FIPR Hydrologic Model

Part IV:

Application:
SWFWMD Regional Data Base

Prepared for:

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CHAPTER 1. DATA COLLECTION AND ASSESSMENT

Introduction

Within recent years, the Florida Institute of Phosphate Research (FIPR) hydrologic model (FHM) has been adapted and greatly improved to allow for regional (watershed) applications. Both the data base and modeling framework have been constructed for the Southwest Florida Water Management District (SWFWMD, District). The data base includes meteorologic, topologic and hydrologic conditions for the eleven major river basins within the regulatory jurisdiction and beyond. This part of the document describes the application of FHM to the SWFWMD data base which was a principal objective of a research project, funded by the District and conducted by the authors. Figure 1.1 depicts the domain of the development project. To meet the needs of the District and the disparate modeling requirements of regulatory and research management staff, the model and data base were designed to provide versatility in application and scale. It must be emphasized that the integrated modeling data base that has been created to date is but a framework from which to build in the future. A systematic review and development effort should be undertaken by the District and the model user community to further complete this work. A very important objective of this document is to describe, assess, and list recommendations concerning the condition of the data base for the intended modeling objective.

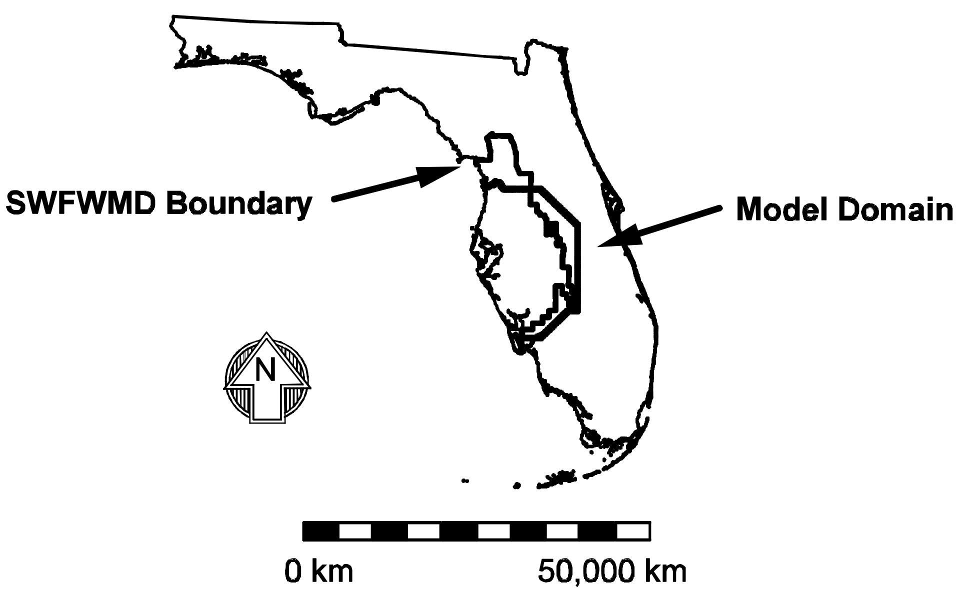

Figure 1.1 Location of Model Domain and Southwest Florida Water Management District Boundary Within Florida

The data needs of an integrated hydrologic model are substantial because they encompass the spatially and temporally dependent data for both traditional surface water and ground water models, plus additional information specific to vadose zone interaction. To efficiently manage and use the spatially dependent (and temporal linkage) data required for an integrated model of the District, a properly attributed Geographic Information System (GIS) data base has been established. In addition, automated methods for retrieving spatially-dependent and temporally-dependent data from District GIS and other data bases have been developed. Task One of the District-scale application project (Geurink et al., 1995) was to identify, acquire and prepare all available data (temporal data limited to 1989-90 only), and evaluate the adequacy and completeness of the data bases with respect to automated processing for integrated hydrologic modeling applications at the District. As part of the data base assessment, demonstration coverages were created and coverage attributes were added to develop a working prototype data base. Assessments and recommendations stressed hydrologic modeling for overall water management as opposed to hydraulic modeling which is performed on streams under extreme events for flood-plain delineation. However, where related to hydrologic modeling, comments were provided on hydraulic modeling utility (e.g., generating hydrographs). Recommendations were developed for the long-term development of the hydrologic data base in relation to automated processing for modeling applications.

Time Series Data Base

The District's temporally-dependent data is stored in various data bases. For user access reasons, some of the data bases contain redundant data; users have experienced difficulties with querying or retrieving data from the original data bases, which resulted in the creation of a secondary data base (a copy of the original data bases in another format). This is mentioned here only to inform the reader that the authors became aware of the various data bases, but an evaluation was made on only those data bases which are currently being used for hydrologic model applications.

At the District, temporally-dependent hydrologic data for model simulation are stored in three different data bases: (1) Regulatory Data Base [RDB], (2) Water Management Data Base [WMDB], and (3) SAS Hydrologic Data Base [SAS HDB]. The SAS HDB is a copy of the RDB and the WMDB and is used as the data retrieval and query data base for hydrologic modeling applications. It was the data contained within the SAS HDB that was evaluated for this project.

The time-series data used in FHM are divided into three different categories which include hydrologic, meteorologic, and water use and diversion; each category is comprised of various data elements. Within the hydrologic category, data elements include streamflow, stream and lake stage, and aquifer levels. Rainfall and evapotranspiration (ET) are the data elements within the meteorologic category. Water use and diversion data include ground water and surface water pumpage, and surface water diversions (discharges) due to structures.

The data elements of the three categories are necessary for hydrologic model simulation, calibration, or both. Table 1.1 summarizes when each of the data elements are necessary in hydrologic modeling applications.

The data base assessment for temporal data is model objective specific. The spatial density and monitoring frequency necessary for each of the data elements is dependent upon the model type and temporal and spatial scale for the model domain simulated. The assessment which follows focuses on the type, availability, adequacy and completeness of the supplemented District temporal data base, especially in the context of temporal density and monitoring frequency for the various applications of the FHM integrated model.

Hydrologic

Temporally-dependent hydrologic data includes the surface water elements of streamflow, stream, wetland, and lake stage, and the ground water elements of aquifer water levels for each

Table 1.1 Temporally-Dependent Data Needs for FHM Hydrologic Modeling

Data Type	Data Element	Simulation[1]			Calibration		
		Surface	Ground	Integrated	Surface	Ground	Integrated
Hydrologic	streamflow	X	X	X	X	X	X
	stream stage	X	(X)[3]	X	X	(X)[3]	X
	lake stage	X	(X)[3]	X	X	(X)[3]	X
	surficial WL		X	X		X	X
	intermediate WL		X	X		X	X
	Floridan WL		X	X		X	X
Meteorologic	rainfall	X		X	X		X
	PET	X	X	X	X		X
Other	recharge[2]		X			X	
Water Use	ground water pumpage		X	X		X	X
	surface water pumpage	X		X	X		X
	surface water diversions	X		X	X		X

[1] Data elements can be user specified (hypothetical)
[2] Combination meteorologic/hydrologic data subjectively specified for ground water only simulation. Can be either gross or net recharge.
[3] (X) Ground water only simulations rarely include dynamic stream and lake stage.

distinct aquifer unit, referred to as a hydrostratigraphic unit (HSU). The spatial density requirements for temporal hydrologic data monitoring sites depends upon the modeling scale desired. For a regional scale (large scale) model, the required spatial density of monitoring sites is generally less than the required density for a local scale (small scale) model. The desired spatial density of monitor sites is also dependent upon spatial changes in the monitored data element (i.e., a high aquifer water level gradient requires greater spatial monitoring density than does a low aquifer water level gradient). The required monitoring frequency of hydrologic data is also dependent upon the model scale. Based on surface water and ground water hydrologic conditions in south-central Florida, it was necessary to extend model boundaries beyond District boundaries. To characterize model boundary conditions and to facilitate the calibration process, temporal hydrologic data from beyond District boundaries were sought and, where available, added to the District data base.

The spatial density of available temporal hydrologic monitor sites within District boundaries for all hydrologic data elements is extensive, except for surficial aquifer water levels. However, temporal hydrologic data for sites outside District boundaries are typically not available within District data bases. There are currently 171 continuous steam flow gaging sites in the District database (Figure 1.2). The sites are mostly USGS stations that are continuous stream stage (water level) recorders. Stage records are later reduced to flows via discharge rating conditions established for the cross-section. Many more sites have been monitored for short term studies which are not in the database. It would be highly desirable to locate and attribute these sites as well. There are currently 548 lake and wetland stage recording stations throughout the District (Figure 1.3). Ground water monitoring wells are mostly Floridan and intermediate (south of Tampa Bay). Very few surficial monitor wells are available (Figure 1.4). Surficial aquifer well sites, where available, are concentrated near major public supply wellfields and are therefore subject to the localized pumping influences of the wellfields.

The monitoring frequency of the hydrologic data elements varies. Streamflow and stream stage data are available as a daily mean. For a limited number of sites and for a limited period, more frequent streamflow or stream stage data are available from the USGS for hydraulic modeling. Most lake stage data are available on a monthly basis; daily data are infrequently available. Aquifer water levels are most often available as monthly values, but many sites are equipped with recorders where daily values are recorded. As stated earlier, relatively little surficial aquifer water level data are available. The recording agency should be consulted regarding what is represented by the daily values (i.e., mean, minimum, or maximum for the day).

Except for areas near District boundaries, the available spatial density of temporal hydrologic data should be adequate for most large scale model applications; supplemental sites may be necessary for small scale models on a case by case basis. Temporal hydrologic data from outside District boundaries must be obtained from other sources. The spatial density of surficial aquifer water level sites must also be increased. For ground water and integrated modeling, it is extremely important to have adequate control sites within the water table to define recharge, leakage, and lateral flux rates during model calibration.

