily potential or pan ET stations. The temporal data for the stations are verified to be acceptable for use in the model over the simulation period. Two supplemental coverages are associated with this coverage and include original temporal data stations and selected potential/pan ET data stations. Specifications for supplemental coverages are provided in the next section.

Required Items: The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
station number classification	statnbr	2	2	I	--
unique ID of the station	hdbuid	[1]		C	
name of the station	name	[1]		C	--

[1] The definitions for the unique ID and name of the station are taken from the original point coverage for potential/pan ET stations. The item names are specified with global variables in the administrator AML, hgisvar.aml.

Names File Coverage Code:	**FLX**
Coverage Description:	Boundary flux
Feature Class:	point
Required for Operation(s):	Boundary Flux (FLX)
Prohibited Items:	none
Other Specifications:	The coverage point attribute table (<cover>.pat) contains all well (stress) attributes. Data for all aquifer layers are stored in the same coverage; the points representing different layers at the same location are stacked. The point coverage associated with GRID is used to create the FLX coverage. All points in the GRID point coverage are copied nlay number of times and the user designates active flux wells for each layer. A HydroGIS data preparation utility creates this coverage.
Required Items:	The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
grid cell unique ID	[1]griduid	8	8	I	--
grid cell row	row	4	4	I	--
grid cell column	col	4	4	I	--
flux well unique ID	[2]welluid	20	20	C	--
active/inactive flux, layer 1	[3]flx1	1	1	I	--
active/inactive flux, layer 2	flx2	1	1	I	--
active/inactive flux, layer k	:	1	1	I	--
active/inactive flux, last layer	flx(nlay)	1	1	I	--

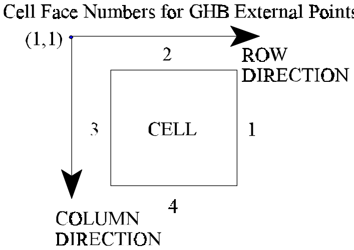
[1] griduid = row * 1000 + col
[2] welluid = concatenate "FLX" and griduid
[3] flx(k): active flux (= 1), inactive flux (= 0)

Names File Coverage Code: **GHB**
Coverage Description: Ground water general head boundaries (GHB)
Feature Class: point
Prohibited Items: lsgriduid, lsrow, lscol, lsx-coord, lsy-coord
Required for Operation(s): General Head Boundary (GHB), Multi-Scale GHB (MSCALE)
Other Specifications: Data for all aquifer layers are stored in the same coverage. When GHBs for multiple layers are assigned to a grid cell, it is acceptable to stack the GHB interior and exterior point locations at the same x-y coordinates. The interior points are copied from the point coverage associated with the coverage referenced by the coverage code GRID. A HydroGIS data preparation utility creates this coverage.
Required Items: The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
grid cell unique ID	[1]griduid	8	8	I	--
grid cell row	row	4	4	I	--
grid cell column	col	4	4	I	--
GHB unique ID	ghbuid	8	8	I	--
aquifer layer	layer	4	4	I	--
GHB head	[5]head	8	10	F	2
GHB conductance	[5]cond	8	12	F	1
cell dimension in GHB flow direction	[5]cellflow	8	10	F	1
cell dimension orthogonal to GHB flow direction	[5]cellcross	8	10	F	1
GHB flow distance	[5]flowdist	8	10	F	1
GHB flow path angle relative to (+) grid row axis	[5]alpha	4	8	F	2
cell face number	[6]face	2	2	I	--
designates exterior/interior	[2]ext	1	1	I	--
designates currently selected	[3]selected	1	1	I	--
active/inactive and calculated/user-defined	[4]ghb	2	2	I	--
x-coordinate of point	[5]x-coord	4	12	F	3
y-coordinate of point	[5]y-coord	4	12	F	3

[1] griduid = row * 1000 + col
[2] ext = interior point (= 0), exterior point (= 1)
[3] selected = currently selected (= 1), currently not selected (= 0); for editing only
[4] ghb = active (ne 0), inactive (= 0); calculated (> 0), user-defined (< 0)
[5] Units head (feet); cond (sq. feet/day)
alpha (degrees, 0 - 360)
cellflow, cellcross, flowdist, x-coord, y-coord (coverage projection units)
[6] The face number designates the side of the cell to which the GHB external point is "connected".
Face numbers 1 to 4 are used for external points as shown in the illustration. Face number 5 is used for all internal points (points which are grid cell centers).

Cell Face Numbers for GHB External Points



Names File Coverage Code:	**GRID**
Coverage Description:	Small-scale polygon ground water grid
Feature Class:	polygon
Required for Operation(s):	create ground water processing grid, Top-Most Active Layer (TACT), Basin to Grid (BASIN2GRD), indirectly used for the following: create processing spot/overlay, Hydraulic Conductivity (HYC), Transmissivity (TRN), Specific Yield (SPY), Storage Coefficient (STC), Leakance (LEK), Aquifer Top (TOP), Aquifer Bottom (BOT), Initial Aquifer Head (EWL), Line Hydrography (STRM), Polygon Hydrography (LAKE), Springs (SPR), Existing Pumping Well (WELL), Proposed Pumping Well (PWEL), Recharge Rate (REC), Ground Water ET Rate (GWET), Ground Water ET Surface (ESRF), Ground Water ET Extinction Depth (EDEP), Soils ET (SOILET), Land Use ET (LANDET)
Prohibited Items:	class, rchclass, mrchclass
Other Specifications:	Three INFO files are associated with the grid coverage. The INFO files use the coverage name for the file prefix. The INFO files include: row/column information (<cover>.rc), delr/delc information (<cover>.del), and x-coord/y-coord information (<cover>.dat). See the Input Data Specifications, INFO Files section for file specifications. The grid coverage is also built for nodes which means a node attribute table is available. A HydroGIS data preparation utility creates this coverage. The grid polygon coverage must be stored in the project/user workspace. There are two supplemental coverages that are associated with this coverage. These coverages include the grid point coverage and the processing grid polygon coverage. Specifications for supplemental coverages are provided in the next section. When archived, the polygon and point grid coverages must be stored in the same workspace or map library.
Required Items:	The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
grid cell unique ID	[1]griduid	8	8	I	--
grid cell row	row	4	4	I	--
grid cell column	col	4	4	I	--

[1] griduid = row * 1000 + col

Names File Coverage Code:	**GWET**
Coverage Description:	Ground water ET maximum rate
Feature Class:	polygon
Required for Operation(s):	Ground Water ET Rate (GWET)
Prohibited Items:	griduid, row, col
Other Specifications:	The PAT of the coverage must contain an item which represents the value of the annual ground water ET maximum rate (inches/year) for each polygon in the coverage.

Names File Coverage Code: **LAKE**

Coverage Description: Classified polygon hydrography (e.g., lakes, wetlands, wide rivers)

Feature Class: polygon

Required for Operation(s): Modify Basins (BASN), Hydraulic Length (HYDL), Reach Length (LENGTH), Invert Elevation (STCOR), Depth/Area/Volume (DAVD), Rainfall Reach (RNFREACH), Potential ET Reach (EVTREACH), Polygon Hydrography (LAKE), indirectly used for the following: Basin Slope (SLOPE), Soils Basins (SOILSW), Land Use Basins (LANDSW), Rainfall Basin (RNFBASIN), Potential ET Basin (EVTBASIN), Basin to Grid (BASIN2GRD)

Prohibited Items: griduid, row, col, class, mrchclass

Other Specifications: The polygon coverage is created by the user from the EPA RF3-Alpha line coverage. Each polygon feature is given a unique ID (rf3polyid) which is a concatenated item of watershed ID and an internal coverage ID (<cover>#). Two expansion tables, which contain hydrologic attributes, are also used for selected operations. See the Input Data Specifications, INFO Files section for expansion table specifications.

Reaches must be consecutively classified with smaller numbered reaches routed to larger numbered reaches. All routed reaches must contain at least one dynamic element. Only the reaches which are not routed can be classified as completely static; these reaches must be given the largest reach numbers. The absolute value of the smallest reach classification must be 1 with no values skipped from lowest to highest.

There are two supplemental coverages associated with this coverage. These coverages include the original polygon hydrography coverage (created from EPA RF3-Alpha line coverage) and the polygon hydrography preparation coverage. Specifications for supplemental coverages are provided in the next section.

Required Items: The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
hydrography polygon unique ID	rf3polyid [1]	14	14	C	--
watershed cataloging unit	cu	8	8	I	--
type of hydrography polygon	reachtype [2]	1	1	C	--
magnitude classification of polygon	order	4	4	I	--
HSPF reach classification	rchclass [3]	6	6	I	--

[1] concatenated items cu and <cover>#

[2] refer to EPA (1994) for a listing of reachtype codes

[3] dynamic reach elements (> 0), static reach elements (< 0). The absolute value of the smallest classification must be 1, and the reaches must be consecutively numbered with no values skipped from highest to lowest. This item is only included in the classified hydrography coverage for the project.

Names File Coverage Code: **LAND**
Coverage Description: Land use/land cover
Feature Class: polygon
Required for Operation(s): Land Use Basins (LANDSW), Land Use ET (LANDET), Ground Water Evapotranspiration Extinction Depth (EDEP)
Prohibited Items: griduid, row, col, class, mrchclass
Other Specifications: The coverage must include a classification index item that is used as a relate link to the look-up table which stores hydrologic attributes by the classification index. No specific definition for the classification index item is provided. See the Input Data Specifications, INFO Files section for relate table and look-up table specifications.

Names File Coverage Code: **LGRD**
Coverage Description: Large-scale polygon ground water grid
Feature Class: polygon
Required for Operation(s): Multi-Scale GHB (MSCALE)
Prohibited Items: class, rchclass, mrchclass
Other Specifications: Three INFO files are associated with the grid coverage. The INFO files use the coverage name for the file prefix. The INFO files include: row/column information (<cover>.rc), delr/delc information (<cover>.del), and x-coord/y-coord information (<cover>.dat). See the Input Data Specifications, INFO Files section for file specifications. The large-scale grid coverage is also built for nodes which means a node attribute table is available. A HydroGIS data preparation utility creates this coverage.
There are two supplemental coverages that are associated with this coverage. These coverages include the grid point coverage (large-scale) and the processing grid polygon coverage (large-scale). Specifications for supplemental coverages are provided in the next section. When archived, the polygon and point grid coverages must be stored in the same workspace or map library.
Required Items: The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
grid cell unique ID	[1]griduid	8	8	I	--
grid cell row	row	4	4	I	--
grid cell column	col	4	4	I	--

[1] griduid = row * 1000 + col

Names File Coverage Code: **PWEL**
Coverage Description: Proposed pumping wells
Feature Class: point
Required for Operation(s): Proposed Pumping Well (PWEL)
Prohibited Items: griduid, row, col
Other Specifications: The coverage point attribute table (<cover>.pat) contains all well attributes.
Required Items: The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
well unique ID	welluid	20	20	C	--
casing depth or casing depth elevation	[2] %cditem%	[3]		F or N	
total depth or total depth elevation	[2] %tditem%			F or N	
other item(s) necessary to assign layers to wells					
upper-most layer open to well	[1] laystart	4	4	I	--
lower-most layer open to well	[1] laystop	4	4	I	--

[1] If the items laystart and laystop are manually added to the <cover>.pat, then the values of laystart and laystop for each well must be manually entered. If these items do not exist, then they will be added through processing and the values will be determined through spatial analysis using well depths and/or elevations.
[2] Units: %cditem%, %tditem% are depths or elevations in feet. The item names are specified with global variables in the administrator AML, hgisvar.aml.
[3] Blank or variable entries in table are user-defined.

Names File Coverage Code: **REC**
Coverage Description: Ground water recharge rate
Feature Class: polygon
Required for Operation(s): Recharge Rate (REC)
Prohibited Items: griduid, row, col
Other Specifications: The PAT of the coverage must contain an item which represents the value of the annual ground water recharge rate (inches/year) for each polygon in the coverage.

Names File Coverage Code: **RNF**
Coverage Description: Rainfall Thiessen
Feature Class: polygon
Required for Operation(s): Rainfall Basin (RNFBASIN), Rainfall Reach (RNFREACH)
Prohibited Items: class, rchclass
Other Specifications: The rainfall Thiessen coverage is created by a HydroGIS data preparation utility from a point coverage of the locations of verified hourly rainfall stations. The temporal data for the stations are verified to be acceptable for use in the model over the simulation period. Two supplemental coverages are associated with this coverage and include original temporal data stations and selected rainfall data stations. Specifications for supplemental coverages are provided in the next section.
Required Items: The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
station number classification	statnbr	2	2	I	--
unique ID of the station	hdbuid	[1]		C	
name of the station	name	[1]		C	--

[1] The definitions for the unique ID and name of the station are taken from the selected point coverage for rainfall stations. The item names are specified with global variables in the administrator AML, hgisvar.aml.

Names File Coverage Code: **SLPE**
Coverage Description: Mean basin slope
Feature Class: polygon
Required for Operation(s): Slope (SLPE)
Prohibited Items: class, mrchclass
Other Specifications: The slope coverage is comprised of the mean basins slope for the smallest surface basin polygons available. Update the basin slope coverage whenever the topography elevation surface and/or the surface basins coverage are altered. The slope coverage must contain an item which represents the value of the slope for each polygon in the coverage. The slope values are dimensionless decimal values.

Names File Coverage Code: **SOIL**
Coverage Description: Soils
Feature Class: polygon
Required for Operation(s): Soils Basins (SOILSW), Soils ET (SOILET)
Prohibited Items: griduid, row, col, class, mrchclass
Other Specifications: The coverage must include a classification index item that is used as a relate link to the look-up table which stores hydrologic attributes by the classification index. No specific definition for the classification index item is provided. See the Input Data Specifications, INFO Files section for relate table and look-up table specifications.

Names File Coverage Code: **SPR**
Coverage Description: Ground water springs (point hydrography)
Feature Class: point
Required for Operation(s): Classified Springs (SPR)
Prohibited Items: griduid, row, col, class, mrchclass
Other Specifications: The coverage must contain a spring unique ID (spruid) that is also contained in an INFO expansion table which holds hydrologic attributes. See the Input Data Specifications, INFO Files section for expansion table specifications.

Typically, springs discharge to a stream which is represented by a reach. The spring must be classified as part of one of the reaches. Reaches must be consecutively classified with smaller numbered reaches routed to larger numbered reaches. All routed reaches must contain at least one dynamic element. Only the reaches which are not routed can be classified as completely static; these reaches must be given the largest reach numbers. The absolute value of the smallest reach classification must be 1 with no values skipped from lowest to highest.

Required Items: The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
spring unique ID	spruid	17	17	C	--
HSPF reach classification	rchclass [1]	6	6	I	--

[1] dynamic reach elements (> 0), static reach elements (< 0). The absolute value of the smallest classification must be 1, and the reaches must be consecutively numbered with no values skipped from highest to lowest. This item is only included in the classified hydrography coverage for the project.

Names File Coverage Code: **STRM**

Coverage Description: Classified line hydrography (i. e., streams)

Feature Class: line or arc

Required for Operation(s): Modify Basins (BASN), Hydraulic Length (HYDL), Reach Length (LENGTH), Invert Elevation (STCOR), Depth/Area/Volume (DAVD), Rainfall Reach (RNFREACH), Potential ET Reach (EVTREACH), Line Hydrography (STRM), indirectly used for the following: Basin Slope (SLOPE), Soils Basins (SOILSW), Land Use Basins (LANDSW), Rainfall Basin (RNFBASIN), Potential ET Basin (EVTBASIN), Basin to Grid (BASIN2GRD)

Prohibited Items: griduid, row, col, class, mrchclass

Other Specifications: The EPA RF3-Alpha coverage has an associated expansion table of connectivity attributes (rf3hydro.ds3_exp) which is used for selected operations. Two other expansion tables, which contain hydrologic attributes, are also used for selected operations. See the Input Data Specifications, INFO Files section for expansion table specifications.

Reaches must be consecutively classified with smaller numbered reaches routed to larger numbered reaches. All routed reaches must contain at least one dynamic element. Only the reaches which are not routed can be classified as completely static; these reaches must be given the largest reach numbers. The absolute value of the smallest reach classification must be 1 with no values skipped from lowest to highest.

There are two supplemental coverages associated with this coverage which includes original line hydrography and line hydrography preparation. Specifications for supplemental coverages are provided in the next section.

Required Items: The following table provides the specifications for required items in the AAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
watershed cataloging unit	cu	8	8	I	--
segment number	seg	4	4	I	--
marker index	mi	5	5	C	--
HSPF reach classification	rchclass [1]	6	6	I	--
stream arc unique ID	rf3rchid [2]	17	17	C	--

[1] dynamic reach elements (> 0), static reach elements (< 0). The absolute value of the smallest classification must be 1, and the reaches must be consecutively numbered with no values skipped from highest to lowest. This item is only included in the classified hydrography coverage for the project.

[2] concatenated items cu, seg, mi

Names File Coverage Code: **WELL**
Coverage Description: Existing pumping wells
Feature Class: point
Required for Operation(s): Existing Pumping Well (WELL)
Prohibited Items: griduid, row, col
Other Specifications: The coverage must contain a unique well ID (welluid) that is also contained in the INFO expansion table which holds well attributes. See the Input Data Specifications, INFO files section for expansion table specifications.
Required Items: The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
well unique ID	welluid	20	20	C	--

Except where noted under other specifications, **a separate primary coverage is required for each ground water layer** for each of the following coverage specifications. The letter K refers to the layer number.

Names File Coverage Code:	**CHYC**(K)
Coverage Description:	Confining bed hydraulic conductivity
Feature Class:	polygon
Required for Operation(s):	Leakance (LEK)
Prohibited Items:	griduid, row, col
Other Specifications:	The PAT of the coverage must contain an item which represents the value of confining bed, vertical hydraulic conductivity (feet/day) for each polygon in the coverage. No coverage is required for the lower-most aquifer layer.

Names File Coverage Code:	**HYC**(K)
Coverage Description:	Hydraulic conductivity
Feature Class:	polygon
Required for Operation(s):	Hydraulic Conductivity (HYC), Transmissivity (TRN), General Head Boundary (GHB), Existing Pumping Well (WELL), Proposed Pumping Well (PWEL)
Prohibited Items:	griduid, row, col, ghbuid, arcuid, cond
Other Specifications:	The PAT of the coverage must contain an item which represents the value of hydraulic conductivity (feet/day) for each polygon in the coverage.

Names File Coverage Code:	**IBD**
Coverage Description:	Small-scale ibound
Feature Class:	polygon
Required for Operation(s):	create processing ground water grid, IBOUND (IBD), Top-Most Active Layer (TACT), indirectly used for the following: create processing spot/overlay, Hydraulic Conductivity (HYC), Transmissivity (TRN), Specific Yield (SPY), Storage Coefficient (STC), Leakance (LEK), Aquifer Top (TOP), Aquifer Bottom (BOT), Initial Aquifer Head (EWL), Line Hydrography (STRM), Polygon Hydrography (LAKE), Springs (SPR), Existing Pumping Well (WELL), Proposed Pumping Well (PWEL), Recharge Rate (REC), Ground Water ET Rate (GWET), Ground Water ET Surface (ESRF), Ground Water ET Extinction Depth (EDEP), Soils ET (SOILET), Land Use ET (LANDET), Basin to Grid (BASIN2GRD)
Prohibited Items:	none
Other Specifications:	**MODFLOW ibound data for all layers are stored in one coverage.** The ibound coverage referenced by the coverage code IBD must contain the same polygon grid cells that exist within the GRID coverage (the polygons cannot be dissolved). A HydroGIS data preparation utility is used to create this coverage.
Required Items:	The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
grid cell unique ID	[1]griduid	8	8	I	--
grid cell row	row	4	4	I	--
grid cell column	col	4	4	I	--
ibound item, layer 1	ibd1	4	4	I	--
ibound item, layer 2	ibd2	4	4	I	--
ibound item, layer k	:	4	4	I	--
ibound item, last layer	ibd(nlay)	4	4	I	--

[1] griduid = row * 1000 + col

Names File Coverage Code: **LIBD**
Coverage Description: Large-scale ibound
Feature Class: polygon
Required for Operation(s): Multi-Scale GHB (MSCALE)
Prohibited Items: none
Other Specifications: **MODFLOW ibound data for all layers are stored in one coverage.** The ibound coverage referenced by the coverage code LIBD must contain the same polygon grid cells that exist within the LGRD coverage (the polygons cannot be dissolved). A HydroGIS data preparation utility is used to create this coverage.
Required Items: The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
grid cell unique ID	[1]griduid	8	8	I	--
grid cell row	row	4	4	I	--
grid cell column	col	4	4	I	--
ibound item, layer 1	ibd1	4	4	I	--
ibound item, layer 2	ibd2	4	4	I	--
ibound item, layer k	:	4	4	I	--
ibound item, last layer	ibd(nlay)	4	4	I	--

[1] griduid = row * 1000 + col

Names File Coverage Code: **SPS**(K)
Coverage Description: Specific storage
Feature Class: polygon
Required for Operation(s): Storage Coefficient (STC)
Prohibited Items: griduid, row, col
Other Specifications: The PAT of the coverage must contain an item which represents the value of specific storage (feet^{-1}) for each polygon in the coverage.

Names File Coverage Code: **SPY**(K)
Coverage Description: Specific yield
Feature Class: polygon
Required for Operation(s): Specific Yield (SPY)
Prohibited Items: griduid, row, col
Other Specifications: The PAT of the coverage must contain an item which represents the value of specific yield (dimensionless decimal) for each polygon in the coverage.

Supplemental Coverages

Supplemental coverages are not specified in the names file and a coverage code is not assigned to these coverages. Each supplemental coverage is associated with one or more primary coverage. In many cases, the supplemental coverage has the same coverage name as the primary coverage with a prefix or suffix added to the name. Specifications for supplemental coverages are provided below.

Names File Coverage Code: None (associated with **BASN**)
Coverage Description: **Modified surface basins** classified for hydrologic modeling with HSPF. The basins are modified by removing routing areas from basins.
Feature Class: polygon
Required for Operation(s): Slope (SLPE), Soils Basins (SOILSW), Land Use Basins (LANDSW), Rainfall Basins (RNFBASIN), Potential ET Basins (EVTBASIN), Basin to Grid (BASIN2GRD)
Prohibited Items: griduid, row, col, rchclass
Other Specifications: The coverage is created by the Modify Basins (BASN) operation of HydroGIS. The coverage must be stored in the project/user workspace. The coverage is given the name provided in the names file for the coverage referenced by the coverage code BASN, with the letter "m" placed in front.
Required Items: The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
HSPF basin classification	class [1]	6	6	I	--
HSPF reach classification	mrchclass	6	6	I	--

[1] The classification values start at 1 and must be numbered consecutively with no values skipped from lowest to highest.

Names File Coverage Code: None (associated with **BASN)**

Coverage Description: **Original surface basins** from centralized data base.

Feature Class: polygon

Required for Operation: None - used only in data preparation to create the supplemental coverage for surface basins which is referred to as Basin Preparation #1.

Prohibited Items: class, rchclass, mrchclass, recno, basinuid, inbasin, ingrid

Other Specifications: Before the basin selection utility is used, the original basins coverage should contain any additional basin delineations that are required for the model project. Subsequent model projects can benefit from the additional basin delineations.

Required Items: The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
watershed code	huc	[1]		C	--
secondary basin code	secondary			C	--
tertiary basin code	tertiary			C	--
quaternary basin code	quaternary			C	--

[1] Blank entries in table are user - defined.

Names File Coverage Code: None (associated with **BASN**)

Coverage Description: **Basin Preparation #1** - The coverage includes all of the original basins with the selected status added. After basin classification, the classification number is added to the coverage.

Feature Class: polygon

Required for Operation: None - Used only in data preparation to select basins and to create the Basin Preparation #2 coverage.

Prohibited Items: none

Other Specifications: The coverage name is the same as the Classified Basins coverage with the prefix letters "uu" added.

Required Items: The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
watershed code	huc	[1]		C	--
secondary basin code	secondary			C	--
tertiary basin code	tertiary			C	--
quaternary basin code	quaternary			C	--
unique ID of original basin polygon	recno	6	6	I	--
selected status of basin	basinuid[2]	6	6	I	--
basin classification value	class[3]	6	6	I	--
discharge status of basin with respect to ground water grid	inbasin[3]	6	6	I	--

[1] Blank entries in table are user - defined.
[2] basinuid: = recno, basin selected
= 0, basin not selected
[3] Items are added after the first execution of basin classification.

Names File Coverage Code: None (associated with **BASN**)
Coverage Description: **Basin Preparation #2** - Used in the data preparation utilities for basin classification. The coverage includes only the selected basins.
Feature Class: polygon
Required for Operation: None - Used only in data preparation to classify basins and to create the Classified Basins coverage. The basin classification values from Basin Preparation #2 are added to Basin Preparation #1 after each basin classification session.
Prohibited Items: none
Other Specifications: The coverage name is the same as the Classified Basins coverage with the prefix letter "u" added. The items inbasin and ingrid exist in this coverage for integrated model applications.
Required Items: The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
watershed code	huc	[1]		C	--
secondary basin code	secondary			C	--
tertiary basin code	tertiary			C	--
quaternary basin code	quaternary			C	--
unique ID of original basin polygon	recno	6	6	I	--
selected status of basin	basinuid[2]	6	6	I	--
basin classification value	class[3]	6	6	I	--
discharge status of basin with respect to ground water grid	inbasin[3, 4]	6	6	I	--
indicates whether the basin is inside or outside the active region of the grid	ingrid[3, 5]	4	4	I	--

[1] Blank entries in table are user - defined.
[2] basinuid: = recno, basin selected
= 0, basin not selected

[3] Items are added after the first execution of basin classification.
[4] inbasin: = 0, basin discharge outward from grid edge
= 1, basin discharge inward from grid edge
[5] ingrid: = 0, outside grid
= 1, inside grid

Names File Coverage Code:	None (associated with **DEM**)
Coverage Description:	**<u>Processing</u> spot/overlay** coverage of regularly-spaced points
Feature Class:	point
Required for Operation(s):	Hydraulic Conductivity (HYC), Transmissivity (TRN), Specific Yield (SPY), Storage Coefficient (STC), Leakance (LEK), Aquifer Top (TOP), Aquifer Bottom (BOT), Initial Aquifer Head (EWL), Line Hydrography (STRM), Polygon Hydrography (LAKE), Springs (SPR), Existing Pumping Well (WELL), Proposed Pumping Well (PWEL), Ground Water ET Surface (ESRF)
Prohibited Items:	class, rchclass
Other Specifications:	This coverage is created, by an overlay between the coverage referenced by the coverage code DEM and the processing ground water grid coverage. The coverage is created, as required, each time spatial analysis operations for ground water are executed. It is created within the spatial analysis management AML for ground water operations. The coverage must be stored in the project/user workspace. The coverage has the same name as the DEM point coverage with the letter "g" placed in the front. At least one point must be located within the boundaries of each small-scale, grid cell polygon referenced by coverage code GRID.
Required Items:	The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
dem point unique ID	[1]demuid	8	8	I	--
grid cell unique ID	[2]griduid	8	8	I	--
grid cell row	row	4	4	I	--
grid cell column	col	4	4	I	--

[1]demuid = value of ARC/INFO <cover>#
[2]griduid = row * 1000 + col

Names File Coverage Code: None (associated with **GRID**)
Coverage Description: **Processing polygon ground water grid**
Feature Class: polygon
Required for Operation(s): create processing spot/overlay, Hydraulic Conductivity (HYC), Transmissivity (TRN), Specific Yield (SPY), Storage Coefficient (STC), Leakance (LEK), Aquifer Top (TOP), Aquifer Bottom (BOT), Initial Aquifer Head (EWL), Line Hydrography (STRM), Polygon Hydrography (LAKE), Springs (SPR), Existing Pumping Well (WELL), Proposed Pumping Well (PWEL), Recharge Rate (REC), Ground Water ET Rate (GWET), Ground Water ET Extinction Depth (EDEP), Ground Water ET Surface (ESRF), Land Use ET (LANDET), Soils ET (SOILET), Basin to Grid (BASIN2GRD)
Prohibited Items: class, rchclass, mrchclass
Other Specifications: The coverage is created by an operation of HydroGIS from the coverages referenced by the coverage codes GRID and IBD (all aquifer layers of ibound data). The processing grid must be stored in the project/user workspace and is always given the coverage name “procgrid”.
Required Items: The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
grid cell unique ID	[1]griduid	8	8	I	--
grid cell row	row	4	4	I	--
grid cell column	col	4	4	I	--
ibound, layer 1	[2]ibd1	4	4	I	--
:	:	:	:	:	:
ibound, layer nlay	[2]ibd(nlay)	4	4	I	--
border/interior cell, layer 1	[3]border1	2	2	I	--
:	:	:	:	:	:
border/interior cell, layer nlay	[3]border(nlay)	2	2	I	--

[1] griduid = row * 1000 + col
[2] ibd(k): active cell (> 0), inactive cell (= 0), constant head cell (< 0); where k = layer number
[3] border(k): border cell (= 1), interior cell (=0); where k = layer number

Names File Coverage Code:	None (associated with **GRID**)
Coverage Description:	**Small-scale point ground water grid**
Feature Class:	point
Required for Operation(s):	none - Used only in data preparation to create the following coverages: general head boundary and boundary flux
Prohibited Items:	class, rchclass, mrchclass
Other Specifications:	The coverage is created at the same time as the grid polygon coverage is created, by a HydroGIS data preparation utility. This point coverage represents the cell centers of each polygon grid cell of the coverage referenced by the coverage code GRID. The grid point coverage must be stored in the project/user workspace. The coverage has the same name as the GRID polygon coverage with the letters "pt" placed at the end. Because the grid point coverage name does not have any characters appended during processing, the coverage name can be the full 13 characters, including the "pt". When archived, the polygon and point grid coverages must be stored in the same workspace or map library.
Required Items:	The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
grid cell unique ID	[1]griduid	8	8	I	--
grid cell row	row	4	4	I	--
grid cell column	col	4	4	I	--
grid cell center x-coord	[2]x-coord	4	12	F	3
grid cell center y-coord	[2]y-coord	4	12	F	3

[1] griduid = row * 1000 + col

[2] x-coord and y-coord are in coverage projection units

Names File Coverage Code: None (associated with **LAKE**)
Coverage Description: **Original polygon hydrography** from centralized data base
Feature Class: polygon
Required for Operation: None - Used only in data preparation to create the supplemental coverage for polygon hydrography which is referred to as Polygon Hydrography Preparation.
Prohibited Items: class, rchclass, reach, dynamic, static, mrchclass, griduid, row, col
Other Specifications: The coverage is created by the user from the EPA RF3 - Alpha line coverage. Each polygon feature is given a unique ID (rf3polyid) which is a concatenated item of watershed ID and an internal coverage ID (<cover>#). Two expansion tables are also required. See the Input Data Specifications, INFO Files section for expansion table specifications.
Required Items: The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
hydrography polygon unique ID	rf3polyid	14	14	C	--
watershed cataloging unit	cu	8	8	I	--
type of hydrography polygon	reachtype[2]	1	1	C	--
magnitude classification of polygon	order	4	4	I	--

[1] concatenated items cu and <cover>#
[2] refer to EPA (1994) for a listing of reachtype codes

Names File Coverage Code: None (associated with **LAKE**)

Coverage Description: **Polygon Hydrography Preparation** - The coverage includes only the polygon label points and lines which are contained within the boundaries of the Classified Basins or Processing Grid coverage.

Feature Class: polygon

Required for Operation: None - used only in data preparation to create the Classified Polygon Hydrography Coverage. Items that are used for element selection by the utilities are removed to create the classified coverage.

Prohibited Items: mrchclass

Other Specifications: Coverage originates from the Original Polygon Hydrography coverage.

Required Items: The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
hydrography polygon unique ID	rf3polyid	14	14	C	--
watershed cataloging unit	cu	8	8	I	--
type of hydrography polygon	reachtype [2]	1	1	C	--
magnitude classification of polygon	order	4	4	I	--
HSPF reach classification	rchclass [3]	6	6	I	--
basin classification	class [4]	6	6	I	--
grid cell unique ID	griduid [4]	8	8	I	--
absolute value of HSPF reach classification	reach	6	6	I	--
for dynamic elements, absolute value of HSPF reach classification	dynamic	6	6	I	--
for static elements, absolute value of HSPF reach classification	static	6	6	I	--

[1] concatenated items cu and <cover>#

[2] refer to EPA (1994) for a listing of reachtype codes

[3] dynamic reach elements (>0), static reach elements (<0). The absolute value of the smallest classification must be 1, and the reaches must be consecutively numbered with no values skipped from highest to lowest.

[4] class is present if coverage is clipped by basins, griduid is present if coverage is clipped by grid

Names File Coverage Code: None (associated with **LGRD**)
Coverage Description: **Large-scale point ground water grid**
Feature Class: point
Required for Operation(s): Multi-Scale GHB (MSCALE)
Prohibited Items: class, rchclass, mrchclass
Other Specifications: The coverage is created at the same time as the large-scale grid polygon coverage is created, by a HydroGIS data preparation utility. This point coverage represents the cell centers of each polygon grid cell (large-scale) of the coverage referenced by the coverage code LGRD. The large-scale, grid point coverage must be stored in the same workspace or map library as the large-scale, polygon grid coverage. The coverage has the same name as the LGRD polygon coverage with the letters "pt" placed at the end. Because the large-scale, grid point coverage name does not have any characters appended during processing, the coverage name can be the full 13 characters, including the "pt". When archived, the large-scale polygon and point grid coverages must be stored in the same workspace or map library.
Required Items: The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
grid cell unique ID	[1]griduid	8	8	I	--
grid cell row	row	4	4	I	--
grid cell column	col	4	4	I	--
grid cell center x-coord	[2]x-coord	4	12	F	3
grid cell center y-coord	[2]y-coord	4	12	F	3

[1] griduid = row * 1000 + col
[2] x-coord and y-coord are in coverage projection units

Names File Coverage Code: None (associated with **STRM**)
Coverage Description: **Original line hydrography** from centralized data base
Feature Class: line
Required for Operation(s): None - used only in data preparation to create the supplemental coverage for line hydrography which is referred to as Line Hydrography Preparation.
Prohibited Items: class, rchclass, reach, dynamic, static, mrchclass, griduid, row, col
Other Specifications: The coverage must conform to the EPA RF3-Alpha format which includes an expansion table (rf3hydro.ds3_exp) of connectivity attributes. From the expansion table the following items are retrieved: reachtype, level, order. See the Input Data Specifications, INFO Files section for the specifications of the three required expansion tables.
Required Items: The following table provides the specifications for required items in the AAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
watershed cataloging unit	cu	8	8	1	--
segment number	seg	4	4	I	--
marker index	mi	5	5	C	--
stream arc unique ID	rf3rchid[1]	17	17	C	--

[1]concatenated items cu, seg, mi

Names File Coverage Code: None (associated with **STRM**)

Coverage Description: **Line Hydrography Preparation**- The coverage includes only the line hydrography which are contained within the boundaries of the Classified Basins or Processing Grid coverage. In addition, any lines associated with hydrography polygons are removed.

Feature Class: line

Required for Operation(s): None - used only in data preparation to create the Classified Line Hydrography coverage. Items that are used for element selection by the utilities are removed to create the classified coverage.

Prohibited Items: mrchclass

Other Specifications: Coverage originates from the Original Line Hydrography coverage.

Required Items: The following table provides the specifications for required items in the AAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
watershed cataloging unit	cu	8	8	I	--
segment number	seg	4	4	I	--
marker index	mi	5	5	C	--
HSPF reach classification	rchclass[1]	6	6	I	--
stream arc unique ID	rf3rchid[2]	17	17	C	--
reachtype code	reachtype	1	1	C	--
stream level	level	2	2	I	--
Strahler stream order	order	4	4	I	--
basin classification	class[3]	6	6	I	--
absolute value of HSPF reach classification	reach	6	6	I	--
for dynamic elements, absolute value of HSPF reach classification	dynamic	6	6	I	--
for static elements, absolute value of HSPF reach classification	static	6	6	I	--
grid cell unique ID	griduid[3]	8	8	I	--

[1] dynamic reach elements (>0), static reach elements (<0). The absolute value of the smallest classification must be 1, and the reaches must be consecutively numbered with no values skipped from highest to lowest. This item is only included in the classified hydrography coverage for the project.

[2] concatenated items cu, seg, mi

[3] class is present if coverage clipped by basins, griduid is present if coverage clipped by grid

Names File Coverage Code:	None (associated with **RNF** or **EVT** unless station type is not rainfall or potential/pan ET.)
Coverage Description:	**Original Temporal Data Stations** from centralized data base. The coverage contains locations for various data station types which include: rainfall, potential/pan ET, stream flow, surface water stage, surface water pumping, and ground water levels.
Feature Class:	point
Required for Operation(s):	None - used only in data preparation to create a station location coverage of selected stations for a specific station type. Information about the selected stations can also be written to an ASCII file. Executable codes can use the ASCII file to retrieve temporal data for the stations.
Prohibited Items:	statnbr, class, rchclass
Other Specifications:	none
Required Items:	The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
unique ID of station	[1]			C	--
station name				C	--
code for station type[2]		3	3	C	--

[1] Blank entries in table are defined by the user. The item names are specified with global variables in the administrator AML, hgisvar.aml.

[2] Codes for station type (codes are all capitalized):

RNF	=	rainfall
EVT	=	potential/pan ET
FLO	=	streamflow
STG	=	surface water stage
SWQ	=	surface water pumping
WEL	=	ground water levels

Names File Coverage Code: None (associated with **RNF** or **EVT** unless station type is not rainfall or potential/pan ET.)

Coverage Description: **Selected Temporal Data Stations** - The selected stations are contained in the coverage for the specified station type.

Feature Class: point

Required for Operation(s): None - used only in data preparation to create a Thiessen polygon coverage for rainfall or potential/pan ET. The station locations can also be used for graphic display.

Prohibited Items: class, rchclass

Other Specifications: none

Required Items: The following table provides the specifications for required items in the PAT of the coverage.

Item Description	Item	Width	Output	Type	No. Decimals
unique ID of station	[1]			C	--
station name				C	--
station number classification	statnbr	2	2	I	--

[1] Blank entries in table are defined by the original stations coverage. The item names are specified with global variables in the administrator AML, hgisvar.aml.

Continuous Surfaces: Triangular Irregular Networks or Lattices

Many continuous surfaces are utilized by the operations of HydroGIS. The surfaces represent topographic elevation (land surface), aquifer top or bottom elevation, and aquifer or confining bed thickness. The continuous surfaces can be in the form of Triangular Irregular Networks (TINs) or lattices. A TIN is a representation of a surface derived from irregularly spaced sample points and breakline features. Each sample point has an x-y coordinate and a surface or z value. A lattice is a representation of a surface using a rectangular array of points spaced at a constant sampling interval in the x and y directions. For both the TIN and the lattice, z values can be interpolated between the sample points with a spot overlay operation ("ARC/INFO" 1991).

ARC/INFO permits the storage of surfaces in workspaces only. HydroGIS utilizes two different workspace storage areas within which surfaces can be stored: a project/user workspace and a protected/shared workspace. Details of the HydroGIS data base structure are found in the Data Base Structure chapter.

HydroGIS imposes general and specific specifications upon input surface data. The general specifications include:

1. ARC/INFO allows surface names to contain up to 13 characters. HydroGIS also allows 13 characters in surface names.

2. All input surfaces are assigned a code which is stored in the HydroGIS "names" file. The codes are found in the specifications summary which immediately follows these general specifications. Refer to the Data Base Structure chapter and to a subsequent section in this appendix for a complete description of specifications for the HydroGIS "names" file.

3. The surfaces must be properly projected into the projection used for the project. The units for elevation or thickness for the surface must match the projection x-y units for the surface. (During spatial analysis operations, the elevation and thickness values are converted to feet units.)

4. The units (feet or meters) for elevation or thickness that are stored in the surface must be specified in the HydroGIS "names" file.

Provided below are the specifications that are unique to each surface. Like primary coverages, surfaces are divided into two groups. The first group contains surfaces for which only one surface is needed for each surface specification. The second group contains surfaces for which a separate surface for each ground water layer may be necessary for each surface specification.

Names File Coverage Code:	**ESRF** (typically the same as TOP for layer 1 and TOPO, topography surface)
Surface Description:	Ground water ET surface elevation for at which ground water ET equals ground water potential ET
Required for Operation(s):	Ground Water ET Surface (ESRF)
Other Specifications:	none

Names File Coverage Code:	**TOPO**
Surface Description:	Topographic surface elevation
Required for Operation(s):	Hydraulic Length (HYDL), Line Hydrography (STRM), Polygon Hydrography (LAKE), Springs (SPR), Existing Pumping Wells (WELL), Proposed Pumping Wells (PWEL), Storage Coefficient (STC)
Other Specifications:	none

Except where noted under other specifications, **a separate surface is required for each ground water layer** for each of the following surface specifications. The letter K refers to the layer number.

Names File Surface Code:	**BOT**(K)
Surface Description:	Aquifer bottom elevation
Required for Operation(s):	Aquifer Bottom (BOT), and the following for laycon 1 or 3: General Head Boundary for GHB conductance (GHB), Transmissivity (TRN) to support Existing Pumping Well (WELL) and Proposed Pumping Well (PWEL) for layer assignment to wells
Other Specifications:	Also required for operations which need the surfaces THK, TOP, or CTHK, if these surfaces are missing.

Names File Surface Code:	**CTHK**(K)
Surface Description:	Confining bed thickness
Required for Operation(s):	Leakance (LEK)
Other Specifications:	No surface is required for the lower-most aquifer layer.

Names File Surface Code:	**EWL**(K)
Surface Description:	Initial aquifer head elevation
Required for Operation(s):	Initial Aquifer Head (EWL), General Head Boundary for GHB head (GHB), and the following for laycon 1 or 3: General Head Boundary for GHB conductance (GHB), Transmissivity (TRN) to support Existing Pumping Well (WELL) and Proposed Pumping Well (PWEL) for layer assignment to wells
Other Specifications:	none

Names File Surface Code:	**THK**(K)
Surface Description:	Aquifer thickness
Required for Operation(s):	Transmissivity (TRN), Storage Coefficient (STC), General Head Boundary (GHB), Existing Pumping Well (WELL), Proposed Pumping Well (PWEL)
Other Specifications:	Also required for operations which need the surfaces TOP, BOT, or CTHK if these surfaces are missing.

Names File Surface Code:	**TOP**(K)
Surface Description:	Aquifer top elevation
Required for Operation(s):	Aquifer Top (TOP), and the following for laycon 1 or 3: General Head Boundary for GHB conductance (GHB), Transmissivity (TRN) to support Existing Pumping Well (WELL) and Proposed Pumping Well (PWEL) for layer assignment to wells
Other Specifications:	Also required for operations which need the surfaces THK, BOT, or CTHK, if these surfaces are missing.

INFO Tables

HydroGIS operations require various types of INFO tables which include: expansion, look-up, and relate. Definitions for the different types of tables are provided below.

Table Definitions

Expansion These tables are an extension of a coverage or of another table. There is typically a one-to-one or one-to-many relationship between the coverage and the expansion table. An expansion table is used when the coverage uses a unique ID for the data elements.

Look-up A look-up table is used when the attributes of many records of a coverage or file can be characterized by one record in another file. Placing the attributes in a look-up table avoids redundancy and makes attribute modification more efficient. A many-to-one relationship exists between the coverage and the look-up table. A look-up table is used when the coverage uses a classification index.

Relate ARC/INFO has provided for a means to associate two or more tables together. Through a relate table, feature attribute tables (e.g., <cover>.pat, <cover>.aat) of coverages or INFO tables can be associated (related) with other coverages or INFO tables. With a relate table, expansion or look-up tables are related to a coverage or an INFO file without physically joining together the tables. The tables are “virtually” joined.

Specifications for INFO tables are provided in this section. The tables are divided into the table types defined above.

Expansion Tables

INFO File Description:	**Line hydrography connectivity attributes**
File Name:	**rf3hydro.ds3_exp**
File Type:	expansion table
Data Base Storage:	project/user workspace or expansion table workspace
Required for Operation(s):	STRM
Required Sort Item(s) in Order:	rf3rchid
Prohibited Item(s):	none
Other Specifications:	The expansion table is provided with the EPA RF3-Alpha hydrography coverage. The user must sort the file. A complete description of the coverage and its related tables are found in EPA (1994).
Required Items:	The following table provides the specifications for required items in the expansion table.