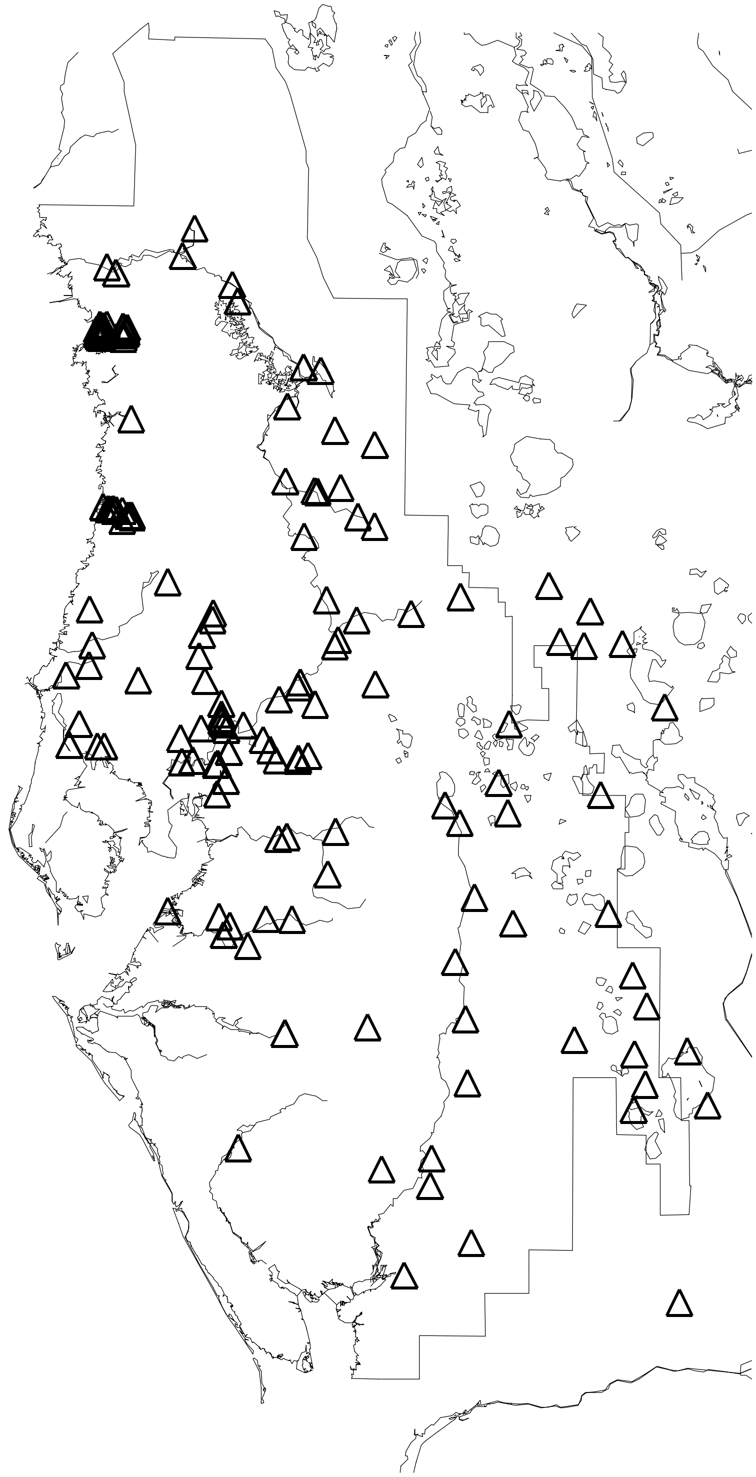

Figure 1.2 Streamflow Gaging Stations, SWFWMD Data Base

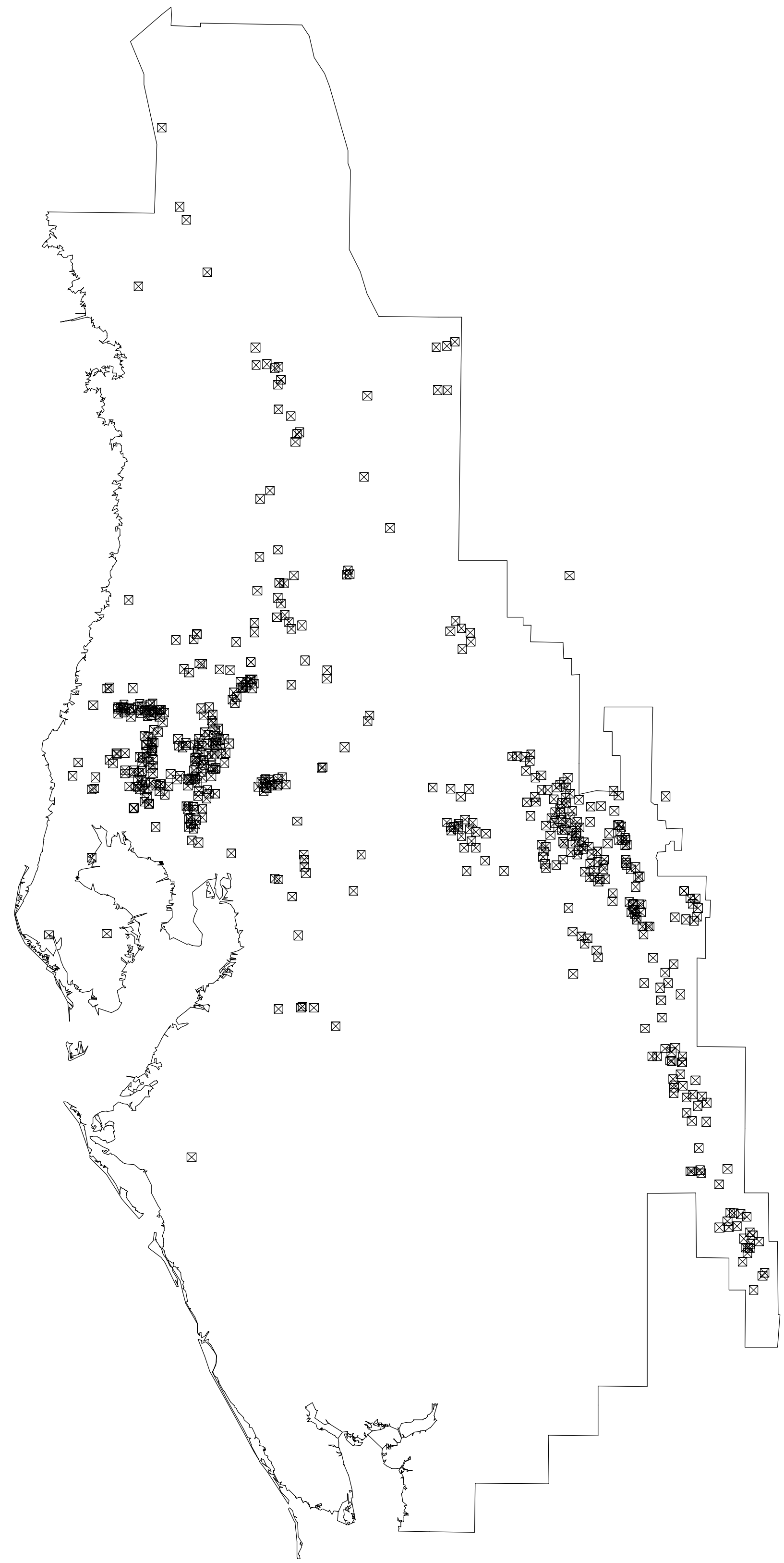

Figure 1.3 Lake and Wetland Stage Monitoring Sites, SWFWMD Data Base

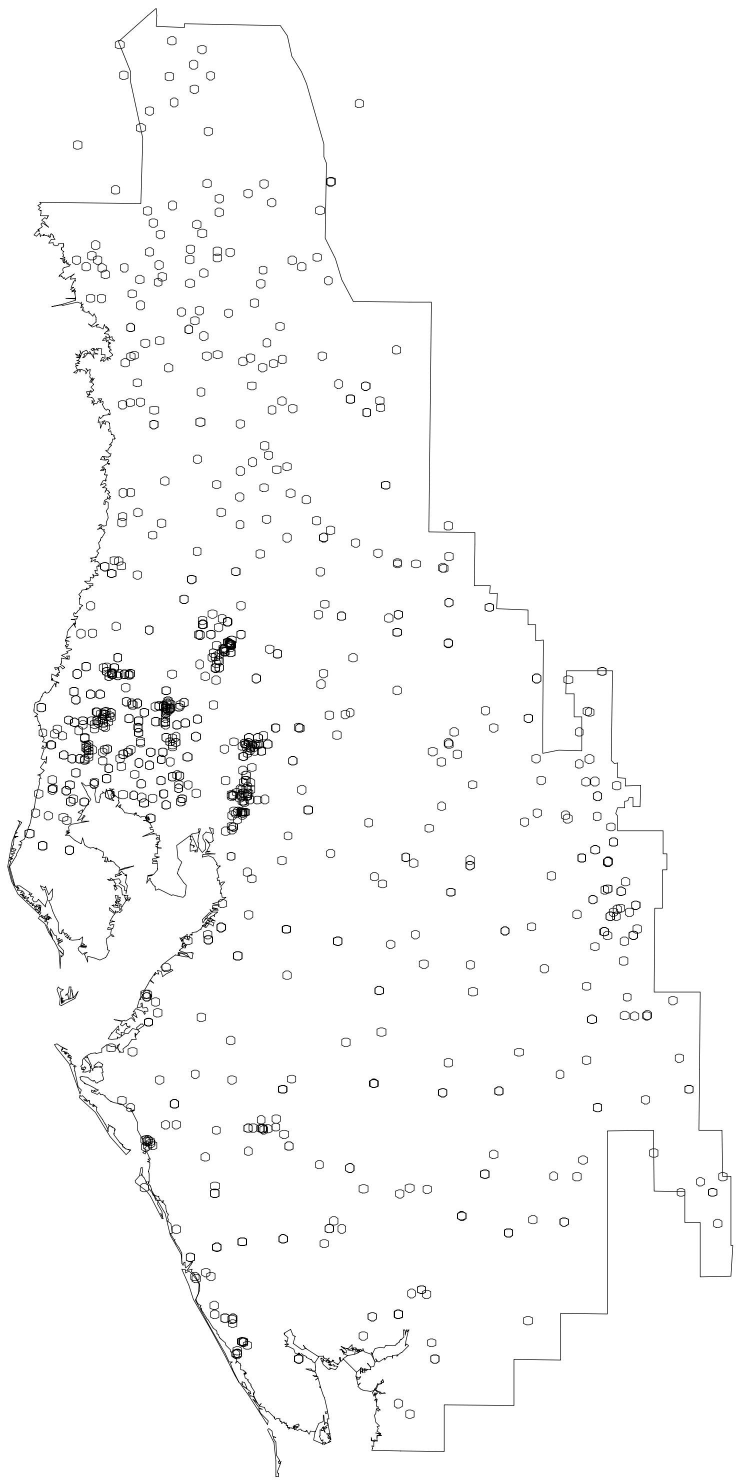

Figure 1.4 Aquifer Water Level Monitoring Sites, SWFWMD Data Base

Presently, the District specified ID given to many, but not all of the hydrological monitoring sites remain unique through time. By keeping the ID the same through time, a consistent link between the temporal data base and the spatial data base (GIS) is maintained.

Meteorologic

Rainfall, potential evapotranspiration (PET) and temperature data are elements of the meteorologic data category. The spatial density and monitoring frequency requirements in west-central Florida for rainfall are significantly different when compared to the requirements for PET and temperature data. In west-central Florida, rainfall varies significantly in both the spatial and temporal domains, while the variability in PET in the region is more moderate. This comparison is based on review of data for West-Central Florida. Temperature variation is on the order of PET variation. Temperatures can be used to derive daily PET estimates, but are no longer used directly in FHM Version 3.0. The period exhibiting the greatest spatial and temporal variation in rainfall occurs during the summer when convective storms predominate. The frontal systems which occur during the winter months exhibit less variability in rainfall. Due to the spatial and temporal variability in rainfall for west-central Florida, a dense set of rainfall monitoring sites is necessary. Both surface water and surface/ground water integrated models are rainfall-driven. To adequately characterize the rainfall-infiltration-runoff process, rainfall data must be available on no less than an hourly basis (Ross et al., 1994). The spatial density of PET and temperature monitoring sites can be much less than what is needed for rainfall; however, the entire District must be represented to characterize any spatial and temporal variability that does exist. Generally, PET rates are lower at the coast, and higher inland due to humidity variations. A daily monitoring frequency for PET or, alternatively, daily minimum and maximum or mean temperature data should be adequate. As with temporal hydrologic data, rainfall, PET, and temperature data from beyond District boundaries must be available within the District's data base.

The number of District rainfall sites is quite extensive (Figure 1.5); many of the sites are equipped with recorders. However, at most District maintained rainfall sites, the data are manually recorded. All of the National Weather Service rainfall stations located within the District and some located outside the District are also available in the District's data base. Relative to the rainfall data sites, there are very few PET data sites maintained by the District or other agencies (Figure 1.6). Available PET sites are mostly ASTM Open Pan Evaporation Stations. However, as stated earlier, PET in west-central Florida does not display the variability that is experienced with rainfall. Many more daily temperature stations are available and can be used to help define variability. Notwithstanding, the present PET monitoring sites are spread across the District fairly well and should be adequate for most modeling investigations. One problem, however, is that extensive "down periods" result in numerous data gaps in the pan records.