Item Description	Item	Width	Output	Type	No. Decimals
Cataloging Unit	cu	8	8	I	--
Segment Number	seg	4	4	I	--
Marker Index	mi	5	5	C	--
Upstream Marker Index	upmi	5	5	C	--
Reach Flag (0,1)	rflag	1	1	C	--
Open Water Flag (0,1)	owflag	1	1	C	--
Terminal Flag (0,1)	tflag	1	1	C	--
Start Flag (0,1)	sflag	1	1	C	--
Reach Type Code	reachtype	1	1	C	--
Stream Level	level	2	2	I	--
Level of Downstream Reach	junc	2	2	I	--
Divergence Code	divergence	1	1	I	--
Upstream Direction of Main Path	usdir	1	1	C	--
Terminal Stream ID (future use)	termid	5	5	I	--
Terminal Base Level (future use)	trmblv	1	1	I	--
Primary Name	pname	30	30	C	--
Primary Name Code	pnmcd	11	11	C	--
Common Name	cname	30	30	C	--
Common Name Code	cnmcd	11	11	C	--
Open Water Name	owname	30	30	C	--
Open Water Name Code	ownmcd	11	11	C	--
Downstream CU	dscu	8	8	I	--
Downstream SEG	dsseg	4	4	I	--
Downstream MI	dsmi	5	5	C	--
Complement CU	ccu	8	8	I	--
Complement SEG	cseg	4	4	I	--
Complement MI	cmi	5	5	C	--
Complement Direction	cdir	1	1	C	--
Upstream Left CU	ulcu	8	8	I	--
Upstream Left SEG	ulseg	4	4	I	--
Upstream Left MI	ulmi	5	5	C	--
Upstream Right CU	urcu	8	8	I	--
Upstream Right SEG	urseg	4	4	I	--
Upstream Right MI	urmi	5	5	C	--

Item Description	Item	Width	Output	Type	No. Decimals
Reach Length (Miles)	segl	6	6	N	2
RF Origin Flag (1,2,3)	rforgflag	1	1	I	--
Alt. Primary Name Code (future use)	altpnmcd	8	8	I	--
Alt. OW Name Code (future use)	altownmc	8	8	I	--
Downstream Latitude	dlat	8	8	N	4
Downstream Longitude	dlong	8	8	N	4
Upstream Latitude	ulat	8	8	N	4
Upstream Longitude	ulong	8	8	N	4
Minimum Latitude	minlat	8	8	N	4
Minimum Longitude	minlong	8	8	N	4
Maximum Latitude	maxlat	8	8	N	4
Maximum Longitude	maxlong	8	8	N	4
No. of DLG Records	ndlgrec	4	4	I	--
DLG Line Attribute 1	ln1at2	4	4	I	--
DLG Line Attribute 2	ln2at2	4	4	I	--
DLG Area Attribute	ar1at2	4	4	I	--
DLG Area Attribute	ar1at4	4	4	I	--
DLG Area Attribute	ar2at2	4	4	I	--
DLG Area Attribute	ar2at4	4	4	I	--
Update Date #1 (mmddyy)	update1	6	6	C	--
Update Type Code #1	updtcd1	8	8	C	--
Update Source #1	updtsrc1	8	8	C	--
Update Date #2 (mmddyy) (future use)	update2	6	6	C	--
Update Type Code #2 (future use)	updtcd2	8	8	C	--
Update Source #2 (future use)	updtsrc2	8	8	C	--
Update Date #3 (mmddyy) (future use)	update3	6	6	C	--
Update Type Code #3 (future use)	updtcd3	8	8	C	--
Update Source #3 (future use)	updtsrc3	8	8	C	--
Divergent CU	divcu	8	8	I	--
Divergent SEG	divseg	4	4	I	--
Divergent MI	divmi	5	5	C	--
DLG number (special use)	dlgid	6	6	I	--
Filler (future used)	filler	7	7	C	--
Strahler stream order	[7] order	4	4	I	--
Redefined Items					
Instant reach unique ID	[1]rf3chid	17	17	C	--
Downstream reach unique ID	[2]dsrf3rchid	17	17	C	--
Complement reach unique ID	[3]curf3rchid	17	17	C	--
Upstream left reach unique ID	[4]ulrf3rchid	17	17	C	--
Upstream right reach unique ID	[5]urrf3rchid	17	17	C	--
Divergence reach unique ID	[6]divrf3rchid	17	17	C	--

[1] Redefined item using items cu, seg, mi
[2] Redefined item using items dscu, dsseg, dsmi
[3] Redefined item using items ccu, cseg, cmi
[4] Redefined item using items ulcu, ulseg, ulmi
[5] Redefined item using items urcu, urseg, urmi
[6] Redefined item using items divcu, divseg, divmi
[7] Item not provided with RF3-Alpha coverage from the EPA

INFO File Description:	**Line hydrography hydrologic attributes**
File Name:	**hydroarc_exp**
File Type:	expansion table
Data Base Storage:	project/user workspace or expansion table workspace
Required for Operation(s):	STRM
Required Sort Item(s) in Order:	rf3rchid
Prohibited Item(s):	none
Other Specifications:	The expansion table is created and sorted by the user. It contains surface water and ground water attributes. There must be a one-to-one relationship between all stream arcs in the line hydrography coverage, for which hydrologic attributes are desired, and the attribute table records.
Required Items:	The following table provides the specifications for required items in the expansion table.

Item Description	Item	Width	Output	Type	No. Decimals
Cataloging Unit	cu	8	8	I	--
Segment Number	seg	4	4	I	--
Marker Index	mi	5	5	C	--
Strahler stream order	order	4	4	I	--
Stream channel bottom width	[1]width	4	8	F	0
Stream channel side slope (H:V) at or below top of bank	sidslope	4	8	F	1
Stream channel Manning n friction coefficient	manningn	8	10	F	4
Mean annual water depth	[1]depthavg	4	8	F	1
Depth from bed bottom to top of bank	[1]depthtob	4	8	F	1
Width of stream channel at top of bank	[1]widthtob	4	8	F	0
Flood plain side slope (H:V) above top of bank	sidslopeb	8	8	F	1
Depth from bed bottom to proxy datum	[1]depthbed	4	8	F	1
Downstream mean annual stage elevation	[1]dsstage	8	10	F	2
Upstream mean annual stage elevation	[1]usstage	8	10	F	2
Downstream bed bottom elevation	[1]dsrbot	8	10	F	2
Upstream bed bottom elevation	[1]usrbot	8	10	F	2
Downstream topographic proxy datum of element	[1]dsdatum	8	10	F	2
Upstream topographic proxy datum of element	[1]usdatum	8	10	F	2
Redefined Items					
Stream arc unique ID	[2]rf3rchid	17	17	C	--

[1] Units - width, depthavg, depthtob, widthdob, depthbed, dsstage, usstage, dsrbot, usrbot, dsdatum, usdatum (feet)
[2] Redefined item using items cu, seg, mi

INFO File Description:	**Line hydrography hydrologic layer attributes**
File Name:	**hydroarclay_exp**
File Type:	expansion table
Data Base Storage:	project/user workspace or expansion table workspace
Required for Operation(s):	STRM
Required Sort Item(s) in Order:	rf3rchid
Prohibited Item(s):	none
Other Specifications:	The expansion table is created and sorted by the user. It contains only ground water attributes. For each record in the expansion table hydroarc_exp, there must be at least one record in this table, which is associated with an aquifer layer of the ground water system. Some stream arcs may be associated with multiple aquifer layers, for which a separate record for each layer is required in this table.
Required Items:	The following table provides the specifications for required items in the expansion table.

Item Description	Item	Width	Output	Type	No. Decimals
Cataloging unit	cu	8	8	I	--
Segment number	seg	4	4	I	--
Marker index	mi	5	5	C	--
Stream arc unique ID	rf3rchid	17	17	C	--
Strahler stream order	order	4	4	I	--
Aquifer layer number	layer	4	4	I	--
Stream bed thickness	[1]bedthk	4	8	F	0
Stream bed vertical hydraulic conductivity	[1]bedhyc	8	18	F	6
Stream bed conductance	[1]cond	8	12	F	0
Unique arc ID which combines items rf3rchid and layer	arcuid	21	21	C	--

[1] Units - bedthk (feet); bedhyc (feet/day); cond (sq. feet/day)

INFO File Description:	**Polygon hydrography hydrologic attributes**
File Name:	**hydropoly_exp**
File Type:	expansion table
Data Base Storage:	project/user workspace or expansion table workspace
Required for Operation(s):	LAKE
Required Sort Item(s) in Order:	rf3polyid
Prohibited Item(s):	none
Other Specifications:	The expansion table is created and sorted by the user. It contains surface and ground water attributes. There must be a one-to-one relationship between all polygon hydrography elements in the polygon hydrography coverage, for which hydrologic attributes are desired, and the attribute table records.
Required Items:	The following table provides the specifications for required items in the expansion table.

Item Description	Item	Width	Output	Type	No. Decimals
Hydrography polygon unique ID	rf3polyid	14	14	C	--
Type of hydrography polygon	reachtype	1	1	C	--
Mean annual water depth	[1]depthavg	4	8	F	1
Depth from bed bottom to top of bank	[1]depthtob	4	8	F	1
Depthtob for downstream connecting stream	[1]depthtobs	8	8	F	1
Depth from bed bottom to proxy datum	[1]depthbed	4	8	F	1
Maximum water depth for which depth/surface area relationship is defined	[1]depthmax	4	8	F	1
At depth = 0, the minimum water surface area factor	[1]samin	8	18	F	4
At depth = depthmax, the maximum water surface area factor	[1]samax	8	18	F	4
Mean annual stage elevation	[1]stage	8	10	F	2
Bed bottom elevation	[1]rbot	8	10	F	2
Topographic proxy datum of element	[1]datum	8	10	F	2

[1] Units - depthavg, depthtob, depthtobs, depthbed, depthmax, stage, rbot, datum (feet); samin, samax (decimal)

INFO File Description:	**Polygon hydrography hydrologic layer attributes**
File Name:	**hydropolylay_exp**
File Type:	expansion table
Data Base Storage:	project/user workspace or expansion table workspace
Required for Operation(s):	LAKE
Required Sort Item(s) in Order:	rf3polyid
Prohibited Item(s):	none
Other Specifications:	The expansion table is created and sorted by the user. It contains only ground water attributes. For each record in the expansion table hydropoly_exp, there must be at least one record in this table which is associated with an aquifer layer of the ground water system. Some hydrography polygons may be associated to multiple aquifer layers, for which a separate record for each layer is required in this table.
Required Items:	The following table provides the specifications for required items in the expansion table.

Item Description	Item	Width	Output	Type	No. Decimals
Hydrography polygon unique ID	rf3polyid	14	14	C	--
Type of hydrography polygon	reachtype	1	1	C	--
Aquifer layer number	layer	4	4	I	--
Bed thickness	[1]bedthk	4	8	F	0
Bed vertical hydraulic conductivity	[1]bedhyc	8	18	F	6
Bed conductance	[1]cond	8	12	F	0
Unique polygon ID which combines items rf3polyid and layer	polyuid	18	18	C	--

[1] Units - bedthk (feet); bedhyc (feet/day); cond (sq. feet/day)

INFO File Description:	**Ground water springs layer hydrologic attributes**
File Name:	**springlay_exp**
File Type:	expansion table
Data Base Storage:	project/user workspace or expansion table workspace
Required for Operation(s):	SPR
Required Sort Item(s) in Order:	spruid
Prohibited Item(s):	none
Other Specifications:	The expansion table is created and sorted by the user. It contains only ground water attributes. For each record in the springs coverage there must be at least one record in this table which is associated with an aquifer layer of the ground water system. Some springs may be associated to multiple aquifer layers, for which a separate record for each layer is required in this table.
Required Items:	The following table provides the specifications for required items in the expansion table.

Item Description	Item	Width	Output	Type	No. Decimals
Spring unique ID	spruid	17	17	C	--
Common spring name	spgname	14	14	C	--
Aquifer layer number	layer	4	4	I	--
Spring conductance	[1]bedhyc	8	18	F	6
Topographic proxy datum of element	[1]datum	8	10	F	2
Mean annual stage elevation	[1]stage	8	10	F	2

[1] Units - bedhyc (sq. feet/day); datum, stage (feet)

INFO File Description:	**Existing pumping well physical attributes**
File Name:	**pumpwell_exp**
File Type:	Expansion table
Data Base Storage:	project/user workspace or expansion table workspace
Required for Operation(s):	WELL
Required Sort Item(s) in Order:	welluid
Prohibited Item(s):	none
Other Specifications:	In most cases, the existing pumping well data base will contain missing data for casing and/or total depth. To attain a complete start and stop aquifer layer assignment for each well in the data base, the user must provide other item(s) in the expansion table. In addition, the user must create an AML (tdcdmiss.aml) which uses the additional items to make layer assignments for wells with missing casing and/or total depth data.
Required Items:	The following table provides the specifications for required items in the expansion table.

Item Description	Item	Width	Output	Type	No. Decimals
Unique well ID	welluid	20	20	C	--
Casing depth or casing depth elevation	[2]%cditem%	[3]		F or N	
Total depth or total depth elevation	[2]%tditem%			F or N	
Other item(s) necessary to assign layers to wells					
Top-most layer open to well	[1]laystart	6	6	I	--
Lower-most layer open to well	[1]laystop	6	6	I	--

[1] These items are optional. If the items do not exist in the expansion table, values for the items will be determined each time that existing wells are processed to create the characteristic file wellchar.dat. However, through either manual assignment or automated assignment, the values for these items can be pre-determined which economizes processing time. If the laystart and laystop items exist in the expansion table, the casing and total depth information are not used during processing for characteristic file wellchar.dat.

[2] Units - %cditem%, %tditem% are depths or elevations in feet. The item names are specified with global variables in the administrator AML, hgisvar.aml.

[3] Blank or variable entries in table are user-defined.

Look-Up Tables

INFO File Description: **Land use hydrologic attributes**
File Name: **Land use <cover>fhm_lut**
File Type: Look-up table
Data Base Storage: project/user workspace or look-up table workspace
Required for Operation(s): LANDSW, LANDET, EDEP (which is processed under LANDET)
Required Sort Item(s) in Order: flucscode
Prohibited Item(s): none
Other Specifications: The look-up table is created and sorted by the user. There must be one and only one record in the land use look-up table for each land use classification index or code.
Required Items: The following table provides the specifications for required items in the look-up table.

Item Description	Item	Width	Output	Type	No. Decimals
Land use classification index or code	flucscode	4	4	I	--
Land use classification description	flucsdesc	50	50	C	--
Modified level 2 land use classification code	[1]flucsmodl2	4	4	I	--
Generalized land use classification code	[1]flucsgen	2	2	C	--
Generalized land use classification description	[1]gendesc	20	20	C	--
Groundwater ET extinction depth	[2]rhizo	4	6	F	2
Plant ET coefficient	[2]et-coef	4	4	F	2
Overland flow Manning n	[2]manng-n	4	6	F	4
Depression storage	[2]depr-st	4	4	F	2
Interception storage	[2]intr-st	4	4	F	2

[1] Optional items for generalized land use classification
[2] Units - rhizo (feet); et-coef, manng-n (decimal); depr-st, intr-st (inches)

INFO File Description: **Soils hydrologic attributes**
File Name: **Soils <cover>fhm_lut**
File Type: look-up table
Data Base Storage: project/user workspace or look-up table workspace
Required for Operation(s): SOILSW, SOILET
Required Sort Item(s) in Order: muid
Prohibited Item(s): none
Other Specifications: The look-up table is created and sorted by the user. There must be one and only one record in the soils look-up table for each soils classification index or code.
Required Items: The following table provides the specifications for required items in the look-up table.

Item Description	Item	Width	Output	Type	No. Decimals
Soils classification index or code	muid	7	7	C	--
Soils classification name	muname	109	109	C	--
Porosity	[1]poros	4	6	F	2
Field capacity	[1]fld-cap	4	6	F	2
Infiltration rate	[1]kv	4	6	F	2
Horizontal hydraulic conductivity	[1]kh	4	6	F	2
Moist bulk density	[1]mblk-dens	4	6	F	2

[1] Units - poros, fld-cap (decimal); kv (inches/hour); kh (feet/day); mblk-dens (grams/cu cm)

INFO File Description: **Slope ranges used to derive slope from a lattice of topographic elevation**
File Name: **slope_lut**
File Type: look-up table
Data Base Storage: project/user workspace or look-up table workspace
Required for Operation(s): HYDL
Required Sort Item(s) in Order: slope-code
Prohibited Item(s): none
Other Specifications: The look-up table is created and sorted by the user. There must be one and only one record in the lattice slope look-up table for each slope-code. Refer to the latticepoly command for more information.
Required Items: The following table provides the specifications for required items in the look-up table.

Item Description	Item	Width	Output	Type	No. Decimals
Upper limit of range for percent slope for topography	percent_slope	4	12	F	8
Integer classification code for slope range	slope-code	4	5	B	0
Mean of percent slope range, used for calculations in HydroGIS operations	calcval	4	12	F	8

INFO File Description:	**Reach Water Depths**
File Name:	**rchdepth.lut**
File Type:	look-up table
Data Base Storage:	project/user workspace only
Required for Operation(s):	DAVD
Required Sort Item(s) in Order:	rchclass
Prohibited Item(s):	all items not contained in the required items list
Other Specifications:	The look-up table is created and sorted by the user. There must be one and only one record in the reach water depths look-up table for each reach class. There is a limit of 11 depth intervals for each reach class.
Required Items:	The following table provides the specifications for required items in the look-up table.

Item Description	Item	Width	Output	Type	No. Decimals
HSPF reach classification	rchclass	6	6	I	--
Water depth for interval 1	d1	4	10	F	2
Water depth for interval 2	d2	4	10	F	2
:	:	:	:	:	:
Water depth for interval 11	d11	4	10	F	2

Relate Tables

INFO File Description:	**Land use hydrologic attribute relate**
File Name:	**Land use <cover>fhm_rel**
File Type:	Relate table
Data Base Storage:	project/user workspace or relate table workspace
Required for Operation(s):	LANDSW, LANDET, EDEP (which is processed under LANDET)
Required Sort Item(s) in Order:	none
Prohibited Item(s):	Only the items in the following table are permitted.
Other Specifications:	The relate table is created by the user.
Required Items:	The following table provides the specifications for required items in the relate table.

Item	Contents
relation	land
table-id	full path to land use hydrologic attributes look-up table
data base	INFO
item	land use classification code item from land use coverage
column	land use classification code item from land use hydrologic attributes look-up table
type	ordered
access	ro

INFO File Description:	**Soils hydrologic attribute relate**
File Name:	**Soils <cover>fhm_rel**
File Type:	Relate table
Data Base Storage:	project/user workspace or relate table workspace
Required for Operation(s):	SOILSW, SOILET
Required Sort Item(s) in Order:	none
Prohibited Item(s):	Only the items in the following table are permitted.
Other Specifications:	The relate table is created by the user.
Required Items:	The following table provides the specifications for required items in the relate table.

Item	Contents
relation	soils
table-id	full path to soils hydrologic attributes look-up table
data base	INFO
item	soils classification code item from soils coverage
column	soils classification code item from soils hydrologic attributes look-up table
type	ordered
access	ro

INFO File Description:	**Lattice slope relate**
File Name:	**slopelatt_rel**
File Type:	Relate table
Data Base Storage:	project/user workspace or relate table workspace
Required for Operation(s):	HYDL
Required Sort Item(s) in Order:	none
Prohibited Item(s):	Only the items in the following table are permitted.
Other Specifications:	The relate table is created by the user.
Required Items:	The following table provides the specifications for required items in the relate table.

Item	Contents
relation	slope
table-id	full path to look-up table with slope ranges for a lattice of topographic elevation
data base	INFO
item	slope-code
column	slope-code
type	ordered
access	ro

Other Supporting Tables (INFO Format)

INFO File Description:	**Characteristics of Ground Water Grid**
File Name:	**Ground Water Grid <cover>.rc**
File Type:	other
Data Base Storage:	project/user workspace only
Required for Operation(s):	used in various operations and utilities
Required Sort Item(s) in Order:	none
Prohibited Item(s):	All items that are not contained in the required items list.
Other Specifications:	The grid characteristics table is created by the utility which creates the ground water grid. The table contains one record.
Required Items:	The following table provides the specifications for required items in the grid characteristics table.

Item Description	Item	Width	Output	Type	No. Decimals
number of rows in grid	nrow	10	10	I	--
number of columns in grid	ncol	10	10	I	--
rotation angle from 90 to -90 degrees, counter-clockwise rotation is positive	angle	4	8	F	2
x-coordinate of grid origin (lower left corner of grid)	xorigin	4	18	F	7
y-coordinate of grid origin (lower left corner of grid)	yorigin	4	18	F	7
x-y coverage units (FEET or METERS)	covunits	10	10	C	--

INFO File Description:	**Row and Column Spacing of Ground Water Grid**
File Name:	**Ground Water Grid <cover>.del**
File Type:	other
Data Base Storage:	project/user workspace only
Required for Operation(s):	used in various operations and utilities
Required Sort Item(s) in Order:	row/col
Prohibited Item(s):	All items that are not contained in the required items list.
Other Specifications:	The table which contains the row and column spacing of the grid is created by the utility which creates the ground water grid. The number of records in the table is equal to the maximum of either the number of rows or the number of columns. The row and column spacing is the same as DELR and DELC respectively.
Required Items:	The following table provides the specifications for required items in the table which contains row and column spacing of the grid.

Item Description	Item	Width	Output	Type	No. Decimals
row/column number of grid	row/col	10	10	I	--
grid spacing along the rows	delr	4	10	F	2
grid spacing along the columns	delc	4	10	F	2

INFO File Description:	**Unique IDs of Ground Water Grid Cells**
File Name:	**Ground Water Grid <cover>.dat**
File Type:	other
Data Base Storage:	project/user workspace only
Required for Operation(s):	used in various operations and utilities
Required Sort Item(s) in Order:	griduid
Prohibited Item(s):	All items that are not contained in the required items list.
Other Specifications:	The table which contains the unique IDs of the grid cells is created by the utility which creates the ground water grid. The number of records in the table is equal to the number of cells in the grid (number of rows * number of columns). The unique ID is equal to: row * 1000 + column.
Required Items:	The following table provides the specifications for required items in the table which contains unique IDs of grid cells.

Item Description	Item	Width	Output	Type	No. Decimals
unique ID of grid cell	griduid	8	8	I	--
row number	row	4	4	I	--
column number	col	4	4	I	--

ASCII Files

The ASCII files are system files which can be viewed and edited by a system editor. The ASCII files consist of Project Index files and other files which support processing within HydroGIS.

Project Index

Three project index files are used by HydroGIS. Examples of the “names”, “paths”, and ground water layer configuration files are provided on subsequent pages.

An example of the HydroGIS “names” file is provided on the following page. The naming convention used for the “names” file includes the project workspace for the prefix and "nam" for the suffix. Above the names table in the "names" file, general information about the GIS data base is provided. The number of GIS layers for the ground water system and the global x-y coordinate units are specified. The x-y coordinate units must be consistent for all coverages to properly complete the GIS spatial analysis processing.

The names table contains all of the spatial data input information that is necessary to perform all of the spatial analysis operations. If NONE exists in any of the columns (NO for the ST column), the data are not needed or are unavailable. The example on the following page includes four ground water layers as represented by the LAY column. Layer 0 is used for surface water and integrated data and for ground water data which do not require separate coverages for each ground water layer. The PARM column contains codes which represent the coverages and surfaces. If data are stored in a library, the LIBRARY column specifies the name of the map library. LAYER/COVER is the name of the library layer, coverage or surface name to be used for processing. The item in the layer/coverage that is used for processing is provided in the ANALYSIS_ITEM column. The x-y and z units for the layer/coverage are provided in their respective columns. The last column, ST, contains a code which specifies whether the data are stored in a map library (LI), in a protected workspace (PT), or in a project workspace (PR).

The "path" file specifies the path to both the protected workspace and the project workspace. The naming convention used for the “paths” file includes the project workspace for the prefix and “pth” for the suffix.

HydroGIS "Names" File (Example)

```
   4       NUMBER OF NAMES FILE LAYERS
   METERS  GLOBAL GROUND UNITS (X-Y)
 LAY PARM        LIBRARY  LAYER/COVER    ANALYSIS_ITEM  X-Y_UNITS    Z_UNITS ST
   0 BASN           NONE     nehbasin             NONE     METERS       NONE PR
   0  DEM           NONE     nehdempt             NONE     METERS       NONE PR
   0 LAND        test100    lulc_90gen            NONE     METERS       NONE LI
   0 SOIL         test2m    fl_statsgo            NONE     METERS       NONE LI
   0 STRM           NONE     nehhydro             NONE     METERS       NONE PR
   0 LAKE           NONE    nehhydpol             NONE     METERS       NONE PR
   0 TOPO           NONE     dist250l             NONE     METERS     METERS PT
   0 SLPE           NONE   slopebasin            slope     METERS       NONE PT
   0  RNF           NONE  nehrnfthies             NONE     METERS       NONE PR
   0  EVT           NONE  disevtthies             NONE     METERS       NONE PR
   0  SPR           NONE   nehsprings             NONE     METERS       NONE PR
   0  GHB           NONE       nehghb             NONE     METERS       NONE PR
   0 GRID           NONE      nehgrid             NONE     METERS       NONE PR
   0 LGRD           NONE      twogrid             NONE     METERS       NONE PR
   0 WELL           NONE     nehwells             NONE     METERS       NONE PR
   0 PWEL           NONE  conerchwell             NONE     METERS       NONE PR
   0  DRN           NONE         NONE             NONE     METERS       NONE NO
   0  FLX           NONE         NONE             NONE     METERS       NONE NO
   0  REC           NONE      nehlay1             rech     METERS       NONE PR
   0 GWET           NONE         NONE             NONE     METERS       NONE NO
   0 ESRF           NONE     dist250l             NONE     METERS     METERS PT
   1 LIBD           NONE      distibd             IBD1     METERS       NONE PR
   1  IBD           NONE       nehibd             IBD1     METERS       NONE PR
   1  EWL           NONE    srfewltin             NONE     METERS     METERS PR
   1  HYC           NONE     disthyc1              hyc     METERS       NONE PT
   1  THK           NONE      srfthkl             NONE     METERS     METERS PT
   1  SPS           NONE         NONE             NONE     METERS       NONE NO
   1  SPY           NONE     distspy1              SPY     METERS       NONE PT
   1  TOP           NONE     dist250l             NONE     METERS     METERS PT
   1  BOT           NONE      srfbotl             NONE     METERS     METERS PT
   1 CTHK           NONE  onethicktin             NONE     METERS     METERS PR
   1 CHYC           NONE     distlek1              lek     METERS       NONE PT
   2 LIBD           NONE      distibd             IBD2     METERS       NONE PR
   2  IBD           NONE       nehibd             IBD2     METERS       NONE PR
   2  EWL           NONE    intewltin             NONE     METERS     METERS PR
   2  HYC           NONE     disttrn2              trn     METERS       NONE PT
   2  THK           NONE  onethicktin             NONE     METERS     METERS PR
   2  SPS           NONE     diststc2              stc     METERS       NONE PT
   2  SPY           NONE         NONE             NONE       NONE       NONE NO
   2  TOP           NONE      inttopl             NONE     METERS     METERS PT
   2  BOT           NONE      intbotl             NONE     METERS     METERS PT
   2 CTHK           NONE  onethicktin             NONE     METERS     METERS PR
   2 CHYC           NONE     distlek2              lek     METERS       NONE PT
   3 LIBD           NONE      distibd             IBD3     METERS       NONE PR
   3  IBD           NONE       nehibd             ibd3     METERS       NONE PR
   3  EWL           NONE    tpaewltin             NONE     METERS     METERS PR
   3  HYC           NONE     disttrn3              trn     METERS       NONE PT
   3  THK           NONE  onethicktin             NONE     METERS     METERS PR
   3  SPS           NONE     diststc3              stc     METERS       NONE PT
   3  SPY           NONE         NONE             NONE       NONE       NONE NO
   3  TOP           NONE      flotopl             NONE     METERS     METERS PT
   3  BOT           NONE      ocatopl             NONE     METERS     METERS PT
   3 CTHK           NONE  onethicktin             NONE     METERS     METERS PR
   3 CHYC           NONE     distlek3              lek     METERS       NONE PT
   4 LIBD           NONE      distibd             IBD4     METERS       NONE PR
   4  IBD           NONE       nehibd             IBD4     METERS       NONE PR
   4  EWL           NONE    apkewltin             NONE     METERS     METERS PR
   4  HYC           NONE     disttrn4              trn     METERS       NONE PT
   4  THK           NONE  onethicktin             NONE     METERS     METERS PR
   4  SPS           NONE     diststc4              stc     METERS       NONE PT
   4  SPY           NONE         NONE             NONE       NONE       NONE NO
   4  TOP           NONE      apktopl             NONE     METERS     METERS PT
   4  BOT           NONE      flobotl             NONE     METERS     METERS PT
   4 CTHK           NONE         NONE             NONE       NONE       NONE NO
   4 CHYC           NONE         NONE             NONE       NONE       NONE NO
```

HydroGIS "Paths" File (Example - The paths are representative of an UNIX OS)

```
HydroGIS paths file
CODE     PATH
homeproj /export/home/sunfish4/projects4/swfwmd
homeprot /home/sunfish6/projects6
workproj /export/home/sunfish4/projects4/swfwmd/nehillsb
workprot /home/sunfish6/projects6/protect
```

Ground Water Layer Configuration File (Example)

The ground water layers are described with the "laycon" parameter used by MODFLOW (McDonald and Harbaugh 1988). The fixed-format, ASCII file called LAYCHAR.DAT, contains the number of ground water layers and the "laycon" value for each layer.

```
LAYCHAR.DAT (complete)
The LAYCON column is a MODFLOW variable which denotes the classification of the layer in the following manner.
0 = strictly confined; 1 = strictly unconfined;
2 = confined/unconfined (transmissivity constant); 3 = confined/unconfined (transmissivity varies)

 NO LAYERS
         4
  LAYER NO    LAYCON
         1         3
         2         0
         3         0
         4         0
```

Other Supporting Files (ASCII Format)

ASCII File Description:	Input name definitions for Ibound (small or large-scale) coverages and analysis items
File Name:	**hgisaml.inp**
File Type:	other
Data Base Storage:	project/user workspace
Input for Operation(s):	TACT, MSCALE or any time procgrid.aml is executed
Other Specifications:	The file is free-format. This is an optional input file for procgrid.aml. See documentation of procgrid.aml for more information. Layer nlay is the lower-most aquifer layer of the ground water system.

record	record description
1	full path for coverage name for layer 1 for small-scale or large-scale ibound
2	item name for layer 1 for small-scale or large-scale ibound coverage
3	:
4	:
(last-l)	repeat for coverage for layer nlay
(last)	repeat for item for layer nlay

ASCII File Description:	Pumping rates for existing pumping wells by stress period
File Name:	**puYYchar.inp**, YY = sequential file number which has a leading zero for file numbers less than 10
File Type:	other
Data Base Storage:	project/user workspace
Input for Operation(s):	WELL
Other Specifications:	Each file has a limit of 20 stress periods, although it is not required to store 20 stress periods in a file before starting to fill a subsequently numbered file. The file is formatted as specified in the following table.

record	record description and format
1	general description of file contents format: C200
2	simulation start and stop date and time format: start year, month, day, hour, minute; stop year, month, day, hour, minute I4, 1X, I2, 1X, I2, 1X, I2, 1X, I2, 1X; I4, 1X, I2, 1X, I2, 1X, I2, 1X, I2
3	number of stress periods in this file format: I2
4	data header format: C20, 20C10
5 to end	well unique ID, stress period rate data (limit of 20 stress periods) format: C20, 20F10.0

ASCII File Description:	Reach Water Depths file: for explicit reach water depths
File Name:	**rchdepth.lut**
File Type:	other
Data Base Storage:	project/user workspace
Input for Operation(s):	DAVD
Other Specifications:	The file is free-format with one record for each reach in HSPF. Each record contains the reach number followed by 11 depth values which are used to define the depths of the HSPF F-Table for the reach. A space separates each value along the record. The file is used as input to the Reach Water Depths utility of HydroGIS. Alternatively, this file is not used to define the water depths. Only the maximum water depth for each reach is provided in the menus of the Reach Water Depths utility.

Example

```
1 0 .25 .5 1 2 3 4 5 6 7 8
2 0 1 1.5 2 2.5 3 3.5 4 4.5 5 7
3 0 1 2 3 4 5 6 7 8 9 10
4 0 1 2 3 4 5 6 7 8 9 10
```

ASCII File Description:	Operations control file: the operations selected for spatial analysis processing are stored in this file.
File Name:	***.inp** (* refers to the name of the project workspace)
File Type:	other
Data Base Storage:	project/user workspace
Input for Operation(s):	all operations
Other Specifications:	The file is fixed-format with 5 characters in each field of each record. The first field contains the layer number. The second field contains the operation code. The first field is right-justified and the second field is left-justified. Both are character fields.

Example

```
    0 basn
    0 landsw
    0 landet
    0 soilsw
    0 soilet
    0 slpe
    0 hydl
    0 length
    0 stcor
    0 davd
    0 rnfbasin
    0 rnfreach
    0 evtbasin
    0 evtreach
    0 basin2grd
    0 strm
    0 lake
    0 spr
    0 ghb
    0 rec
    0 esrf
    0 gwet
    0 tact
    0 well
    0 pwel
    0 flx
    1 hyc
    1 ewl
    1 spy
    1 bot
    1 lek
    1 ibd
    2 ibd
    2 trn
    2 stc
    2 lek
    3 ibd
    3 trn
    3 stc
    3 lek
    4 ibd
    4 trn
    4 stc
```

Project Workspace Listing (Example)

The listing of a project workspace is an example of input data for HydroGIS and output data from HydroGIS. The coverages and continuous surfaces contained in the listing correspond to the "names" file example provided earlier in this appendix.

```
PROJECT WORKSPACE:  nehillsb

|---APKEWLTIN        continuous surface for initial aquifer water levels for layer 4
|---CONERCHWELL      proposed pumping wells coverage
|---DISEVTTHIES      Thiessen polygon coverage of potential ET spatial distribution
|---DISTIBD          MODFLOW IBOUND data for large-scale
|---INTEWLTIN        continuous surface for initial aquifer water levels for layer 2
|---MNEHBASIN        modified basins coverage
|---NEHBASIN         basins coverage
|---NEHDEM           spot/overlay polygon coverage (not used for spatial analysis)
|---NEHDEMPT         spot/overlay point coverage
|---NEHGHB           GHB coverage
|---NEHGRID          small-scale polygon grid coverage for this project
|---NEHGRIDPT        small-scale point grid coverage for this project
|---NEHHYDPOL        polygon hydrography (i.e., lakes, wetlands, wide rivers) coverage
|---NEHHYDRO         line hydrography (i.e., streams) coverage
|---NEHIBD           MODFLOW IBOUND data for small-scale
|---NEHLAY1          recharge coverage
|---NEHRNFTHIES      Thiessen polygon coverage of rainfall spatial distribution
|---NEHSPRINGS       point hydrography (i.e., springs) coverage
|---NEHWELLS         existing pumping wells coverage
|---ONETHICKTIN      continuous surface for thickness with a thickness value of one everywhere
|---SRFEWLTIN        continuous surface for initial aquifer water levels for layer 1
|---TPAEWLTIN        continuous surface for initial aquifer water levels for layer 3
|---TWOGRID          large-scale polygon grid coverage for this project
|---TWOGRIDPT        large-scale point grid coveragefor this project
|---INFO
|    |  NEHGRID.RC      number of rows and columns, rotation angle, and origin coordinates of grid
|    |  NEHGRID.DEL     distances along rows and columns of grid
|    |  NEHGRID.DAT     unique id for each cell of grid
|    |  TWOGRID.RC      number of rows and columns, rotation angle, and origin coordinates of grid
|    |  TWOGRID.DEL     distances along rows and columns of grid
|    |  TWOGRID.DAT     unique id for each cell of grid
|    |  RCHDEPTH.LUT    look-up table containing water depths for the HSPF F-Table of each reach
|    |  DRAWAP.DAT      information that is used to create the background AML (drawap.aml)
|    |  DAVDCHAR.DAT    characteristic table containing HSPF F-Table data
|    |  EVTCHAR.DAT     characteristic table containing spatial distribution data for potential ET stations
|    |  GHBCHAR.DAT     characteristic table containing MODFLOW GHB data
|    |  GHBDCHAR.DAT    characteristic table containing data for multi-scale ground water models
|    |  LY01CHAR.DAT    characteristic table containing ground water hydraulics data for layer 1
|    |  LY02CHAR.DAT    characteristic table containing ground water hydraulics data for layer 2
|    |  LY03CHAR.DAT    characteristic table containing ground water hydraulics data for layer 3
|    |  LY04CHAR.DAT    characteristic table containing ground water hydraulics data for layer 4
|    |  PU01CHAR.DAT    characteristic table containing pumping rates by well for up to 20 stress periods
|    |  RCETCHAR.DAT    characteristic table containing ground water recharge and ET, and integration data
|    |  RIVCHAR.DAT     characteristic table containing HSPF reach characteristics
|    |  RIV2CHAR.DAT    characteristic table containing MODFLOW hydrography characteristics
|    |  RNFCHAR.DAT     characteristic table containing spatial distribution data for rainfall stations
|    |  STACHAR.DAT     characteristic table containing temporal data station location data
|    |  SUBCHAR.DAT     characteristic table containing surface basin data for HSPF
|    |  WELLCHAR.DAT    characteristic table containing vertical distribution of pumping rates by well
|
|---GRAPHICS
|    |---SLOPE.MAP       map composition for basin slope
|    |---HYDR_LENGTH.MAP    map composition for basin hydraulic length
|    |---HYC1.MAP        map composition for hydraulic conductivity for layer 1
|    |---SPY1.MAP        map composition for aquifer specific yield for layer 1
|    |---LEK1.MAP        map composition for confining bed leakance for layer 1
|    |---BOT1.MAP        map composition for aquifer bottom elevation for layer 1
|
|              ASCII SYSTEM FILES ARE LISTED BELOW
|
|    LOG              log file used by ARC/INFO
|    NEHILLSB.NAM     HydroGIS names file
|    NEHILLSB.PTH     HydroGIS paths file
|    NEHILLSB.INP     HydroGIS spatial analysis operations control file
|    HYDROGIS.ERR     HydroGIS error file
|    HYDROGIS.TIM     HydroGIS performance timer file
|    HYDROGIS.VAR     used to override values of selected global variables contained in hgisvar.aml
|    PU01CHAR.INP     used to create INFO table pu01char.dat and characteristic file pu01char.dat
|    VARTEMP.AML      contains global variables from the contents of the paths and names files
|    DRAWAP.AML       background AML
|    LOG971101        HydroGIS log file for November 1, 1997
|    DAVDCHAR.DAT     characteristic file containing HSPF F-Table data
|    EVTCHAR.DAT      characteristic file containing spatial distribution data for potential ET stations
|    GHBCHAR.DAT      characteristic file containing MODFLOW GHB data
|    GHBDCHAR.DAT     characteristic file containing data for multi-scale ground water models
|    GRD2CHAR.DAT     characteristic file combining contents of INFO tables <grid>.rc and <grid>.del
|    GRD3CHAR.DAT     characteristic file containing unique id of cell, row, column, and cell coordinates
|    LAYCHAR.DAT      characteristic file containing number of MODFLOW layers and MODFLOW laycon type
|    LY01CHAR.DAT     characteristic file containing ground water hydraulics data for layer 1
|    LY02CHAR.DAT     characteristic file containing ground water hydraulics data for layer 2
|    LY03CHAR.DAT     characteristic file containing ground water hydraulics data for layer 3
|    LY04CHAR.DAT     characteristic file containing ground water hydraulics data for layer 4
|    PNUMCHAR.DAT     characteristic file with number of elements for wells, drains, rivers, GHB, streams
|    PU01CHAR.DAT     characteristic file containing pumping rates by well for up to 20 stress periods
|    RCETCHAR.DAT     characteristic file containing ground water recharge and ET, and integration data
|    RIVCHAR.DAT      characteristic file containing HSPF reach characteristics
|    RIV2CHAR.DAT     characteristic file containing MODFLOW hydrography characteristics
|    RNFCHAR.DAT      characteristic file containing spatial distribution data for rainfall stations
|    STACHAR.DAT      characteristic file containing temporal data station location data
|    SUBCHAR.DAT      characteristic file containing surface basin data for HSPF
|    WELLCHAR.DAT     characteristic file containing vertical distribution of pumping rates by well
```

APPENDIX B. OUTPUT DATA SPECIFICATIONS

Coverages and Continuous Surfaces

Refer to the Input Data Specifications in Appendix A for format specifications and assumptions for coverages and continuous surfaces.

INFO Tables

Output from HydroGIS in the form of INFO tables consists of characteristic tables and other supporting tables.

FHM and HydroGIS Characteristic Tables (INFO Format)

The characteristic tables are divided into four categories which include surface water, ground water, ground water/integration, and temporal/spatial link.

Surface Water

Five characteristic tables are documented for the surface water category.

SUBCHAR.DAT

The INFO characteristic table SUBCHAR.DAT contains surface basin characteristics. The data are sorted by class. The items are formatted and ordered as shown in the following table.

Table B.1. INFO Table Format for Characteristic Table SUBCHAR.DAT.

Item Description	Item	Width	Output	Type	No. Decimals	Source Process or Coverage
surface basin unique ID	class	6	6	I	--	basin coverage
modified surface basin area	area	8	18	F	2	BASN
mean slope	slope	8	10	F	6	SLPE
mean infiltration rate	kv	8	8	F	2	SOILSW
mean overland flow Manning-n	manng-n	8	8	F	4	LANDSW
mean interception storage	intr-st	8	6	F	2	LANDSW
mean depression storage	depr-st	8	6	F	2	LANDSW
mean hydraulic length	hydl	4	8	F	0	HYDL
basin area in inactive region of grid	outrarea	8	18	F	2	BASIN2GRD
modified basin area (grid basis)	gridarea	8	18	F	2	BASIN2GRD
modified basin area (grid basis) divided by modified basin area	areafactor	4	4	F	2	BASIN2GRD

RIVCHAR.DAT

The INFO characteristic table RIVCHAR.DAT contains reach characteristics. The data are sorted by rchclass. The items are formatted and ordered as shown in the following table.

Table B.2. INFO Table Format for Characteristic Table RIVCHAR.DAT.

Item Description	Item	Width	Output	Type	No. Decimals	Source Operation or Coverage
reach unique ID	rchclass	6	6	I	--	hydrography coverage(s)
length of each reach	length	8	8	F	2	LENGTH
invert elevation of downstream end of reach	stcor	8	10	F	2	STCOR

DAVDCHAR.DAT

The INFO characteristic table DAVDCHAR.DAT contains reach routing characteristics for the depth-surface area-volume relationship. For each reach, there are multiple records which contain values for each of the fields listed below. The data are sorted by rchclass and depth. The items are formatted and ordered as shown in the following table.

Table B.3. INFO Table Format for Characteristic Table DAVDCHAR.DAT.

Item Description	Item	Width	Output	Type	No. Decimals	Source Operation or Coverage
reach unique ID	rchclass	6	6	I	--	hydrography coverage(s)
depth of water	depth	4	10	F	2	DAVD
surface area of water in reach for a given depth	sarea	8	14	F	3	DAVD
volume of water in reach for a given depth	volume	8	14	F	3	DAVD
discharge rate for a given depth (entries are always the no data flag [-9999])	q	8	8	F	0	DAVD

RNFCHAR.DAT

The INFO characteristic table RNFCHAR.DAT contains the spatial distribution characteristics for rainfall over the surface basins and the reaches. For each basin and reach, there is one record which contains the percentage contribution from each of the ten rainfall stations. The station characteristics are stored alongside the spatial distribution data on the first ten records. The data are sorted by code and basin/reach number. The items are formatted and ordered as shown in the following table.

Table B.4. INFO Table Format for Characteristic Table RNFCHAR.DAT.

Item Description	Item	Width	Output	Type	No. Decimals	Source Operation or Coverage
surface basin/reach unique ID	bas/rch	6	6	I	--	basin/ hydrography coverage(s)
percentage contribution from station 1	stn1	4	8	F	2	RNFBASIN/ RNFREACH
percentage contribution from station 2	stn2	4	8	F	2	RNFBASIN/ RNFREACH
:	:	:	:	:	:	:
percentage contribution from station 10	stn10	4	8	F	2	RNFBASIN/ RNFREACH
code indicating whether the record represents a basin (1) or a reach (2)	code	2	2	I	--	RNFBASIN/ RNFREACH
sequential station number	statnbr	2	2	I	--	rainfall Thiessen coverage
station unique ID	hdbuid	14	14	C	--	rainfall Thiessen coverage

EVTCHAR.DAT

The INFO characteristic table EVTCHAR.DAT contains the spatial distribution characteristics for potential or pan evapotranspiration (PET) over the surface basins and the reaches. For each basin and reach, there is one record which contains the percentage contribution from each of the ten PET stations. The station characteristics are stored alongside the spatial distribution data on the first ten records. The data are sorted by code and basin/reach number. The items are formatted and ordered as shown in the following table.

Table B.5. INFO Table Format for Characteristic Table EVTCHAR.DAT.

Item Description	Item	Width	Output	Type	No. Decimals	Source Operation or Coverage
surface basin/reach unique ID	bas/rch	6	6	I	--	basin/ hydrography coverage(s)
percentage contribution from station 1	stn1	4	8	F	2	EVTBASIN/ EVTREACH
percentage contribution from station 2	stn2	4	8	F	2	EVTBASIN/ EVTREACH
:	:	:	:	:	:	:
percentage contribution from station 10	stn10	4	8	F	2	EVTBASIN/ EVTREACH
code indicating whether the record represents a basin (1) or a reach (2)	code	2	2	I	--	EVTBASIN/ EVTREACH
sequential station number	statnbr	2	2	I	--	PET Thiessen coverage
station unique ID	hdbuid	14	14	C	--	PET Thiessen coverage

Ground Water

Six characteristic tables are documented for the ground water category.

LYXXCHAR.DAT

The INFO characteristic table LY**XX**CHAR.DAT contains hydraulic characteristics for ground water aquifer layer **XX**. There exists one table for each aquifer layer. The data are sorted by griduid. The items are formatted and ordered as shown in the following table.

Table B.5. INFO Table Format for Characteristic Table LY**XX**CHAR.DAT.

Item Description	Item	Width	Output	Type	No. Decimals	Source Operation or Coverage
grid cell unique ID	griduid	8	8	I	--	grid coverage
grid cell row	row	4	4	I	--	grid coverage
grid cell column	col	4	4	I	--	grid coverage
IBOUND	ibd(k)	4	4	I	--	IBD
mean hydraulic conductivity	hyc(k)	8	12	F	3	HYC
mean transmissivity	trn(k)	8	14	F	2	TRN
mean confined storage coefficient	stc(k)	8	8	F	2	STC
mean specific yield	spy(k)	8	8	F	2	SPY
mean leakance	lek(k)	8	14	F	8	LEK
mean aquifer top elevation	top(k)	8	10	F	2	TOP
mean aquifer bottom elevation	bot(k)	8	10	F	2	BOT
mean initial aquifer water level elevation	ewl(k)	8	10	F	2	EWL
mean physical thickness of aquifer	thk(k)	8	10	F	2	TRN/STC
mean specific storage	sps(k)	8	16	F	8	STC
mean physical thickness of confining bed	cthk(k)	8	10	F	2	LEK
mean confining bed hydraulic conductivity	chyc(k)	8	16	F	8	LEK
mean unsaturated aquifer thickness	uthk(k)	8	10	F	2	TRN for WELL

[1] **XX** = aquifer layer number with a leading zero if layer < 10
[2] k = aquifer layer number without leading zero

RIV2CHAR.DAT

The INFO characteristic table RIV2CHAR.DAT contains hydrography characteristics for hydrography connections to the ground water system. All types of hydrography are classified into three groups with include line hydrography (i.e., streams), polygon hydrography (i.e., lakes, wetlands, wide rivers), and ground water springs. The hydrography connections to all ground water layers are represented in this table. The data are sorted by the aggregation items where griduid and layer are always the first two items. The items are formatted and ordered as shown in the following table.

Table B.7. INFO Table Format for Characteristic Table RIV2CHAR.DAT.

Item Description	Item	Width	Output	Type	No. Decimals	Source Operation or Coverage
grid cell unique ID	griduid	8	8	I	--	grid coverage
aquifer layer	layer	4	4	I	--	attribute table
grid cell row	row	4	4	I	--	grid coverage
grid cell column	col	4	4	I	--	grid coverage
shifted model elevation for mean surface water stage	mstage	8	10	F	2	STRM,LAKE,SPR
hydrography conductance	cond	8	18	F	2	STRM,LAKE,SPR
shifted model elevation for hydrography mean bed bottom	mrbot	8	10	F	2	STRM,LAKE,SPR
reach unique ID	rchclass	6	6	I	--	hydrog. coverages
code for hydrography type	code [1]	1	1	I	--	STRM,LAKE,SPR
aggregation item	relateitm	30	30	C	--	STRM,LAKE,SPR
unique ID of hydrography	hydrouid	17	17	C	--	hydrog. coverages
depth correction for hydrography polygons (depthtob - depthtobs)	depthcor	4	8	F	2	STRM,LAKE,SPR
bed vertical hydraulic conductivity of hydrography	bedhyc	8	18	F	6	attribute table
bed thickness of hydrography	bedthk	4	8	F	0	attribute table
bed conductance area of hydrography	condarea	8	18	F	2	STRM,LAKE,SPR
mean topographic elevation within grid cell	gridtopo	8	18	F	6	STRM,LAKE,SPR
absolute elevation for mean topographic proxy datum	datum	8	10	F	2	STRM,LAKE,SPR
absolute elevation for mean surface water stage	stage	8	10	F	2	STRM,LAKE,SPR
absolute elevation for hydrography mean bed bottom	rbot	8	10	F	2	STRM,LAKE,SPR
magnitude of elevation shift	elevcor	4	8	F	2	STRM,LAKE,SPR
Depth from bed bottom to top of bank	depthtob	4	8	F	1	attribute table
Mean annual water depth	depthavg	4	8	F	1	attribute table
Depth from bed bottom to proxy datum	depthbed	4	8	F	1	attribute table
Strahler stream order	order	4	4	I	--	attribute table
Stream level	level	2	2	I	--	attribute table
Reach type code	reachtype [2]	1	1	C	--	attribute table

[1] code: 1 = STRM (line hydrography)
2 = LAKE (polygon hydrography)
3 = SPR (springs)

[2] Refer to EPA (1994).

GHBCHAR.DAT

The INFO characteristic table GHBCHAR.DAT contains General Head Boundary characteristics for ground water models. All ground water layers are represented in this table. The data are sorted by layer and ghbuid. The items are formatted and ordered as shown in the following table.

Table B.8. INFO Table Format for Characteristic Table GHBCHAR.DAT.

Item Description	Item	Width	Output	Type	No. Decimals	Source Operation or Coverage
grid cell unique ID	griduid	8	8	I	--	GHB coverage
aquifer layer	layer	4	4	I	--	GHB coverage
grid cell row	row	4	4	I	--	GHB coverage
grid cell column	col	4	4	I	--	GHB coverage
GHB head	head	8	10	F	2	GHB
GHB conductance	cond	8	12	F	1	GHB
active/inactive, calculated/user-defined	ghb	2	2	I	--	GHB coverage
GHB unique ID	ghbuid	8	8	I	--	GHB coverage
mean aquifer thickness	thk	8	10	F	2	GHB
length weighted mean hydraulic conductivity	hyc	8	12	F	3	GHB
length weighted harmonic mean transmissivity	ghbtrn	4	14	F	2	GHB
cell dimension in GHB flow direction	cellflow	8	10	F	1	GHB coverage
cell dimension orthogonal to GHB flow direction	cellcross	8	10	F	1	GHB coverage
GHB flow distance	flowdist	8	10	F	1	GHB coverage
GHB flow path angle relative to (+) grid row axis	alpha	4	8	F	2	GHB coverage

[1] Code: $\neq 0$ = active
$=0$ = inactive
>0 = calculated
<0 = user defined

GHBDCHAR.DAT
The INFO characteristic table GHBDCHAR.DAT contains General Head Boundary characteristics for multi-scale models. All ground water layers are represented in this table. The data are sorted by layer and ghbuid. The items are formatted and ordered as shown in the following table.

Table B.9. INFO Table Format for Characteristic Table GHBDCHAR.DAT.

Item Description	Item	Width	Output	Type	No. Decimals	Source Operation or Coverage
GHB unique ID	ghbuid	8	8	I	--	GHB coverage
large-scale (LS) grid cell row	lsrow	4	4	I	--	MSCALE
large-scale grid cell column	lscol	4	4	I	--	MSCALE
inverse distance between GHB point and LS grid cell node	invdist	8	10	F	8	MSCALE
aquifer layer	layer	4	4	I	--	GHB coverage
grid cell unique ID	griduid	8	8	I	--	GHB coverage
grid cell row	row	4	4	I	--	GHB coverage
grid cell column	col	4	4	I	--	GHB coverage
GHB point x-coordinate	x-coord	4	12	F	3	GHB coverage
GHB point y-coordinate	y-coord	4	12	F	3	GHB coverage
LS grid node x-coordinate	lsx-coord	4	12	F	3	MSCALE
LS grid node y-coordinate	lsy-coord	4	12	F	3	MSCALE
grid rotation angle	theta	8	10	F	4	grid coverage
counterclockwise angle from (+) x-axis to a line formed by the GHB point and the LS grid node	phi	8	10	F	4	MSCALE
counterclockwise angle from (+) LS grid row axis to a line formed by GHB point and LS grid node (phi-theta)	gamma	8	10	F	4	MSCALE

WELLCHAR.DAT

The INFO characteristic table WELLCHAR.DAT contains characteristics for pumping wells and boundary flux for ground water. All ground water layers are represented in this table. There must be a one-to-one relationship between the existing wells in this table and the wells in the characteristic table PUYYCHAR.DAT. The data are sorted by code, welluid, and layer. The items are formatted and ordered as shown in the following table.

Table B.10. INFO Table Format for Characteristic Table WELLCHAR.DAT.

Item Description	Item	Width	Output	Type	No. Decimals	Source Operation or Coverage
grid cell unique ID	griduid	8	8	I	--	WELL/PWEL/FLX
aquifer layer	layer	4	4	I	--	WELL/PWEL/FLX
grid cell row	row	4	4	I	--	WELL/PWEL/FLX
grid cell column	col	4	4	I	--	WELL/PWEL/FLX
decimal value of pumping rate assigned to layer	wellcoeff	8	12	F	4	WELL/PWEL/FLX
designates existing, proposed, or flux	code [1]	2	2	I	--	WELL/PWEL/FLX
unique well ID	welluid	20	20	C	--	wells coverage(s)
top-most layer open to well	laystart	6	6	I	--	WELL/PWEL/well attrib. table
lower-most layer open to well	laystop	6	6	I	--	WELL/PWEL/well attrib. table
casing depth elevation[2]	%cditem%el	4	8	F	1	WELL/PWEL/well attrib. table
total depth elevation[2]	%tditem%el	4	8	F	1	WELL/PWEL/well attrib. table
total contributing transmissivity for well	totaltrn	8	14	F	2	WELL/PWEL/FLX
transmissivity of layer 1	trn(1)	8	14	F	2	TRN, WELL/PWEL/FLX
:	:	:	:	:	:	: :
transmissivity of layer nlay [3]	trn(nlay)	8	14	F	2	TRN, WELL/PWEL/FLX

[1] code: 1 = WELL (existing pumping wells)
2 = PWEL (proposed pumping wells)
3 = FLX (boundary flux)

[2] If casing and total depth elevations are not supplied by the user, then the items are defined as shown in the table.

[3] nlay = bottom-most aquifer layer

PUYYCHAR.DAT

The INFO characteristic table PU**YY**CHAR.DAT contains ground water pumping rates, by stress period, for existing wells only. There must be a one-to-one relationship between the wells in this table and the existing pumping wells in the characteristic table WELLCHAR.DAT. The data are sorted by welluid. The items are formatted and ordered as shown in the following table.

Table B.11. INFO Table Format for Characteristic Table PU**YY**CHAR.DAT.

Item Description	Item	Width	Output	Type	No. Decimals	Source Operation or Coverage
unique well ID	welluid	20	20	C	--	pu**YY**char.inp and WELL
pumping rate, stress period 1	rate 1	8	10	F	0	pu**YY**char.inp and WELL
pumping rate, stress period 2	rate 2	8	10	F	0	pu**YY**char.inp and WELL
:	:	:	:	:	:	pu**YY**char.inp and WELL
pumping rate, stress period 12	rate 12	8	10	F	0	pu**YY**char.inp and WELL

YY = table number with leading zero for table numbers < 10

Ground Water/Integration

One characteristic table is documented for the ground water/integration category.

RCETCHAR.DAT

The INFO characteristic table RCETCHAR.DAT contains ground water recharge and ET and FHM integration characteristics. The data are sorted by griduid. The items are formatted and ordered as shown in the following table.

Table B.12. INFO Table Format for Characteristic Table RCETCHAR.DAT.

Item Description	Item	Width	Output	Type	No. Decimals	Source Operation or Coverage
grid cell unique ID	griduid	8	8	I	--	grid coverage
grid cell row	row	4	4	I	--	grid coverage
grid cell column	col	4	4	I	--	grid coverage
recharge	rec	8	12	F	8	REC
GW maximum ET rate	gwet	8	12	F	8	GWET
GW ET surface for maximum rate	esrf	8	10	F	2	ESRF
GW ET extinction depth	edep	8	8	F	2	EDEP/ LANDET
porosity	poros	8	6	F	2	SOILET
field capacity	fld-cap	8	6	F	2	SOILET
plant ET coefficient	et-coef	8	6	F	2	LANDET
basin assigned to grid cell	class	6	6	I	--	BASN2GRD
top-most active layer	topactive	4	4	I	--	TACT

Temporal/Spatial Link

One characteristic table is documented for the temporal/spatial link category.

STACHAR.DAT

The INFO characteristic table STACHAR.DAT contains data base retrieval information for temporal data stations. The data are sorted by code then hdbuid. The items are formatted and ordered as shown in the following table.

Table B.13. INFO Table Format for Characteristic Table STACHAR.DAT.

Item Description	Item	Width	Output	Type	No. Decimals	Source Operation or Coverage
code for station type	code [2]	3	3	C	--	stations coverage
unique ID of station	hdbuid	[1]		C	--	stations coverage
station name	name			C	--	stations coverage
beginning date of retrieval period	begdate	8	10	D	--	stations utility
ending date of retrieval period	end date	8	10	D	--	stations utility

[1] Blank entries in table are defined from the original stations coverage.

[2] Codes for station type (codes are capitalized)

RNF = rainfall
EVT = potential/pan ET
FLO = streamflow
STG = surface water stage
SWQ = surface water pumping
WEL = ground water levels

Other Supporting Tables (INFO Format)

INFO Table Description:	The INFO table contains the top-most active layer for each grid cell which has at least one layer which is designated as active or constant head.
Table Name:	TOPACTIVE.DAT
Table Type:	other
Data Base Storage:	project/user workspace
Output for Operation(s):	TACT and whenever the processing ground water polygon grid is created
Sort Item(s) in Order:	griduid
Other Specifications:	If the top-most active layer for a cell is active, the item topactive is the positive value of the layer number. If the top-most active layer for a cell is a constant head, the item topactive is the negative value of the layer number. The items are formatted and ordered as shown in the table below.

Table B.14. INFO Table Format for Output Table TOPACTIVE.DAT.

Item Description	Item	Width	Output	Type	No. Decimals
Grid cell unique ID	[1]griduid	8	8	I	--
Top-most active layer	topactive	4	4	I	--

[1] griduid = row * 1000 + col
[2] active (layer > 0), constant head (layer < 0)

INFO Table Description:	The INFO table contains aquifer layer (start and stop) assignments for existing or proposed pumping wells.
Table Name:	WELLLAYR.DAT
Table Type:	other
Data Base Storage:	project/user workspace
Output for Operation(s):	EXISTLAY, PROPLAY
Sort Item(s) in Order:	welluid
Other Specifications:	The items are formatted and ordered as shown in the following table. For existing wells, the items laystart and laystop are joined to the attribute table, pumpwell_exp, which contains physical attributes for existing pumping wells. For proposed wells, the items laystart and laystop are joined to the point attribute table (PAT) of the proposed well coverage. Layer nlay represents the lower-most aquifer layer of the ground water system.

Table B.15. INFO Table Format for Output Table WELLLAYR.DAT.

Item Description	Item	Width	Output	Type	No. Decimals
unique well ID	welluid	20	20	C	--
casing depth or casing depth elevation	[2]%cditem%	[3]		ForN	
total depth or total depth elevation	[2]%tditem%			ForN	
casing depth elevation	[1,2]%cditem%el	4	8	F	1
total depth elevation	[1,2]%tditem%el	4	8	F	1
top-most layer open to well	laystart	4	4	I	--
lower-most layer open to well	laystop	4	4	I	--
topographic surface elevation at well	[1,2]topo	8	10	F	2
aquifer top elevation of layer 1 at well	[2]top(1)	8	10	F	2
aquifer bottom elevation of layer 1 at well	[2]bot(1)	8	10	F	2
:	:	:	:	:	:
:	:	:	:	:	:
aquifer top elevation of layer nlay at well	[2]top(nlay)	8	10	F	2
aquifer bottom elevation of layer nlay at well	[2]bot(nlay)	8	10	F	2

[1] These items are available only when %cditem% and %tditem% are elevations.
[2] Units are feet.
[3] Blank or variable entries are user-defined.

ASCII Files

Output from HydroGIS in the form of ASCII system files consists of characteristic files that are used by the pre-processors of FHM and other supporting files.

FHM and HydroGIS Characteristic Files (ASCII Format)

The characteristic files are divided into four categories which include surface water, ground water, ground water/integration, and temporal/spatial link.

Surface Water

Five characteristic files are documented for the surface water category.

SUBCHAR.DAT

The ASCII characteristic file SUBCHAR.DAT contains surface basin characteristics. The data are sorted by class. The field output specifications and order are described in the following table and the file is in comma delimited format.

Table B.16. ASCII File Format for characteristic file SUBCHAR.DAT

Item Description	Item	Output	Type	No. Decimals	Source Operation or Coverage
surface basin unique ID	class	6	I	--	basin coverage
modified surface basin area	area	18	F	2	BASN
mean slope	slope	10	F	6	SLPE
mean infiltration rate	kv	8	F	2	SOILSW
mean overland flow Manning-n	manng-n	8	F	4	LANDSW
mean interception storage	intr-st	6	F	2	LANDSW
mean depression storage	depr-st	6	F	2	LANDSW
mean hydraulic length	hydl	8	F	0	HYDL
basin area in inactive region of grid	outrarea	18	F	2	BASN2GRD

```
class, area, slope, kv, manng-n, intr-st, depr-st, hydl, outrarea
 , acre, ,in/hr, ,inches ,inches, feet, acre
1,8587.14,0.003033,11.776802,0.290436,0.117207,0.125234,1591.,0.00
2,23175.54,0.006836,12.428293,0.273063,0.121025,0.129628,2039.,0.00
3,21328.42,0.007671,12.232713,0.311434,0.127716,0.139732,1884.,0.00
4,4734.83,0.002263,11.750865,0.320922,0.097954,0.171839,2951.,0.00
5,5255.44,0.002740,10.317563,0.332397,0.103153,0.178761,2767.,0.00
6,8823.30,0.002868,11.582549,0.335614,0.152016,0.203224,2942.,0.00
7,7371.40,0.002782,11.473696,0.355135,0.165281,0.234602,1974.,0.00
8,5187.08,0.002808,11.556905,0.326801,0.173082,0.234197,4952.,0.00
9,5863.08,0.002580,11.701103,0.315043,0.123844,0.179109,2369.,0.00
10,6353.43,0.002802,11.777594,0.312300,0.196394,0.257989,1181.,0.00
11,13217.87,0.004248,12.747340,0.328601,0.154300,0.178815,1483.,0.00
12,60326.21,0.002551,11.935210,0.311861,0.167186,0.220076,1900.,24353.36
13,10076.73,0.004341,11.772117,0.341878,0.152062,0.193577,1364.,0.00
14,17819.86,0.010691,12.955981,0.295373,0.123989,0.124883,2379.,5038.60
15,5546.72,0.005614,13.009851,0.292878,0.101385,0.116109,1686.,0.00
16,3230.07,0.008737,12.388446,0.314656,0.155145,0.143358,1734.,0.00
17,11855.00,0.003190,12.588967,0.323605,0.126880,0.162470,2876.,59.50
18,19250.31,0.002991,12.201914,0.328795,0.126001,0.168314,1532.,0.00
19,6799.16,0.003154,12.440000,0.306816,0.104080,0.124085,1904.,0.00
20,13253.91,0.004172,12.991412,0.279895,0.131416,0.126360,1654.,0.00
21,10708.96,0.008383,12.872003,0.279794,0.131488,0.092838,2073.,5071.40
22,9971.68,0.004263,13.019754,0.290796,0.149518,0.114008,2130.,0.00
23,24045.00,0.007213,12.074037,0.291373,0.146468,0.140628,1809.,0.86
24,6469.91,0.017237,12.122006,0.216998,0.101731,0.071998,3025.,0.00
```

RIVCHAR.DAT

The ASCII characteristic file RIVCHAR.DAT contains reach characteristics. The data are sorted by rchclass. The field output specifications and order are described in the following table and the file is in comma delimited format.

Table B.17. ASCII File Format for Characteristic File RIVCHAR.DAT.

Item Description	Item	Output	Type	No. Decimals	Source Operation or Coverage
reach unique ID	rchclass	6	I	--	hydrography coverage(s)
length of each reach	length	8	F	2	LENGTH
invert elevation at downstream end of reach	stcor	10	F	2	STCOR

```
rchclass,length,stcor
 , miles, feet NGVD
1,17.27,81.16
2,38.24,78.36
3,2.43,78.36
4,2.98,80.78
5,2.40,75.08
6,38.17,75.08
7,1.45,75.08
8,1.93,80.78
9,2.04,49.32
10,7.55,55.92
11,4.55,24.97
12,18.74,64.38
13,6.10,64.38
14,2.43,61.10
15,4.47,48.35
16,2.34,48.35
17,2.41,38.96
18,8.35,44.66
19,17.56,41.41
20,3.11,25.87
21,4.17,31.57
22,1.47,24.97
```

DAVDCHAR.DAT

The ASCII characteristic file DAVDCHAR.DAT contains reach routing characteristics for the depth-surface area-volume relationship. For each reach, there are multiple records which contain values for each of the fields listed below. The data are sorted by rchclass and depth. The field output specifications and order are described in the following table and the file is in comma delimited format.

Table B.18. ASCII File Format for Characteristic File DAVDCHAR.DAT.

Item Description	Item	Output	Type	No. Decimals	Source Operation or Coverage
reach unique ID	rchclass	6	I	--	hydrography coverage(s)
depth of water	depth	10	F	2	DAVD
surface area of water in reach for a given depth	sarea	14	F	3	DAVD
volume of water in reach for a given depth	volume	14	F	3	DAVD
discharge rate for a given depth (entries are always the no data flag [-9999])	q	8	F	0	DAVD

```
reach,depth,surface area,volume, discharge (excerpt)
 , feet, acres, acre-feet, (cfs) - entries are always the no data flag
1,0.00,15.494,0.000,-9999.00
1,0.70,19.203,5.220,-9999.00
1,1.30,22.381,10.608,-9999.00
1,2.00,26.090,17.959,-9999.00
1,2.60,29.268,25.173,-9999.00
1,3.30,32.977,34.656,-9999.00
1,4.00,36.686,45.285,-9999.00
1,4.60,39.864,55.309,-9999.00
1,5.30,43.573,68.070,-9999.00
1,5.90,376.010,131.561,-9999.00
1,6.60,947.535,319.447,-9999.00
2,0.00,34.866,0.000,-9999.00
2,0.70,44.517,16.115,-9999.00
2,1.30,52.790,32.827,-9999.00
2,2.00,62.441,55.710,-9999.00
2,2.60,70.714,78.224,-9999.00
2,3.30,80.365,107.875,-9999.00
2,4.00,90.017,141.171,-9999.00
2,4.60,98.289,172.610,-9999.00
2,5.30,107.941,212.673,-9999.00
2,5.90,861.133,360.990,-9999.00
2,6.60,2157.673,802.230,-9999.00
3,0.00,5.604,0.000,-9999.00
3,1.10,6.742,3.973,-9999.00
3,2.30,7.985,9.143,-9999.00
3,3.40,9.124,14.649,-9999.00
3,4.50,10.263,20.888,-9999.00
3,5.60,11.402,27.859,-9999.00
3,6.80,12.644,36.301,-9999.00
3,7.90,13.783,44.805,-9999.00
3,9.00,14.922,54.043,-9999.00
3,10.20,131.636,97.158,-9999.00
3,11.30,291.549,227.079,-9999.00
```

RNFCHAR.DAT

The ASCII characteristic file RNFCHAR.DAT contains the spatial distribution characteristics for rainfall over the surface basins and the reaches. For each basin and reach, there is one record which contains the percentage contribution from each of the ten rainfall stations. The file has two parts. The first part contains the total number of stations available (up to 10) and the station unique IDs. The second part contains the spatial distributions. The data are sorted by code and basin/reach number. The field output specifications and order are described in the following table and the file is in comma delimited format.

Table B.19. ASCII File Format for Characteristic File RNFCHAR.DAT.

Item Description	Item	Output	Type	No. Decimals	Source Operation or Coverage
surface basin/reach unique ID	bas/rch	6	I	--	basin/ hydrography coverage(s)
percentage contribution from station 1	stn1	8	F	2	RNFBASIN/ RNFREACH
percentage contribution from station 2	stn2	8	F	2	RNFBASIN/ RNFREACH
:	:	:	:	:	:
percentage contribution from station 10	stn10	8	F	2	RNFBASIN/ RNFREACH
station unique ID	hdbuid	14	C	--	rainfall Thiessen coverage

```
Area factors associated with rainfall for surface basins and reaches.
10
1048
3186
4797
5076
6628
6880
7851
7886
8788
9176
bas# stn1 stn2 stn3 stn4 stn5 stn6 stn7 stn8 stn9 stn10
1,0.00,0.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
2,0.00,0.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
3,0.00,0.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
4,0.00,0.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
5,0.00,0.00,0.80,0.00,0.00,0.00,0.20,0.00,0.00,0.00
6,0.00,0.00,0.30,0.00,0.00,0.00,0.70,0.00,0.00,0.00
7,0.00,0.00,0.00,0.00,0.00,0.00,1.00,0.00,0.00,0.00
8,0.00,0.00,0.00,0.00,0.00,0.00,1.00,0.00,0.00,0.00
9,0.00,0.00,0.30,0.00,0.00,0.00,0.70,0.00,0.00,0.00
10,0.00,0.00,0.30,0.00,0.00,0.00,0.70,0.00,0.00,0.00
11,0.00,0.00,0.74,0.00,0.00,0.00,0.26,0.00,0.00,0.00
12,0.00,0.00,0.69,0.00,0.00,0.00,0.31,0.00,0.00,0.00
13,0.00,0.00,0.00,0.00,0.00,0.00,1.00,0.00,0.00,0.00
14,0.00,0.00,0.00,0.00,0.00,0.00,1.00,0.00,0.00,0.00
15,0.00,0.00,0.00,0.00,0.00,0.00,1.00,0.00,0.00,0.00
16,0.00,0.00,0.00,0.00,0.00,0.00,1.00,0.00,0.00,0.00
17,0.00,0.00,0.00,0.00,0.00,0.00,1.00,0.00,0.00,0.00
18,0.00,0.00,0.36,0.00,0.00,0.00,0.64,0.00,0.00,0.00
19,0.00,0.00,0.67,0.00,0.00,0.00,0.15,0.00,0.18,0.00
20,0.00,0.00,1.00,0.00,0.0,0.00,0.00,0.00,0.00,0.00
21,0.00,0.00,0.16,0.00,0.00,0.00,0.00,0.00,0.84,0.00
22,0.00,0.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
23,0.00,0.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
24,0.00,0.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
rch# stn1 stn2 stn3 stn4 stn5 stn6 stn7 stn8 stn9 stn10
```

1,0.00,0.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
2,0.00,0.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
3,0.00,0.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
4,0.00,0.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
5,0.00,0.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
6,0.00,0.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
7,0.00,0.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
8,0.00,0.00,1.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00
9,0.00,0.00,0.44,0.00,0.00,0.00,0.56,0.00,0.00,0.00
10,0.00,0.00,0.66,0.00,0.00,0.00,0.34,0.00,0.00,0.00
11,0.00,0.00,0.00,0.00,0.00,0.00,1.00,0.00,0.00,0.00
12,0.00,0.00,0.60,0.00,0.00,0.00,0.40,0.00,0.00,0.00
13,0.00,0.00,0.00,0.00,0.00,0.00,1.00,0.00,0.00,0.00
14,0.00,0.00,0.00,0.00,0.00,0.00,1.00,0.00,0.00,0.00
15,0.00,0.00,0.00,0.00,0.00,0.00,1.00,0.00,0.00,0.00
16,0.00,0.00,0.00,0.00,0.00,0.00,1.00,0.00,0.00,0.00
17,0.00,0.00,0.00,0.00,0.00,0.00,1.00,0.00,0.00,0.00
18,0.00,0.00,0.00,0.00,0.00,0.00,1.00,0.00,0.00,0.00
19,0.00,0.00,0.10,0.00,0.00,0.00,0.90,0.00,0.00,0.00
20,0.00,0.00,0.00,0.00,0.00,0.00,1.00,0.00,0.00,0.00
21,0.00,0.00,0.00,0.00,0.00,0.00,1.00,0.00,0.00,0.00
22,0.00,0.00,0.00,0.00,0.00,0.00,1.00,0.00,0.00,0.00

EVTCHAR.DAT

The ASCII characteristic file EVTCHAR.DAT contains the spatial distribution characteristics for potential or pan evapotranspiration (PET) over the surface basins and the reaches. For each basin and reach, there is one record which contains the percentage contribution from each of the ten PET stations. The file has two parts. The first part contains the total number of stations available (up to 10) and the station unique IDs. The second part contains the spatial distributions. The data are sorted by code and basin/reach number. The field output specifications and order are described in the following table and the file is in comma delimited format.

Table B.20. ASCII File Format for Characteristic File EVTCHAR.DAT.

Item Description	Item	Output	Type	No. Decimals	Source Operation or Coverage
surface basin/reach unique ID	bas/rch	6	I	--	basin/ hydrography coverage(s)
percentage contribution from station 1	stn1	8	F	2	EVTBASIN/ EVTREACH
percentage contribution from station 2	stn2	8	F	2	RNFBASIN/ RNFREACH
:	:	:	:	:	:
percentage contribution from station 10	stn10	8	F	2	EVTBASIN/ EVTREACH
station unique ID	hdbuid	14	C	--	PET Thiessen coverage

```
Area factors associated with potential ET for surface basins and reaches.
10
5076
5895
EVT03
EVT05
EVT08
EVT09
EVT10
EVT11
EVT16
EVT18
bas# stn1 stn2 stn3 stn4 stn5 stn6 stn7 stn8 stn9 stn10
1,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
2,0.00,0.00,0.00,0.00,0.00,0.06,0.00,0.00,0.00,0.94
3,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
4,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
5,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
6,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
7,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
8,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
9,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
10,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
11,0.00,0.00,0.00,0.00,0.00,0.29,0.00,0.00,0.00,0.71
12,0.00,0.00,0.00,0.00,0.00,0.77,0.00,0.00,0.00,0.23
13,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.07,0.00,0.93
14,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.50,0.00,0.50
15,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
16,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.66,0.00,0.34
17,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
18,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
19,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
```

20,0.00,0.00,.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
21,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
22,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
23,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
24,0.00,0.00,0.00,0.00,0.00,0.94,0.00,0.00,0.00,0.06
rch# stn1 stn2 stn3 stn4 stn5 stn6 stn7 stn8 stn9 stn10
1,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
2,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
3,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
4,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
5,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
6,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
7,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
8,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
9,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
10,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
11,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
12,0.00,0.00,0.00,0.00,0.00,0.32,0.00,0.00,0.00,0.68
13,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
14,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
15,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
16,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
17,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
18,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
19,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
20,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
21,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00
22,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,1.00

Ground Water

Nine characteristic files are documented for the ground water category.

LYXXCHAR.DAT

The ASCII characteristic file LY**XX**CHAR.DAT contains hydraulic characteristics for ground water aquifer layer **XX**. There exists one file for each aquifer layer. The data are sorted by griduid. The field output specifications and order are described in the following table and the file is in comma delimited format.

Table B.21. ASCII File Format for Characteristic File LY**XX**CHAR.DAT.

Item Description	Item	Output	Type	No. Decimals	Source Operation or Coverage
grid cell row	row	4	I	--	grid coverage
grid cell column	col	4	I	--	grid coverage
IBOUND	ibd(k)	4	I	--	IBD
mean hydraulic conductivity	hyc(k)	12	F	3	HYC
mean transmissivity	trn(k)	14	F	2	TRN
mean confined storage coefficient	stc(k)	8	F	2	STC
mean specific yield	spy(k)	8	F	2	SPY
mean leakance	lek(k)	14	F	8	LEK
mean aquifer top elevation	top(k)	10	F	2	TOP
mean aquifer bottom elevation	bot(k)	10	F	2	BOT
mean initial aquifer water level elevation	ewl(k)	10	F	2	EWL
mean physical thickness of aquifer	thk(k)	10	F	2	TRN/STC
mean specific storage	sps(k)	16	F	8	STC
mean physical thickness of confining bed	cthk(k)	10	F	2	LEK
mean confining bed hydraulic conductivity	chyc(k)	16	F	8	LEK

XX = aquifer layer number with a leading zero if layer < 10
k = aquifer layer number without leading zero

file excerpt

```
row,col,ibd(k),hyc(k),trn(k),stc(k),spy(k),lek(k),top(k),bot(k),ewl(k),thk(k),sps(k),cthk(k),chyc(k)
 , , ,ft/day, sq. ft./day, , , 1/day, feet NGVD, feet NGVD, feet NGVD, feet, 1/feet, feet, ft./day
1,1,1,1.000,-9999.00,1.00,0.20,0.00030200,179.68,153.21,119.96,-9999.00,-9999.00000000,1.00,0.00030200
1,2,1,1.000,-9999.00,1.00,0.20,0.00012080,171.42,142.71,114.90,-9999.00,-9999.00000000,1.00,0.00012080
1,3,1,2.200,78.49,1.00,0.20,0.00012080,124.67,99.67,110.19,-9999.00,-9999.00000000,1.00,0.00012080
1,4,1,1.600,-9999.00,1.00,0.20,0.00012080,147.08,108.76,109.03,-9999.00,-9999.00000000,1.00,0.00012080
1,5,1,1.000,45.13,1.00,0.20,0.00012080,118.22,95.03,104.48,-9999.00,-9999.00000000,1.00,0.00012080
1,6,1,1.800,213.25,1.00,0.20,0.00012080,98.94,77.02,97.79,-9999.00,-9999.00000000,1.00,0.00012080
1,7,1,12.700,-9999.00,1.00,0.20,0.00012080,105.51,80.45,87.90,-9999.00,-9999.00000000,1.00,0.00012080
1,8,1,10.000,122.34,1.00,0.20,0.00302000,95.14,68.96,73.45,-9999.00,-9999.00000000,1.00,0.00302000
1,9,1,10.000,156.39,1.00,0.20,0.00724800,88.58,63.58,73.92,-9999.00,-9999.00000000,1.00,0.00724800
1,10,1,1.000,161.71,1.00,0.20,0.00060000,91.86,65.89,88.86,-9999.00,-9999.00000000,1.00,0.00060000
1,11,1,1.000,158.21,1.00,0.20,0.00060000,95.87,72.84,92.20,-9999.00,-9999.00000000,1.00,0.00060000
1,12,1,1.000,221.77,1.00,0.20,0.00060000,88.58,66.40,85.58,-9999.00,-9999.00000000,1.00,0.00060000
1,13,1,1.000,205.54,1.00,0.20,0.00060000,96.49,69.72,94.20,-9999.00,-9999.00000000,1.00,0.00060000
1,14,1,1.000,250.00,1.00,0.20,0.00060000,95.14,70.14,92.14,-9999.00,-9999.00000000,1.00,0.00060000
1,15,1,1.000,232.48,1.00,0.20,0.00060000,95.14,70.14,92.14,-9999.00,-9999.00000000,1.00,0.00060000
1,16,1,1.000,217.69,1.00,0.20,0.00060000,98.42,73.42,95.42,-9999.00,-9999.00000000,1.00,0.00060000
1,17,1,1.000,204.19,1.00,0.20,0.00060000,98.42,73.42,95.42,-9999.00,-9999.00000000,1.00,0.00060000
1,18,1,1.000,189.91,1.00,0.20,0.00060000,98.42,73.42,95.42,-9999.00,-9999.00000000,1.00,0.00060000
```

RIV2CHAR.DAT

The ASCII characteristic file RIV2CHAR.DAT contains hydrography characteristics for hydrography connections to the ground water system. All types of hydrography are classified into three groups with include line hydrography (i.e., streams), polygon hydrography (i.e., lakes, wetlands, wide rivers), and ground water springs. The hydrography connections to all ground water layers are represented in this file. The data are sorted by the aggregation items where griduid and layer are always the first two items. The field output specifications and order are described in the following table and the file is in comma delimited format.

Table B.22. ASCII File Format for Characteristic File RIV2CHAR.DAT.

Item Description	Item	Output	Type	No. Decimals	Source Operation or Coverage
aquifer layer	layer	4	I	--	STRM, LAKE,SPR
grid cell row	row	4	I	--	STRM, LAKE,SPR
grid cell column	col	4	I	--	STRM, LAKE,SPR
shifted model elevation for surface water stage	mstage	10	F	2	STRM, LAKE,SPR
hydrography conductance	cond	12	F	1	STRM, LAKE,SPR
shifted model elevation for hydrography bed bottom	mrbot	10	F	2	STRM, LAKE,SPR
reach unique ID	rchclass	6	I	--	hydrography coverage(s)
code for hydrography type	code[1]	8	I	--	STRM, LAKE,SPR

[1] code: 1 = STRM (line hydrography)
2 = LAKE (polygon hydrography)
3 = SPR (springs)

```
layer, row, column, stage, conductance, bottom, reach ID, code (excerpt)
 , , , feet, sq. ft./day, feet, ,
1,12,4,46.27,744.41,41.37,11,1
1,12,5,59.35,939.17,59.10,10,1
1,12,5,57.40,804.83,52.50,11,1
1,12,6,67.03,2261.90,66.78,10,1
1,12,6,65.08,5135.75,60.18,11,1
1,12,6,65.08,316.45,60.18,9,1
1,12,7,72.54,6983.75,67.64,9,1
1,12,8,78.61,2643.01,76.81,5,1
1,12,8,78.61,1041.48,76.81,7,1
1,12,8,80.81,2668.78,75.91,9,1
1,12,8,80.81,3293.36,75.91,9,1
1,12,9,83.49,836.12,83.24,-8,1
1,12,9,79.34,1260.20,77.54,5,1
1,12,9,79.34,6099.99,77.54,7,1
1,12,9,79.34,236.18,77.54,7,1
1,12,10,84.49,713.85,84.24,-6,1
1,12,10,84.49,913.88,84.24,-6,1
1,12,10,84.49,857.17,84.24,-6,1
1,12,10,80.34,123.90,78.54,-6,1
1,12,10,80.34,1558.65,78.54,7,1
1,12,10,80.34,1360.55,78.54,6,1
1,12,10,80.34,2579.41,78.54,6,1
1,12,10,80.34,2180.56,78.54,6,1
1,12,11,90.87,1486.81,90.62,-6,1
1,12,11,90.87,2179.45,90.62,-6,1
1,12,11,86.72,1023.08,84.92,6,1
1,12,12,97.44,2132.13,97.19,-6,1
1,12,12,97.44,2066.03,97.19,-6,1
1,12,12,97.44,425.48,97.19,-6,1
1,12,12,97.44,156.50,97.19,-6,1
1,12,12,97.44,158.86,97.19,-6,1
1,12,12,97.44,286.48,97.19,-6,1
1,12,12,97.44,374.78,97.19,-6,1
```

GHBCHAR.DAT

The ASCII characteristic file GHBCHAR.DAT contains General Head Boundary characteristics for ground water models. All ground water layers are represented in this file. The data are sorted by layer and ghbuid. The field output specifications and order are described in the following table and the file is in comma delimited format.

Table B.23. ASCII File Format for Characteristic File GHBCHAR.DAT.

Item Description	Item	Output	Type	No. Decimals	Source Operation or Coverage
aquifer layer	layer	4	I	--	GHB coverage
grid cell row	row	4	I	--	GHB coverage
grid cell column	col	4	I	--	GHB coverage
GHB head	head	10	F	2	GHB
GHB conductance	cond	12	F	1	GHB
active/inactive, calculated/user-defined	ghb[1]	2	I	--	GHB coverage
GHB unique ID	ghbuid	8	I	--	GHB coverage

[1] Codes for item ghb: $\neq 0$ = active
$= 0$ = inactive
> 0 = calculated
< 0 = user-defined

```
layer, row, col, head, conductance, ghb, ghbuid (excerpt)
 , , , feet NGVD, sq. ft./day, ,
1,1,1,-9999.00,137.,1,433
1,1,2,-9999.00,137.,1,434
1,1,3,-9999.00,137.,1,435
1,1,4,-9999.00,137.,1,436
1,1,5,-9999.00,137.,1,437
1,1,6,-9999.00,137.,1,438
1,1,7,-9999.00,94.,1,439
1,1,8,-9999.00,94.,1,440
1,1,9,-9999.00,101.,1,441
1,1,10,-9999.00,101.,1,442
1,1,11,-9999.00,137.,1,443
1,1,12,-9999.00,137.,1,444
1,1,13,-9999.00,137.,1,445
1,1,14,-9999.00,137.,1,446
1,1,15,-9999.00,137.,1,447
1,1,16,-9999.00,137.,1,448
1,1,17,-9999.00,137.,1,449
1,1,18,-9999.00,137.,1,450
1,24,1,-9999.00,137.,1,505
1,24,2,-9999.00,137.,1,506
1,24,3,-9999.00,137.,1,507
1,24,4,-9999.00,137.,1,508
1,24,5,-9999.00,137.,1,509
1,24,6,-9999.00,137.,1,510
1,24,7,-9999.00,137.,1,511
1,24,8,-9999.00,137.,1,512
1,24,9,-9999.00,137.,1,513
1,24,10,-9999.00,137.,1,514
1,24,11,-9999.00,137.,1,515
1,24,12,-9999.00,137.,1,516
1,24,13,-9999.00,137.,1,517
1,24,14,-9999.00,137.,1,518
1,24,15,-9999.00,137.,1,519
1,24,16,-9999.00,137.,1,520
1,24,17,-9999.00,137.,1,521
1,24,18,-9999.00,137.,1,522
```

GHBDCHAR.DAT

The ASCII characteristic file GHBDCHAR.DAT contains General Head Boundary characteristics for multi-scale models. All ground water layers are represented in this file. The data are sorted by layer and ghbuid. The field output specifications and order are described in the following table and the file is in comma delimited format.

Table B.24. ASCII File Format for Characteristic File GHBDCHAR.DAT.