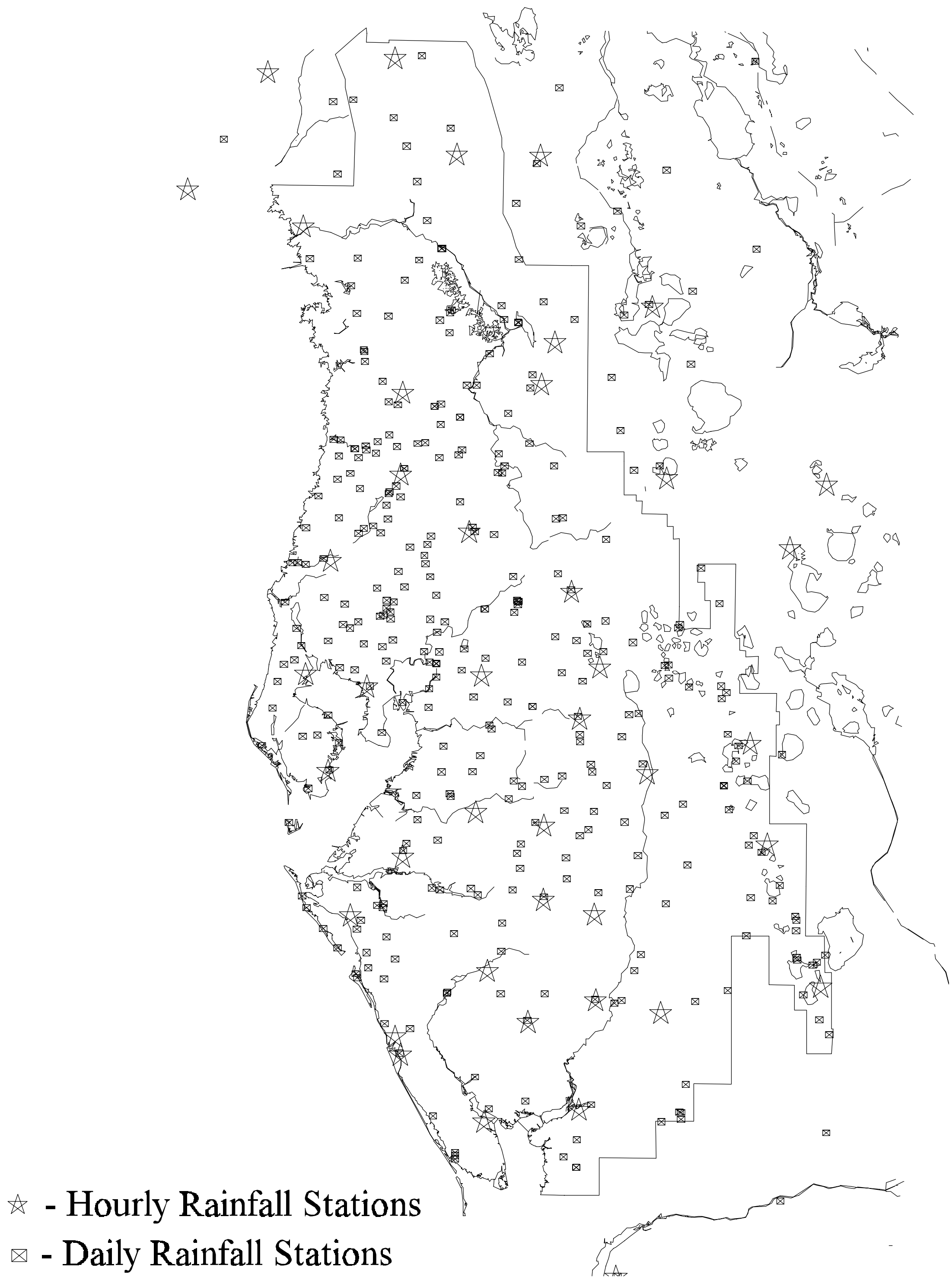

Figure 1.5 Rainfall Monitoring Sites, SWFWMD Data Base

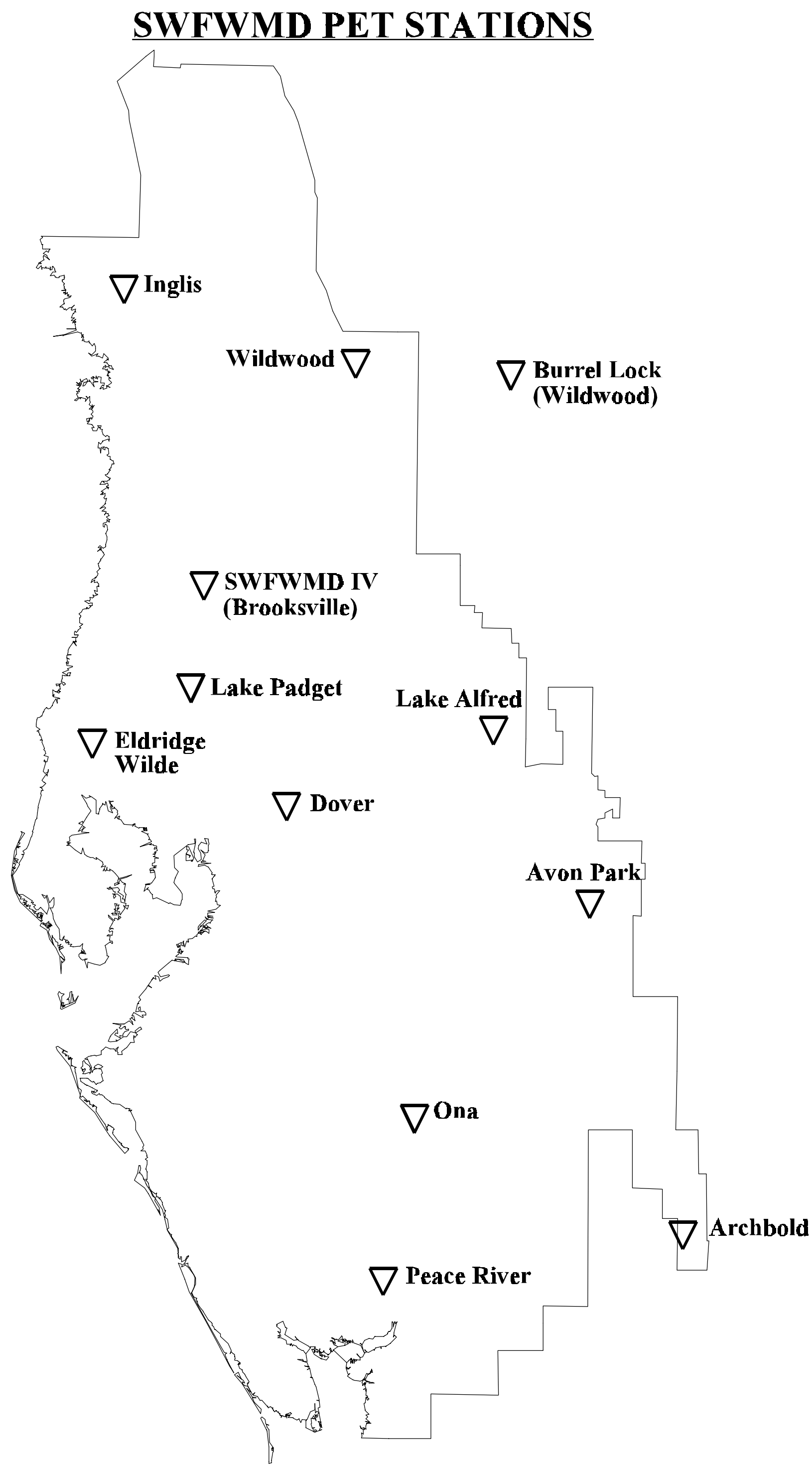

Figure 1.6 PET (Pan Evaporation) Sites, SWFWMD Data Base

The spatial density of rainfall data within the District is relatively good. However, due to the convective nature of rainfall during the summer, spatial differences in rainfall are significant. The rainfall variability may cause problems with characterizing the rainfall-infiltration-runoff process with a hydrologic model (especially for individual events). The technology exists and the data is being commercially marketed which "fills in" the areas between rainfall stations based on satellite and/or Doppler radar images of rainfall intensities. The acquisition of additional rainfall and PET stations located outside District boundaries may also be necessary to characterize spatial differences in these water budget terms near model boundaries.

Rainfall and PET data are typically available from the District's data base on no less than a daily monitoring frequency (daily total for rainfall and PET). More frequent rainfall data (mostly hourly, some 15 minute) are available at the District from paper records or from pen or punch rainfall recorder tapes. The original pen or punch rainfall recorder tapes are preserved with exceptions. Until recently, according to District procedures, when the weekly total rainfall was less than two inches and there were no days during the week which experienced an event greater than 0.5 inch, the original recorder tapes were destroyed and the data was not logged into the data base. The authors have recommended that this practice be discontinued.

The monitoring (and storage) frequency of rainfall data is one of the most important issues associated with temporally-dependent data. The District currently records rainfall on at least an hourly basis at the sites equipped with recorders; however, the hourly data is presently not available in digital form. In addition, the practice of destroying the rainfall recorder tapes for minor rainfall events, without recording the rainfall, results in the loss of important hydrologic information. The small rainfall events can significantly influence the antecedent moisture conditions of the unsaturated storage zone by satisfying PET demand from interception and depression storages, which has a significant affect on the rainfall-infiltration-runoff process. Most of the NWS stations in the data base have hourly recorded precipitation, but it is not readily available from the District. This data is available from the NWS or commercial sources such as EarthInfo, Inc.

Presently, the District ID given to each meteorological monitoring site is unique through time. By keeping the ID the same through time, a consistent link between the temporal data base and the spatial data base (GIS) can be maintained.

Water Use and Diversions

Included in the water use and diversions data category are ground water pumpage, surface water pumpage, and surface water diversions due to structure operations. As summarized in Table 1.1, the ground water pumpage data are required for the ground water model, and the surface water pumpage and surface water diversion data are necessary for the surface water model. Therefore, all three are used in an integrated model. Spatial density of the data elements in this category is solely dependent upon the location of the pumping or diversion points, which renders the spatial density issue immaterial. As with the previously discussed temporal data categories, the necessary recording frequency for the data elements in the water use and diversion category are dependent upon the scale of the model.

The ground water and surface water pumpage data base for the District is probably the best available within the State of Florida. Beginning in 1989, flow meter installation was initiated on all agricultural use wells and sources permitted for greater than or equal to 100,000 gallons per day average annual. These meter installations supplemented the meters which had been recording ground water and surface water pumpage on non-agricultural uses prior to that time. Presently, all permitted users within the District with permits at or above 100,000 gpd average annual are required to record ground water and surface water pumpage with a permanently installed flow meter. The pumpage data are attributed to individual wells or surface water withdrawals in the data base. For periods when meters are not functional or for small wells where pumpage data are not available, temporal estimates of agricultural pumpage by withdrawal source are calculated through a District-developed algorithm which accounts for the soil type, location, historic crop type, area irrigated, and other factors. All withdrawal sources are identified in the pumpage data base by a permit number and a well ID within the permit number. The spatial location for each of the withdrawal sources can be found in one of two ways: (1) by using the latitude/longitude coordinates in the pumpage data base, or (2) by linking the permit number and withdrawal ID in the pumpage data base to the same identifiers in the GIS coverage of Water Use Permit (WUP) withdrawals. The magnitude, location and type of surface and ground water withdrawals are depicted in Figures 1.7 and 1.8, respectively.

The identification system currently employed for permitted water sources presents significant problems when trying to apply the data to hydrologic models. It is the non-uniqueness of the ID through time which poses the obstacle. With the present system, the identification of a well through its "life" is allowed to change under circumstances such as the combination of two permits, the sale of the source and subsequent inclusion of the source in a different permit, or the cancellation of a permit and the subsequent reinstatement of the well under a new permit. Historically, the District has archived the pumpage data base on an annual basis. Archiving was necessary because much of the water use was not recorded by meters and estimates of water use were made based on permitted data which was subject to change. Because the source identification was also subject to change, the spatial link to the GIS was lost for many sources. A latitude/longitude coordinate for each source is available within each annually archived pumpage data base file; however, it has been shown that the latitude/longitude coordinates are subject to error. The coordinate errors are being corrected as permits are reviewed for renewal or modification, but the error remains in all previously archived pumpage data bases. Also, duplicate records for a given withdrawal point exist within the water use pumpage data base. Resolving the changing source identification issue, developing a way to tie all historic pumpage records to current GIS spatial coordinates, and removing duplicate records will make the most efficient and effective use of the pumpage data base and associated GIS coverage of WUP withdrawals.

A water use (ground water and surface water) data base for regions outside the District, but within the District-scale model domain, must be established to fully characterize the man-induced point stresses to the west-central Florida ground water system. Permitted water use records from the St. John's River and the South Florida Water Management Districts were

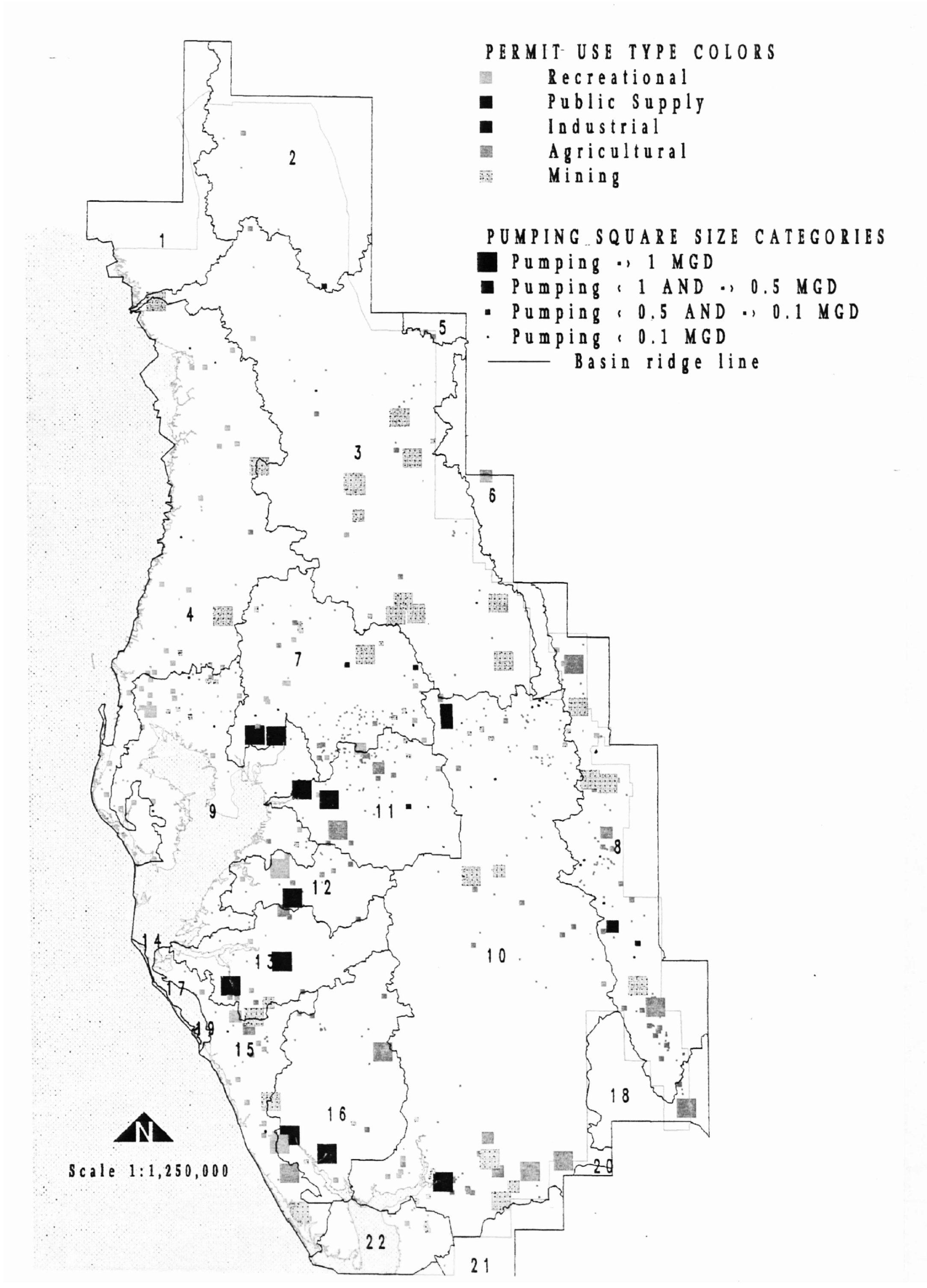

Figure 1.7 SWFWMD Permitted Surface Water Withdrawals: February, 1997

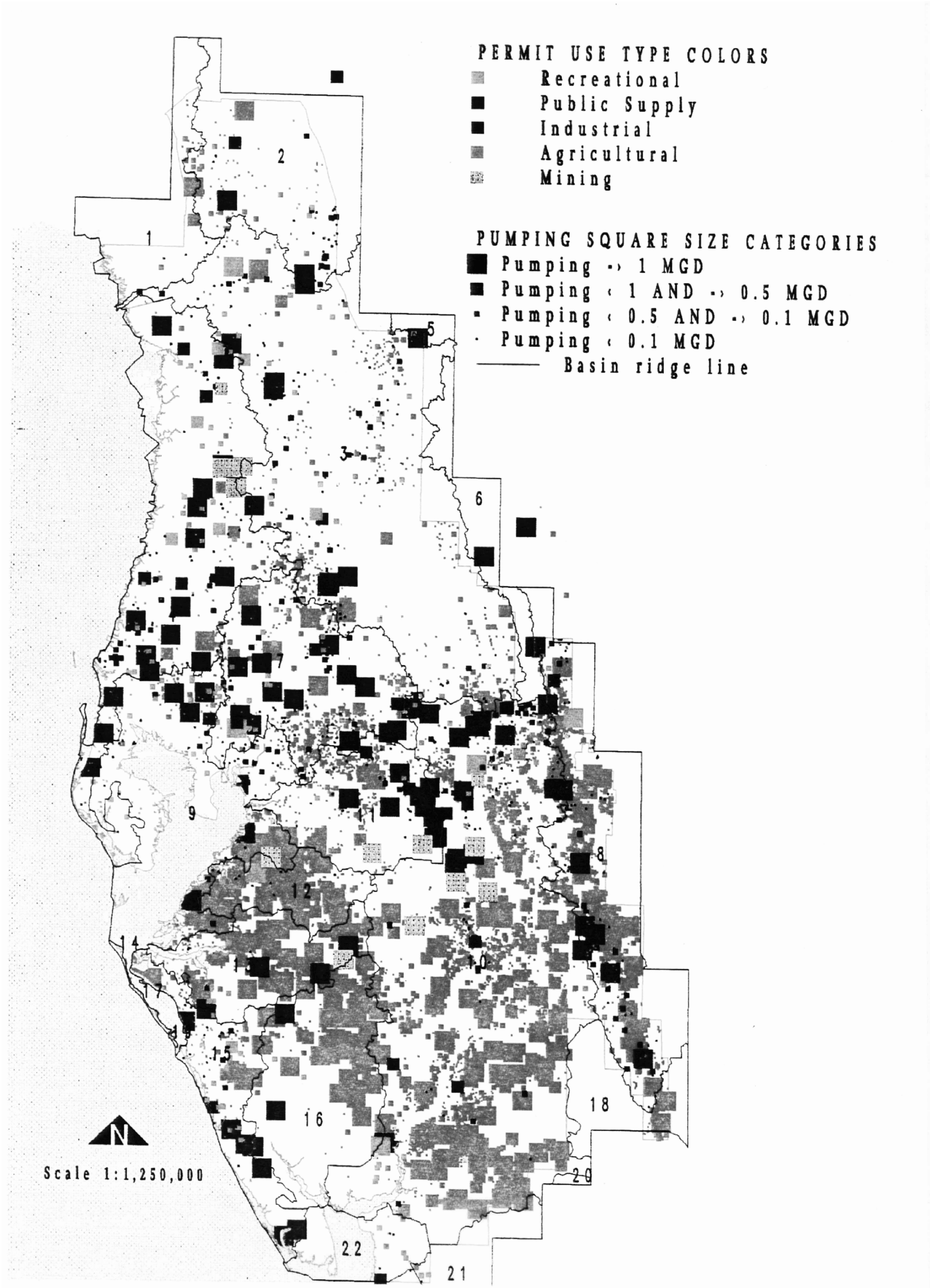

Figure 1.8 SWFWMD Permitted Ground Water Withdrawals: February, 1997

acquired and reviewed for completeness with respect to hydrologic modeling requirements. The data bases of both agencies contained critical missing data for many permits, including location, permitted quantities, and use type. Too much critical data was missing to prepare a reasonable data set at this time. Coordination with the three water management districts which border SWFWMD must be pursued to establish a reliable pumpage data set for regions outside the District. At this time, only the St. John's River Water Management District collects actual pumpage data besides SWFWMD.

The recording frequency for ground water and surface water pumpage varies from daily to monthly, according to individual WUP stipulations. The recording frequency should be adequate for resource investigations for most model scales that the District will employ, however, calibrating to some individual monitoring wells will be problematic.

Surface water diversions caused by structure discharges are an important element of a data base for hydrologic modeling. Many structures are operable which requires a data base of all operations performed at the structure, including the time the structure was altered and the new elevation at which the structure was set. In addition to structure settings, water levels and rating conditions must be available to reduce all data to discharges. Structures such as those along the Tampa Bypass Canal, in the Hillsborough River and at Lake Tarpon are examples of operable structures, with appreciable discharges, where the reduced data are poor or incomplete. The recording frequency for structure operations would be variable, dependent upon the structure operation schedule. Structure operation data is not readily available from the data base at the present time. A unique ID, which is consistent through time, should be established for the structures operation data base to maintain a compatible link between the temporal and spatial (GIS) data bases.

The magnitude of permitted water use within the District is 2.3 billion gallons per day (SWFWMD 1997). Permitted ground water withdrawals account for 80% of this use (Table 1.2). Permitted surface water withdrawals (diversions) make up the difference. For integrated modeling, it is important to quantify the magnitude of pumping and diversions as a water budget term (in inches) for the drainage and/or ground water basin. Permitted water use in the District is approximately 5.0 inches of rainfall on an annual average basis (Table 1.3).

Recommendations

Based on the assessment of the District's temporal data base with respect to its use in hydrologic modeling applications, the following recommendations are offered:

1. Establish a set of monitoring sites for all temporal data located outside District boundaries, for which data will be retrieved. Coordination with other agencies should be strengthened to facilitate data transfer.
2. Establish a surficial aquifer water level monitoring network throughout the District.

Table 1.2 Annual Water Use Permitted Withdrawals[1], West Central Florida: February 1997 (MGD)

River Basin	Area (mi^2)	Σ Ground Water (MGD)	Σ Ground Water (MGD)	% SW
Peace	2390	544	29	5.1
Alafia	432	105	12	10.3
Little Manatee	227	93	12	11.4
Manatee	369	125	44	26.0
Myakka	612	101	30	22.9
Hillsborough	691	135	91	40.3
A/P/CNW	1179	194	25	11.4
Withlacoochee	2035	127	124	49.4
Other basins	1827	451	98	17.9
TOTAL[2]	9762	1875	465	19.9%

Total estimated/permitted water use: 2340 MGD[2]

1 Data obtained from SWFWMD Water Use Permit (WUP) database using permitted withdrawals assigned to the centroid of the permit.

2 Please note this figure is higher than actual use because many permittees pump less than the permitted amount. Also, some double accounting of SW & GW pumping occurs.

Table 1.3 Annual Water Use Permitted Withdrawals[1], West Central Florida: February 1997 (inches)

River Basin	Area (mi^2)	Σ Ground Water (inches)	Σ Ground Water (inches)	Total (inches)
Peace	2390	4.8	0.3	5.1
Alafia	432	5.1	0.6	5.7
Little Manatee	227	8.6	1.1	9.7
Manatee	369	7.1	2.5	9.6
Myakka	612	3.5	1.0	4.5
Hillsborough	691	4.1	2.8	6.9
A/P/CNW	1179	3.4	0.4	3.8
Withlacoochee	2035	1.3	1.3	2.6
Other basins	1827	5.2	1.1	6.3
Average[2]	9762	4.0	1.0	5.0

Total estimated/permitted water use: 5.0"[3]

1 Data obtained from SWFWMD Water Use Permit (WUP) database using permitted withdrawals assigned to the centroid of the permit.