Item Description	Item	Output	Type	No. Decimals	Source Operation or Coverage
GHB unique ID	ghbuid	8	I	--	GHB coverage
large-scale (LS) grid cell row	lsrow	4	I	--	MSCALE
large-scale grid cell column	lscol	4	I	--	MSCALE
inverse distance between GHB point and LS grid cell node	invdist	10	F	8	MSCALE

```
ghbuid, lsrow, lscol, invdist (excerpt)
 , , , 1/grid coverage ground units (x-y)
433,48,24,0.0003395980
433,48,25,0.0005351311
433,47,24,0.0003498427
433,47,25,0.0005781560
434,48,25,0.0005350423
434,48,26,0.0003396659
434,47,25,0.0005780440
434,47,26,0.0003499168
435,48,25,0.0003395330
435,48,26,0.0005352159
435,47,25,0.0003497716
435,47,26,0.0005782627
436,48,26,0.0005349576
436,48,27,0.0003397309
436,47,26,0.0005779371
436,47,27,0.0003499880
437,48,26,0.0003394680
437,48,27,0.0005353004
437,47,26,0.0003497005
437,47,27,0.0005783697
438,48,27,0.0005348729
438,48,28,0.0003397960
438,47,27,0.0005778302
438,47,28,0.0003500590
439,48,27,0.0003394031
439,48,28,0.0005353852
439,47,27,0.0003496296
439,47,28,0.0005784764
440,48,28,0.0005347879
440,48,29,0.0003398611
440,47,28,0.0005777234
440,47,29,0.0003501301
441,48,28,0.0003393381
441,48,29,0.0005354698
441,47,28,0.0003495586
441,47,29,0.0005785832
442,48,29,0.0005347030
442,48,30,0.0003399261
442,47,29,0.0005776163
442,47,30,0.0003502014
443,48,29,0.0003392732
443,48,30,0.0005355544
443,47,29,0.0003494876
443,47,30,0.0005786896
444,48,30,0.0005346181
444,48,31,0.0003399913
```

444,47,30,0.0005775092
444,47,31,0.0003502725
445,48,30,0.0003392083
445,48,31,0.0005356390
445,47,30,0.0003494166
445,47,31,0.0005787965
446,48,31,0.0005345332
446,48,32,0.0003400564
446,47,31,0.0005774022
446,47,32,0.0003503437
447,48,31,0.0003391435
447,48,32,0.0005357233
447,47,31,0.0003493458
447,47,32,0.0005789030
448,48,32,0.0005344481
448,48,33,0.0003401215
448,47,32,0.0005772952
448,47,33,0.0003504149
449,48,32,0.0003390787
449,48,33,0.0005358077
449,47,32,0.0003492750
449,47,33,0.0005790096
450,48,33,0.0005343633
450,48,34,0.0003401866
450,47,33,0.0005771879
450,47,34,0.0003504863
505,60,24,0.0003745015
505,60,25,0.0007159159
505,59,24,0.0003141043
505,59,25,0.0004491628
506,60,25,0.0007157038
506,60,26,0.0003745927
506,59,25,0.0004491106
506,59,26,0.0003141581
507,60,25,0.0003744145
507,60,26,0.0007161190
507,59,25,0.0003140529
507,59,26,0.0004492131
508,60,26,0.0007155010
508,60,27,0.0003746799
508,59,26,0.0004490604
508,59,27,0.0003142095
509,60,26,0.0003743274
509,60,27,0.0007163221
509,59,26,0.0003140015
509,59,27,0.0004492631
510,60,27,0.0007152983
510,60,28,0.0003747672
510,59,27,0.0004490102
510,59,28,0.0003142609
511,60,27,0.0003742403
511,60,28,0.0007165248
511,59,27,0.0003139501
511,59,28,0.0004493132
512,60,28,0.0007150953
512,60,29,0.0003748545
512,59,28,0.0004489600
512,59,29,0.0003143124
513,60,28,0.0003741532
513,60,29,0.0007167277
513,59,28,0.0003138987
513,59,29,0.0004493631
514,60,29,0.0007148923
514,60,30,0.0003749417
514,59,29,0.0004489098
514,59,30,0.0003143639
515,60,29,0.0003740663
515,60,30,0.0007169307
515,59,29,0.0003138473
515,59,30,0.0004494131

516,60,30,0.0007146895
516,60,31,0.0003750292
516,59,30,0.0004488596
516,59,31,0.0003144154
517,60,30,0.0003739793
517,60,31,0.0007171337
517,59,30,0.0003137960
517,59,31,0.0004494631
518,60,31,0.0007144868
518,60,32,0.0003751166
518,59,31,0.0004488093
518,59,32,0.0003144669
519,60,31,0.0003738923
519,60,32,0.0007173364
519,59,31,0.0003137446
519,59,32,0.0004495131
520,60,32,0.0007142837
520,60,33,0.0003752040
520,59,32,0.0004487589
520,59,33,0.0003145184
521,60,32,0.0003738055
521,60,33,0.0007175392
521,59,32,0.0003136933
521,59,33,0.0004495629
522,60,33,0.0007140807
522,60,34,0.0003752914
522,59,33,0.0004487086
522,59,34,0.0003145699

WELLCHAR.DAT

The ASCII characteristic file WELLCHAR.DAT contains characteristics for pumping wells and boundary flux for ground water. All ground water layers are represented in this file. There must be a one-to-one relationship between the existing pumping wells in this file and the wells in the characteristic file PUYYCHAR.DAT. The data are sorted by code, welluid, and layer. The field output specifications and order are described in the following table and the file is in comma delimited format.

Table B.25. ASCII File Format for Characteristic File WELLCHAR.DAT.

Item Description	Item	Output	Type	No. Decimals	Source Operation or Coverage
aquifer layer	layer	4	I	--	WELL/PWEL/FLX
grid cell row	row	4	I	--	WELL/PWEL/FLX
grid cell column	col	4	I	--	WELL/PWEL/FLX
decimal value of pumping rate assigned to layer	wellcoeff	12	F	4	WELL/PWEL/FLX
designates existing, proposed, or flux	code	2	I	--	WELL/PWEL/FLX
unique well ID	welluid	20	C	--	wells coverage(s)

code: 1 = WELL (existing pumping wells)
2 = PWEL (proposed pumping wells)
3 = FLX (boundary flux)

```
layer, row, col, wellcoeff, code, welluid (excerpt)
no unis for any of the characteristics
3,16,16,1.000000,1,'000018001'
3,20,8,1.000000,1,'000026001'
3,20,10,1.000000,1,'000071001'
3,20,10,1.000000,1,'000071002'
3,20,10,0.300000,1,'000071003'
4,20,10,0.700000,1,'000071003'
3,23,2,0.300000,1,'000074001'
4,23,2,0.700000,1,'000074001'
3,23,2,0.300000,1,'000074002'
4,23,2,0.700000,1,'000074002'
3,23,2,1.000000,1,'000074003'
3,23,2,1.000000,1,'000074004'
3,22,3,0.300000,1,'000075001'
4,22,3,0.700000,1,'000075001'
3,22,3,0.300000,1,'000075002'
4,22,3,0.700000,1,'000075002'
3,23,3,0.300000,1,'000075003'
4,23,3,0.700000,1,'000075003'
3,15,1,1.000000,1,'000085001'
```

PUYYCHAR.DAT

The ASCII characteristic file PU**YY**CHAR.DAT contains ground water pumping rates, by stress period, for existing wells only. The file is divided into two parts. The first part is the header which contains a general file description, the beginning and ending dates of the simulation, and the number of stress period rates included in the file. The second part includes the well unique ID and the stress period rates for each well. There must be a one-to-one relationship between the wells in this file and the existing pumping wells (code = 1) in the characteristic file WELLCHAR.DAT. Up to 20 stress periods can be stored in each file with sequential numbering starting at 01. The data are sorted by welluid. The field output specifications and order are described in the following table.

Table B.26. ASCII File Format for Characteristic File PU**YY**CHAR.DAT.

Item Description	Item	Output	Type	No. Decimals	Source Operation or Coverage
unique well ID	welluid	20	C	--	pu**YY**char.inp and WELL
pumping rate, stress period 1	rate 1	10	F	0	pu**YY**char.inp and WELL
pumping rate, stress period 2	rate 2	10	F	0	pu**YY**char.inp and WELL
:	:	:	:	:	pu**YY**char.inp and WELL
pumping rate, stress period 20	rate 20	10	F	0	pu**YY**char.inp and WELL

YY = file number with leading zero for file numbers < 10

```
welluid, rate 1, rate 2, ..., rate 20 (excerpt)    The rate units must be in cubic feet/day for MODFLOW time step.
NE Hillsborough Model Well Pumping
1989 01 01 00 00 1989 12 31 00 00
12
welluid                  rate1     rate2     rate3     rate4     rate5     rate6     rate7     rate8     rate9    rate10    rate11    rate12
000018001               -7977.    -7080.    -6849.    -7101.    -6282.    -5298.    -5287.    -5175.    -6657.    -6680.    -6872.       -2.
000026001                 -32.      -36.      -34.      -35.      -38.      -31.      -27.      -31.      -27.      -32.      -34.      -27.
000071001                -949.     -984.    -1063.    -1094.    -1061.     -166.      -99.     -258.     -291.     -391.     -324.     -198.
000071002                -949.     -984.    -1063.    -1094.    -1061.     -166.      -99.     -258.     -291.     -391.     -324.     -198.
000071003               -8858.    -9185.    -9921.   -10210.    -9905.    -1551.     -928.    -2406.    -2716.    -3648.    -3026.    -1850.
000074001               -3363.    -4780.    -3864.    -3185.    -5176.      -69.      -61.      -65.    -1578.    -9931.    -3255.    -6308.
000074002               -2152.    -3059.    -2473.    -2038.    -3312.      -44.      -39.      -41.    -1010.    -6356.    -2083.    -4037.
000074003              -11838.   -16824.   -13599.   -11211.   -18218.     -242.     -214.     -228.    -5555.   -34957.   -11457.   -22204.
000074004                -807.    -1147.     -927.     -764.    -1242.      -17.      -15.      -16.     -379.    -2383.     -781.    -1514.
000075001               -3993.    -4947.    -4555.    -4175.    -5350.     -123.        0.     -347.    -1401.    -6913.    -2503.    -4187.
000075002              -14621.   -13464.   -12339.   -15812.     -364.        0.    -1027.    -4141.   -20432.    -7399.   -12375.      -10.
000075003               -4947.    -4555.    -4175.    -5350.     -123.        0.     -347.    -1401.    -6913.    -2503.    -4187.      -10.
000085001               -3463.    -7535.    -3851.    -5236.    -8311.    -3241.    -1053.    -1579.     -471.    -1801.    -2826.    -5014.
```

PNUMCHAR.DAT

The ASCII characteristic file pnumchar.dat contains the number of records in each of the following characteristic files: WELLCHAR.DAT, DRNCHAR.DAT, RIV2CHAR.DAT, GHBCHAR.DAT, and STRCHAR.DAT. The drains (DRNCHAR.DAT) and MODFLOW streams (STRCHAR.DAT) are not supported. The field output specifications and order are described in the following table.

Table B.27. ASCII File Format for Characteristic File PNUMCHAR.DAT

Item Description	Item	Output	Type	No. Decimals	Source Operation or Coverage
no. of records	nrecords	10	I	--	WELL/PWEL/FLX, STRM/LAKE/SPR,GHB
characteristic file prefix	charfile	10	C	--	WELL/PWEL/FLX, STRM/LAKE/SPR,GHB

```
no. of records, characteristic file
     1254      well
       0      drn
      613      riv2
      336      ghb
       0      str
```

GRD2CHAR.DAT

The ASCII characteristic file GRD2CHAR.DAT contains the characteristics for the ground water grid. The row and column spacing (delr and delc) data are sorted by row/col. The file is created by the grid utility. The field output specifications are described in the following table.

Table B.28. ASCII File Format for Characteristic File GRD2CHAR.DAT.

Record 1
- Field 1: C20 "XORIGIN"
- Field 2: C20 "YORIGIN"
- Field 3: C10 "ANGLE"
- Field 4: C20 "COVERAGE UNITS"

Record 2
- Field 1: F20.3 x-coordinate of grid origin
- Field 2: F20.3 y-coordinate of grid origin
- Field 3: F10.2 rotation angle of grid from 90 to -90 degrees (counter-clockwise rotation is positive)
- Field 4: C20 x-y coverage units (FEET or METERS)

Record 3
- Field 1: C10 "NUM_ROW"
- Field 2: C10 "NUM_COL"

Record 4
- Field 1: I10 number of rows
- Field 2: I10 number of columns

Record 5
- Field 1: C10 "ROW/COL#"
- Field 2: C10 "DELR"
- Field 3: C10 "DELC"

Repeat record 6 for the maximum of either the number of rows or the number of columns.

Record 6
- Field 1: I10 row/column number
- Field 2: F10.1 distance along row
- Field 3: F10.1 distance along column

<u>Example</u>

```
                    XORIGIN          YORIGIN    ANGLE     COVERAGE UNITS
      377490.531       3092533.750        0           METERS
  NUM_ROW   NUM_COL
     24        18
 ROW/COL#     DELR      DELC
      1    5280.0    5280.0
      2    5280.0    5280.0
      3    5280.0    5280.0
      4    5280.0    5280.0
      5    5280.0    5280.0
      6    5280.0    5280.0
      7    5280.0    5280.0
      8    5280.0    5280.0
      9    5280.0    5280.0
     10    5280.0    5280.0
     11    5280.0    5280.0
     12    5280.0    5280.0
     13    5280.0    5280.0
     14    5280.0    5280.0
     15    5280.0    5280.0
     16    5280.0    5280.0
     17    5280.0    5280.0
     18    5280.0    5280.0
     19     0.000    5280.0
     20     0.000    5280.0
     21     0.000    5280.0
     22     0.000    5280.0
     23     0.000    5280.0
     24     0.000    5280.0
```

GRD3CHAR.DAT

The ASCII characteristic file GRD3CHAR.DAT contains the x and y coordinates of the grid cell centers for the ground water grid. The file is created by the grid utility. The data are sorted by griduid and the file is free-format.

Table B.29. ASCII File Format for Characteristic File GRD3CHAR.DAT (Example Excerpt).

```
griduid, row, column, x-coordinate, y-coordinate
 1001 1 1   378295.20324707   3130353.3320312
 1002 1 2   379904.54724121   3130353.3320312
 1003 1 3   381513.89147949   3130353.3320312
 1004 1 4   383123.23535156   3130353.3320312
 1005 1 5   384732.57910156   3130353.3320312
 1006 1 6   386341.92285156   3130353.3320312
 1007 1 7   387951.26660156   3130353.3320312
 1008 1 8   389560.61035156   3130353.3320312
 1009 1 9   391169.95410156   3130353.3320312
 1010 1 10   392779.29785156   3130353.3320312
 1011 1 11   394388.64257812   3130353.3320312
 1012 1 12   395997.98632812   3130353.3320312
 1013 1 13   397607.33007812   3130353.3320312
 1014 1 14   399216.67382812   3130353.3320312
 1015 1 15   400826.01757812   3130353.3320312
 1016 1 16   402435.36132812   3130353.3320312
 1017 1 17   404044.70507812   3130353.3320312
 1018 1 18   405654.04882812   3130353.3320312
```

Ground Water/Integration

One characteristic file is documented for the ground water/integration category.

RCETCHAR.DAT

The ASCII characteristic file RCETCHAR.DAT contains ground water recharge and ET and FHM integration characteristics. The data are sorted by griduid. The field output specifications and order are described in the following table and the file is in comma delimited format.

Table B.30. ASCII File Format for Characteristic File RCETCHAR.DAT.

Item Description	Item	Output	Type	No. Decimals	Source Operation or Coverage
grid cell unique ID	griduid	8	I	--	grid coverage
grid cell row	row	4	I	--	grid coverage
grid cell column	col	4	I	--	grid coverage
recharge	rec	12	F	8	REC
GW maximum ET rate	gwet	12	F	8	GWET
GW ET surface for maximum rate	esrf	10	F	2	ESRF
GW ET extinction depth	edep	8	F	2	EDEP/LANDET
porosity	poros	6	F	2	SOILET
field capacity	fld-cap	6	F	2	SOILET
plant ET coefficient	et-coef	6	F	2	LANDET
basin assigned to grid cell	class	6	I	--	BASN2GRD

```
griduid, row, col, rec, gwet, esrf, edep, poros, fld-cap, et-coef, class (excerpt)
 , , , inches/yr,inches/yr,feet NGVD,feet, ,inches water/inch soil, ,
1,1,21.020021952479,-9999.,176.84,2.220919,0.48,0.08,0.650645,16
1,2,21.020021952479,-9999.,159.80,2.426843,0.49,0.07,0.711497,14
1,3,8.728766356749,-9999.,125.99,2.674953,0.47,0.09,0.605251,14
1,4,8.728766356749,-9999.,130.32,1.677034,0.46,0.09,0.568165,14
1,5,7.251177793561,-9999.,115.16,1.899749,0.48,0.06,0.547390,14
1,6,7.251177793561,-9999.,109.59,1.605023,0.49,0.05,0.492950,13
1,7,22.405229317321,-9999.,105.48,1.961362,0.49,0.05,0.510293,13
1,8,22.405229317321,-9999.,92.68,1.710695,0.48,0.06,0.666954,13
1,9,0.612017583506,-9999.,87.76,2.679854,0.49,0.11,0.713761,13
1,10,0.612017583506,-9999.,92.22,4.049238,0.49,0.08,0.733980,13
1,11,28.830003873967,-9999.,95.96,4.430018,0.49,0.10,0.735365,13
1,12,28.830003873967,-9999.,93.43,4.239416,0.49,0.11,0.697126,13
1,13,17.984482610193,-9999.,94.32,3.335795,0.48,0.10,0.653003,12
1,14,17.984482610193,-9999.,97.55,4.737747,0.48,0.09,0.741679,12
1,15,5.791892648072,-9999.,94.32,4.995467,0.48,0.09,0.715543,12
1,16,5.791892648072,-9999.,98.42,2.926744,0.48,0.09,0.732377,12
1,17,-5.331518487431,-9999.,98.42,3.912798,0.48,0.10,0.752110,12
1,18,-5.331518487431,-9999.,99.21,3.518701,0.48,0.10,0.749521,12
2,1,21.020021952479,-9999.,152.83,3.167303,0.48,0.09,0.662862,16
2,2,21.020021952479,-9999.,165.41,1.391938,0.47,0.09,0.705350,14
2,3,8.728766356749,-9999.,130.01,2.296477,0.46,0.09,0.531395,14
2,4,8.728766356749,-9999.,130.16,1.595315,0.46,0.09,0.520789,14
2,5,7.251177793561,-9999.,107.71,1.543898,0.47,0.08,0.477660,14
2,6,7.251177793561,-9999.,106.09,1.350226,0.49,0.05,0.454661,13
2,7,22.405229317321,-9999.,97.08,2.199412,0.49,0.05,0.512997,13
2,8,22.405229317321,-9999.,85.90,2.387898,0.48,0.08,0.653378,13
2,9,0.612017583506,-9999.,82.55,4.775712,0.49,0.11,0.728523,13
2,10,0.612017583506,-9999.,82.91,3.330757,0.49,0.11,0.790946,13
2,11,28.830003873967,-9999.,95.16,4.321930,0.48,0.10,0.732570,13
2,12,28.830003873967,-9999.,90.91,2.266145,0.48,0.10,0.571773,13
2,13,17.984482610193,-9999.,90.21,4.578408,0.48,0.10,0.723660,12
2,14,17.984482610193,-9999.,94.46,4.574935,0.48,0.09,0.708003,12
2,15,5.791892648072,-9999.,98.42,4.783196,0.48,0.09,0.734573,12
2,16,5.791892648072,-9999.,97.37,4.180337,0.48,0.09,0.720269,12
2,17,-5.331518487431,-9999.,100.06,2.603539,0.48,0.09,0.630633,12
2,18,-5.331518487431,-9999.,104.99,1.756366,0.48,0.09,0.605532,12
```

Spatial/Temporal Link

One characteristic file is documented for the spatial/temporal link category.

STACHAR.DAT

The ASCII file STACHAR.DAT contains data base retrieval information for temporal data stations. The file is free-format except for record 2 as shown below.

Table B.31. ASCII File Format for Characteristic File STACHAR.DAT.

Record 1
Field 1: header for general description of file contents
Record 2
Field 1: begin date for data retrieval period YYYY/MM/DD
Field 2: end date for data retrieved period YYYY/MM/DD

Record 3
Field 1: number of data types in this file

Repeat records 4 to 6 for the number of data types in this file as specified in record 3.
Record 4
Field 1: data type code
Record 5
Field 1: number of stations for preceding data type code in record 4
Record 6
Field 1: station ID (repeat for number of stations in record 5)
Field 2: station name (repeat for number of stations in record 5)

Example

```
Selected Stations for Temporal Data
1988/11/01 1990/02/28
3
FLO
3
FLO0029     'Blackwater Creek Nr Knights'
FLO0061     'Hillsborough River Abv Crystal Springs'
FLO0075     'Hillsborough River Nr Zephyrhills'
RNF
2
ATM0141     'St. Leo'
ATM0079     'Lakeland'
EVT
2
ATM0214     'SWFWMD IV'
ATM0105     'Ona Research Center'
```

Other Supporting Files (ASCII Format)

HYDROGIS.ERR

The ASCII file HYDROGIS.ERR is the error file which can be used to assess the source of errors. Before spatial analysis operations are initiated, the input data are reviewed for errors in the verification process. Insufficiencies or errors in the input data are denoted by an error message that is written to the error file. Any errors encountered during operations processing are also denoted by an error message that is written to the error file.

Example

ERROR FILE FOR GIS SPATIAL ANALYSIS PROCESSING OF GROUND WATER, SURFACE WATER, AND INTEGRATION PARAMETERS.

VERIFYING AVAILABILITY OF INPUT DATA FOR USER-SELECTED SPATIAL ANALYSIS PROCESSING CODES.
VERIFICATION BY: mross, STARTED: 04/30/97.22:13:02.Wed

SURFACE BASIN COVERAGE: /export/home/sunfish4/projects4/swfwmd/nehillsb/nehbasin
SMALL-SCALE GRID COVERAGE: /export/home/sunfish4/projects4/swfwmd/nehillsb/nehgrid
LARGE-SCALE GRID COVERAGE: /export/home/sunfish4/projects4/swfwmd/nehillsb/twogrid
PROJECT WORKSPACE: /export/home/sunfish4/projects4/swfwmd/nehillsb
PROTECTED WORKSPACE: /home/sunfish6/projects6/protect

1. CONFIRM ALL NAMES FILE ENTRIES FOR RECORDS WITH ERRORS.
2. CONFIRM THE EXISTANCE OF COVERAGES AND ITEMS IN THE SPECIFIED WORKSPACES OR MAP LIBRARIES.
3. CONFIRM THE VALIDITY OF THE PROJECT WORKSPACE AND PROTECTED WORKSPACE PATHS IN THE PATHS FILE.

AN ERROR OCCURRED DURING PROCESSING FOR PARAMETER CODE hydl.
ADDITIONAL PROCESSING ASSOCIATED WITH THIS PARAMETER CODE WILL BE TERMINATED.
AN ATTEMPT WILL BE MADE TO COMPLETE PROCESSING FOR THE UNPROCESSED PARAMETER CODES.

HYDROGIS.TIM

The ASCII file HYDROGIS.TIM is the performance timer file which can be used to assess the performance efficiency and processing time for individual or groups of spatial analysis operations. A system administrator can use the information in this file to determine which spatial analysis operations can be executed with interactive mode (immediate) processing.

Example

```
:::::::::::::::::::::::::::::::::::::::::::::::::::::::
PROCESSING PERFORMANCE TIME FOR GROUND WATER LAYER 1
FORMAT: LAYER,PARAMETER,COMPLETE TIME,ELAPSED SECONDS,CPU SECONDS,DISK I/O
1 procgrid 10:59:37,4310.00,212.40,0
1 dem 10:59:53,15.00,4.65,0
1 spy 11:04:24,271.00,150.03,0
1 stc 11:07:03,159.00,116.18,0
1 top 11:08:53,110.00,59.47,0
1 lek 11:13:41,288.00,203.18,0
1 bot 11:15:12,91.00,53.99,0
1 hyc 11:18:10,178.00,126.84,0
1 ibd 11:19:12,62.00,36.51,0
```

APPENDIX C. CODE FLOWCHARTS FOR HydroGIS

Appendix C contains flowcharts for the codes which execute spatial analysis operations. The flowcharts are organized in alphabetical order by the name of the code. Multiple flowcharts have been developed for most codes which document an overview structure of the code, followed by documentation of the three-part processing sequence of initialization, overlays, and summarization.

This appendix begins with example codes for the administrator AML (HGISVAR.AML) and the AML (MKBATCH.AML) which creates a system batch file to execute spatial analysis operations. Both AMLs must be customized for the system on which ARC/INFO is executed and for ARC/INFO preferences. All other codes of HydroGIS, including AMLs, menus, and FORTRAN are provided in electronic format only.

Management of the "engine" of HydroGIS is discussed in the Operations Management section of Chapter 3. Various flowcharts are also included in that section.

HGISVAR.AML: Administrator AML, contains global variables which specify system and ARC/INFO preferences, and spatial analysis default parameters.

```
/*  **********************************************************
/*  **********************************************************
/*  **                                                      **
/*  **          device:[directory]hgisvar.aml               **
/*  **                                                      **
/*  **********************************************************
/*  **********************************************************
/*
/*  Arc Module  (Arc)                Version  6.1.2
/*  ==========                       =======
/*
/*  Author  Jeffrey S. Geurink       Title  HGISVAR
/*  ======                           =====
/*  Center for Modeling Hydrologic and Aquatic Systems
/*  University of South Florida
/*  Tampa, Florida
/*
/*                                   Release Number:  1.0
/*                                   ==============
/*  Revision History
/*  ================
/*
/*  Rev  Who     Date     Description
/*  ---  ---     ----     -----------
/*  1.0  jsg   07-NOV-97  original release
/*
/*  Activation
/*  ==========
/*  This AML may be invoked as follows:
/*
/*  Arc:  &RUN path/hgisvar
/*
/*
/*  General Description
/*  ===================
/*  This aml is referred to as the administrator aml because it is used to establish administrator
/*  controlled settings and default values for spatial analysis variables.  Operating system
/*  and ARC/INFO preferences are set here.  The variable settings from this aml are used
/*  throughout HydroGIS.
/*
/*
/*  Variables
/*  =========
/*  Name       Type    Description              Where Set      Datatype  Range
/*  ----       ----    -----------              ---------      --------  -----
/*  aggrmeth   global  hydrography aggregation  main           Character (NONE | REACH | GRID)
/*                     method
/*  apath      global  full path to amls        main           Character
/*  basinresol global  distance between points  main           Real      (gt 0)
/*                     along the basin boundary
/*                     which is used to retrieve
/*                     topographic elevation
/*                     for the hydraulic length
/*                     secondary calculation method
/*  cditem     global  item in pumping well     main           Character
/*                     coverage which provides
/*                     the casing depth
/*  depthtype  global  indicates whether the    main           Character (DEPTH | ELEVATION)
/*                     casing and total depth
/*                     data are depths or
/*                     elevations
/*  dia        global  item in pumping well     main           Character
/*                     coverage which provides
/*                     the well diameter
/*  display    global  portrait graphic         main           Character
/*                     display settings
```

```
/*  displayl   global   landscape graphic        main           Character
/*                      display settings
/*  exp        global   full path to INFO        main           Character
/*                      expansion tables
/*  fuzzy      global   fuzzy tolerance for      main           Real      gt 0
/*                      overlays and buffers
/*  ghbnseg    global   number of line segments  main           Integer   gt 0
/*                      to create from the
/*                      shortest ghb travel path
/*  hgisaml    global   full path to amls        main           Character
/*  hgishelp   global   full path to help files  main           Character
/*  hgismenu   global   full path to menus       main           Character
/*  hgisproj   global   full path to projections main           Character
/*  hgisutil   global   full path to FORTRAN     main           Character
/*                      executable utilities
/*  hydlerror  global   error criterion for the  main           Real      (gt 0)
/*                      primary method of
/*                      hydraulic length calculation
/*  liblist    global   list of map libraries    main           Character
/*                      that are accessible to
/*                      HydroGIS
/*  limslope   global   maximum number of        main           Integer   (gt 0)
/*                      surface basins to process
/*                      within one processing
/*                      subset for basin slope
/*  linelim    global   limit on number of       main           Integer   (gt 0)
/*                      stream arcs in coverage
/*                      which can be processed in
/*                      one processing subset
/*  lut        global   full path to INFO        main           Character
/*                      look-up tables
/*  minhydl    global   default basin hydraulic  main           Real      gt 0
/*                      length to use if it
/*                      cannot be calculated
/*                      with the given data
/*  minslope   global   default basin slope to   main           Real      gt 0
/*                      use if it cannot be
/*                      calculated with the
/*                      given data
/*  mpath      global   full path to menus       main           Character
/*  opsys     global   identifies the operating hgisvar.aml    Character (vms | unix | data_general
/*                      system
/*  polyfctr   global   decimal fraction         main           Real      (le 1)
/*                      considered to be the
/*                      percentage of the maximum
/*                      hydrography polygon area
/*                      which conducts water
/*                      through the bed
/*  polylim    global   limit on number of       main           Integer   (gt 0)
/*                      hydrog. polys in coverage
/*                      which can be processed in
/*                      one processing subset
/*  rel        global   full path to INFO        main           Character
/*                      relate tables
/*  statname   global   item in station          main           Character
/*                      locations coverage which
/*                      provides the station name
/*  stattype   global   item in station          main           Character
/*                      locations coverage which
/*                      provides the code for
/*                      the station type
/*  statuid    global   item in station          main           Character
/*                      locations coverage which
/*                      provides the unique id
/*  strtpath   global   full path to workspace   main           Character
/*                      containing user list and
/*                      HydroGIS project index
/*                      files
/*  tditem     global   item in pumping well     main           Character
/*                      coverage which provides
/*                      the total depth
/*  upath      global   full path to FORTRAN     main           Character
```

```
/*                      executable utilities
/*
/*  Map Libraries and Layers
/*  ========================
/*  Library         Layer         Purpose
/*  -------         -----         -------
/*  Only information about the map libraries and the layers is used in this aml.
/*
/*  Coverages
/*  =========
/*  No coverages are used in this aml.
/*
/*  Cover Name           Purpose
/*  ----------           -------
/*
/*
/*  Files
/*  =====
/*  No files are used in this aml.
/*
/*  File name           Type    Purpose
/*  ---------           ----    -------
/*
/*
/*  Constraints or special notes
/*  ============================
/*  none
/*
/*  ::::::::::::::::::::::::
/*  :: Initialize section ::
/*  ::::::::::::::::::::::::
/*
&severity &error &fail

&TYPE INSIDE HGISVAR.AML . . .
&TYPE SETTING HYDROGIS ADMINISTRATOR VARIABLES . . .; &TYPE


/*  ::::::::::::::::::::::::
/*  ::     Main Body      ::
/*  ::::::::::::::::::::::::


/* Display variable
&sv .display 9999 size frame 500 700 position ur screen ur   /* portrait
&sv .displayl 9999 size frame 700 500 position ur screen ur  /* landscape
&terminal 9999


/* HydroGIS PATH VARIABLES

    /* AML CODE PATH(S)
    /* The amlpath is set in the HydroGIS atool
&sv .hgisaml [pathname $HYDROGISAML]     /* needed for batch processing
&sv .apath %.hgisaml%   /* temporary until all occurrences of .apath
                        /* are removed from codes

    /* MENUS
    /* The menupath is set in the HydroGIS atool
&sv .hgismenu [pathname $HYDROGISMENU]   /* needed for batch processing
&sv .mpath %.hgismenu%  /* temporary until all occurrences of .mpath
                        /* are removed from codes

    /* FORTRAN UTILITIES
&SV .HGISUTIL [PATHNAME $HYDROGISFORT]
&SV .UPATH %.HGISUTIL%  /* temporary until all occurrences of .upath
                        /* are removed from codes
    /* HELP FILES
&SV .HGISHELP [PATHNAME $HYDROGISHELP]

    /* PROJECTION FILES
&SV .HGISPROJ [PATHNAME $HYDROGISPROJ]
```

```
    /* INFO EXPANSION FILES
&SV .EXP [PATHNAME $EXP]

    /* INFO RELATE TABLES
&SV .REL [PATHNAME $REL]

    /* INFO LOOK-UP TABLES
&SV .LUT [PATHNAME $LUT]

    /* PATH TO USERS LISTING
&SV .STRTPATH /home/sunfish3/projects3/swfwmd/userinfo

/* SPECIFY OPERATING SYSTEM FLAG
/* THE FOLLOWING ARE VALID OPERATING SYSTEM FLAGS (NOT CASE SENSITIVE):
/*              UNIX SYSTEM:  unix
/*               VMS SYSTEM:  vms
/*      DATA GENERAL SYSTEM:  data_general
&SV .OPSYS unix


    /* COORDINATE SYSTEM COMPARISON LEVEL
/* PROJECTCOMPARE <NONE | PARTIAL | FULL>
PROJECTCOMPARE NONE




    /* MAP LIBRARY VARIABLES
    /* A LIBRARY LIST VARIABLE AND A TILE EXTRACTION LIMIT
    /* VARIABLE FOR EACH LIBRARY IN THE LIBRARY LIST ARE REQUIRED.
    /* THE TILE EXTRACTION LIMIT VARIABLE LIMITS THE NUMBER OF TILES
    /* WHICH CAN BE EXTRACTED AT ONE TIME FROM A SPECIFIC LIBRARY.
        /* Library list variable
&sv .liblist test2m test500 test100 test24

        /* Tile extraction limit variables
&sv .test2mlim 1
&sv .test500lim 1
&sv .test100lim 2
&sv .test24lim 1


    /* [GLOBAL XY UNITS] FUZZY TOLERANCE FOR OVERLAYS AND BUFFERS
&sv .fuzzy 0.7


/* VARIABLES FOR SPECIFIC UTILITIES

    /* FOR STATION SELECTION/COVERAGE CREATION
&sv.statuid hdbuid
&sv .statname hdbsite
&sv .stattype uidtype


/* VARIABLES FOR SPECIFIC SPATIAL ANALYSIS PROCESSING
    /* Of the variables below this point, only selected variables
    /* are permitted to have the default values contained herein
    /* to be overridden by the user.  The variables which can
    /* can be user controlled are:  aggrmeth, ghbnseg,
    /* minhydl, and hydlerror
    /* The user can supply other values in a file called
    /* hydrogis.var contained within the project workspace.
    /* The hydrogis.var file has a free-format where each
    /* record contains the variable (without the period) followed
    /* by the value for the variable.


    /* FOR GROUND WATER HYDROGRAPHY PROCESSING
    /* Hydrography aggregation method < NONE | REACH | GRID >
&SV .AGGRMETH none
```

```
    /* FOR WELL PROCESSING
&SV .DEPTHTYPE depth     /* depths in cditem and tditem are < DEPTH | ELEVATION >
&SV .CDITEM cd           /* casing depth of well [feet]
&SV .TDITEM td           /* total depth of well  [feet]
&SV .DIA    dia          /* casing diameter [inches]

    /* FOR GHB PROCESSING
&SV .GHBNSEG 4           /* number of line segments to create from the shortest
                         /*   ghb travel path in the ghb coverage

    /* For LAKE processing (polygon hydrography for ground water)
&sv .polyfctr 0.8  /* A decimal fraction considered to be the percentage of
                   /* the maximum hydrography polygon area which conducts water
                   /* through the bed between surface water and ground water.

    /* For BASN (modified basin area) processing
        /* Limit on the number of stream arcs in the coverage which can be
        /* processed in one processing subset.
&sv .linelim 100000

        /* Limit on the number of polygons which can be processed in one subset;
        /* an indirect limit on the 10,000 arcs in a polygon - the arc limit in
        /* a polygon is a problem for hydrography polygons whose arcs are added
        /* up for the container plygon.
&sv .polylim 2000

    /* For HYDL (basin mean hydraulic length) processing
        /* Maximum number of surface basins to process within one processing subset
        /* for basin slope. Used in slope.aml.
&sv .limslope 20

        /* Minimum (default) basin slope [dimensionless] if a slope cannot
        /* be calculated with given data.  Used in slope.aml.
&sv .minslope 0.000001

        /* Minimum (default) basin hydraulic length [feet] if it cannot
        /* be calculated with given data.
&sv .minhydl 300

        /* Hydraulic length primary calculation method error criterion [feet].
&sv .hydlerror 10

        /* Distance between points [feet] along the basin boundary which is used to retrieve
        /* topographic elevation for the hydraulic length secondary calculation method.
&sv .basinresol 100

&type ADMINISTRATOR VARIABLES ESTABLISHED . . .
&type LEAVING HGISVAR.AML . . .; &type

&return    /* end of hgisvar.aml
```

MKBATCH.AML: creates system batch file to execute spatial analysis operations

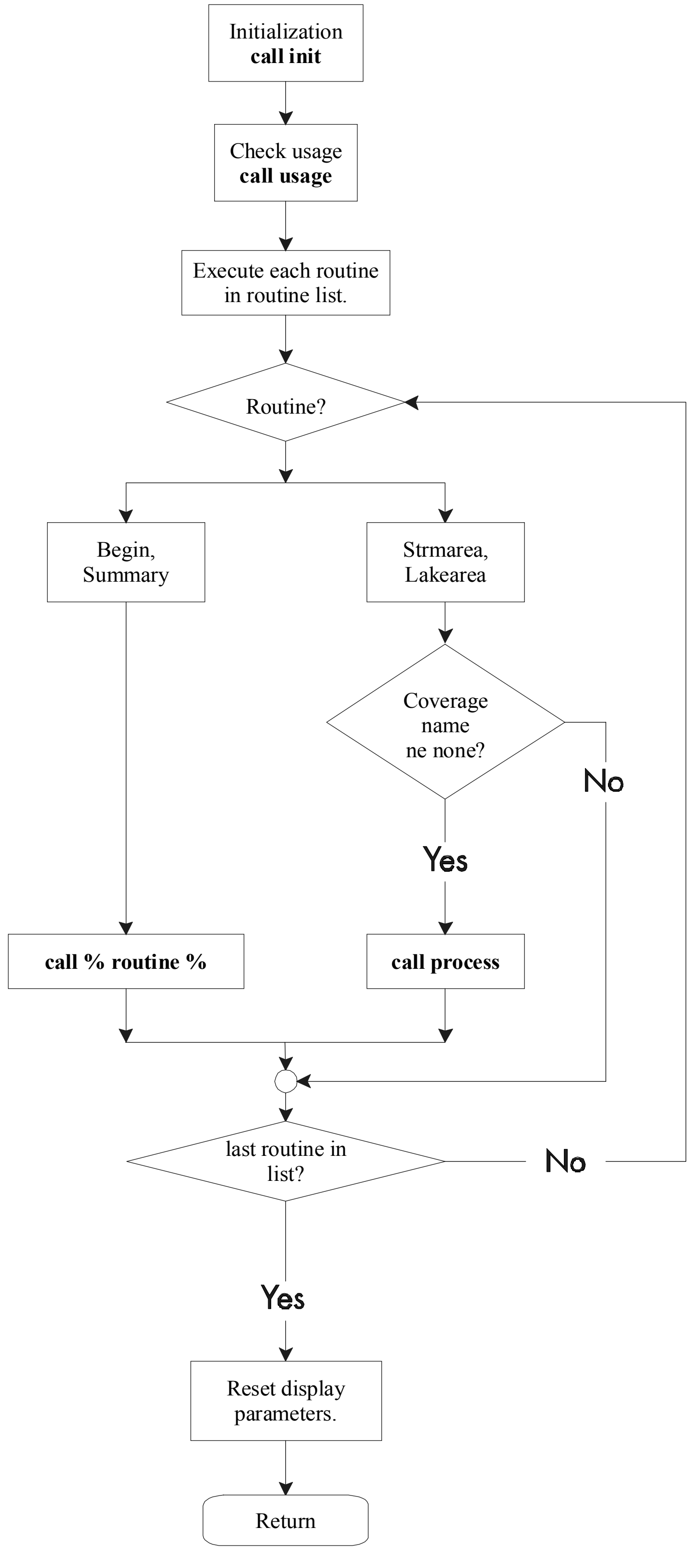
```
/* mkbatch.aml
/* Jeff Geurink           10/04/97
/*
/* Creates a system batch file to execute HydroGIS for user-selected operations.
/* The AML is customized for the system which executes ARC/INFO.
/* The argument list is mandatory.
/* System batch file written to project workspace.
/* The variables at the top of the AML must be customized for the operating system.
/* In addition, the beginning and ending system execution lines of the batch file must be
/* customized within routine BEGIN and END respectively.
/*
&args workproj project debug procmode
&severity &error &ROUTINE BAILOUT


/* ::::::::::::::::::::::::::::::::::::::::::::::::::::
    /* SET VARIABLES TO BE COMPATIBLE WITH OPERATING SYSTEM

        /* Define name of system batch file.
&sv batchfile hydrogis.sh
        /* Define path to system batch file.
&sv batchpath [show &workspace]
        /* Define system command to change directory.
&sv changedir cd

/* ::::::::::::::::::::::::::::::::::::::::::::::::::::


    /* Set system path delimiter
&call SETDELIM


    /* Create system batch file.
&sv fn [close -all]
&sv batchfile [unquote [subst [quote %batchpath%%delim%%batchfile%] ' ']]
&if [exists %batchfile% -file] &then &sv fn [delete %batchfile% -file]
&sv filunit1 [open %batchfile% openstatus -write]
&if %openstatus% ne 0 &then
  &do
    &messages &popup
    &type FILE %batchfile% COULD NOT BE OPENED PROPERLY TO CREATE BATCH FILE
    &messages &on
    &call BAILOUT
  &end


    /* Write beginning system execution lines of batch file.
&call BEGIN

    /* Write aml execution lines of batch file.
&sv record1 [quote %changedir% [locase %workproj%]]
&sv record2 [quote arc << ENDAML]
&sv record3 [quote &terminal 9999]
&sv record4 [quote &amlpath [show &amlpath]]
&sv record5 [quote &menupath [show &menupath]]
&sv record6 [quote &run hgisproc.aml %project% %procmode% %debug%]
&sv record7 [quote quit]
&sv record8 [quote ENDAML]

&do i = 1 &to 8
  &sv fn [write %filunit1% [value record%i%]]
  &dv record%i%
&end


    /* Write ending system execution lines of batch file.
&call END
```

```
&sv fn [close %filunit1%]

&return  /* end of mkbatch.aml
/* ::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::::

/*  ::::::::::::::::::::::::
/*  ::   Subroutines      ::
/*  ::::::::::::::::::::::::



&ROUTINE BEGIN
    /* Write beginning system execution lines of batch file.


&sv record1 [quote #!/bin/csh]
&sv record2 [quote echo "Starting Arc/Info for HydroGIS batch processing"]


&sv i 1
&sv number 0
&do &until [variable record%i%] eq .FALSE.
  &sv number %number% + 1
  &sv i %i% + 1
&end

&do i = 1 &to %number%
  &sv fn [write %filunit1% [value record%i%]]
  &dv record%i%
&end

&return  /* end of ROUTINE BEGIN



&ROUTINE END
    /* Write ending system execution lines of batch file.



&sv i 1
&sv number 0
&do &until [variable record%i%] eq .FALSE.
  &sv number %number% + 1
  &sv i %i% + 1
&end

&do i = 1 &to %number%
  &sv fn [write %filunit1% [value record%i%]]
  &dv record%i%
&end

&return  /* end of ROUTINE END



&ROUTINE SETDELIM
    /* Set path delimiter

    /* For Prime:  >
    /* For VMS:    null
    /* For Data General:  :
    /* For UNIX:  /

    /* To concatenate a path to a file, the following is used:
    /* [unquote [subst [quote %path%%delim%%file%] ' ']]

    /* The above nested function command is necessary to allow for concatenation with
    /* VAX systems which have a null delimiter that leaves a blank space between the
    /* %path% and %file% strings when concatenated.  The nested function deletes the
    /* blank space.
```

```
&sv delim [before [after [pathname temp.xx] [dir [pathname temp.xx]]] temp.xx]

&return  /* end of ROUTINE SETDELIM



&ROUTINE BAILOUT

&severity &error &fail
&return &warning TERMINATING EXECUTION FROM MKBATCH.AML . . .
```