2 Averages based on weighted basin area.

3 Please note this figure is higher than actual use because many permittees pump less than the permitted amount. Also, some double accounting of SW & GW pumping occurs.

3. Establish a unique ID for all temporal data monitoring sites which currently do not have one. This is especially critical for the WUP withdrawals (pumping and monitor sites). The unique ID must stay the same through time. The IDs should be attributed to the appropriate GIS coverages.
4. Digitally record rainfall data on no less than an hourly frequency, where possible. Historic recorder tapes should be interpreted and all hourly data recorded (even trace events). Until such time as hourly frequency rainfall data are stored digitally, the entire recorder tape should be retained. Small rainfall amounts are also important. From sources other than the District, retrieve and store hourly rainfall data to supplement District maintained sources.
5. After unique IDs are established for all WUP withdrawals, associate the unique ID in the GIS coverage of WUP withdrawals to the WUP withdrawals in all of the annually archived WUP pumpage and permitted quantity data files. Duplicate pumpage records for a given source must be purged.
6. Ensure that a one-for-one relationship exists between all temporal data records and the spatial location of the monitoring sites in the GIS data base.
7. Establish a structure operations data base and a procedure to record, store, maintain, and retrieve settings, stages, rating and estimated discharges. Structure rating tables and stage data must be associated with the structure operations data to provide for effective use.

Spatial Data Base

The District currently stores most of its spatially-related data in a GIS data base and employs ESRI ARC/INFO to manage, analyze, and query the data base. Some spatially-related data necessary for hydrologic modeling are maintained in paper form, which is not easily accessible for modeling and computational manipulations. The goal for the District should be to store all spatially-related data in a common data base, to which automated analysis and querying capabilities can be applied.

The spatially-related data base required for the integrated model was divided into six categories which include hydrogeologic, land features, hydrography, hydrologic, temporal data sites, and political. Each category is comprised of various data elements which are discussed later in this section. Unlike the temporally-dependent data, very little of the spatially-related data is used for model calibration assessment purposes; ground water level data is likely the only data element of those to be identified in this section that would be used for calibration comparisons. The spatial data base is used to construct the model and is assumed fixed over a period of time, in most cases, the simulation period.

An assessment of the spatially-related data base was performed with respect to hydrologic modeling requirements. The spatially-related data needs of the integrated hydrologic model were identified, the current availability, adequacy and completeness of the data base was evaluated. Where necessary, demonstration data were developed to complete a spatially-related data base for hydrologic modeling.

Hydrogeologic

The hydrogeologic category includes aquifer hydraulic parameters (e.g., hydraulic conductivity, storage coefficient), hydrostratigraphic unit (HSU) surface elevations (e.g., top and bottom of surficial aquifer), HSU thicknesses (e.g., intermediate aquifer thickness), and spatially-dependent boundary conditions (e.g., general head boundary, flux wells, estimated recharge, and ground water PET data). A tremendous modeling advantage is afforded the user when hydrogeologic data are available within a GIS data base. A permanent and centrally-accessible record of data for ground water model simulations are available to multiple users and the data can be updated as better information is developed. Facilitated by user utilities, the same data may be used at different spatial scales. Automated development of model parameter values with a hydrogeologic GIS data base affords more time to concentrate on interpretation of model results.

The GIS data base must include data (coverages) for all aquifer hydraulic parameters of all defined HSUs, or the data base must include data from which all aquifer hydraulic parameters can be derived. Non-HSU GIS coverages include spatially-dependent boundary conditions, point (pumping wells) data, and hydrography (streams, lakes, springs). The point stress and hydrography coverages are discussed in later sections. Boundary condition coverages are typically related to a specific model domain or grid. The HSU and non-HSU data requirements were summarized in Part II (see Tables 3.6 to 3.9, Part II).

Prior to this project, the District's GIS data base did not contain HSU hydrogeologic data which could be applied to numerical ground water modeling techniques. The District's previous hydrogeologic data base was comprised of MODFLOW formatted data sets of three separate ground water model domains: Northern Tampa Bay, Southern Water Use Caution Area (Eastern Tampa Bay), and Highlands Ridge (Figure 1.9). Some GIS coverages were created for the separate model domains, but were primarily used for display purposes.

Because one did not exist at the District, a conceptual hydrogeologic GIS data base was developed that could be used for ground water and integrated modeling throughout the intended domain. The actual demonstration data base was completed based on a review of the hydrogeology of west-central Florida and the data from MODFLOW data sets of the regional models. The data base was later enhanced in the northern extent to include one more model domain referred to as the Hernando County model.

For the conceptual data base to support all previous and future model coverages, a minimum four layer system was required. These layers are based on hydrostratigraphic units (HSU) within the District which are depicted graphically, north to south, in Figure 1.10. The uppermost HSU (HS1) corresponds to the shallow sandy overburden which comprise the surficial aquifer. The second layer (HS2) corresponds to the intermediate aquifer in the south and a relatively thin intermediate confining unit to the north. The last two layers (HS3 and HS4) correspond to the upper and lower parts of the Upper Floridan aquifer (Miller 1986), respectively. The GIS coverages that represent the HSU boundaries were obtained directly or derived from published data and maps. For example, the elevation of the bottom of the surficial aquifer is derived by subtracting the thickness of surficial deposits (Wolansky et al. 1979) from land surface elevation. In addition to

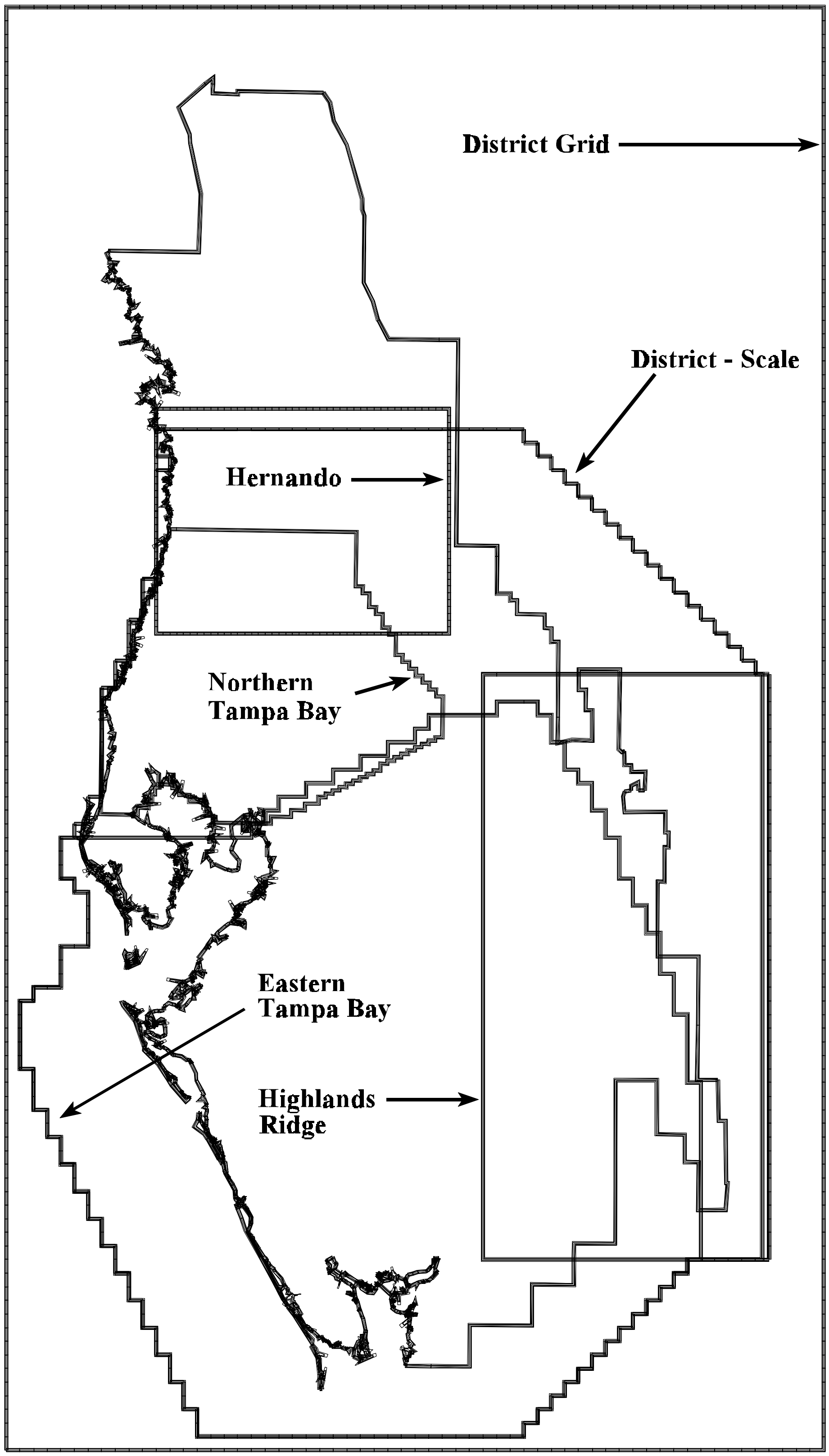

Figure 1.9 Regional Ground Water Models of the SWFWMD

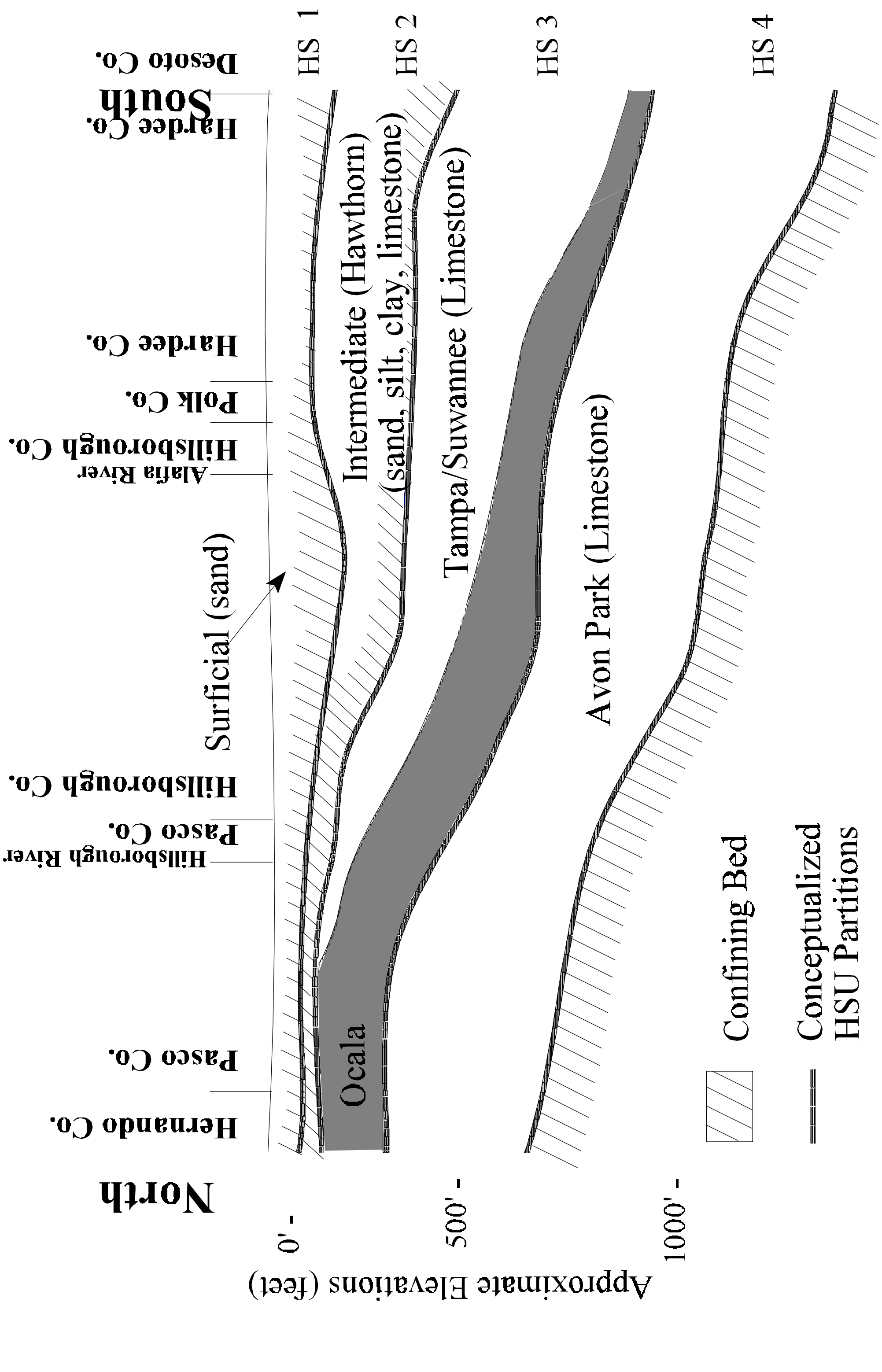

Figure 1.10 Hydrostratigraphic Units, West-Central Florida

the top and bottom elevations of each HSU, the elevations of the surfaces of subunits within the HSU's were also derived. For example, within model layers 1 and 2, the elevations of the tops and bottoms of the confining beds above and below the intermediate aquifer are defined by the bottom of the surficial aquifer, the top and bottom of the intermediate aquifer, and the top of the Floridan aquifer.