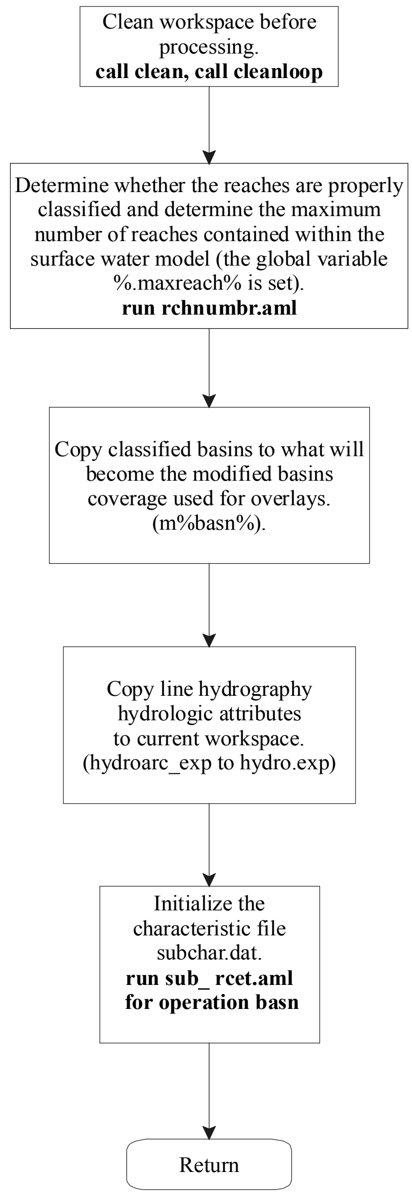
AML: basnarea.aml
Flowchart: overview

basnare.cfl



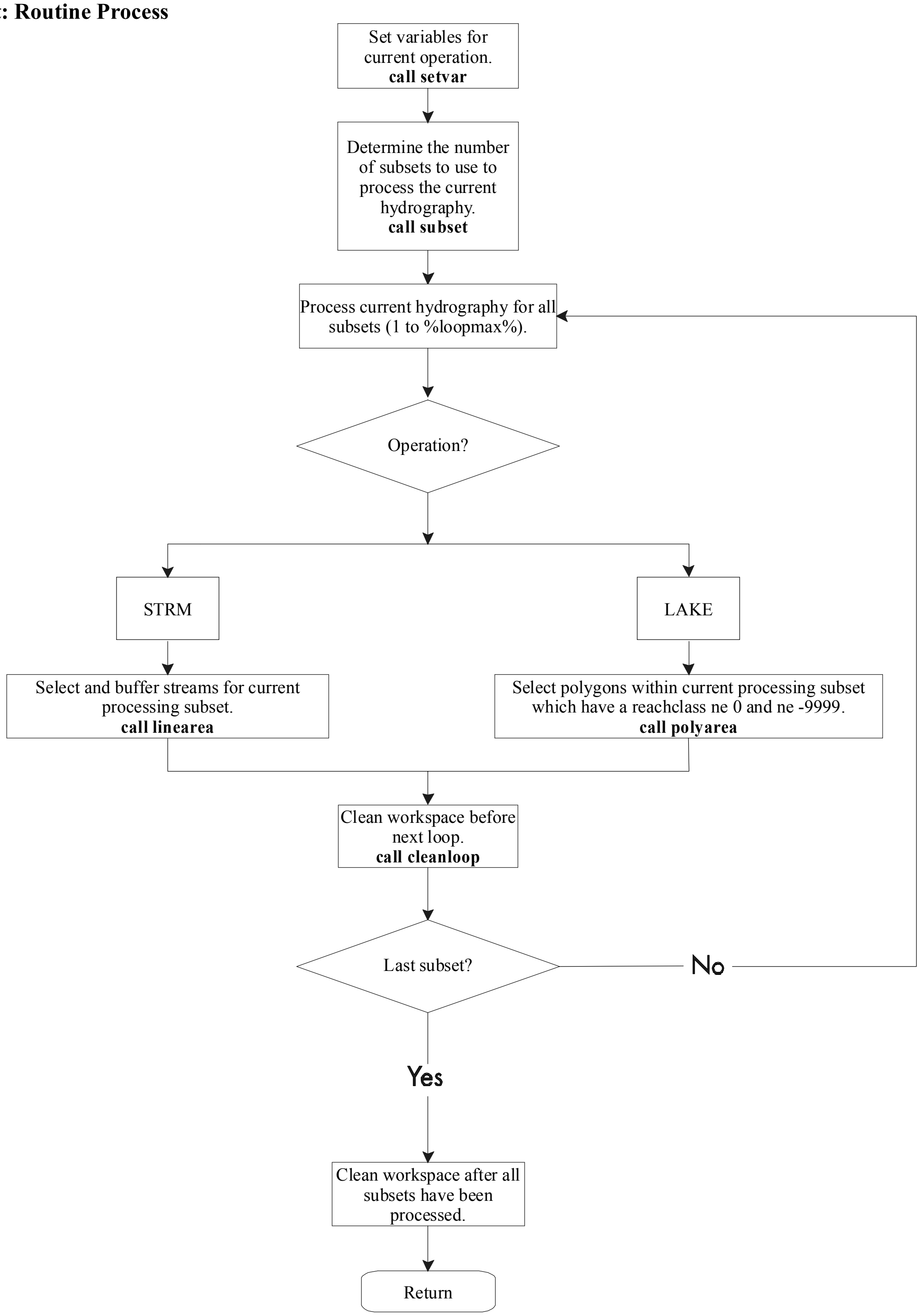
AML: basnarea.aml
Flowchart: Routine Begin

basnare1.cfl



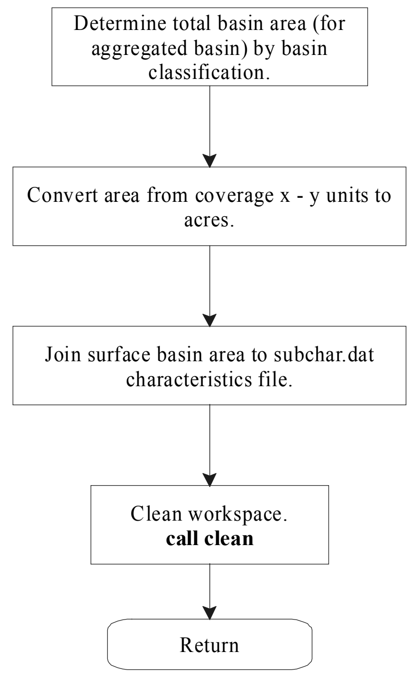
AML: basnarea.aml
Flowchart: Routine Process

basnare2.cfl



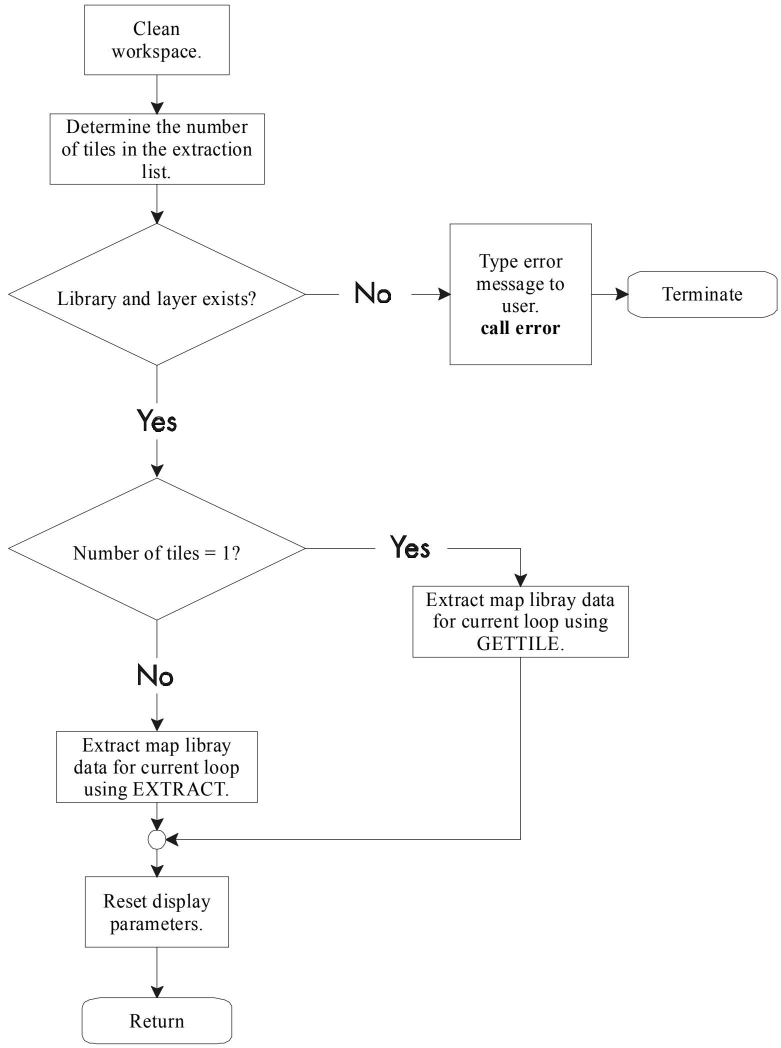
AML: basnarea.aml
Flowchart: Routine Summary

basnare3.cfl



AML:extract.aml
Flowchart: Overview

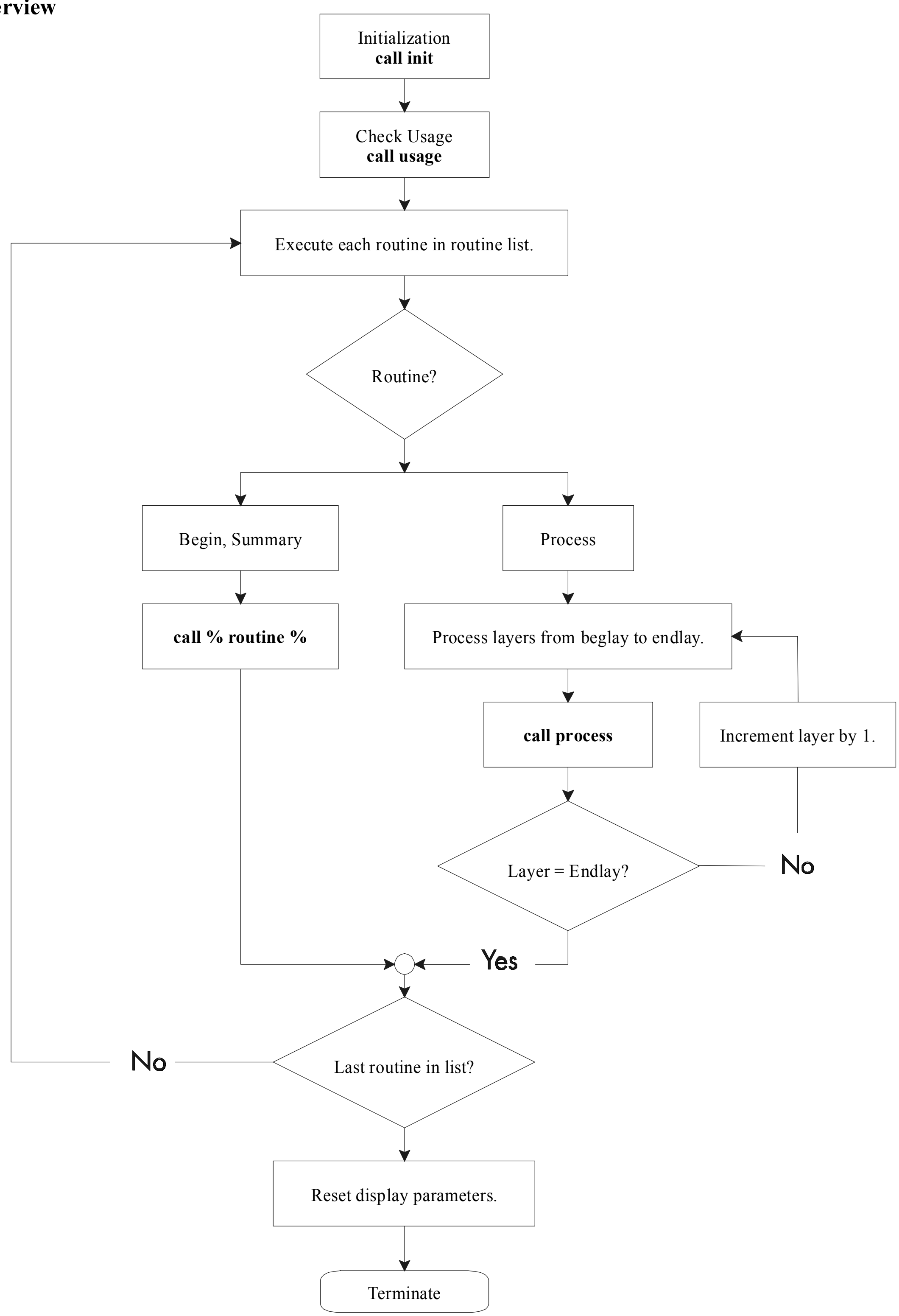
extract.cfl



AML: ghbmscal.aml

Flowchart: Overview

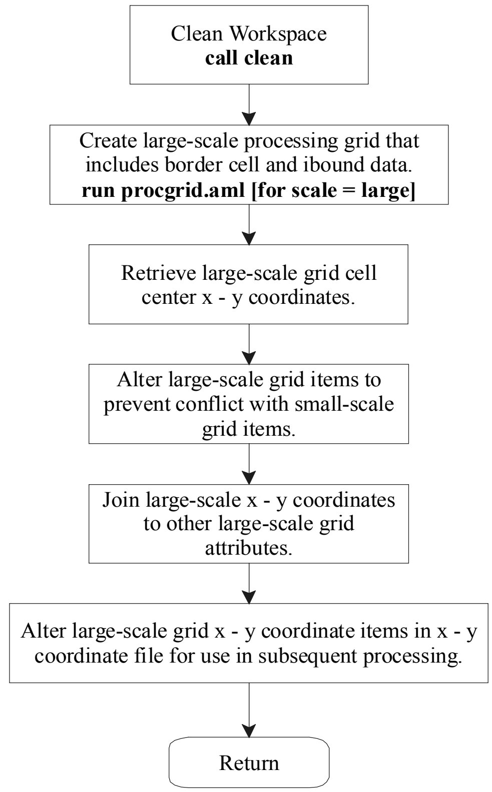
ghbmsca.cfl



AML: ghbmscal.aml

Flowchart: Routine Begin

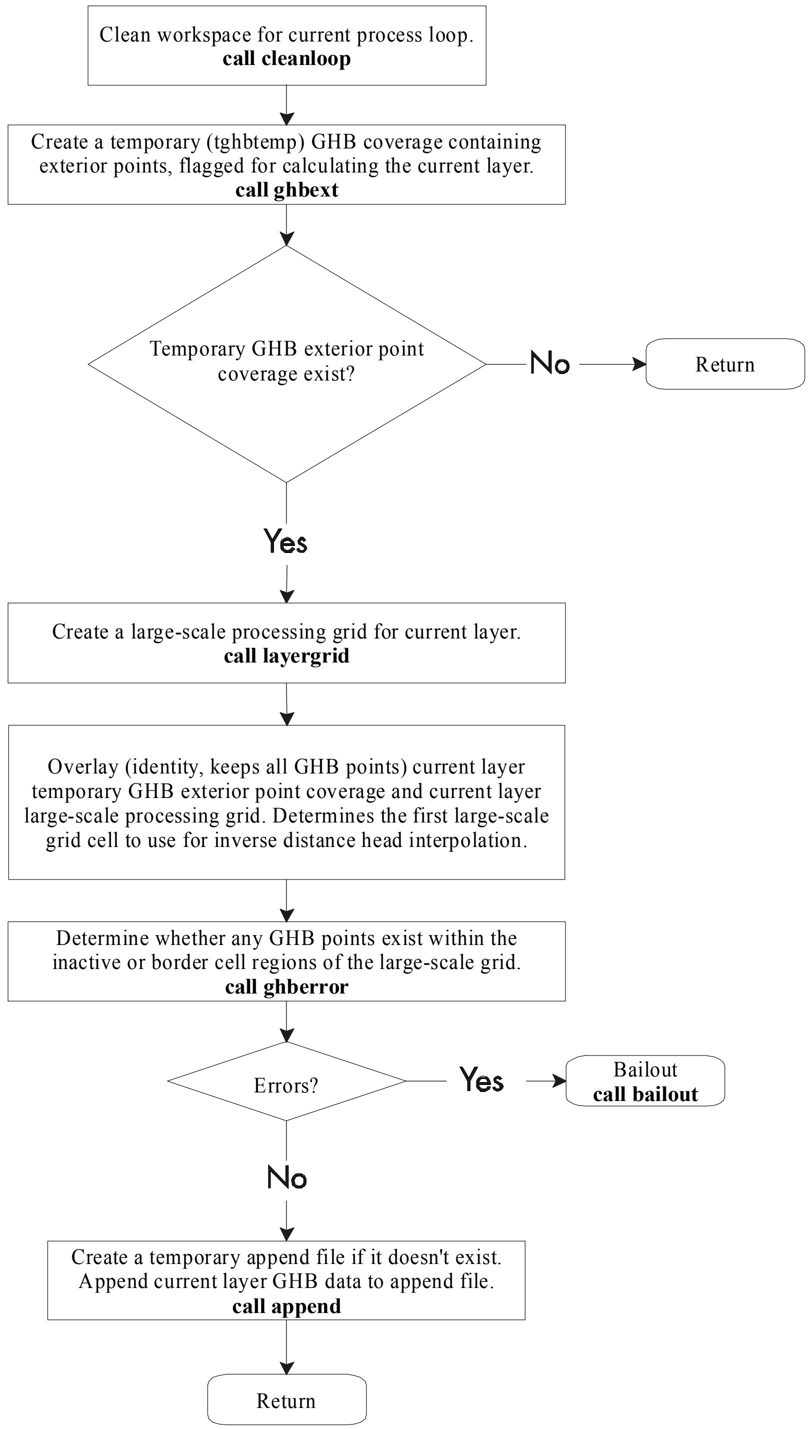
ghbmsca1.cfl



AML: ghbmscal.aml

Flowchart: Routine Process

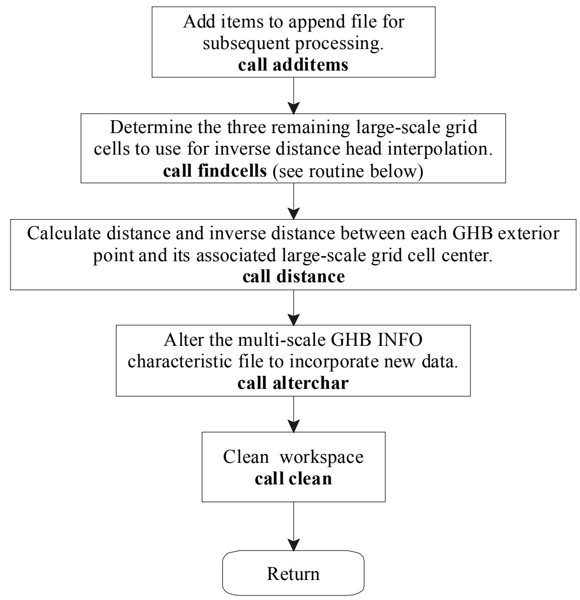
ghbmsca2.cfl



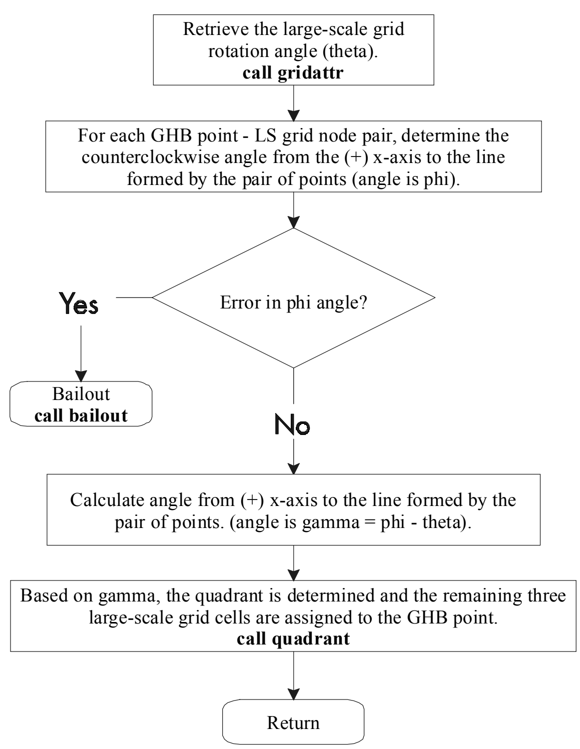
AML: ghbmscal.aml

Flowchart: Routine Summary

ghbmsca3.cfl

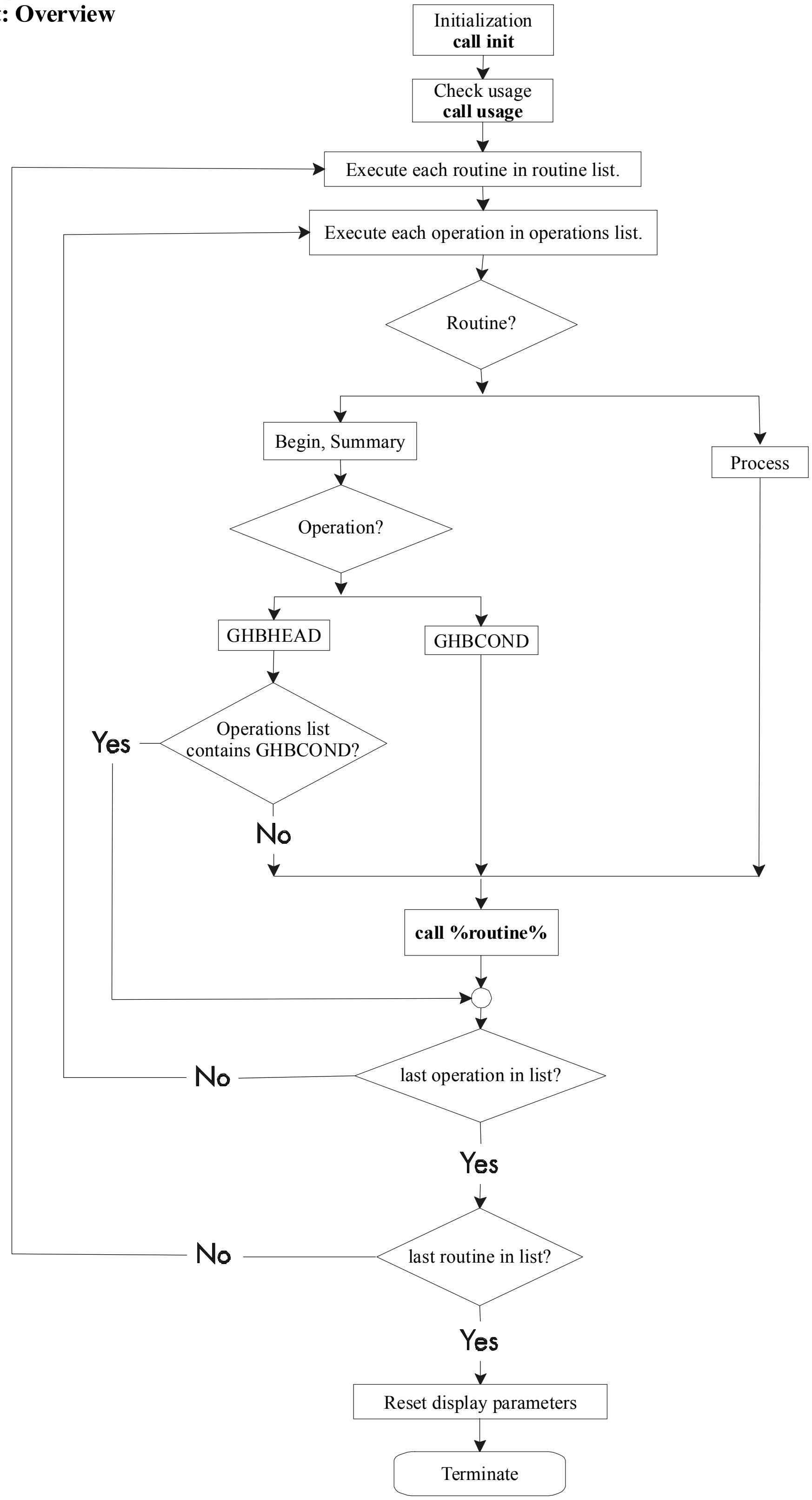


ROUTINE FINDCELLS



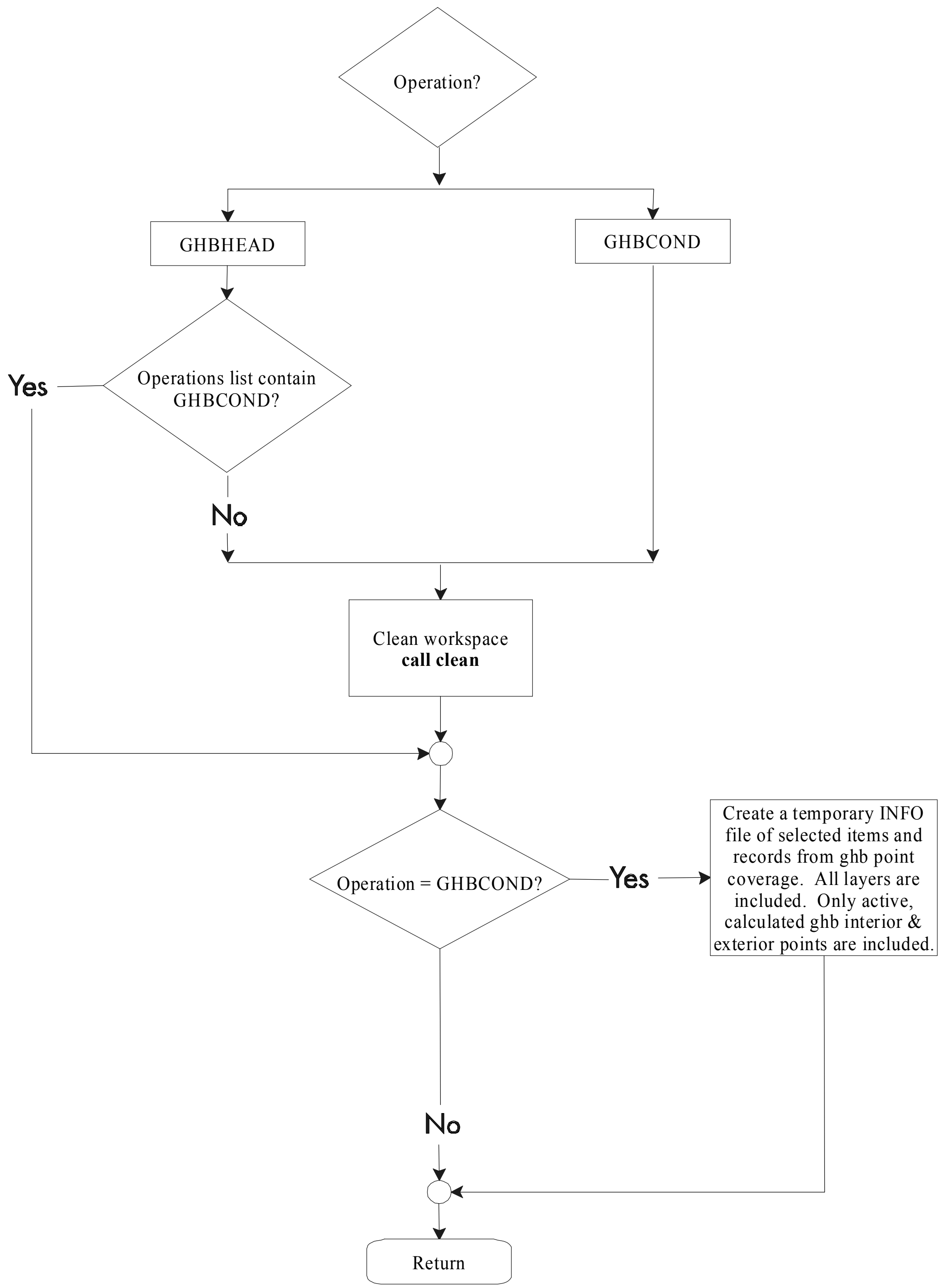
AML: ghbproc.aml
Flowchart: Overview

ghbproc.cfl



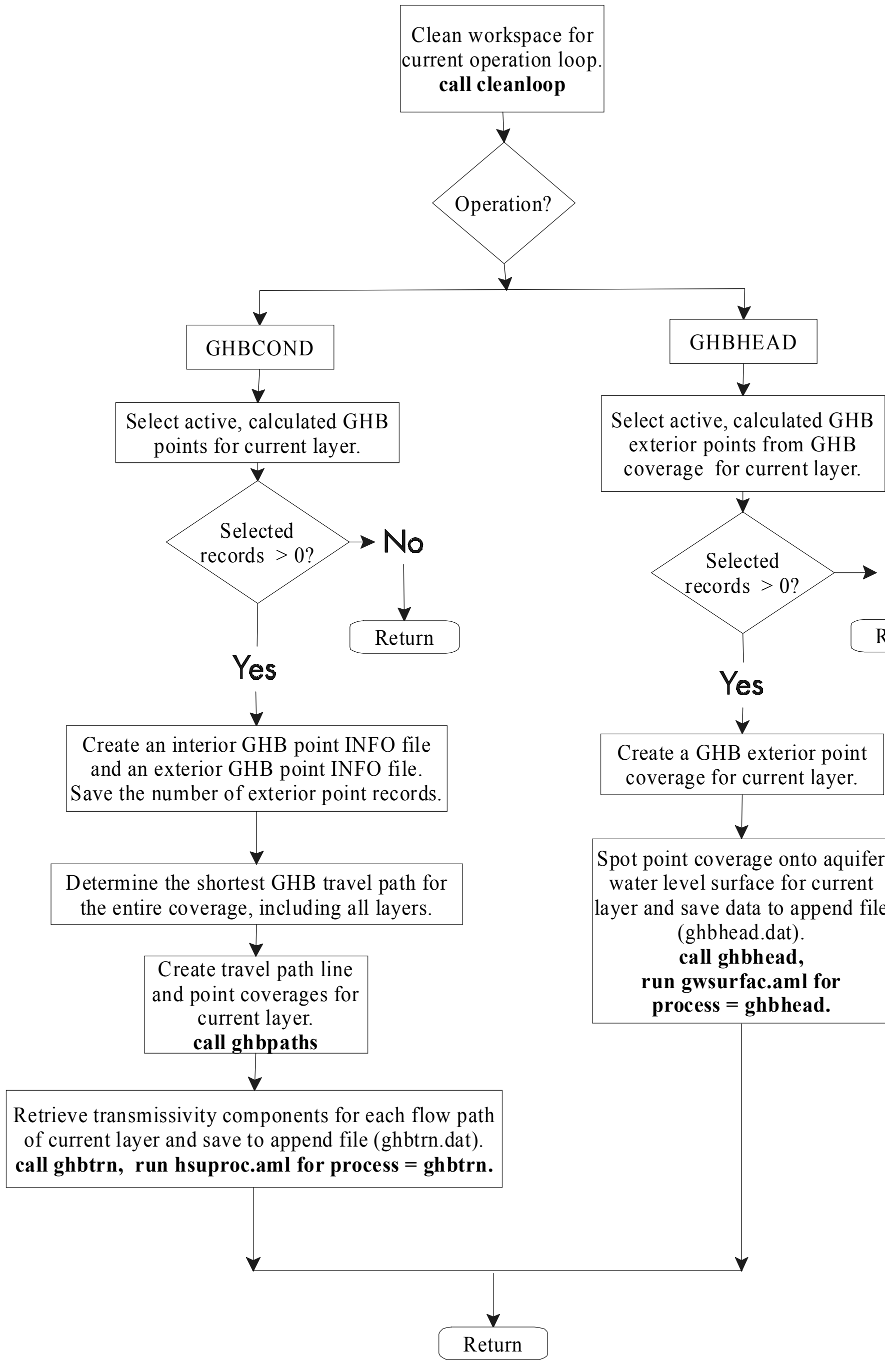
AML: ghbproc.aml
Flowchart: Routine Begin

ghbproc1.cfl



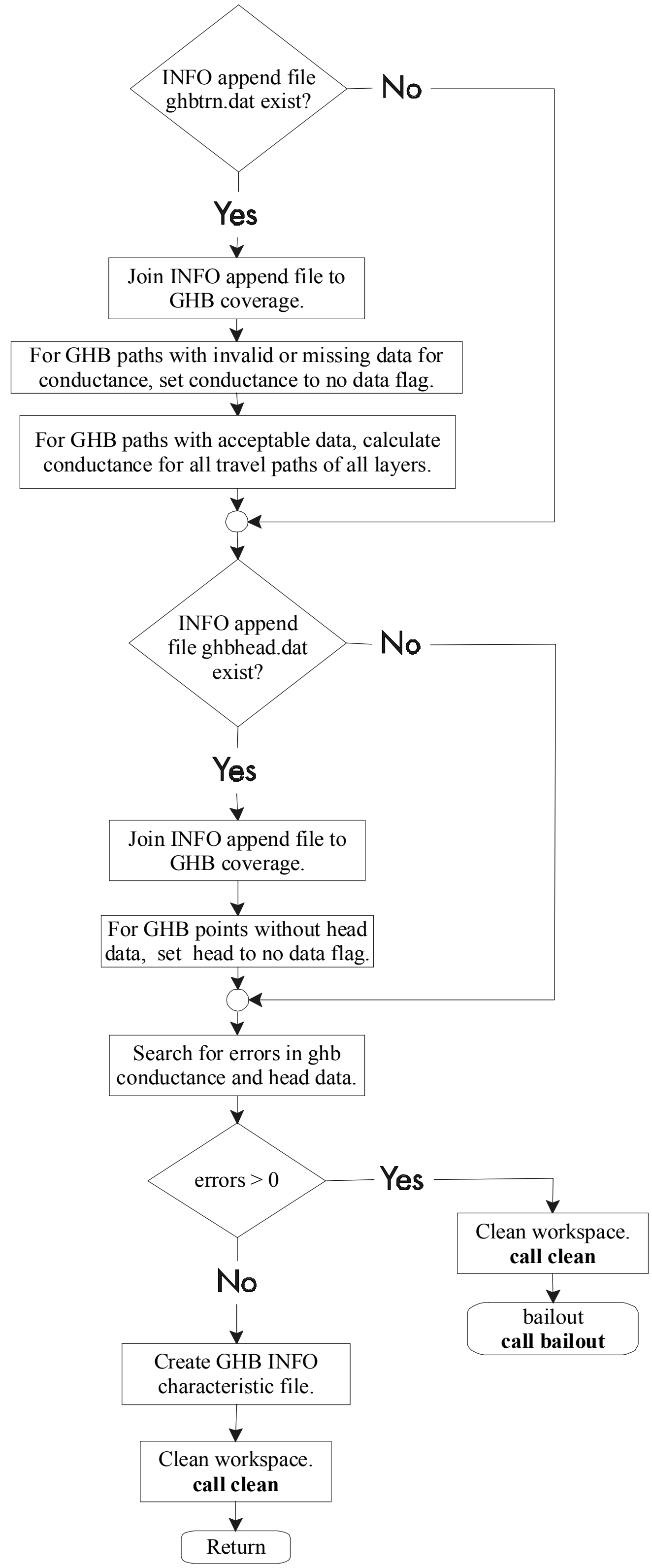
AML: ghbproc.aml
Flowchart: Routine Process

ghbproc2.cfl

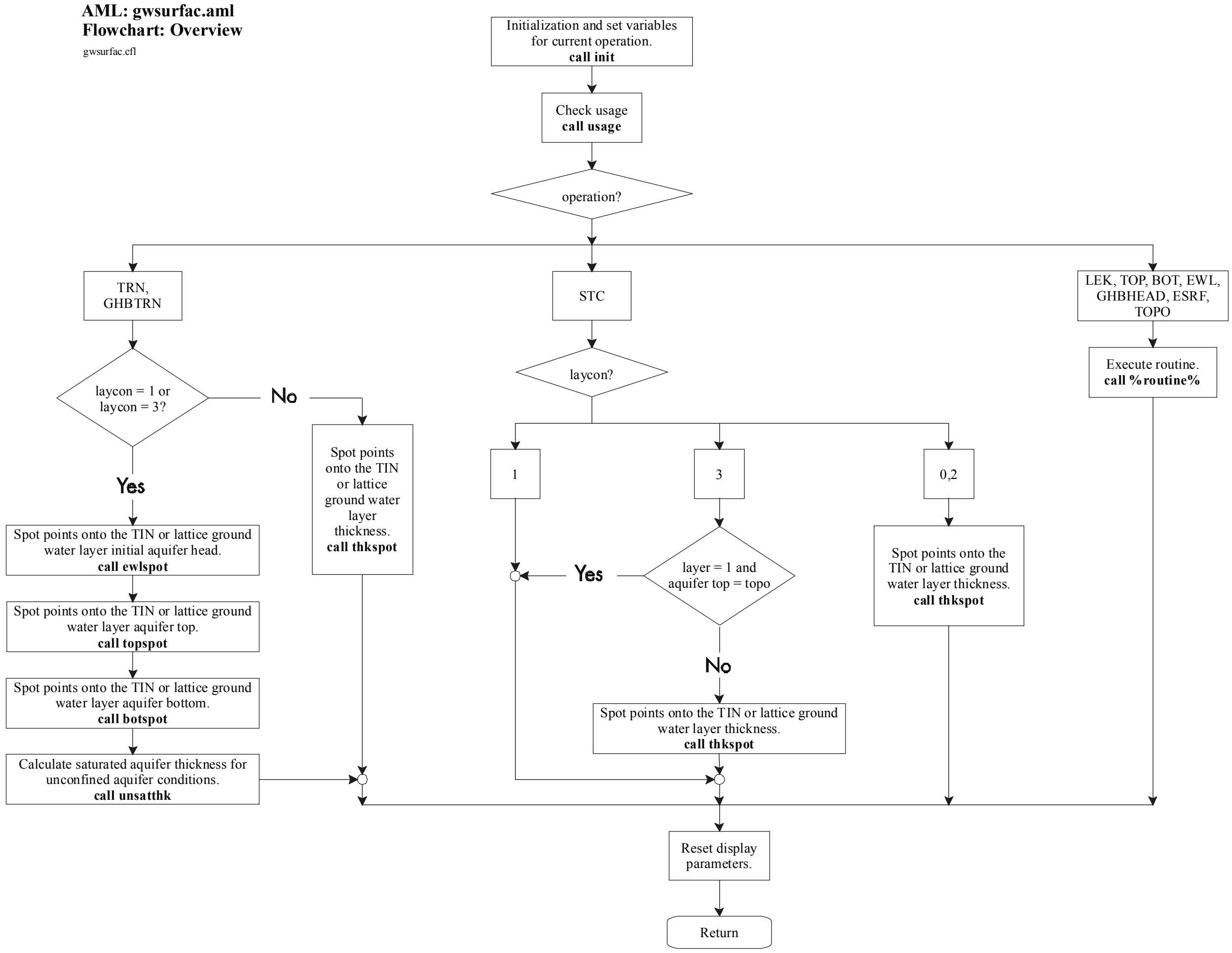


AML: ghbproc.aml
Flowchart: Routine Summary

ghbproc3.cfl

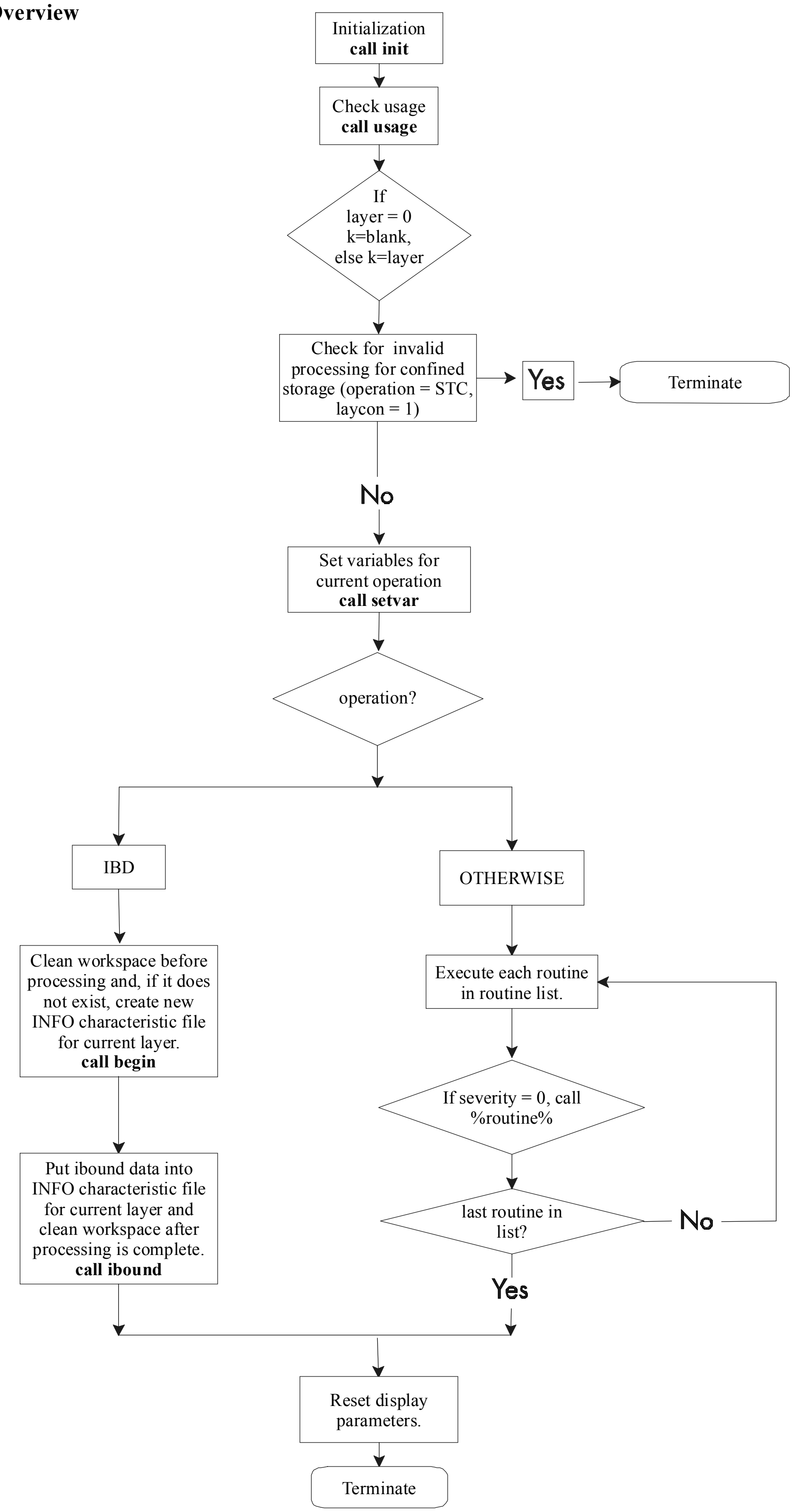


AML: gwsurfac.aml
Flowchart: Overview
gwsurfac.cfl



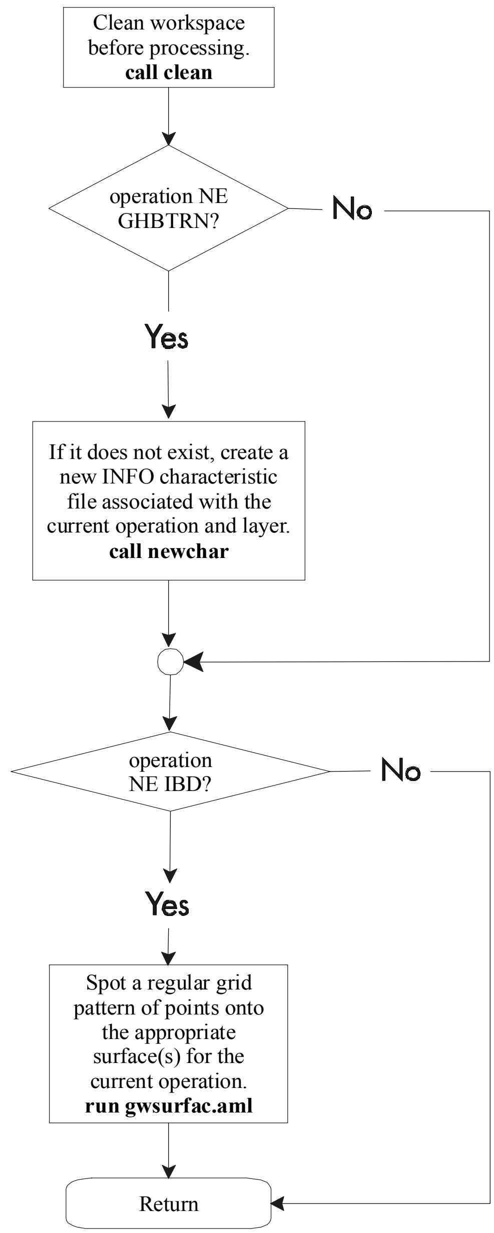
AML: hsuproc.aml
Flowchart: Overview

hsuproc.cfl



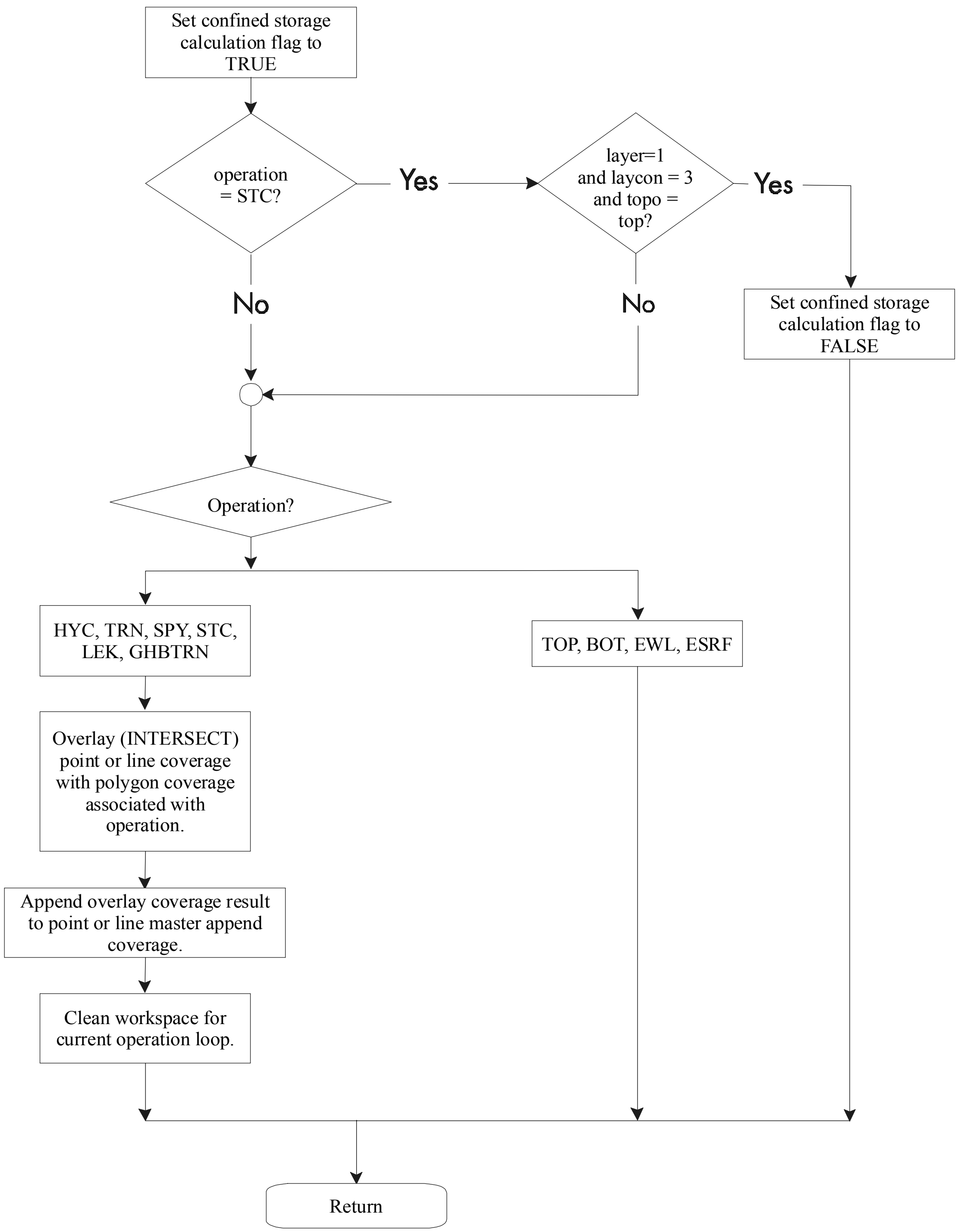
AML: hsuproc.aml
Flowchart: Routine Begin