For MODFLOW and FHM applications within the District data base, each HSU will correspond to a model layer. Model layer 1 corresponds to HS1, and represents the surficial aquifer throughout the model. Model layer 2 corresponds to HS2. In the southern part of the District, HS2 and model layer 2 both correspond to the intermediate aquifer. The low permeability unit between the surficial aquifer and the intermediate aquifer is represented by a leakance term (MODFLOW **VCONT** array) between model layers 1 and 2. The low permeability unit between the intermediate aquifer and the Upper Floridan aquifer is represented by a leakance term (MODFLOW **VCONT** array) between model layers 2 and 3. In the northern part of the District, HS2 and model layer 2 represent the intermediate confining unit. Model layer 2 transmissivities are set to a very low value and leakance terms are used between model layers 1 and 2, and 2 and 3 to simulate a semi-confining unit. HS3 and model layer 3 represent the upper section of the Upper Floridan. In the southern part of the District, a leakance term between model layers 3 and 4 simulates the lower permeability unit between the upper and lower sections of the Upper Floridan aquifer. HS4 and model layer 4 represent the lower part of the Upper Floridan aquifer, and the base of layer 4 is the bottom of the Upper Floridan aquifer.

Hydrostratigraphic surfaces were developed for the District-scale conceptual four layer model as shown in Figure 1.11. Surfaces or thicknesses were digitized or derived from mapped data. The land surface is taken from USGS 1:250,000 digital elevation model (DEM) data. The surficial thickness was digitized from a USGS report (Wolansky et al., 1979). The intermediate aquifer (Corral and Wolansky 1984) and Floridan aquifer (Miller 1986) data were also digitized from USGS reports. The original mapped data were supplemented with extrapolated data to provide complete spatial coverage of the entire ground water model domain. The extrapolated data were not developed from well logs and should in no way be assumed as completely accurate. The extrapolated data were added only to meet demonstration objectives and complete the data set for the entire District domain.

From the original and extrapolated data, all HSU thicknesses and surfaces were either directly available or were calculated. In some locations, negative HSU thicknesses resulted from the calculated and original mapped data. The negative thicknesses were the result of multiple data sources, inadequate vertical control and resolution in the data for this type of use. The correction of negative values was accomplished by adjusting the aquifer or confining bed elevations to reasonable thicknesses for the region exhibiting the problems. In addition to the negative values, many small positive values were present. The aquifer and confining bed thicknesses, following adjustments, are displayed in Appendix A. A minimum thickness of 0.5 meters (1.8 feet) was used for all confining beds and aquifers, except for the intermediate aquifer in the northern half of the District, which was assigned zero thickness. Large areas (shaded regions) for some of the units were set to the minimum thickness. The surface elevation and thickness maps were stored as tins or lattices to permit automated processing to occur. Map libraries cannot store tins and lattices so these types of GIS data must be stored in a protected workspace (ARC/INFO directory, refer to

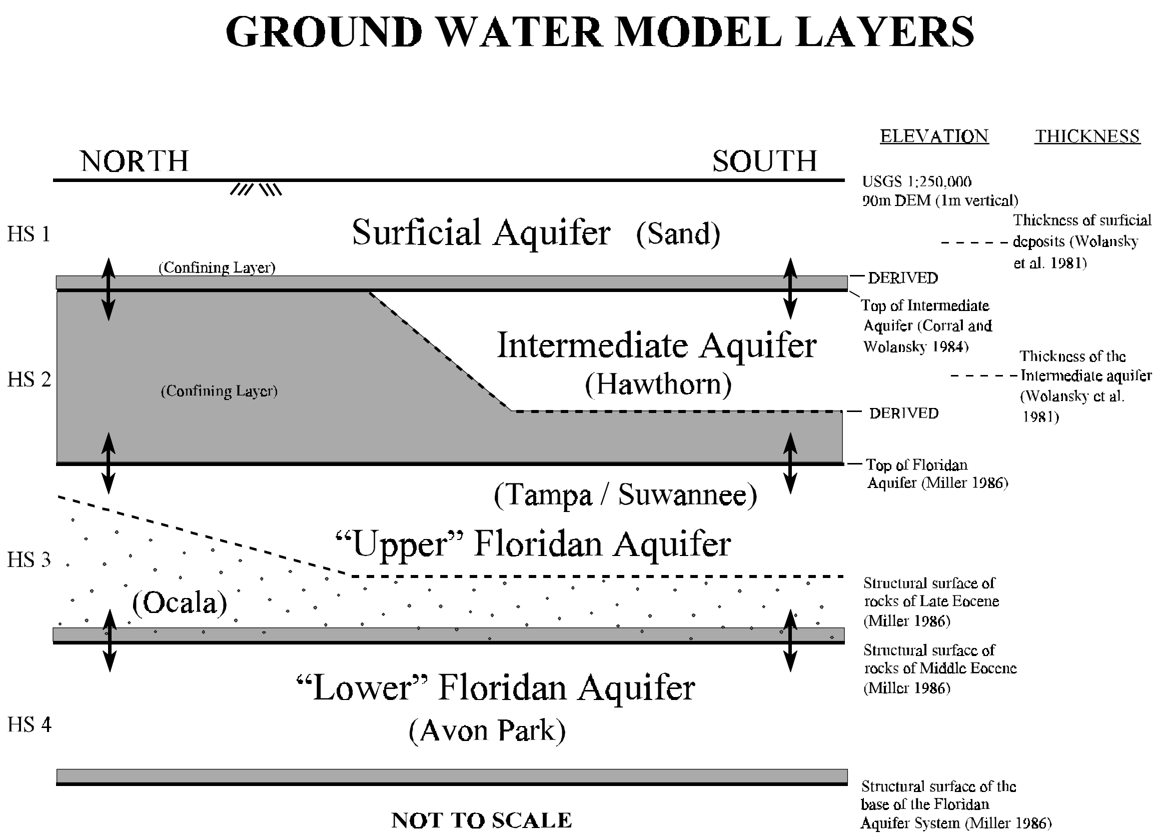

Figure 1.11 GIS Coverages of Hydrostratigraphic Layers, SWFWMD Data Base

Part II). Procedures must be established at the District to update the hydrogeologic coverages including the surface tins and lattices as better information is gathered and entered into the original contour or point data coverages.

It is important to maintain original point values (well log interpretations) for HSU surface elevation and thickness data. Although it may be desired to obtain a thickness map, it is very important to maintain the surface elevation data from which the thickness map was derived. Generalizations are made in interpreting contours from point data. All of the HSU surface and thickness coverages developed for this project were digitized from contoured data, which is part of the reason for the problems encountered.

Land Features

Included within the land features category are the data elements: land use, soils, topography, and surface basins. GIS data in this category are used for surface water, ground water, and PET model data sets. All four elements are used to develop the surface water model data set, land use and topography are used to develop the ground water model data set, and land use, soils, and topography are used to develop the ET data set. Except for topography, each of the data elements have associated attributes which are hydrologic modeling parameters.

Data in the topography coverage represent land surface elevations. The surface water model parameters for basins including slope, hydraulic length, minimum elevation, and maximum elevation are derived from land surface elevation (topography) and assigned as a surface basin attribute. All basin attributes are assigned to the smallest scale (smallest defined) surface basin classification to permit compatible use for all model scales. Assignment of these attributes to the smallest scale surface basins permits averaging for larger scales. The land use, soils, and surface basin attributes are stored in data base files which are linked (related) to the GIS coverage.

Prior to the initiation of this project, GIS land features data, available at the District, were constrained to within District boundaries. During the project, SWFWMD acquired from the other water management districts land features data for regions outside the District to fully cover the model domain. The land use, soils, and topography (5 foot contours) data are available on a 1:24,000 scale, and a state-wide coverage (excluding the South Florida Water Management District) of the surface basins is also available (Figure 1.12). One and two foot contour topography data are also available for selected areas of the District (typically completed on an as needed basis).

As part of the project, attributes were added to the appropriate land features coverages. Also generalized coverages and/or the ability to create and use them were developed. For example, for regional applications (e.g., District-scale model), a generalized land use coverage is available, stored in the 1:100,000 map library. The generalized land use coverage was made from first and select second order FLUCCS codes. Attributes for this coverage are shown in Table 1.4. Also for regional modeling, the soils coverage was generalized by a broad hydrologic classification using STATSGO GIS soils coverage. Attributes by STATSGO class are shown in Appendix B.

Hydrography (Hydrographic)

Streams, lakes, springs, and stream cross sections comprise the hydrography category. Stream cross sections are associated with the streams data element. However, a separate cross-section coverage is believed to provide the best format to store the data.

Hydrography data elements are used in the surface water and ground water component models. The coverages provide only the spatial location of the water features; attributes must be added. The attributes for the streams, lakes, and springs data elements are summarized in Appendix C. Lake attributes are associated with the lake polygons and spring attributes are assigned to the point location of the spring. The stream attributes are assigned to the stream arcs. Further discussion on attribute assignment is provided later in this section. Stream cross-section data are necessary to define stage-storage-volume-discharge relationships and cross-sectional flow paths for hydraulic models, which is not the intended application of FHM, but is accounted for in the design of the GIS data base. The cross-sections must have a spatial location along the stream. Stream cross-section information for FHM are assigned to the arcs (stream elements).

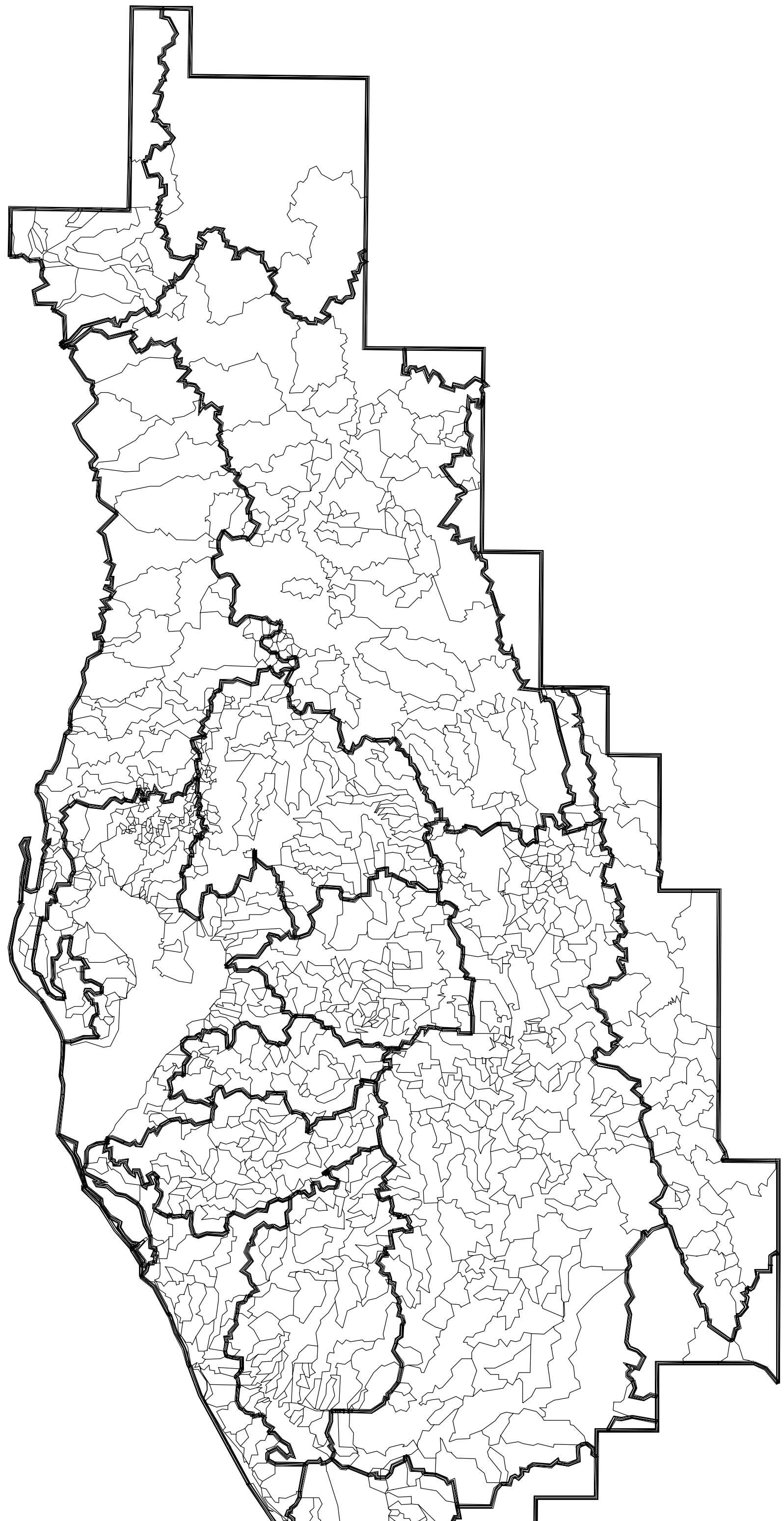

Figure 1.12 Basin Delineations, SWFWMD Data Base

Table 1.4 Land Use Attributes for a Generalized GIS Coverage of Land Use

Code	Florida Land Use, Cover and Forms Classification System FLUCFCS Description	Rhizo Depth	Plant ET Coeff	Manning n	Depress Storage	Intercep Storage
1000	URBAN AND BUILT-UP	1	0.2	0.25	0.05	0.1
1100	RESIDENTIAL LOW DENSITY < 2 DWELLING UNITS	1.5	0.3	0.3	0.05	0.1
1200	RESIDENTIAL MED DENSITY 2->5 DWELLING UNIT	1	0.2	0.25	0.05	0.1
1300	RESIDENTIAL HIGH DENSITY	0.5	0.1	0.2	0.05	0.1
1400	COMMERCIAL AND SERVICES	0.5	0.2	0.1	0.05	0.1
1500	INDUSTRIAL	0.5	0.2	0.1	0.05	0.1
1600	EXTRACTIVE	0.5	0.1	0.2	0.5	0.5
1700	INSTITUTIONAL	0.5	0.5	0.2	0.05	0.1
1800	RECREATIONAL	2	0.5	0.3	0.05	0.1
1900	OPEN LAND	1.5	0.2	0.35	0.1	0.05
2000	AGRICULTURE	1.5	0.5	0.3	0.1	0.05
2100	CROPLAND AND PASTURELAND	1.5	0.5	0.3	0.1	0.05
2140	ROW CROPS	1	0.7	0.3	0.1	0.05
2150	FIELD CROPS	2	0.7	0.4	0.2	0.1
2200	TREE CROPS	3	0.7	0.3	0.1	0.5
2300	FEEDING OPERATIONS	0.5	0.2	0.2	0.1	0.05
2400	NURSERIES AND VINEYARDS	1	0.7	0.2	0.1	0.05
2500	SPECIALTY FARMS	1	0.7	0.2	0.1	0.05
2600	OTHER OPEN LANDS <RURAL>	1	0.7	0.3	0.1	0.05
3000	RANGELAND	1	0.7	0.3	0.1	0.05
3100	HERBACEOUS	2.5	0.7	0.25	0.2	0.15
3200	SHRUB AND BRUSHLAND	2.5	0.7	0.25	0.2	0.2
3300	MIXED RANGELAND	1	0.7	0.3	0.1	0.05
4000	UPLAND FORESTS	7	0.7	0.45	0.3	0.25
4100	UPLAND CONIFEROUS FOREST	8	0.7	0.45	0.3	0.25
4200	UPLAND HARDWOOD FORESTS - PART 1	6	0.7	0.45	0.3	0.25
4300	UPLAND HARDWOOD FORESTS - PART 2	6	0.7	0.45	0.3	0.25
4400	TREE PLANTATIONS	7	0.7	0.4	0.3	0.25
5000	WATER	99	1	0	0	0
6000	WETLANDS	2	0.85	0.3	0.35	0.1
6100	WETLAND HARDWOOD FORESTS	3	0.8	0.4	0.3	0.2
6200	WETLAND CONIFEROUS FORESTS	2	0.8	0.3	0.3	0.1
6300	WETLAND FORESTED MIXED	2.5	0.85	0.35	0.35	0.2
6400	VEGETATED NON-FORESTED WETLANDS	2	0.9	0.4	0.3	0.1
6500	NON-VEGETATED	0.5	0.5	0.2	0.1	0.05
7000	BARREN LAND	0.5	0.3	0.2	0.05	0.05
8000	TRANSPORTATION COMMUNICATION AND UTILITIES	0.5	0.3	0.2	0.05	0.1
8100	TRANSPORTATION	0.5	0.3	0.2	0.05	0.1
8200	COMMUNICATIONS	0.5	0.3	0.2	0.05	0.1
8300	UTILITIES	0.5	0.2	0.2	0.05	0.1
9000	SPECIAL CLASSIFICATIONS	0	0	0	0	0

At the initiation of this project, the District had a streams and lakes coverage for 1:100,000 and 1:500,000 scales. The streams and lakes were stored in the same coverage (map library layer). This District hydrography coverage originated from an EPA coverage, but lacked topology (it had line work, but no classification). As topology is required for attribute assignment, a newly available EPA coverage, RF3-Alpha, was acquired, corrected and attributed (Figure 1.13). A significant feature of the EPA-RF3 coverage was routing provided by a tagged river and tributary level code. However, the stream level attribute assignment was later found to be unusable.

The RF3-Alpha coverage only contained stream arc topology. Since polygon topology was also required to create surface water and ground water model data sets, the authors created a separate hydrography coverage which contains only hydrography polygons. The polygon coverage was created from the RF3-Alpha coverage but was provided with attribute assignment. Additionally, a ground water springs (point) coverage was provided by the District. Feature (arc, polygon, point) attribute tables which contain physically-based data describing hydraulic and elevation attributes of individual hydrography elements were also created by the authors based on a field survey and the preliminary model calibrations performed for this project. For arc topology only, the EPA provides a connectivity attribute file which contains one record for each arc in the RF3-Alpha coverage. The connectivity file provides upstream and downstream connection data to facilitate routing. By combining data from the EPA, District, and USF, a hydrologic modeling data base was constructed for hydrography.

After working with this data base, it was determined that the attribute values assigned and the procedures used to assign them needed to be modified. Following a January, 1996 field survey of streams in the Hillsborough River watershed, a revised data base was constructed with its attribute values based on stream order (Strahler method, Viessman et al. 1996) for streams and polygon type for lakes, wetlands, etc. The ground water related hydrography attributes were refined within selected District watersheds based on model calibration efforts discussed in the following chapters. The data base refinement encompassed the addition of attribute records where they did not previously exist, the addition of more aquifer-hydrography connection (i.e., hydrography connection to more than one aquifer), the modification of the attributes which establish river bed and stage elevations, and the adjustment of the magnitude of the bed vertical hydraulic conductivity.

The attribute data base for hydrography consists of two separate but related expansion files for line and polygon type data and one file for point type data which represents ground water springs. The complete hydrography GIS file structure was presented in Part II. As stated, two expansion files are necessary for line and polygon hydrography elements. One of the files contains a mix of surface water and ground water related attributes, while the second file contains only ground water attributes. The point hydrography data has a ground water only attribute file. The ground water only attribute file provides the connection between ground water model layers and hydrography elements.

The initial attribute data base was missing many records which was, for the most part, caused by the lack of adequate stream ordering for the stream arcs. A major basis for the attribute assignment process was the stream order and reach type for line and polygon hydrography elements, respectively. Due to errors and omissions in the EPA RF3-Alpha version of the hydrography, GIS coverage and associated attribute table, the automated stream order assignment