hsuproc1.cfl

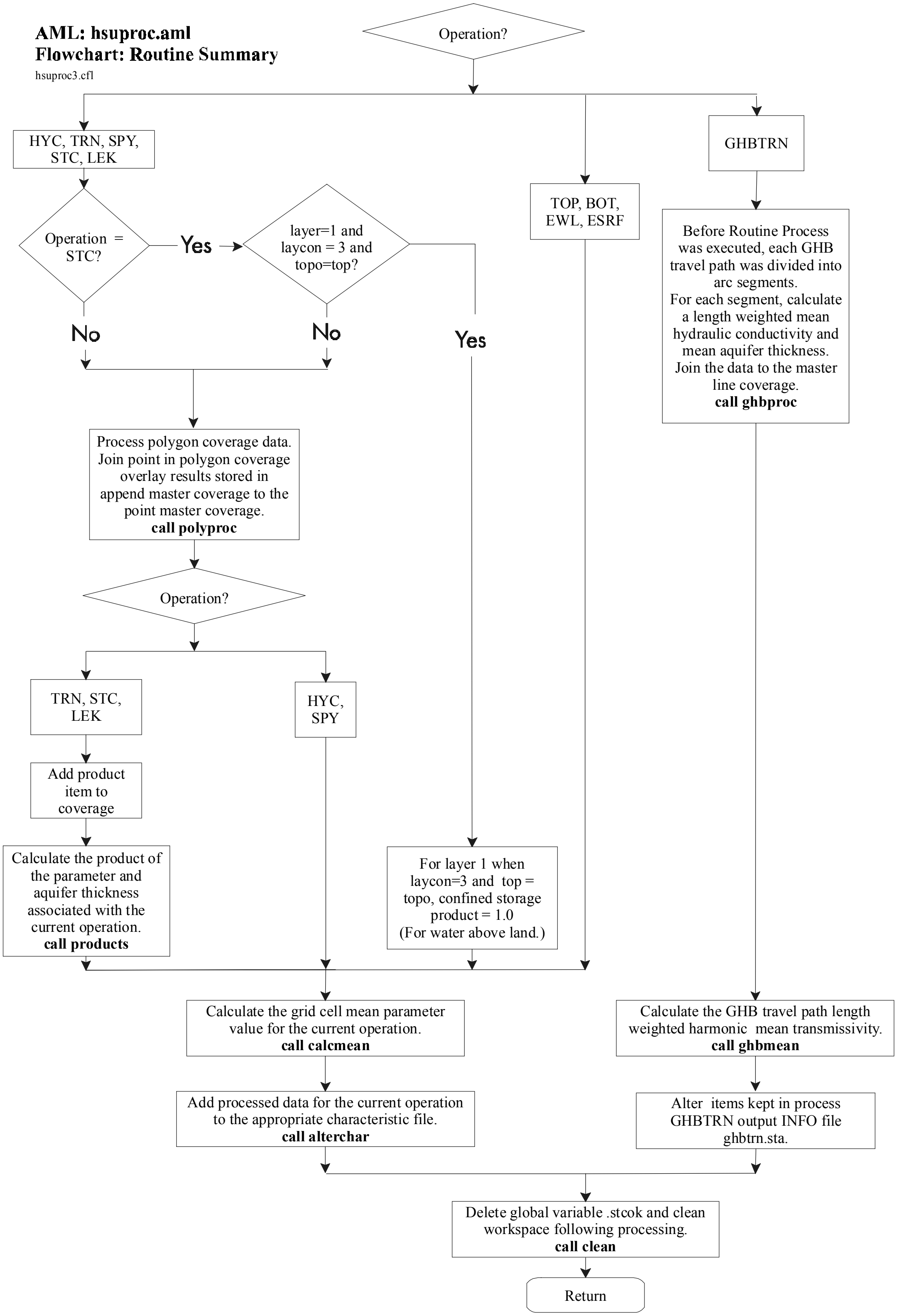


AML: hsuproc.aml
Flowchart: Routine Process

hsuproc2.cfl

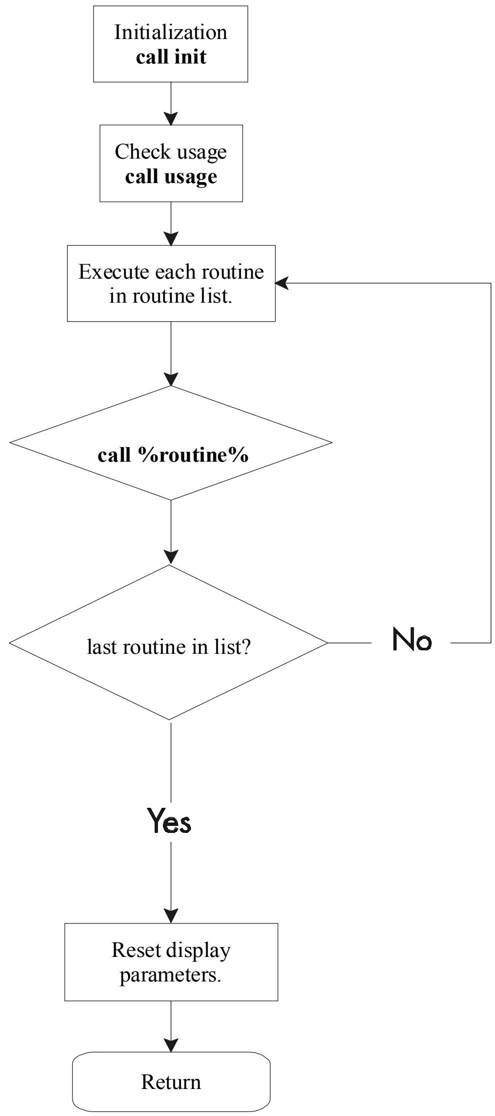


AML: hsuproc.aml
Flowchart: Routine Summary
hsuproc3.cfl



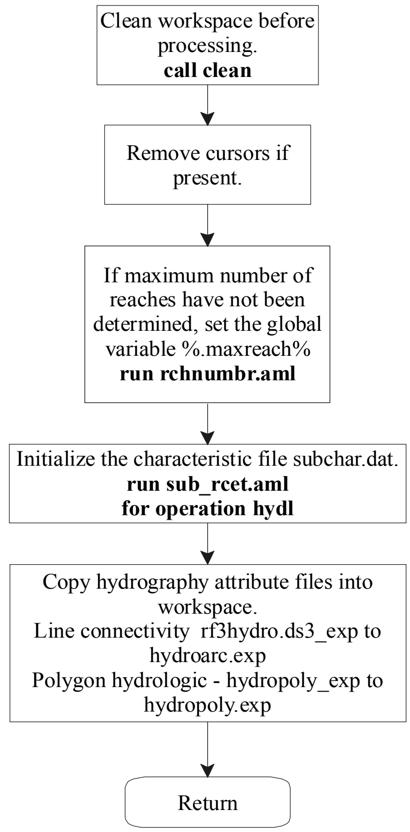
AML: hydlen.aml
Flowchart: Overview

hydlen.cfl

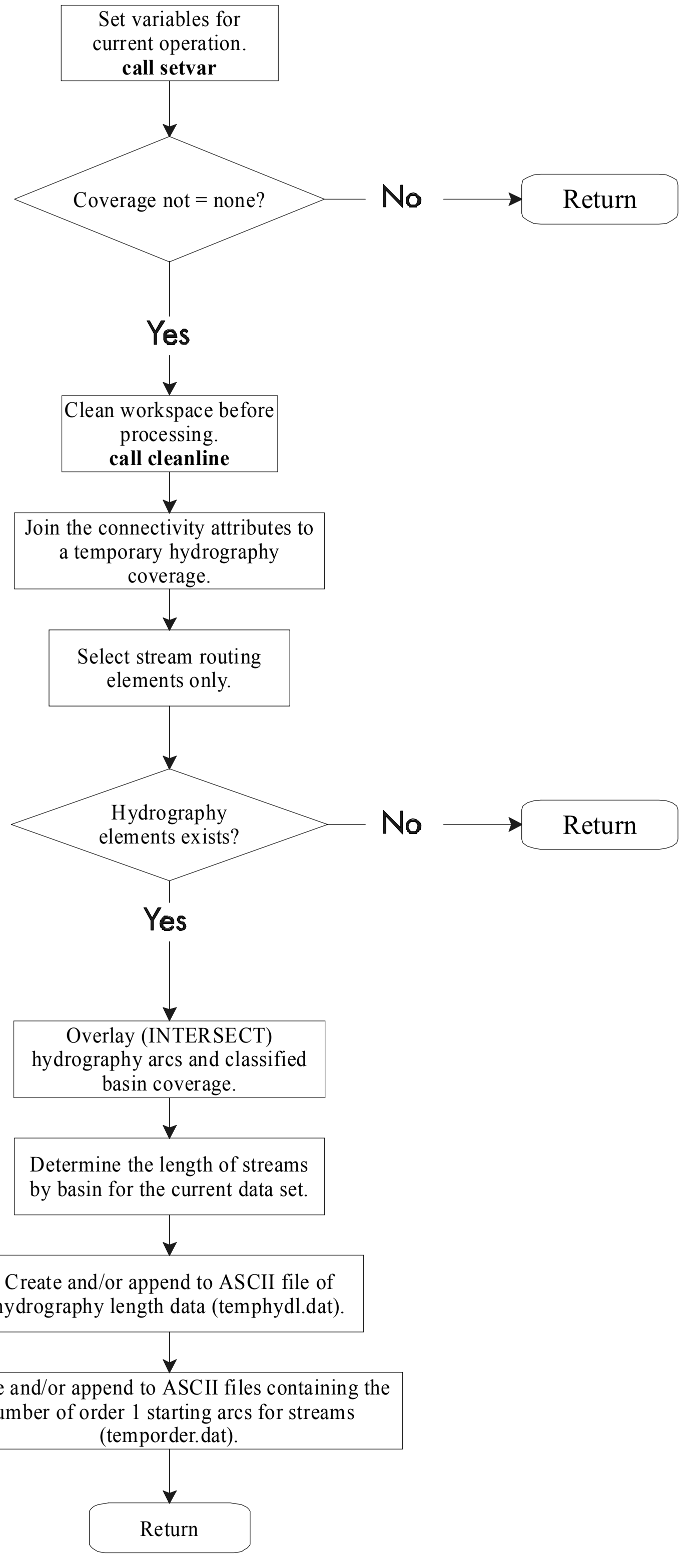


AML: hydlen.aml
Flowchart: Routine Begin

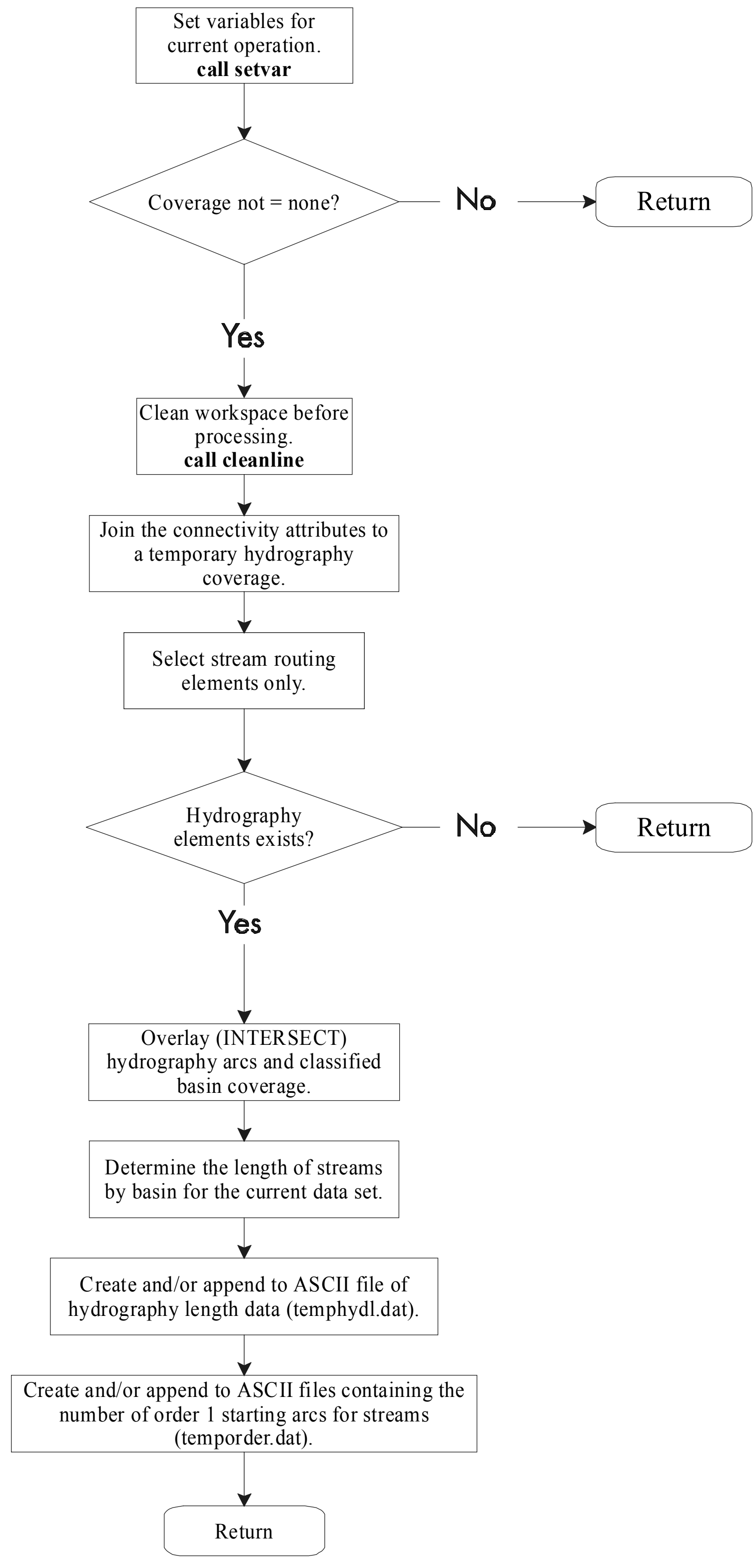
hydlen1.cfl



AML: hydlen.aml
Flowchart: Routine Linelen
hydlen2.cfl

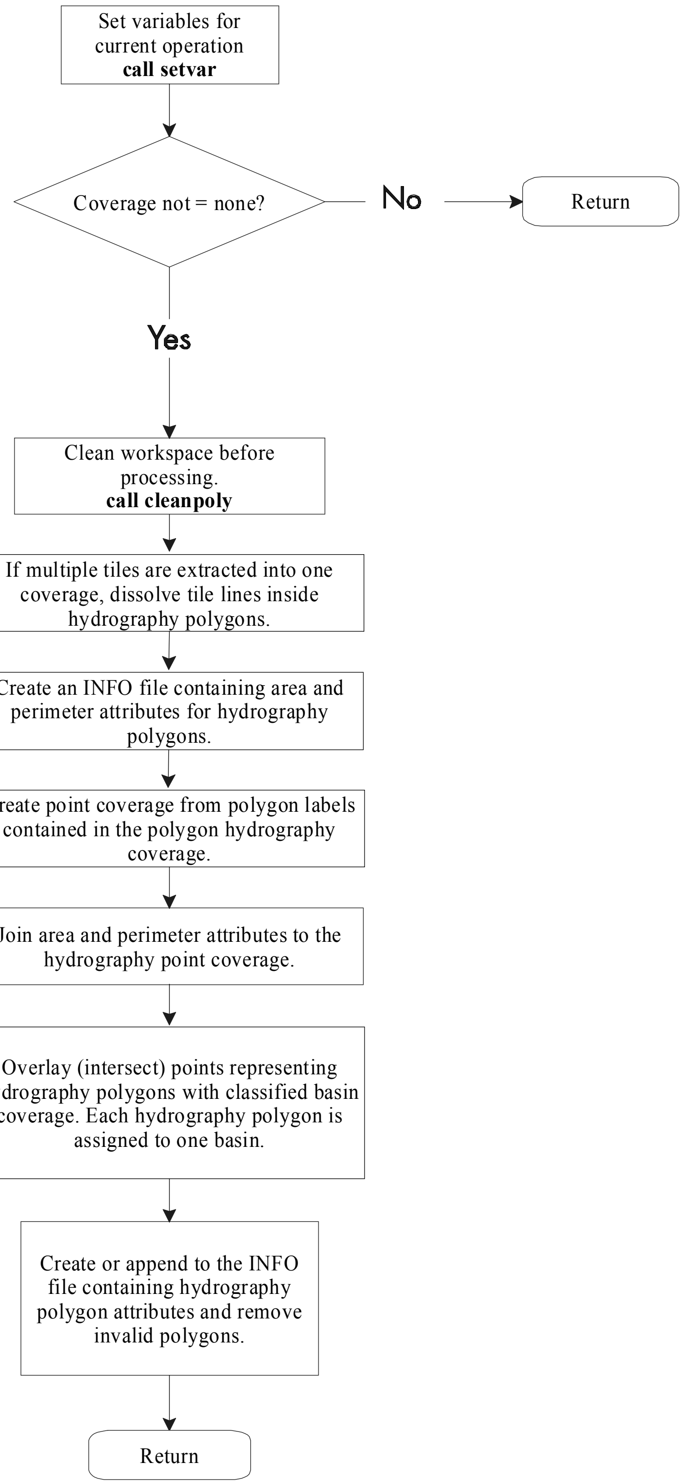


AML: hydlen.aml
Flowchart: Routine Linelen
hydlen2.cfl



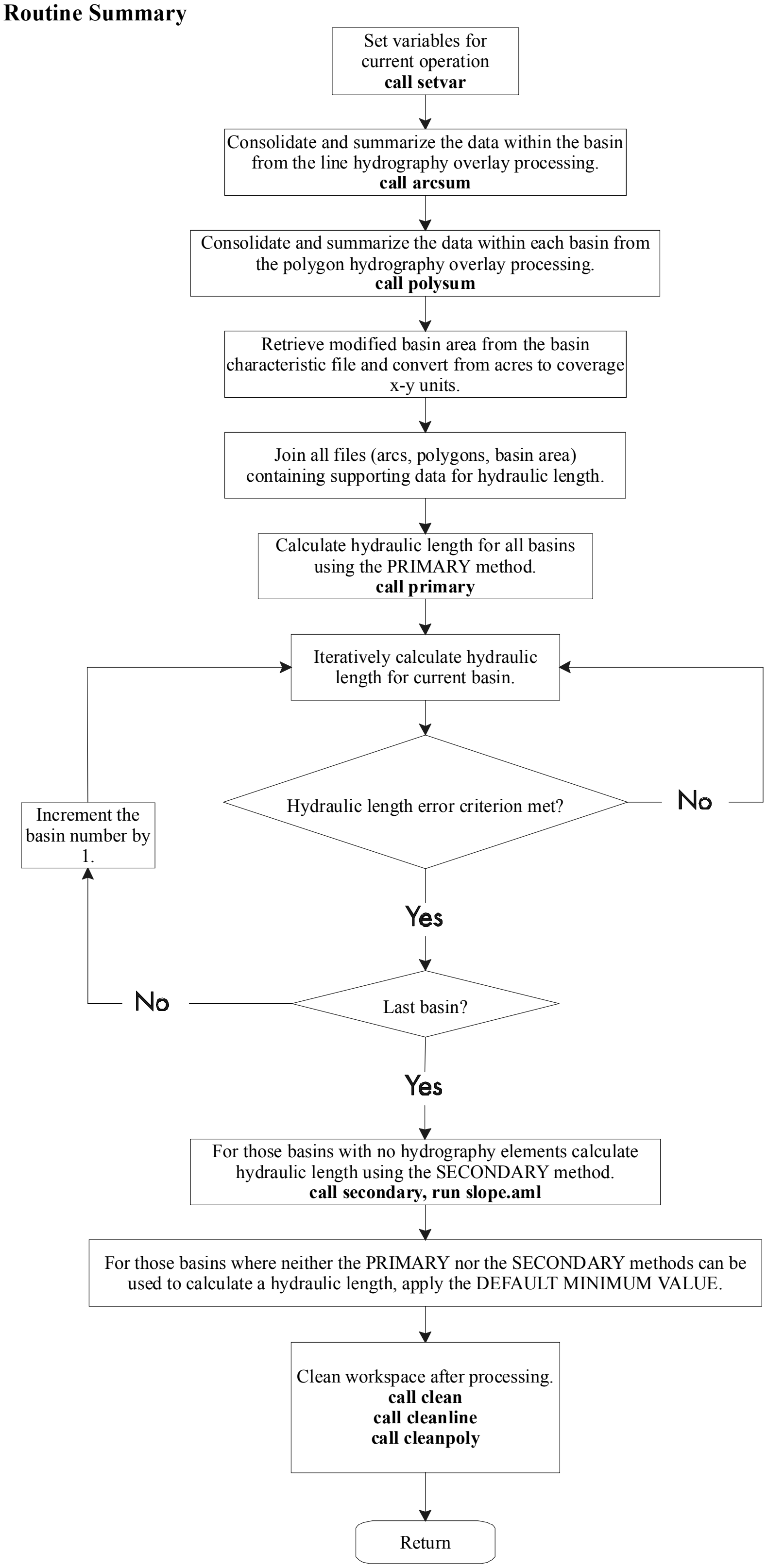
AML: hydlen.aml
Flowchart: Routine Polylen

hydlen3.cfl



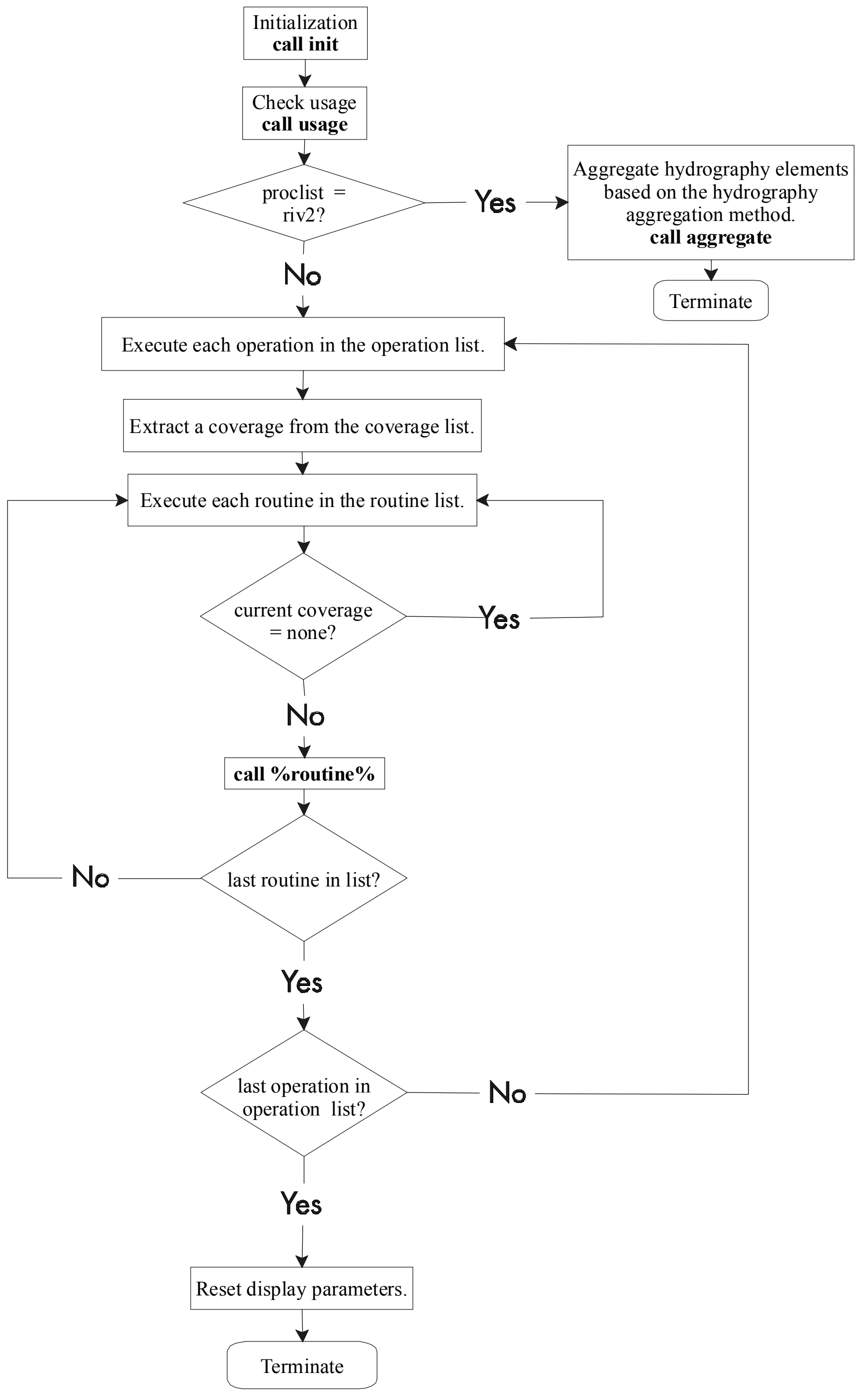
AML: hydlen.aml
Flowchart: Routine Summary

hydlen4.cfl



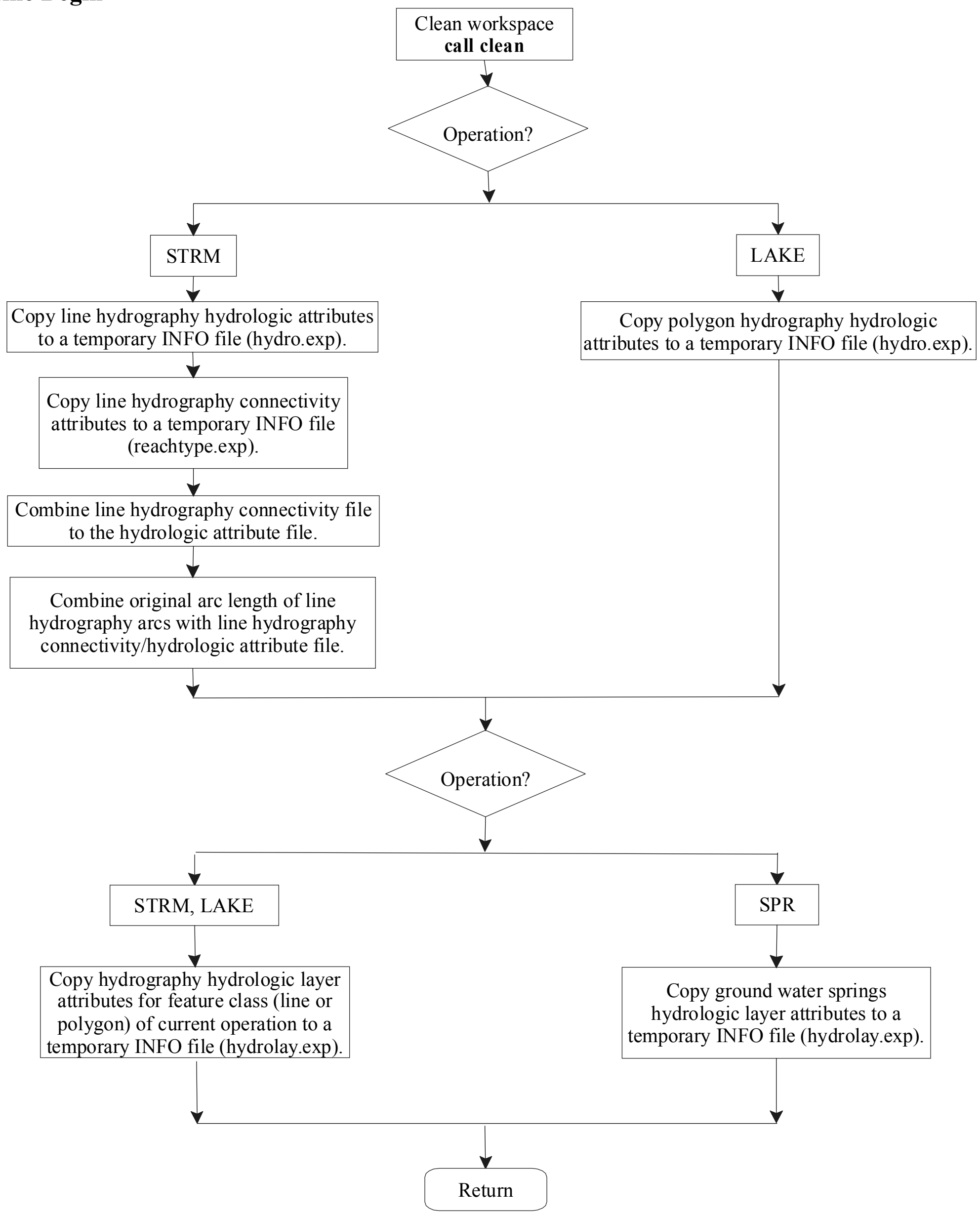
AML: hydrogw.aml
Flowchart: Overview

hydrogw.cfl



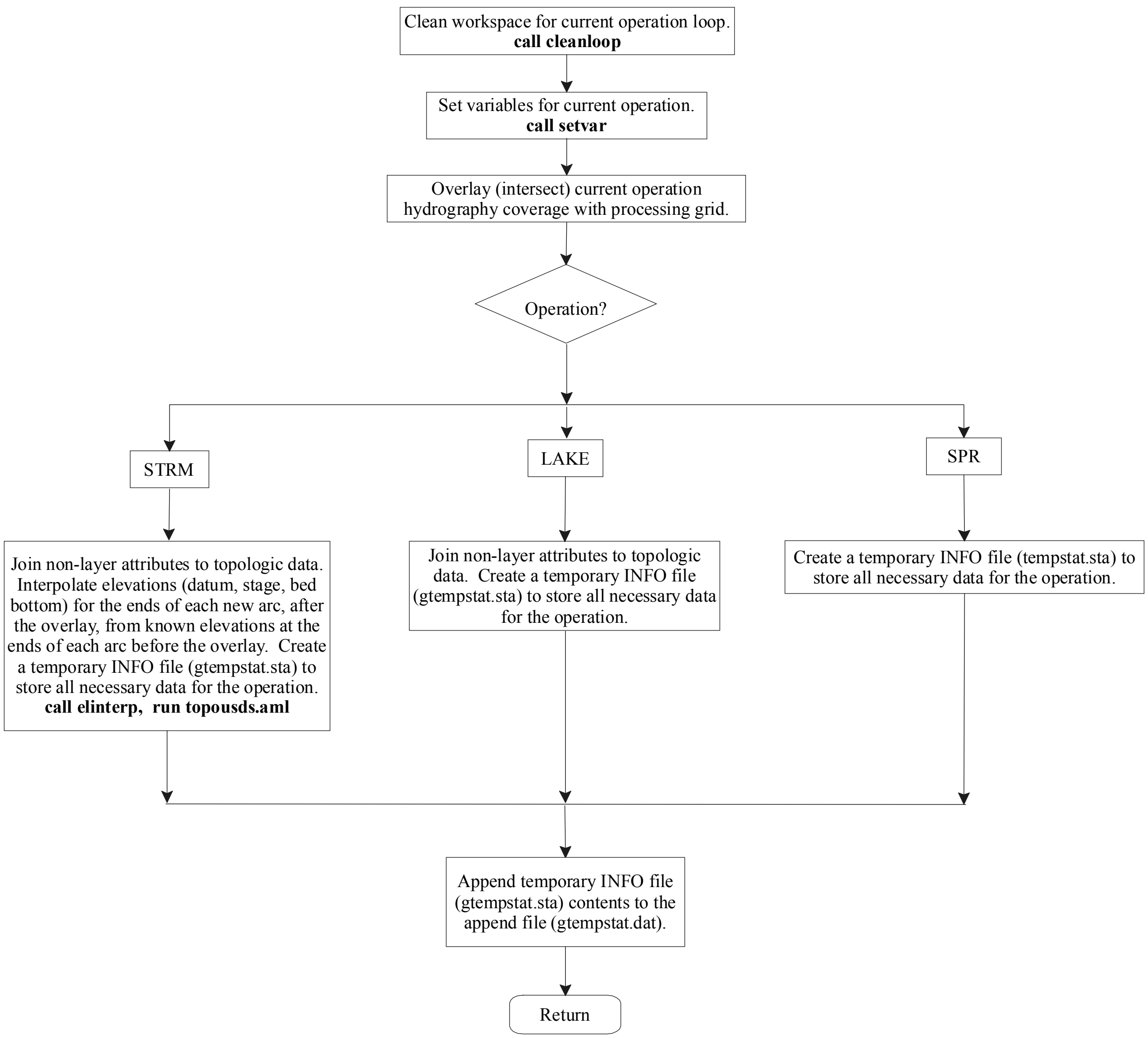
AML: hydrogw.aml
Flowchart: Routine Begin

hydrogw1.cfl



AML: hydrogw.aml
Flowchart: Routine Process

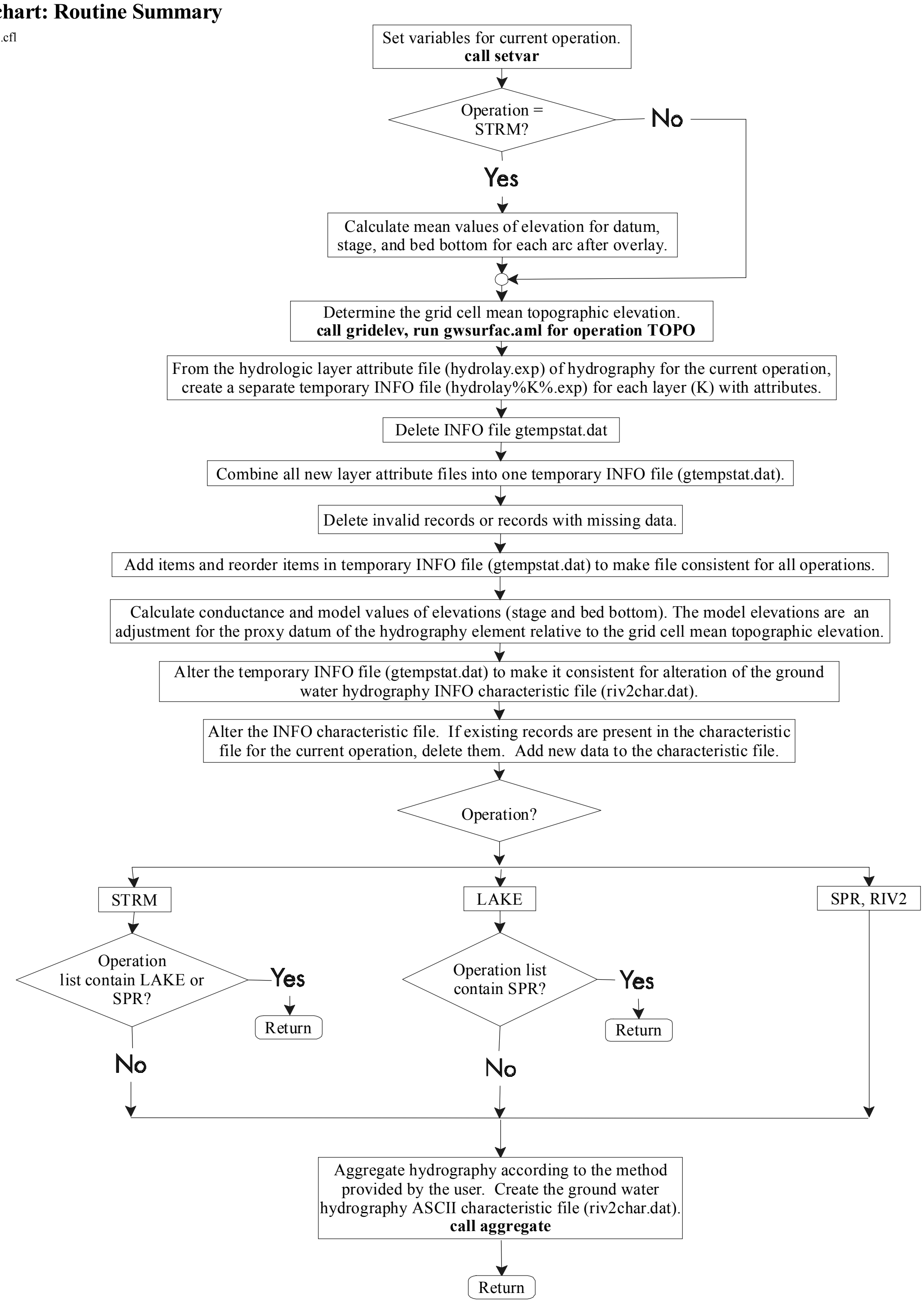
hydrogw2.cfl



AML: hydrogw.aml

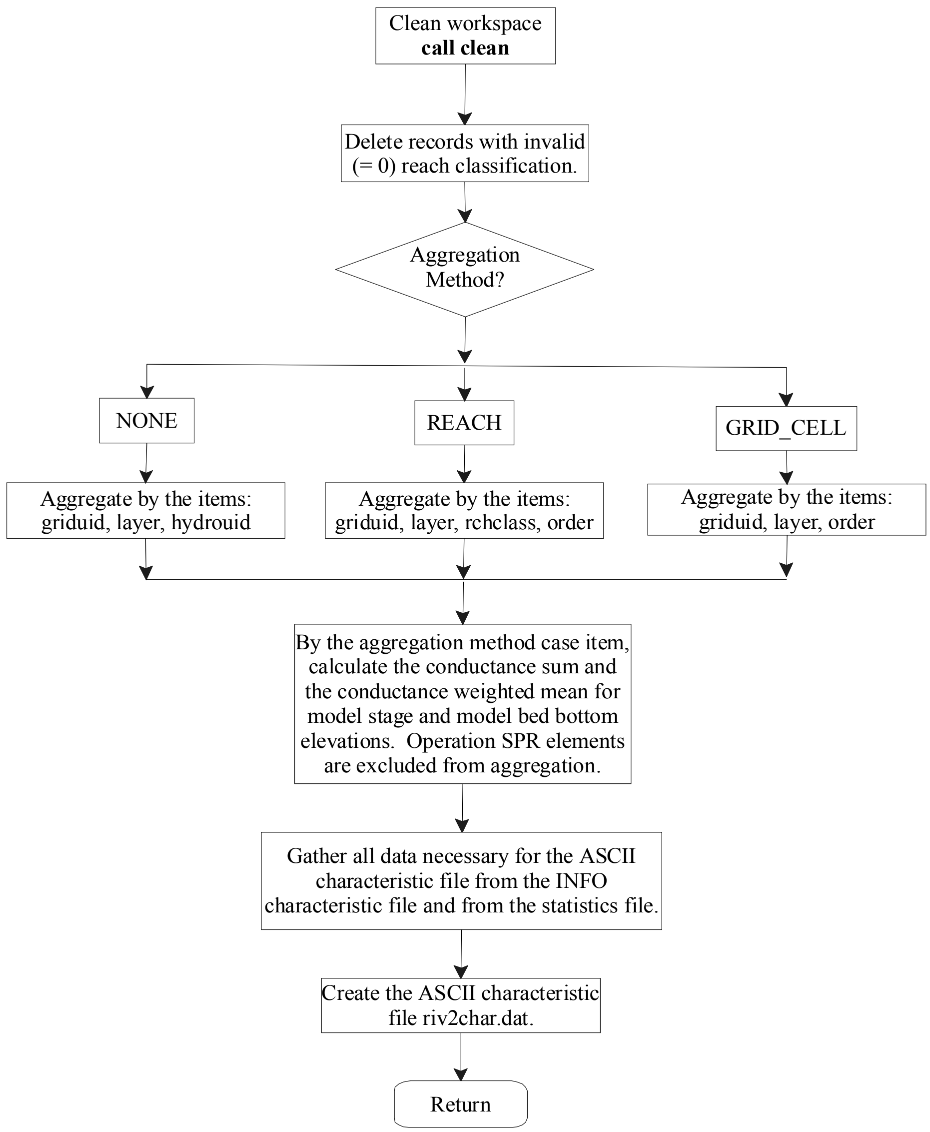
Flowchart: Routine Summary

hydrogw3.cfl



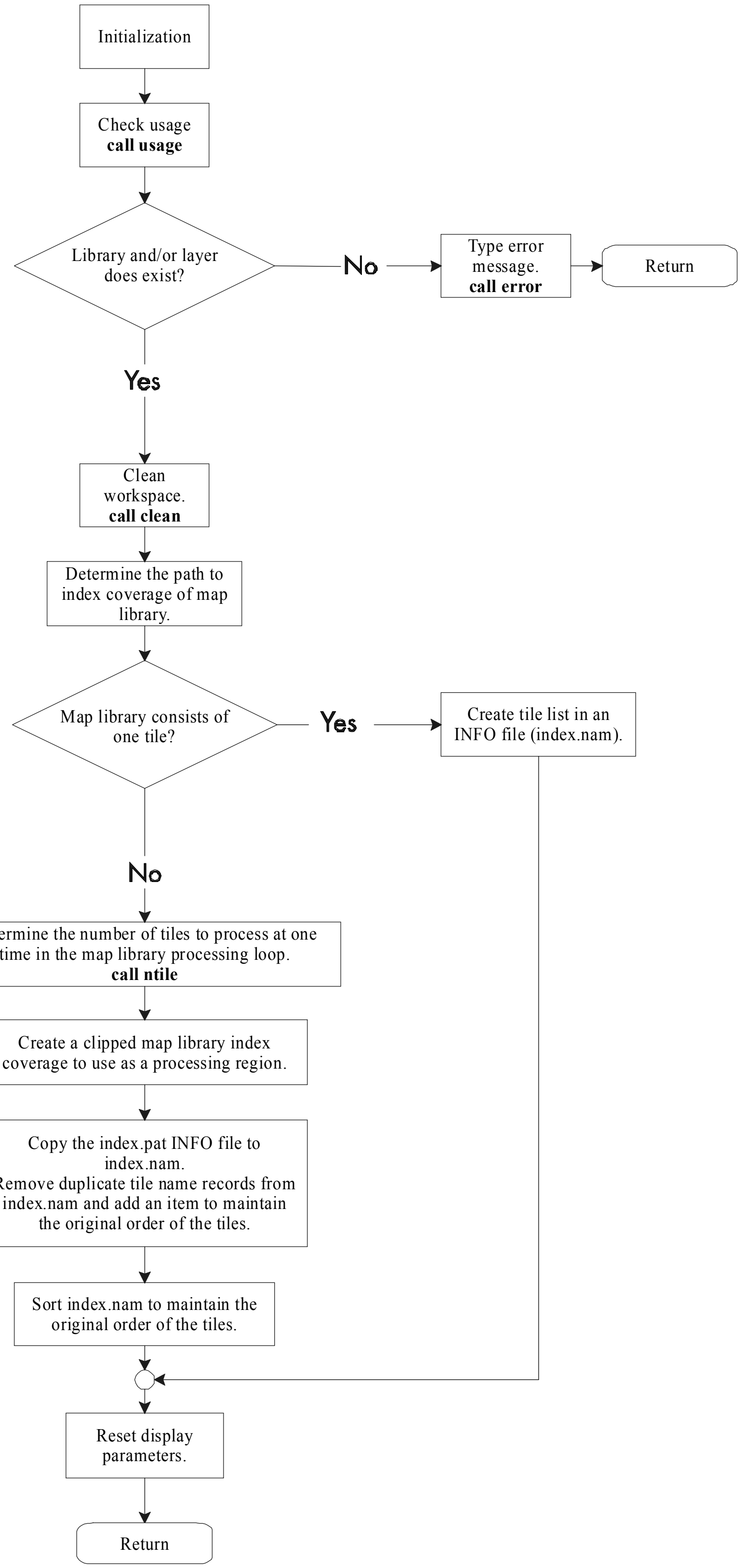
AML: hydrogw.aml
Flowchart: Routine Aggregate

hydrogw4.cfl



AML: librpre.aml
Flowchart: overview

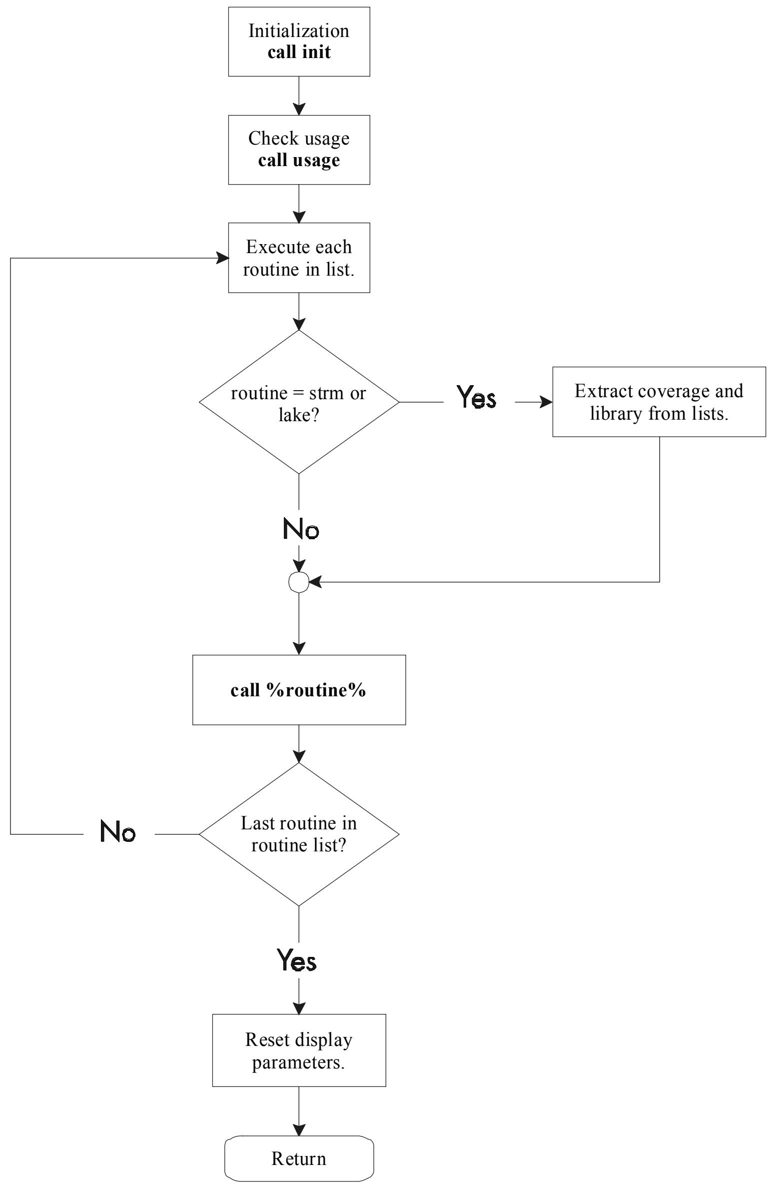
librpre.cfl



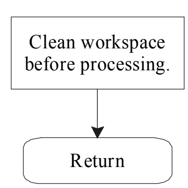
AML: outfall.aml
Flowchart: Overview
and Routine Cleanbeg

outfall.cfl

Overview

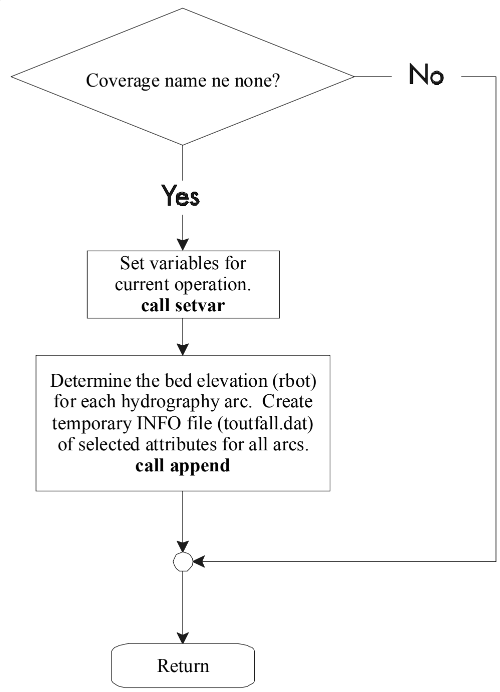


Routine Cleanbeg

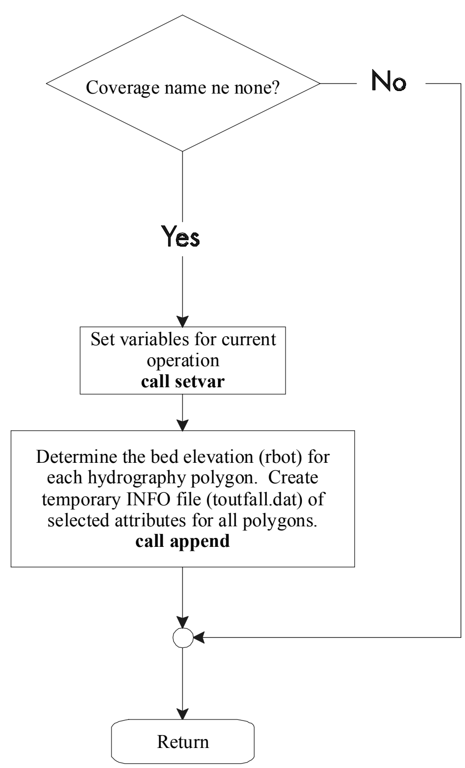


AML: outfall.aml
Flowchart: Routines Strm and Lake
outfall1.cfl

Routine Strm

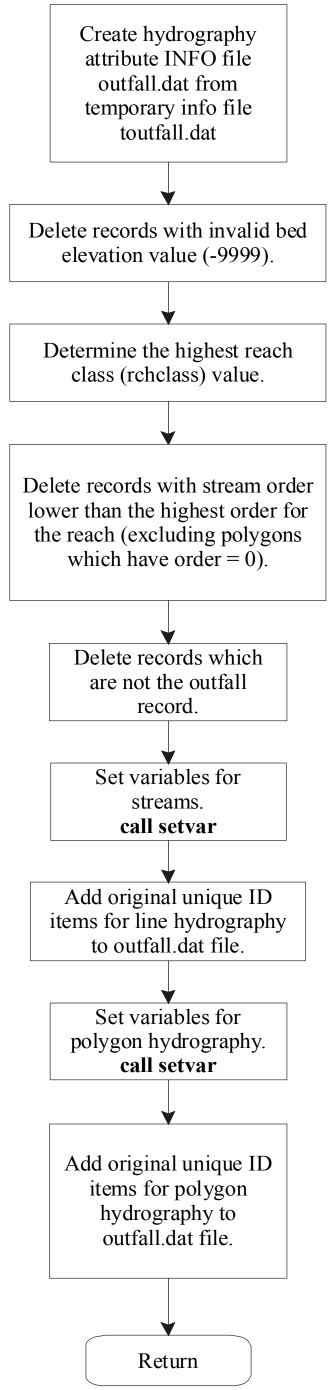


Routine Lake



AML: outfall.aml
Flowchart: Routine Combine

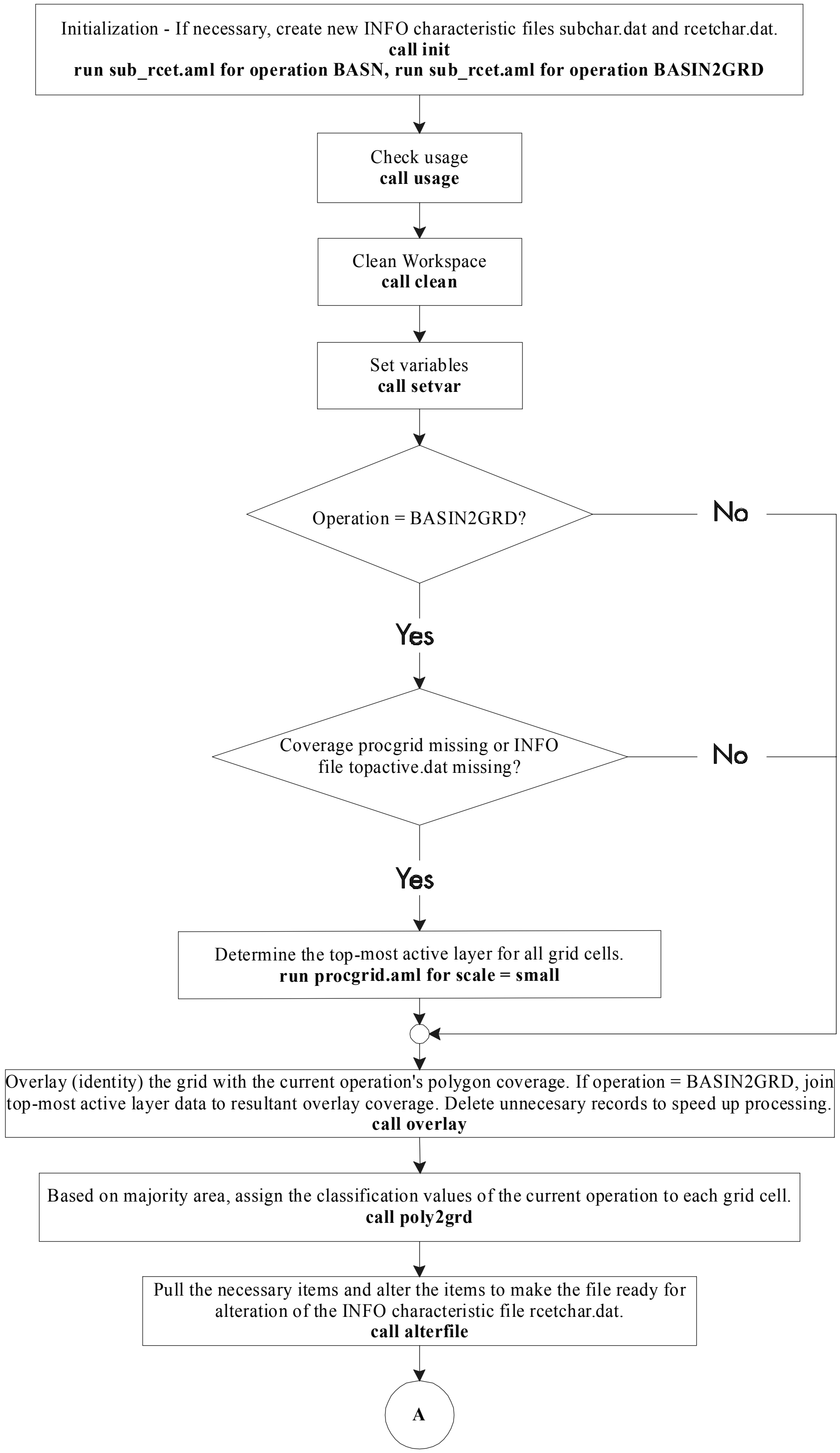
outfall2.cfl



AML: poly2grd.aml

Flowchart: All

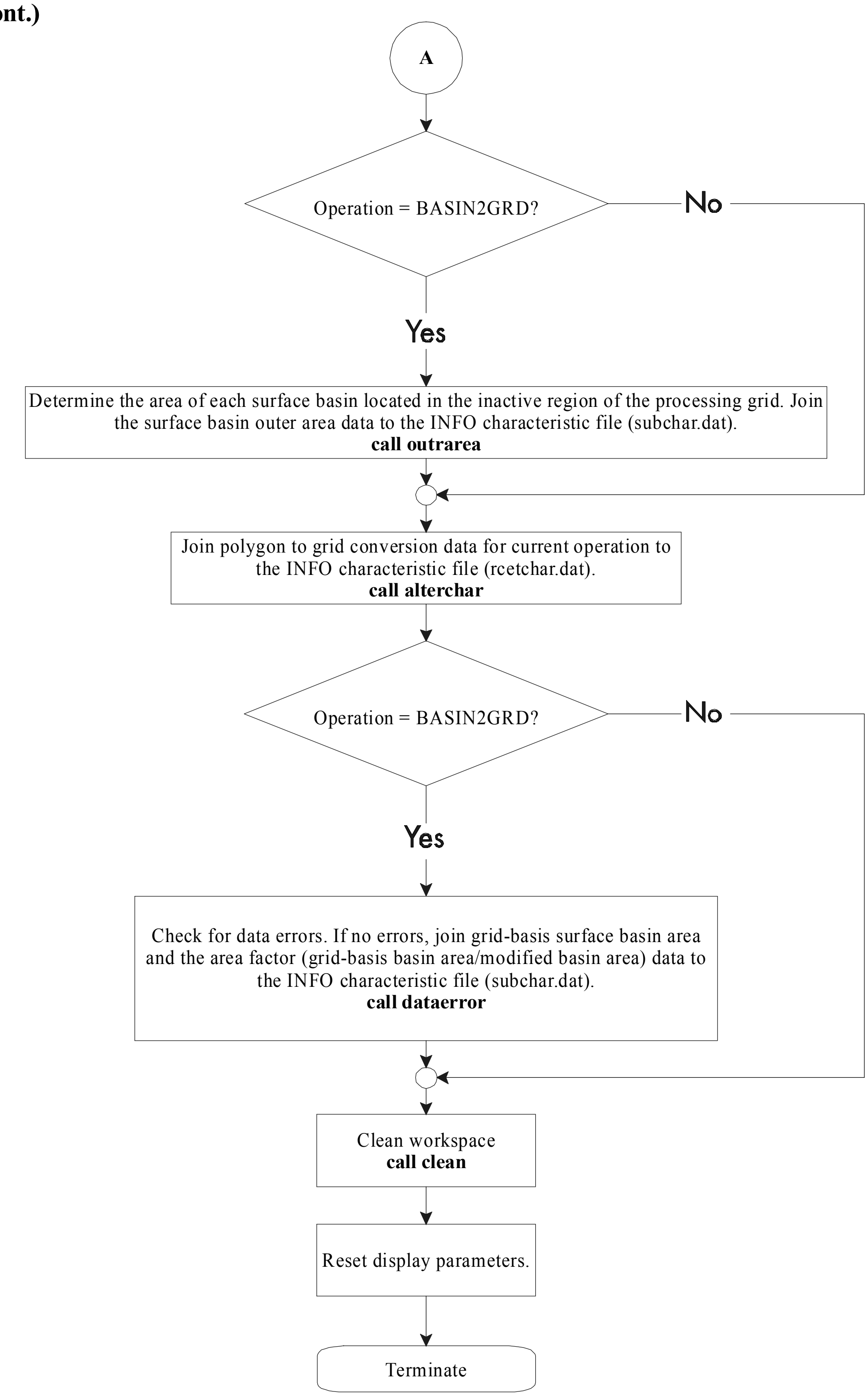
poly2gr.cfl



AML: poly2grd.aml

Flowchart: All (cont.)

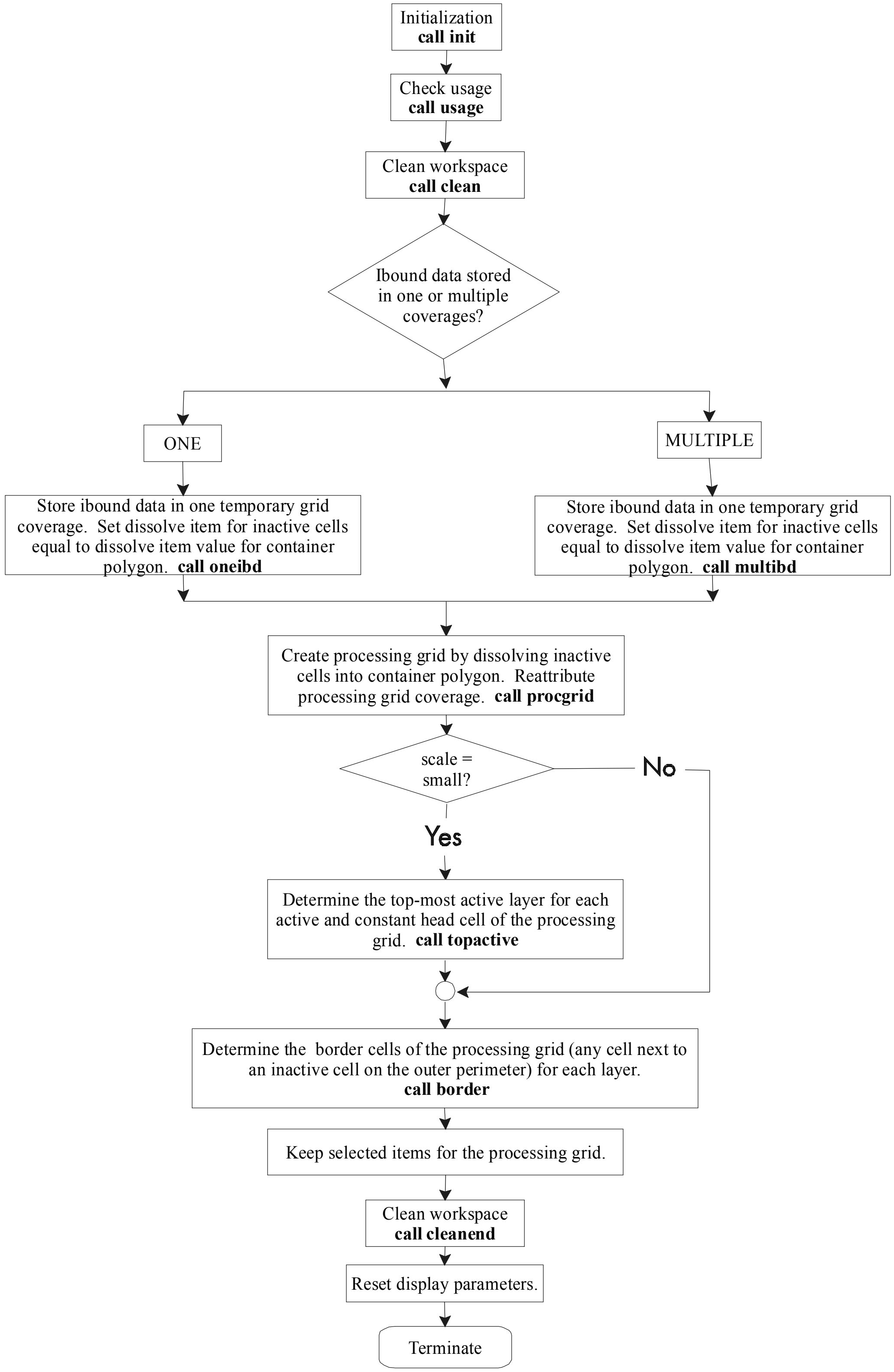
poly2gr1.cfl



AML: procgrid.aml

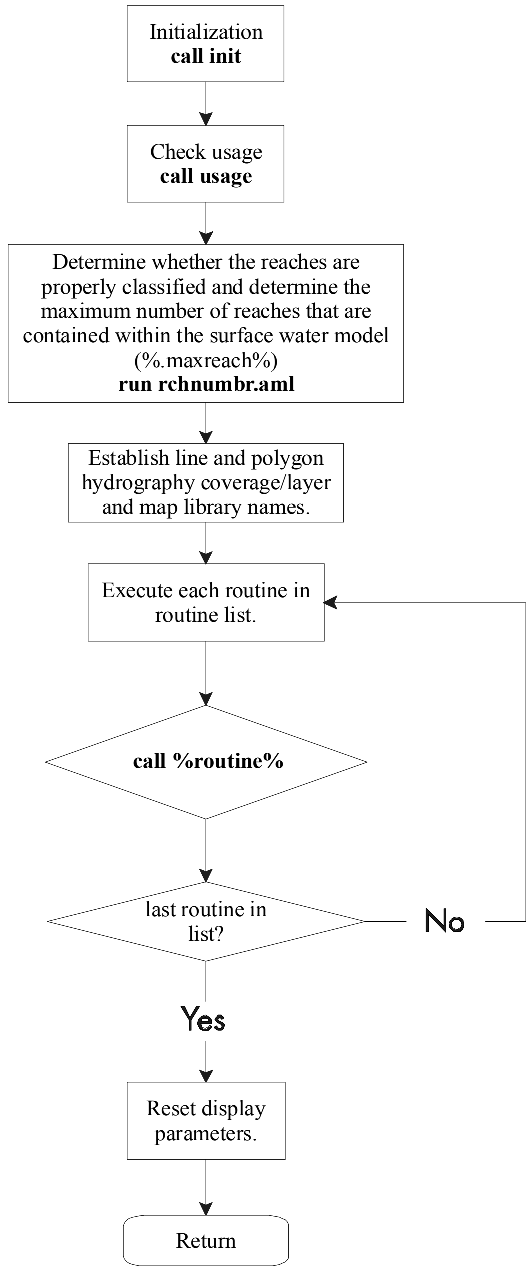
Flowchart: All

procgrid.cfl



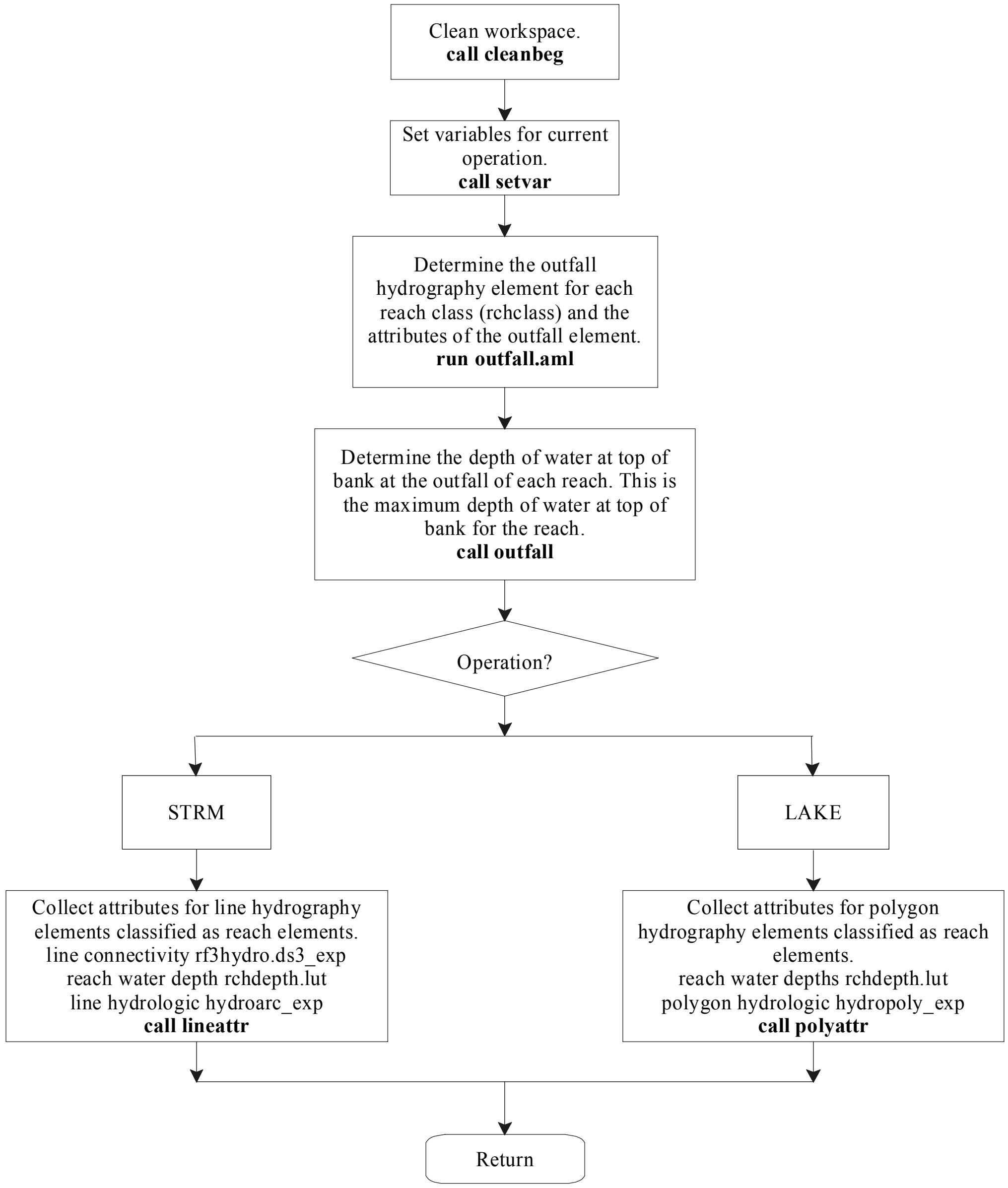
AML: rchdavd.aml
Flowchart: Overview

rchdavd.cfl



AML: rchdavd.aml
Flowchart: Routine Attribute

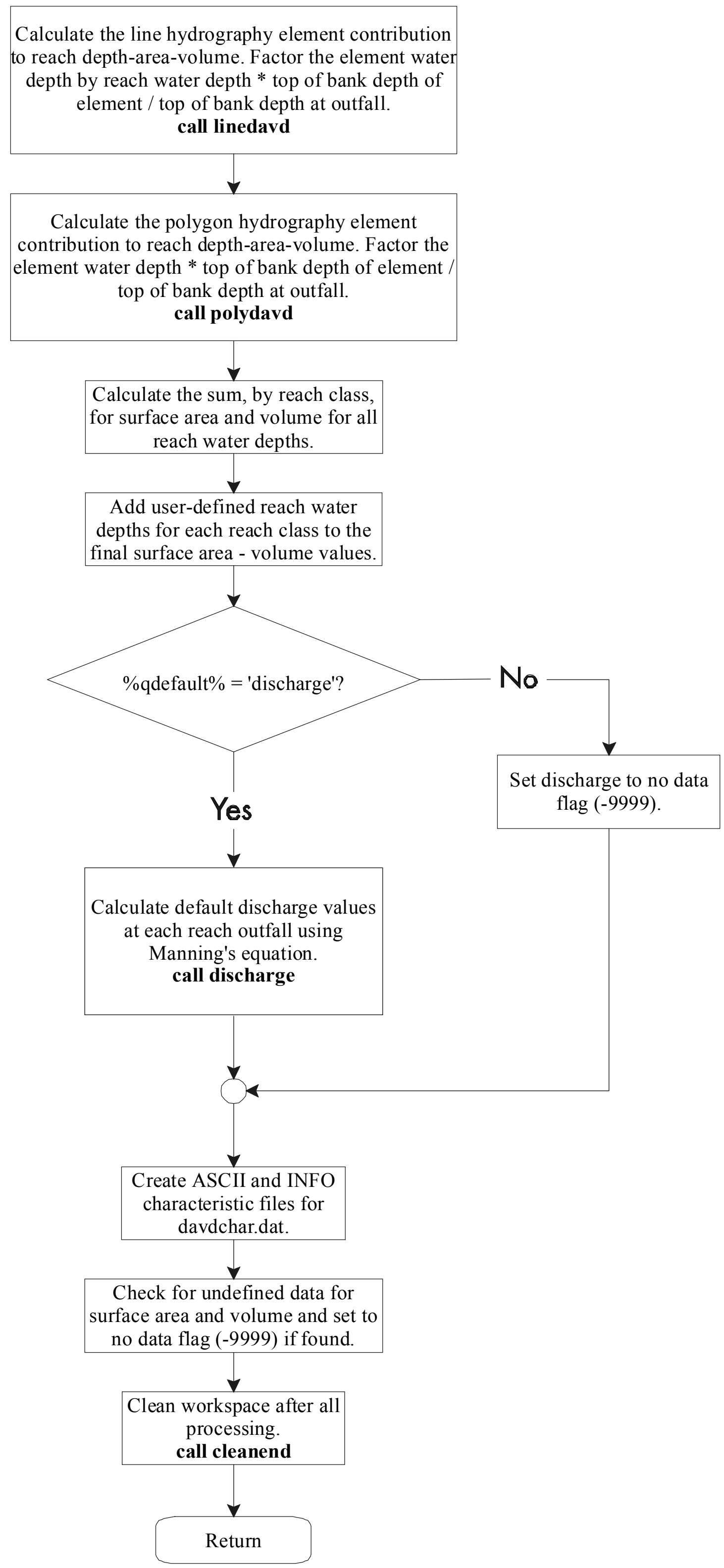
rchdavd1.cfl



AML: rchdavd.aml

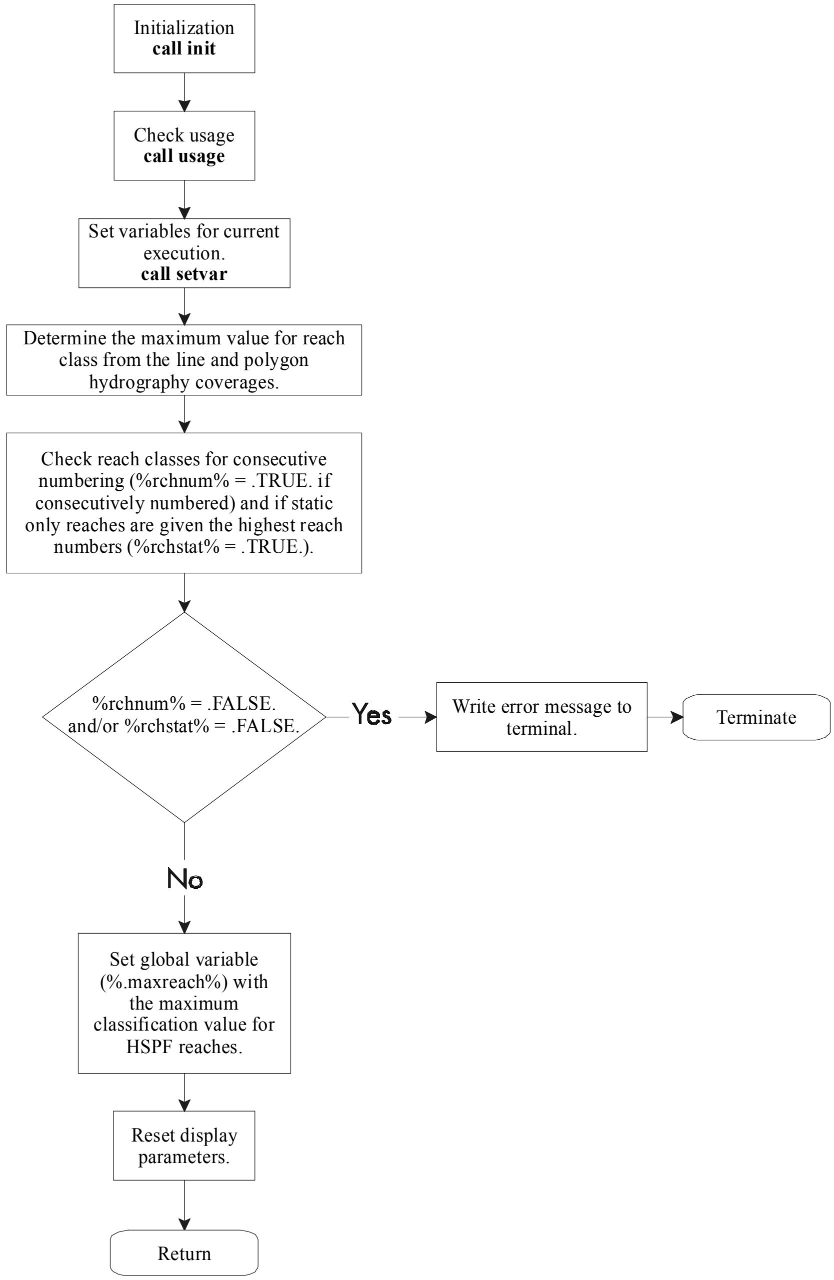
Flowchart: Routine Davd

rchdavd2.cfl



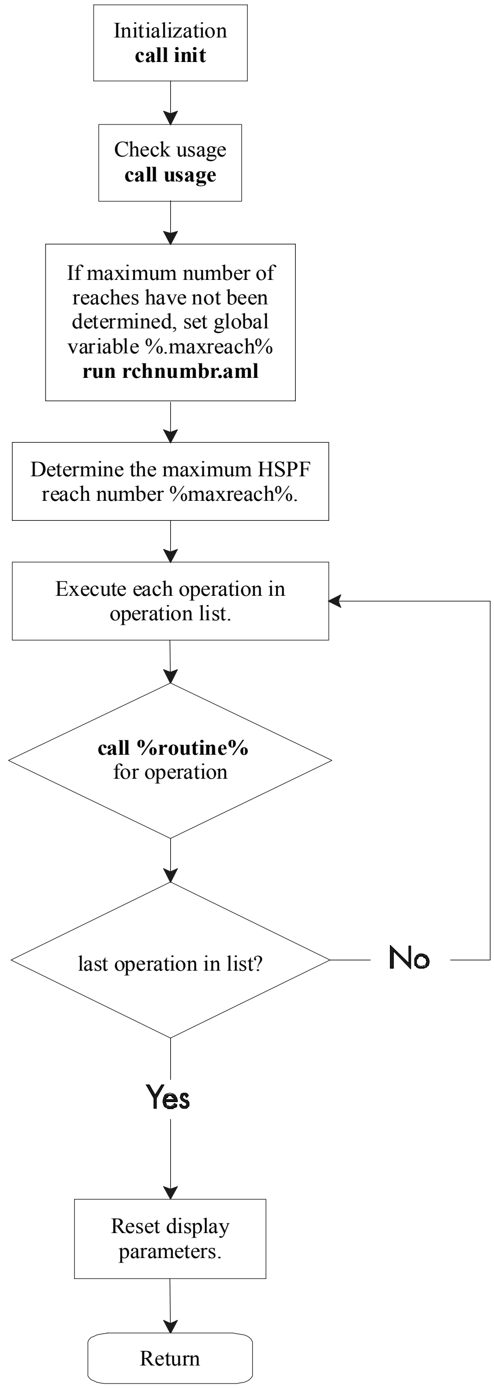
AML: rchnumbr.aml
Flowchart: overview

rchnumbr.cfl



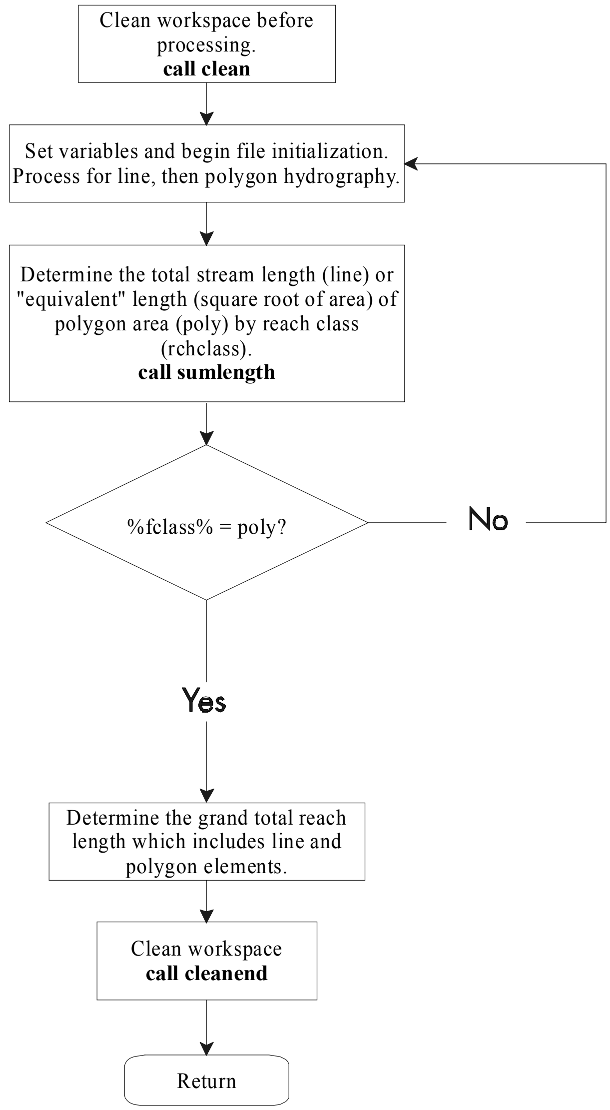
AML: rivchar.aml
Flowchart: Overview

rivchar.cfl



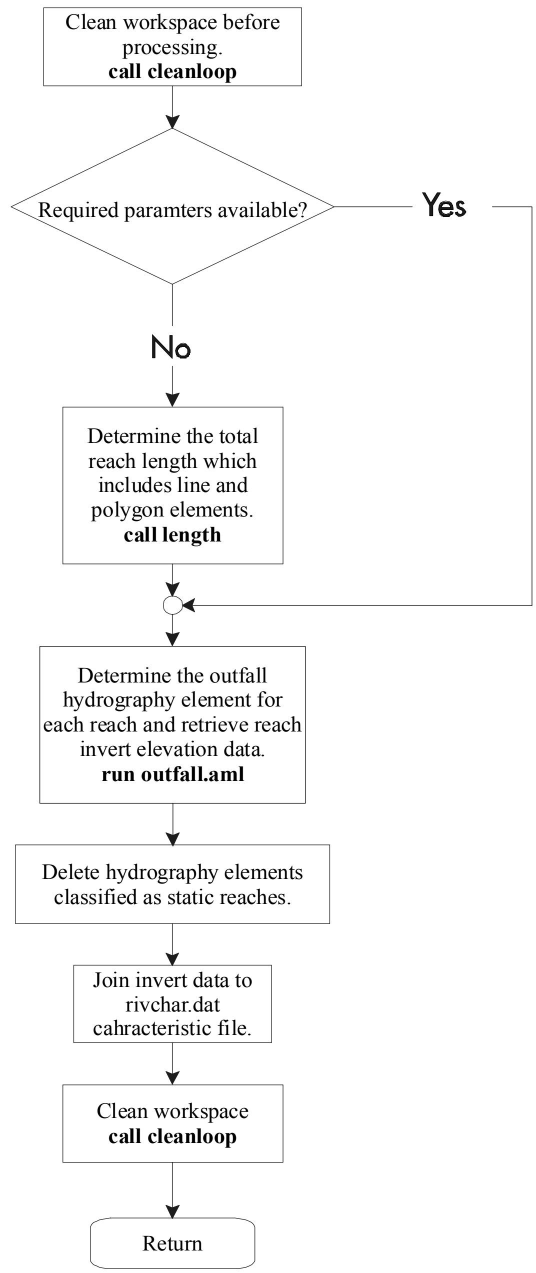
AML: rivchar.aml
Flowchart: Routine Length

rivchar1.cfl

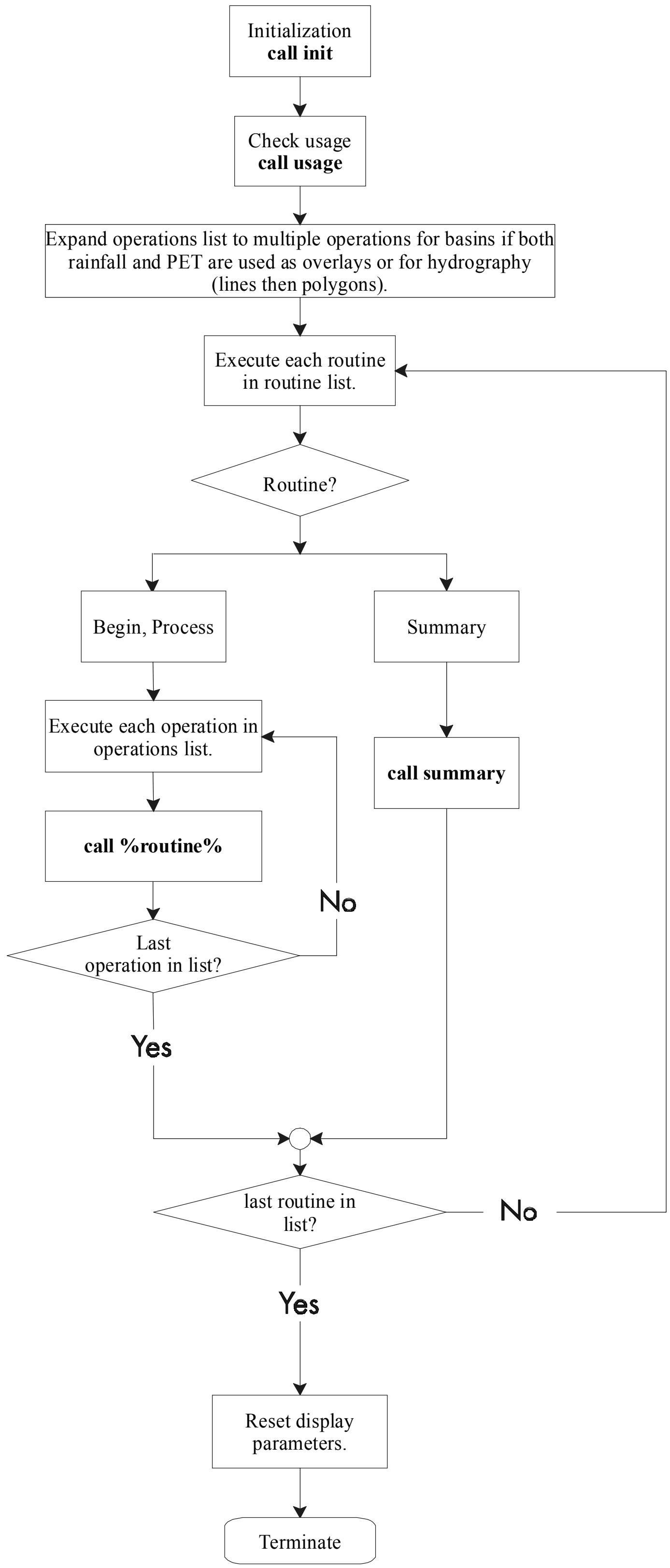


AML: rivchar.aml
Flowchart: Routine Stcor

rivchar2.cfl



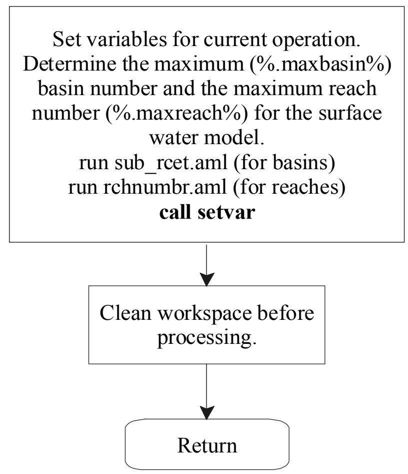
AML: thieschr.aml
Flowchart: Overview
thiesch.cfl