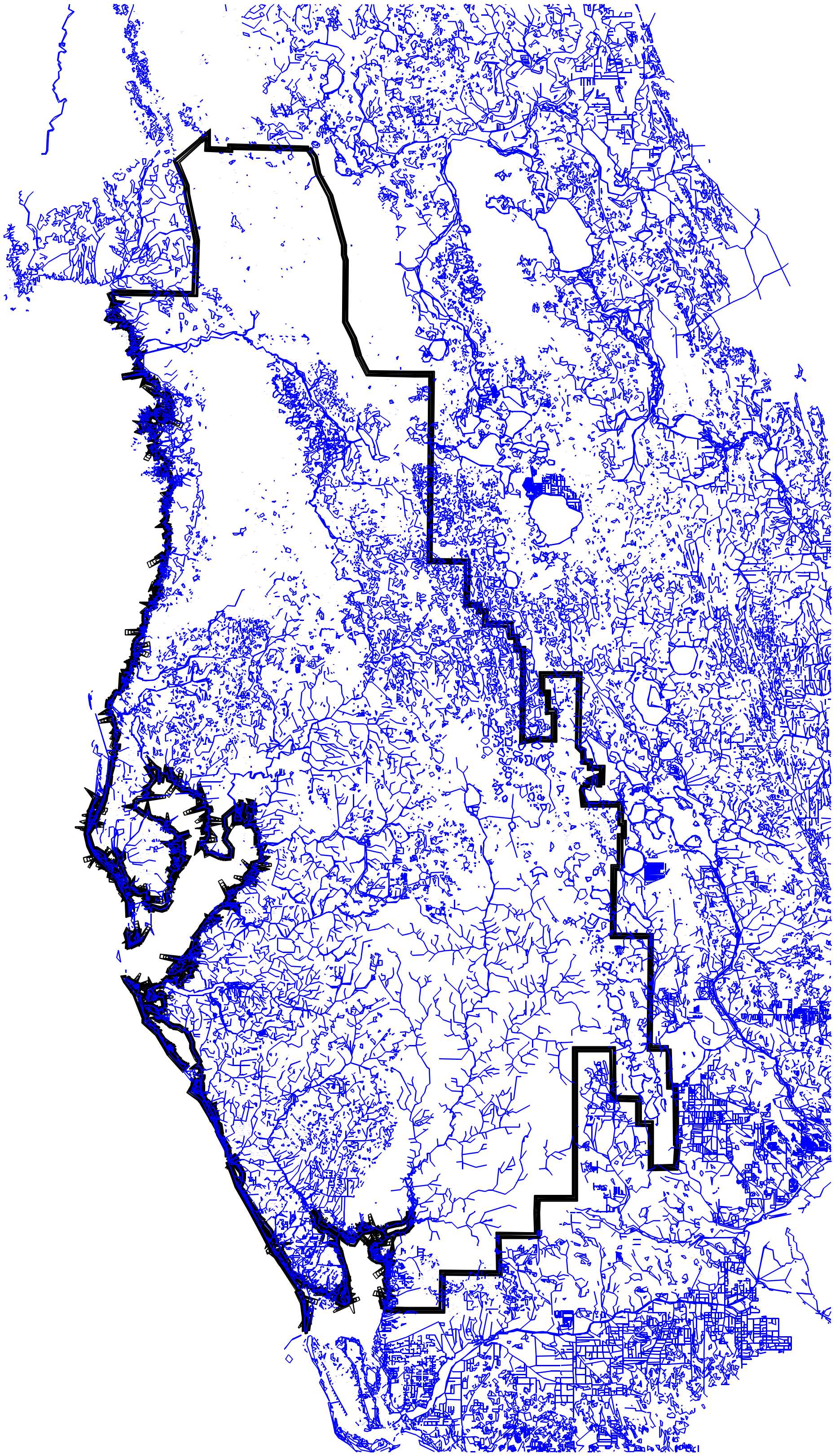

Figure 1.13 Hydrography Coverage (EPA RF3-Alpha), SWFWMD Data Base

processing was not able to correctly establish the order for all streams (some stream elements were not ordered). Through manual means, the streams in the Hillsborough, Peace, upper Withlacoochee (southern reaches), and Pithlachascotee watersheds were re-ordered. In addition, some of the significant hydrography polygons which were mislabeled were assigned the correct reach type. Following the revised stream ordering and reach type labeling, the missing attribute records were added to the expansion files.

The ground water only attribute file which is associated with ground water model layers was initially attributed with layer one records only. However, District regional models have linked the hydrography with the surficial aquifer (layer 1) and the Floridan aquifer (layer 3). In addition, there is evidence from USGS potentiometric surface maps for the intermediate aquifer that at least the main stem of the Peace River is linked with the intermediate aquifer (layer 2). Based on the content of the District's regional models and the USGS intermediate potentiometric surface maps, the ground water only attribute files were updated to include links between layers 2 and 3 and the hydrography. Generally, the main stem of the Hillsborough and Withlacoochee Rivers are linked with layer 3 and the main stem of the Peace River is linked with layer 2. Since some hydrography elements of the main stems of the rivers named above are polygons, the ground water model layer links are in both the line and polygon attribute files. Presently, most aquifer-hydrography connections are established with the surficial aquifer, which is represented by layer 1.

Through model simulations described in the following chapters, further modifications to the data base attribute values were found to be necessary. The final attribute descriptions, source information and default attribute assignments by order are contained in Appendix C.

Hydrologic

The hydrologic category includes aquifer water levels for defined HSUs. The sources for the aquifer water level GIS data may be observed or simulated data. The GIS data may be stored as point values, contoured, or as interpolatable surfaces such as tins or lattices. Observed aquifer water level GIS data can be used for calibration purposes, either in point value form or as an interpreted contoured coverage. Simulated aquifer water level GIS data can be used in the calibration process by comparing results to observed data. By saving the water level results from a calibrated model as a GIS coverage, water levels from the calibrated model can be used as initial conditions for a subsequent model. Saving the water level results as an x-y-z or formatted file does not permit easy access to the data when the scale of the subsequent model domain is different from the original model scale.

The District maintains some historic observed aquifer water level data as GIS coverages. The observed data is stored as contoured data only. Model simulation results are not presently stored as GIS coverages.

The addition of point values to the interpreted contoured data will make the observed aquifer water level coverages useful for more applications. A protocol for storage of simulated aquifer level data as GIS coverages should be established. Establishment of utilities would facilitate the conversion of x-y-z or formatted files to GIS coverages of simulated aquifer water level data.

Temporal Data Sites

In the Time Series Data Base section, various data elements were identified as necessary for hydrologic modeling. Temporally-dependent data are collected at locations which can be spatially identified. It is necessary to store in a GIS data base the locations for monitoring sites where streamflow, stream stage, lake stage, rainfall, ET, ground water levels, pumpage, and surface water diversions are recorded. Station IDs which remain consistent and unique through time are essential to maintain a link between the temporal and spatial data bases.

The District has established a comprehensive GIS data base to store the locations of temporal data sites. In one coverage, the locations of all monitoring stations of streamflow, stream stage, lake stage, rainfall, ET, and ground water levels data are stored. The locations of all structures and pumpage sources are located in two other separate coverages.

The pumpage sources coverage is the only coverage of temporal data sites which, at this time, requires modification. A unique ID must be established between all records in the pumpage source GIS location coverage and the pumpage rate data base. Any duplicate records for a given source must be purged. Any source which becomes plugged or inactive, whether a surface water or a ground water source, must remain in the GIS data base to facilitate historic modeling applications. In addition, the sources GIS coverage must contain a field which identifies whether the individual withdrawal point is a surface water or ground water source. For ground water wells, well casing depth and/or aquifer connection should be included.

Political

The political category includes data elements such as state, water management district, county, city, water service area, quadrangles, section, township and range (S-T-R), and permit boundaries. These data are used by the modeler for spatial referencing.

The political coverages available at the District are sufficient to meet the needs of hydrologic modeling. No additions or changes are anticipated at this time.

Recommendations

Based on the assessment of the District's spatial data base (GIS) with respect to its use in hydrologic modeling applications, the following recommendations are offered:

1. A critical review of the conceptual description and bounds of the four layer hydrostratigraphic unit (HSU) designation is strongly recommended. Ground water modeling requires an accurate conceptual picture of the structure of the aquifer units, which is essential to build a valid model. It is inappropriate to solely base HSUs on geologic formations and /or prior model descriptions. A more complete review of original well and geophysical logs is required.

2. A comprehensive review of well logs to further establish a more reliable set of HSU surface elevation and thickness coverages must be performed. The study region should encompass the entire active region of the anticipated District-wide ground water grid. HSU surfaces and thicknesses must be characterized for all regions, including those regions covered at the surface by Tampa Bay and the Gulf of Mexico. Only then can full characterization of the ground water flow system be achieved. In addition, regions outside the active domain should be included to characterize the model border areas, at least at a cursory level. Other Water Management Districts should be queried for data contributions to assist in the HSU characterization. Maintenance of vertical control through the four layer HSU system is vital for establishing a good set of HSU surface coverages. A system for supplementing HSU coverages with new well logs should be established.
3. Critically review all other data for the hydrogeologic GIS data base which includes HSU (e.g., hydraulic conductivity) and non-HSU (e.g., stream attributes) dependent data and establish a program to facilitate completion and refinement of the hydrogeologic GIS data.
4. Use the present HSU surface and thickness coverages with caution due to the inclusion of extrapolated data and thickness corrections which were necessary.
5. The GIS WUP source location coverage must be cleared of any duplicates and procedures must be established to maintain the location of any withdrawal source (surface water or ground water) in the GIS coverage. Removal of plugged or unused sources from the GIS data base will hamper simulation of historic water resource conditions.
6. The attribute values developed during this project are intended for demonstration purposes. Although reasonable values were established, a comprehensive assessment should be performed on the attributes to ensure the contents of the data base meet the credibility requirements of the District. The University-assigned attribute values are based on the best available information at this time and should be acceptable for at least preliminary applications.
7. For elevation coverages, maintain original point elevation values, where available, in the GIS coverage.
8. Review and further establish generalized coverages for land use, soils, surface basins, and hydrography, or establish an automated procedure to create the generalized coverages on an as needed basis.
9. Review and/or refine the stream cross-section GIS coverage and attributes. In addition, a generic but regional stream cross-section assignment based on stream order and/or contributing drainage basin area may be invaluable for rapidly building these coverages and attributes.

Summary

The temporal and spatial (GIS) data bases of the District are significant and sufficient to progress from framework to operational models to better manage water resources from a holistic perspective. However, many important data components are insufficient to enable staff to <u>fully</u>

utilize the GIS automated processing capacity provided to the District from this project. The data deficiencies described in this report limit the quality and utility of automated data processing which can ultimately be achieved.

District staff and other potential model users can now develop data sets, through automated processing, for surface water, ground water, and integrated model applications for any region within the District. However, the condition of the data base and the complexity of the system still require significant efforts for model calibration.

The status of temporal and spatial data for hydrologic modeling throughout the District has been described briefly in this chapter. The temporal data currently available at the District is adequate for hydrologic modeling with some notable exceptions including the lack of hourly rainfall data and missing hydrologic data for regions outside the District, and errors in the WUP pumpage data base; these data have been acquired or have been corrected for years 1989 and 1990 only. Although the GIS attribute data which was developed for the FHM must be critiqued by the District, the spatial data base (GIS coverages) are sufficiently complete for hydrologic modeling with the exception of hydrography, stream cross-sections, and WUP well source locations. Only a partially attributed hydrography coverage and a partially corrected WUP source locations coverage (applicable to 1989 and 1990 corrected WUP pumpage data base) have been assembled to demonstrate the coverage requirements, structure and the automated data processing capabilities available for a completed coverage.

The scope of achievable automated data processing to create hydrologic model data sets will continue to be dictated by the status of the temporal and spatial data bases. For surface water modeling, automated data processing can be used to develop all surface basin characteristics and temporal data assignments. For ground water modeling, all hydraulic parameters and boundary conditions can be prepared through automated data processing. However, the temporal data sets must be constructed and inspected for each new application. For 1989 and 1990 only, pumping well data sets were created for the District; development of well data sets for other years or for regions outside the District will require additional data base development or manual entry. Due to attribute deficiencies (primarily lack of cross-section information), stream and lake hydraulic properties for all modeling types must be prepared in conjunction with traditional methods (field data collection and modeler subjective estimation) until attribute deficiencies are corrected. The limitations to the scope and benefit of automated data processing within the District data base can be removed through a program of attribute assignment on a project by project basis and/or as the need arises.

An overall assessment of hydrologic data needs for District-wide water resource modeling, unfortunately, is not constrained by political boundaries. For both data base types, spatial and temporal, representative data for regions outside District boundaries are deficient. Future data acquisition and cooperative agreements should encompass regions outside District boundaries to enable the District to characterize hydrologic model boundary conditions including stresses which will effect those boundaries.

Hourly frequency rainfall data, including minor events, must be digitally recorded to approach any reasonable simulation of hydrologic conditions with either a surface water model or an integrated surface/ground water model.

Surficial aquifer water level data are severely lacking across the District. This data is critical for calibrating ground water and integrated models that are intended to represent wetland or lake/aquifer interactions and for accurately characterizing the spatial and temporal variability in the rainfall/infiltration/ runoff process which ultimately drives recharge. Infiltration in Florida sandy soils is completely regulated by the vadose zone soil moisture and depth-to-water table. Very little monitoring data exists for model calibration.

Unique IDs are a necessity for all temporal data monitoring sites, especially for historical pumping records. Better characterization of the elevations of the hydrostratigraphic surfaces can be achieved with a review and interpretation of available well logs. Attribute assignment has been accomplished up to the point of developing a framework modeling program. However, further attribute characterization will be necessary, including fundamental data gathering, to yield the most credible data base. Because a GIS is so adept at summarizing data at different scales and hydrologic modelers have historically struggled with scale issues, it is essential to maintain scale issues in focus whenever discussing any modifications to the GIS data base.

Finally, it must be re-emphasized at every opportunity that the objective of this test application was to develop a modeling strategy that will meet the needs of the District for many years to come. This strategy includes the expectation that data resources will continue to evolve and, perhaps, will be more focused on the specific needs of a comprehensive assessment model. Holistic water management modeling requires and must include further advancements in the models including the incorporation of new and additional modeling strategies to meet the various needs throughout the District's divisions.