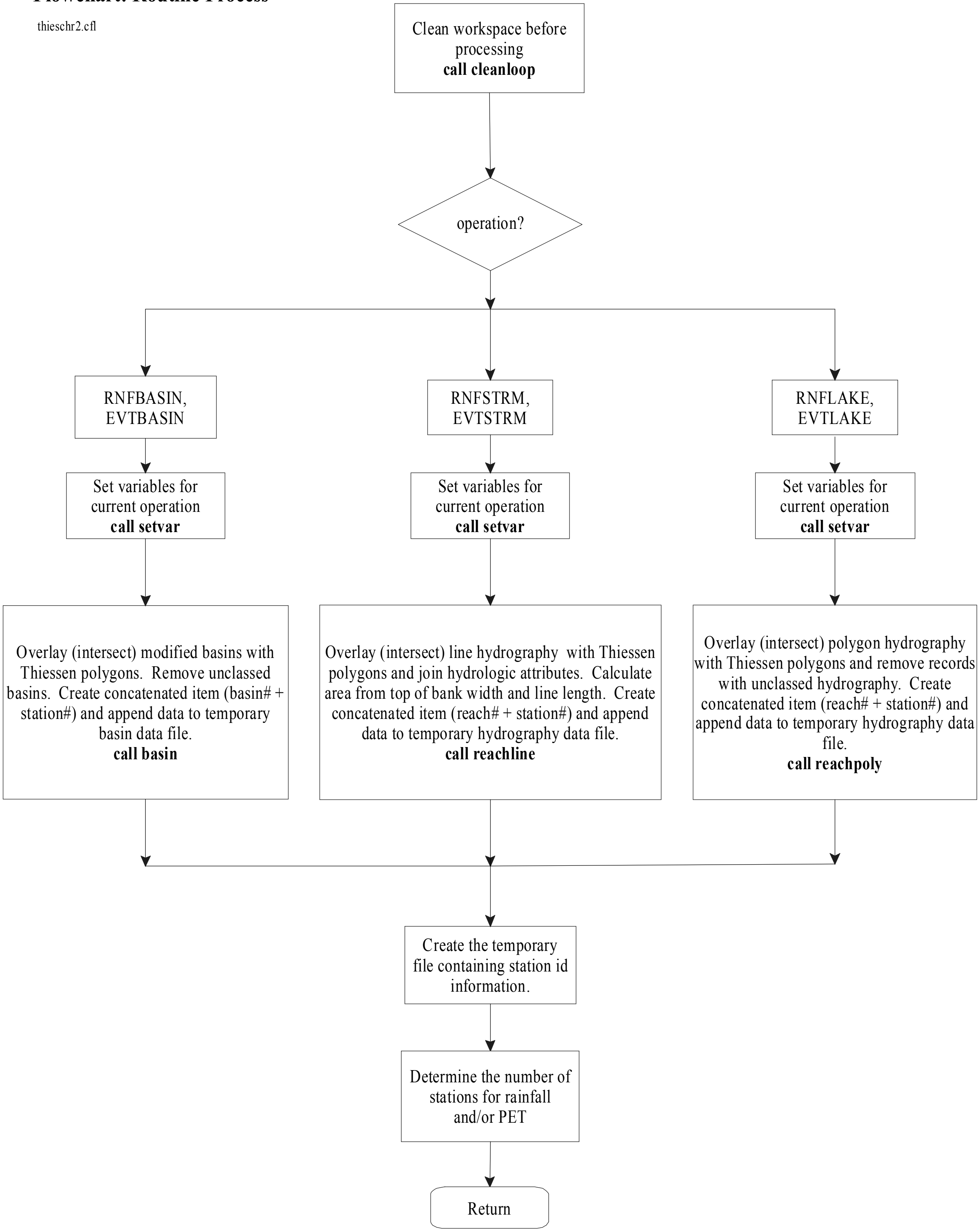
AML: thieschr.aml

Flowchart: Routine Begin

thiesch1.cfl

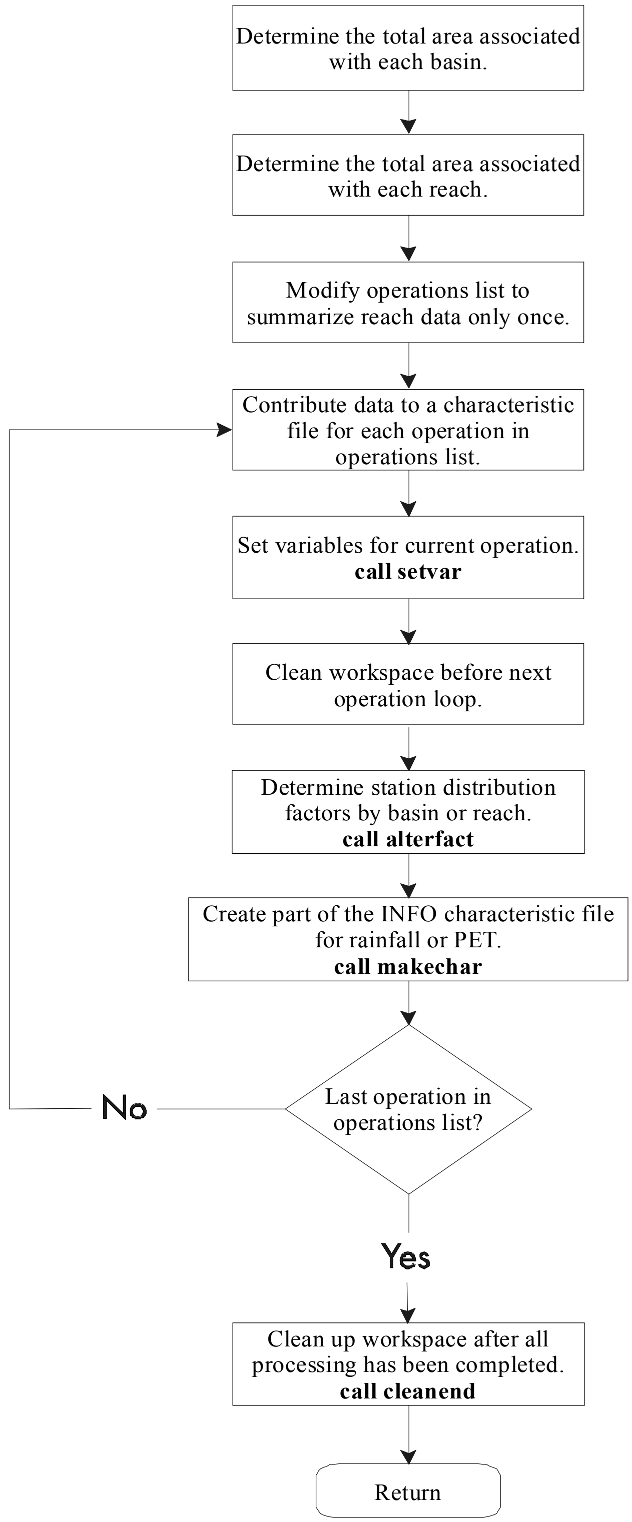


AML: thieschar.aml
Flowchart: Routine Process



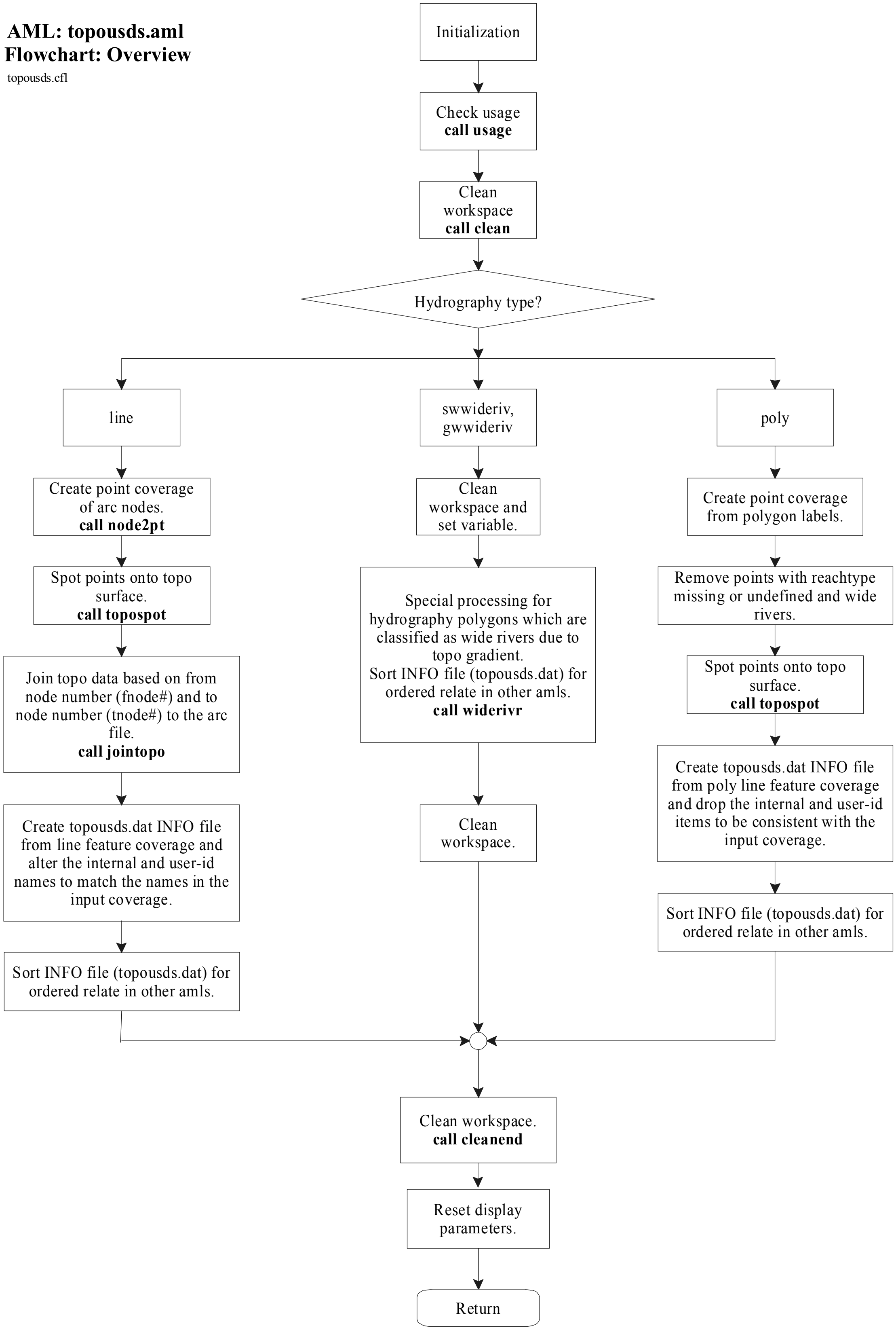
AML: thieschr.aml
Flowchart: Routine Summary

thiesch3.cfl



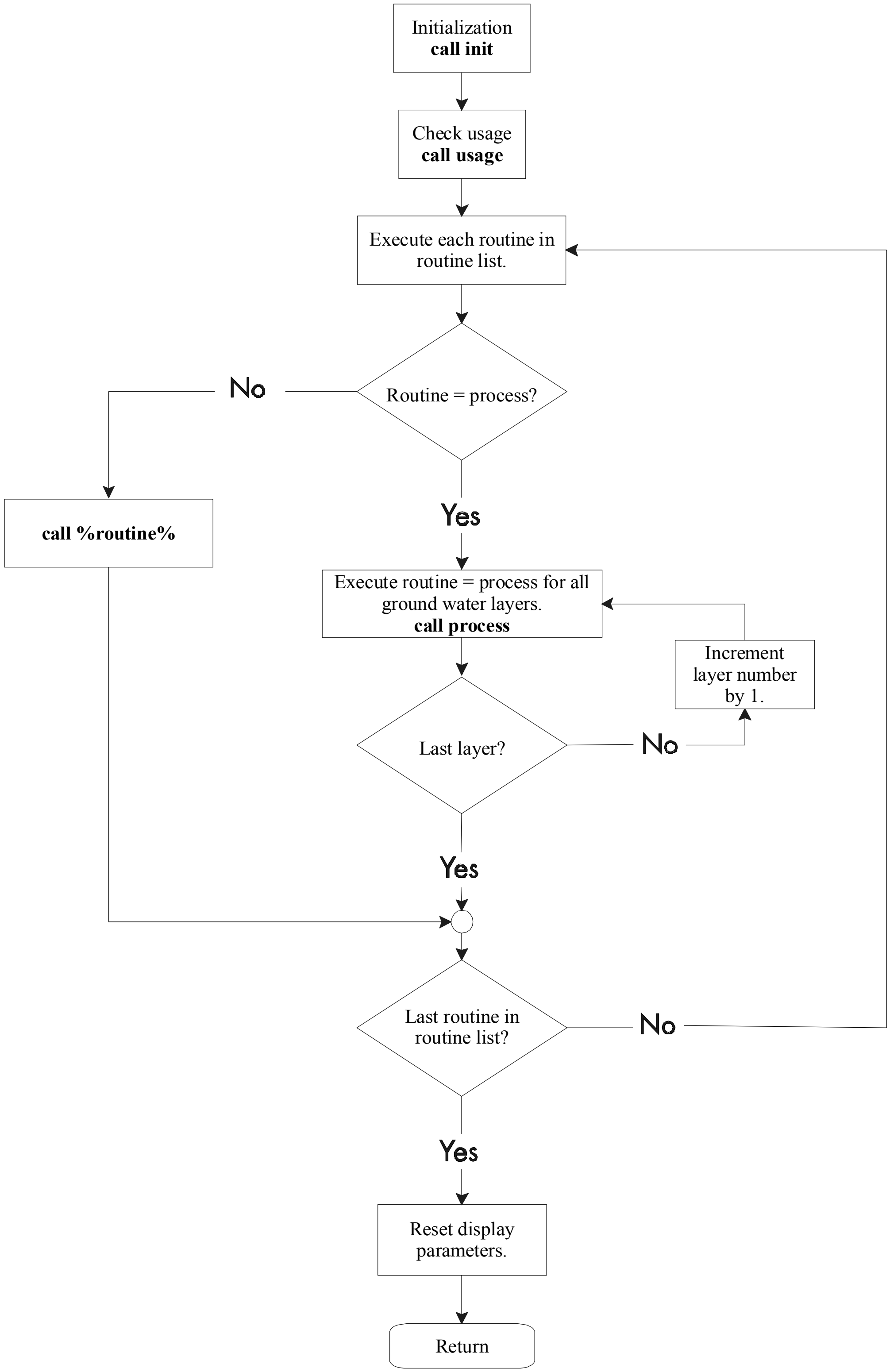
AML: topousds.aml
Flowchart: Overview

topousds.cfl



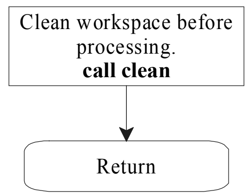
AML: welllayr.aml
Flowchart: overview

welllay.cfl

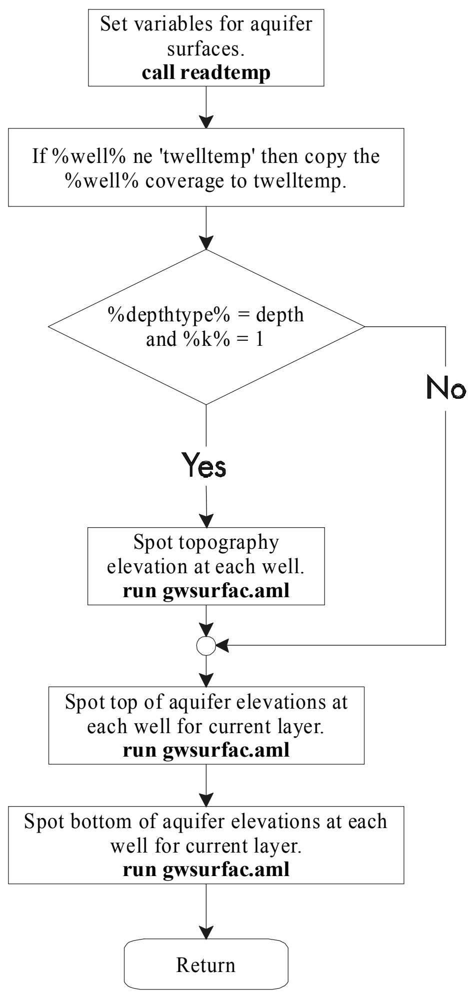


AML: welllayr.aml
Flowchart: Routines Begin and Process
welllay1.cfl

Routine Begin

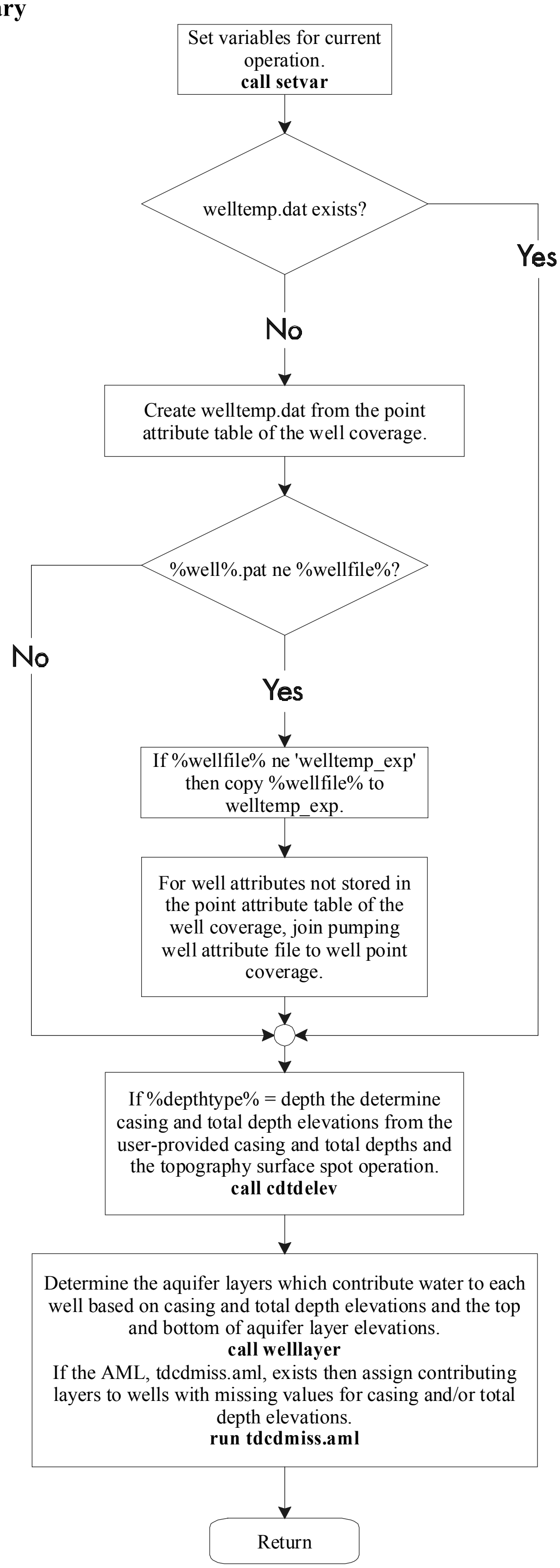


Routine Process



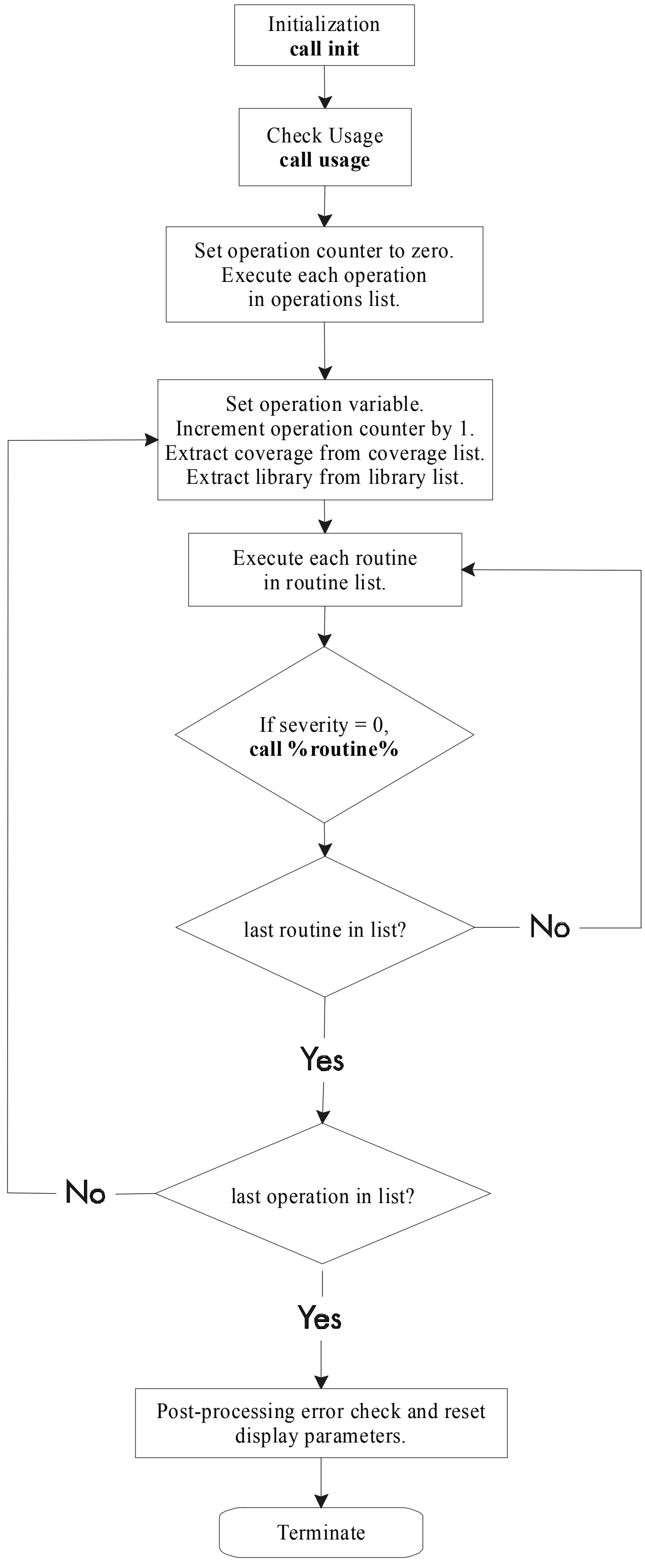
AML: welllayr.aml
Flowchart: Routine Summary

welllay2.cfl

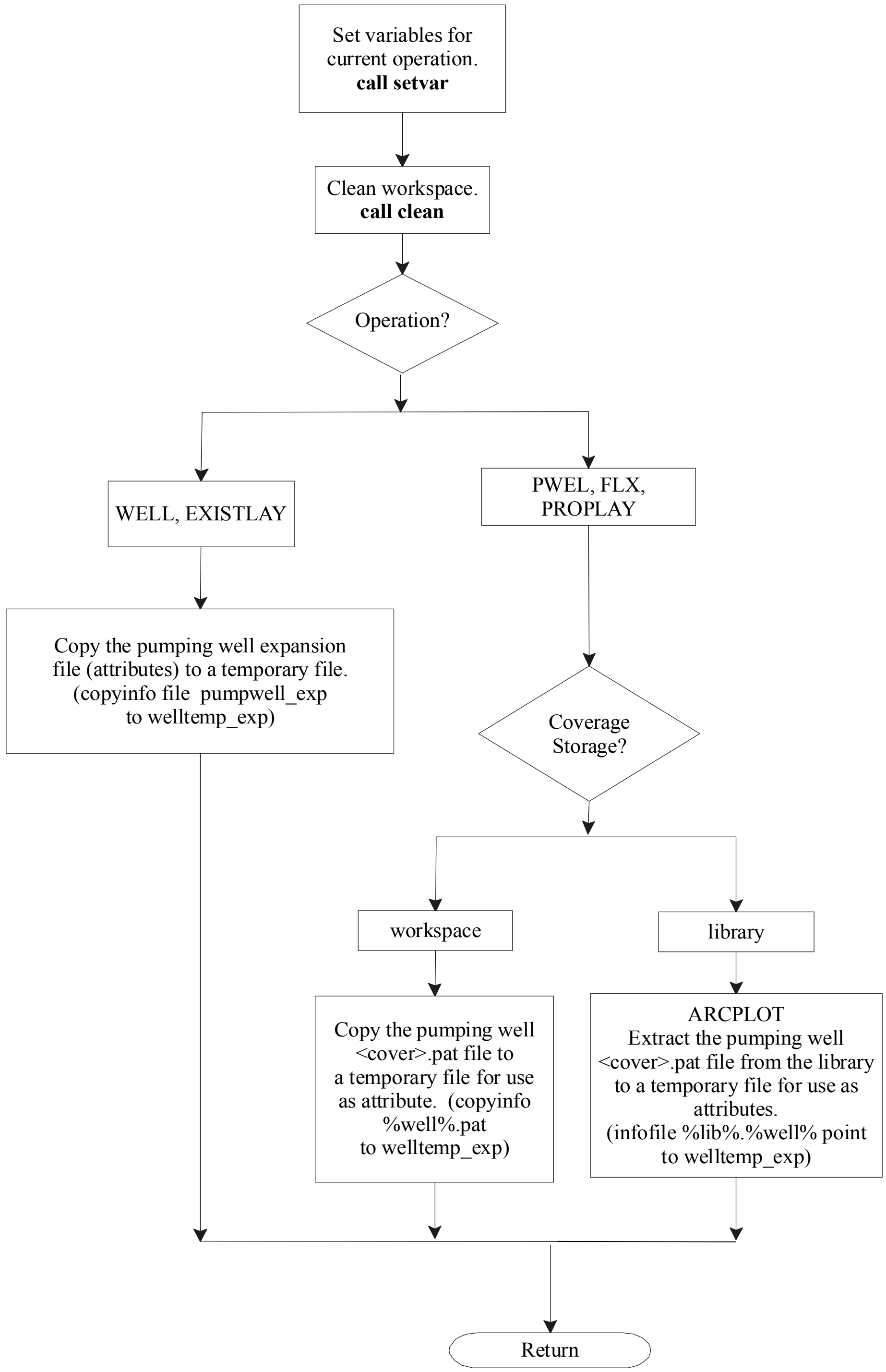


AML: wellproc.aml
Flowchart: Overview

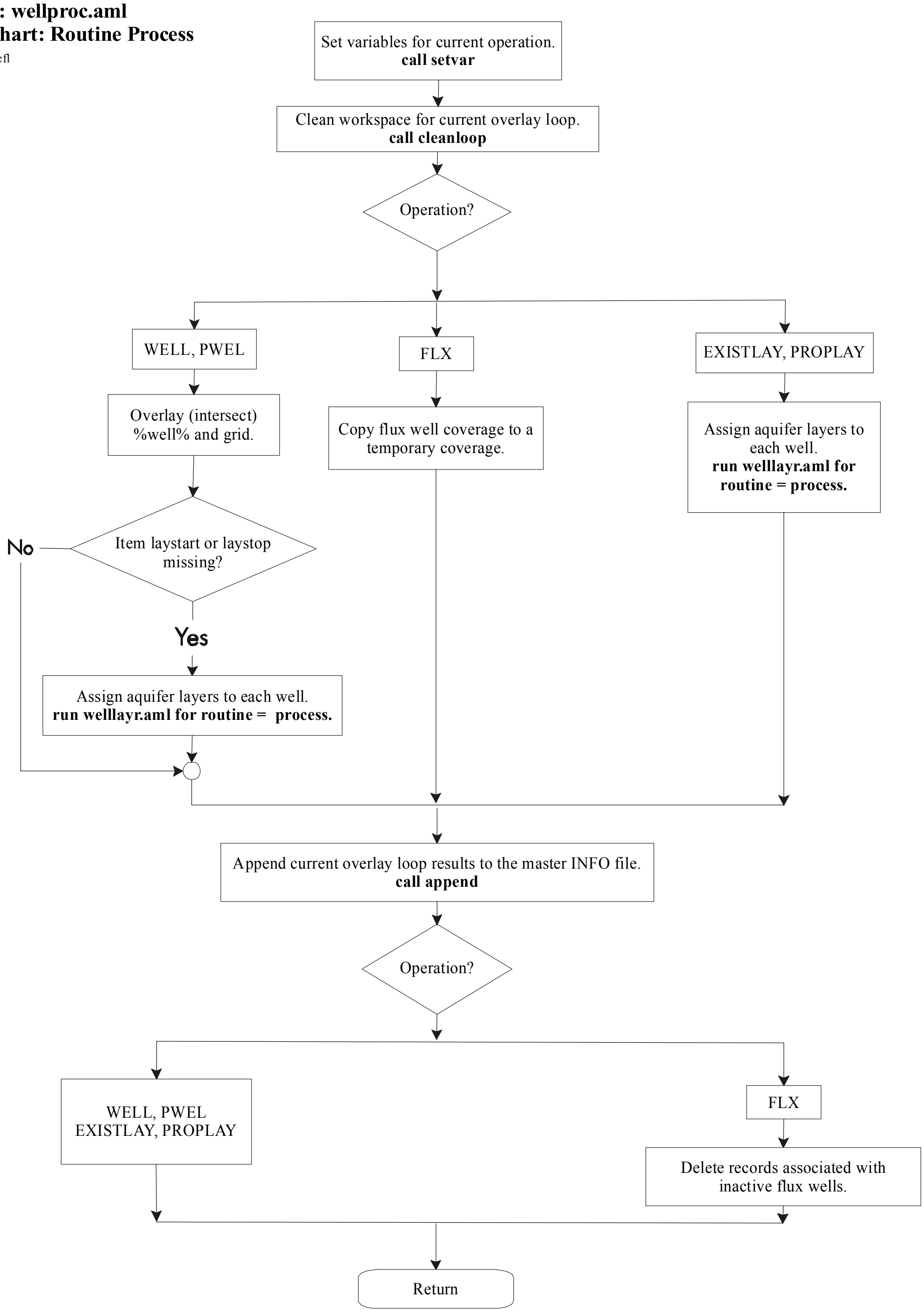
wellpro.cfl



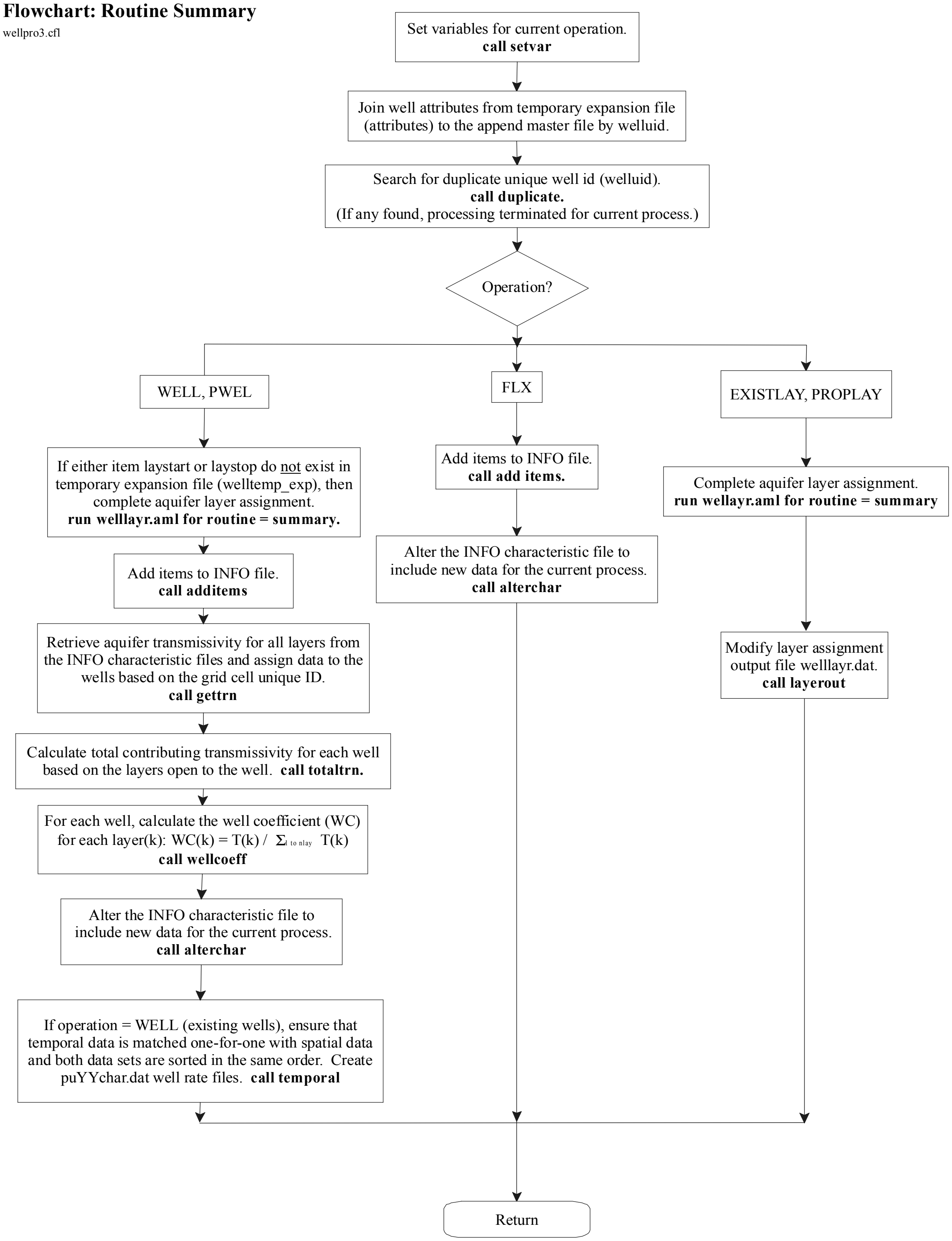
AML: wellproc.aml
Flowchart: Routine Begin
wellpro1.cfl



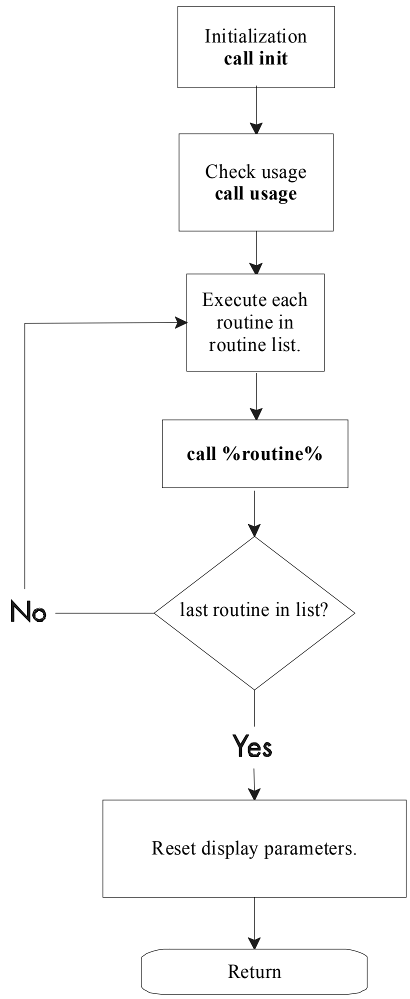
AML: wellproc.aml
Flowchart: Routine Process
wellpro2.cfl



AML: wellproc.aml
Flowchart: Routine Summary
wellpro3.cfl

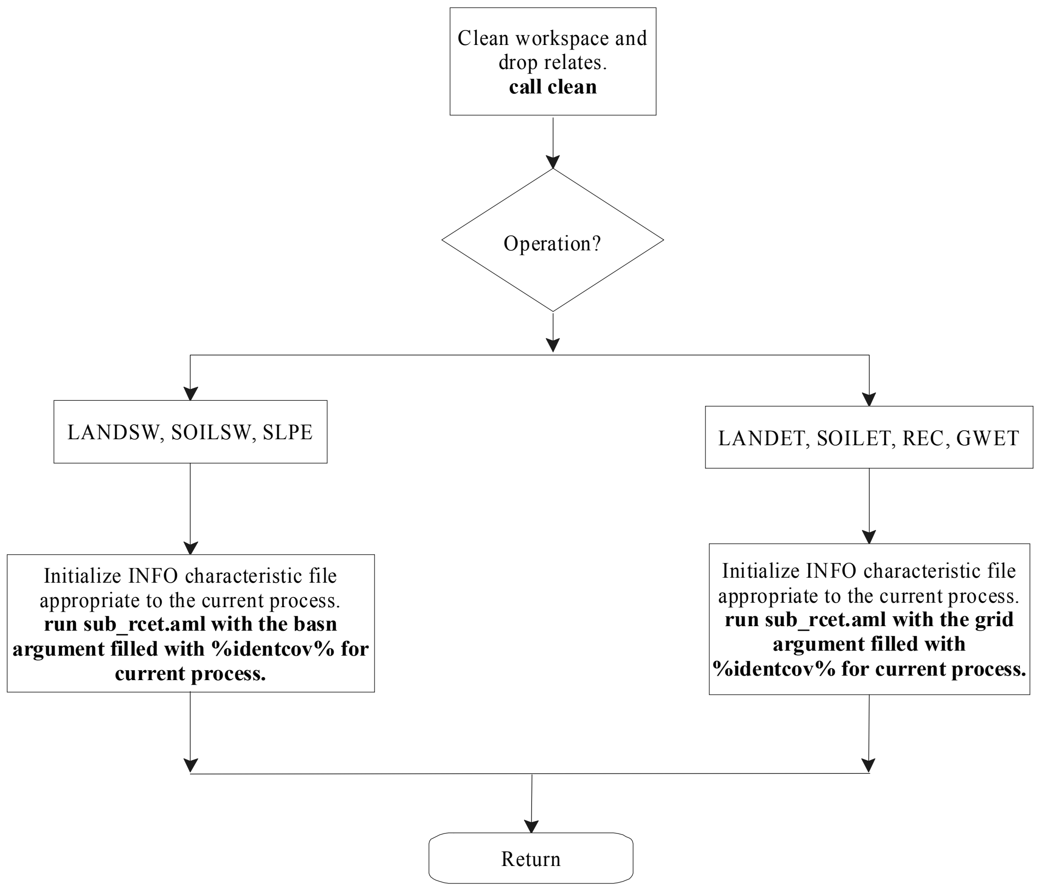


AML: wtmean.aml
Flowchart: Overview
wtmean.cfl



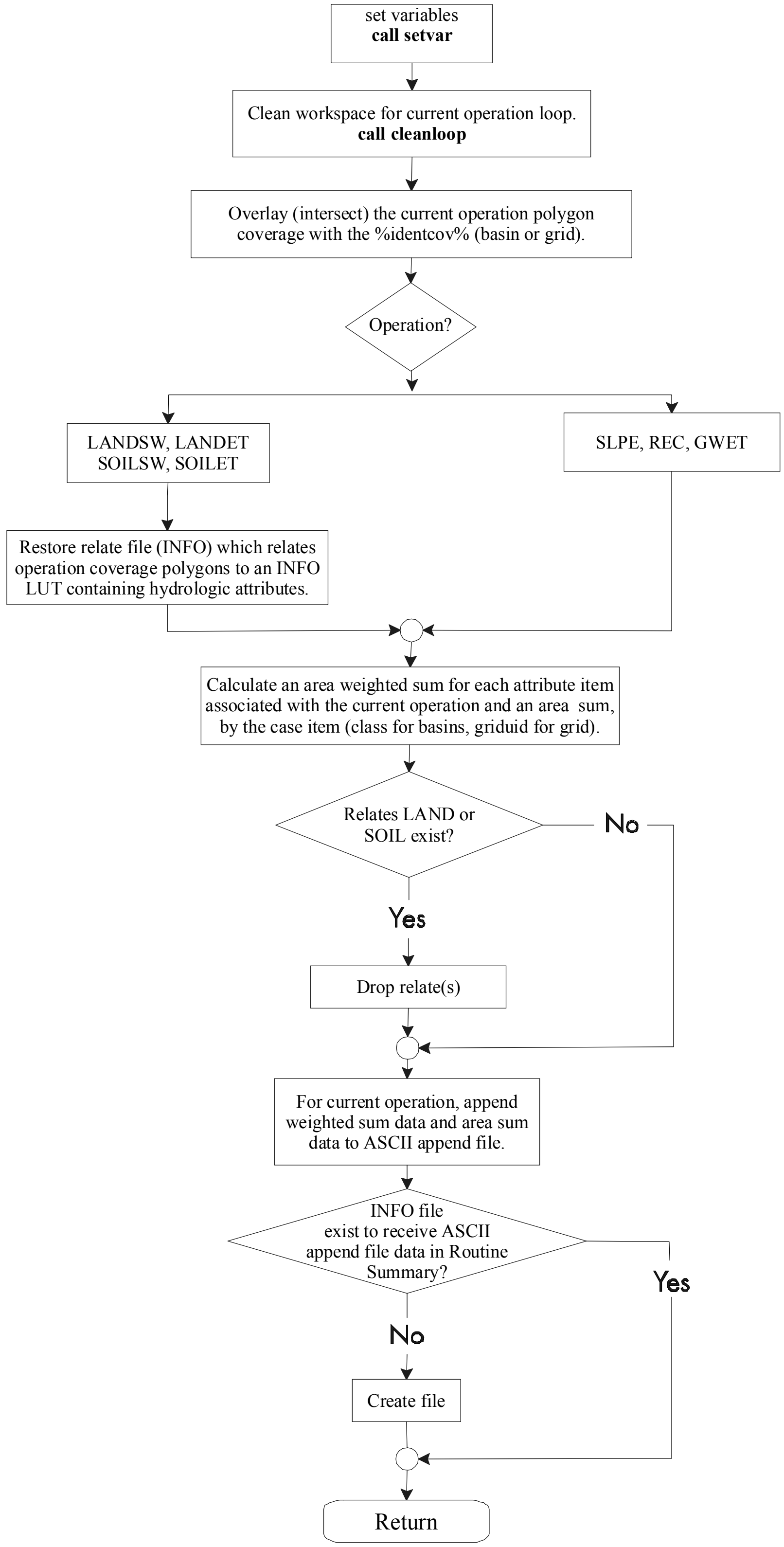
AML: wtmean.aml
Flowchart: Routine Begin

wtmean1.cfl



AML: wtmean.aml
Flowchart: Routine Process

wtmean2.cfl



AML: wtmean.aml
Flowchart: Routine Summary

wtmean3.cfl