Rhode Island Water Supply System Management Plan Database (WSSMP—Version 1.0)

By Gregory E. Granato

In cooperation with the
Rhode Island Water Resources Board

A contribution to the
Rhode Island Water Use Compilation

Open-File Report 2004-1231

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
Gale A. Norton, Secretary

U.S. Geological Survey
Charles G. Groat, Director

U.S. Geological Survey, Reston, Virginia: 2004
For sale by U.S. Geological Survey, Information Services
Box 25286, Denver Federal Center
Denver, CO 80225

For more information about the USGS and its products:
Telephone: 1-888-ASK-USGS
World Wide Web: http://www.usgs.gov/

Suggested citation:
Granato, G.E., 2004, Rhode Island Water Supply System Management Plan Database (WSSMP–Version 1.0): U.S. Geological Survey Open-File Report 2004-1231, 77 p.

Preface

In Rhode Island, about half of the state’s geographic area and nearly 90 percent of its population is served by the 31 largest water suppliers. These water-suppliers, which obtain, transport, purchase, or sell more than 50,000,000 gallons of water per year are required to prepare, maintain, and carry out a Water Supply Systems Management Plan (WSSMP). Historically, water-suppliers have largely generated WSSMP information using a variety of sampling and data compilation methods and nonstandard reporting formats. By statute, completed water supply plans are circulated information among agencies having complementary authority over water resources. Each of these entities analyzes the data, primarily for mission-specific regulatory compliance purposes. Over the years, the Rhode Island Water Resources Board (RIWRB) and other responsible State agencies have been manually evaluating data presented in “hard copy” water-supply plans from suppliers, their consultants or other government agencies. Collaboration regarding computer architecture or the way in which information is collected, classified, stored and electronically shared is informal. Because an integrated system has been lacking, the ability to maximize water resource management decisions has been notably compromised.

The WSSMP database developed by the U.S. Geological Survey (USGS) in cooperation with the RIWRB has been designed to address these problems. Cooperative water-use studies between the RIWRB and the USGS have resulted in implementation of the New England Water Use Database System (NEWUDS) to catalog water-use data by basin in Rhode Island. Wide-spread accessibility of this water-use and availability data is necessary for public administration and planning purposes. The WSSMP reporting structure does include some water-use data but is focused on water-supply infrastructure and planning. The USGS water use compilations are organized by water-use transaction processes, whereas data elements in the WSSMP structure are strictly aligned with state WSSMP regulations. Furthermore, the terrorist events of September 11, 2001, resulted in a reevaluation of information that should be protected. The current design that is documented in this report addresses the need for secure information and addresses methods for integration with applicable State and Federal databases within current security constraints.

Connie McGreavy
Programming Services Officer
Rhode Island Water Supply Board
100 North Main Street
5th Floor
Providence, RI, 02903

Contents

Plate

Figures

Tables

Rhode Island Water Supply System Management Plan Database (WSSMP—Version 1.0)

By Gregory E. Granato

Abstract

In Rhode Island, the availability of water of sufficient quality and quantity to meet current and future environmental and economic needs is vital to life and the State's economy. Water suppliers, the Rhode Island Water Resources Board (RIWRB), and other State agencies responsible for water resources in Rhode Island need information about available resources, the water-supply infrastructure, and water use patterns. These decision makers need historical, current, and future water-resource information. In 1997, the State of Rhode Island formalized a system of Water Supply System Management Plans (WSSMPs) to characterize and document relevant water-supply information. All major water suppliers (those that obtain, transport, purchase, or sell more than 50 million gallons of water per year) are required to prepare, maintain, and carry out WSSMPs. An electronic database for this WSSMP information has been deemed necessary by the RIWRB for water suppliers and State agencies to consistently document, maintain, and interpret the information in these plans. Availability of WSSMP data in standard formats will allow water suppliers and State agencies to improve the understanding of water-supply systems and to plan for future needs or water-supply emergencies. In 2002, however, the Rhode Island General Assembly passed a law that classifies some of the WSSMP information as confidential to protect the water-supply infrastructure from potential terrorist threats. Therefore the WSSMP database was designed for an implementation method that will balance security concerns with the information needs of the RIWRB, suppliers, other State agencies, and the public.

A WSSMP database was developed by the U.S. Geological Survey in cooperation with the RIWRB. The database was designed to catalog WSSMP information in a format that would accommodate synthesis of current and future information about Rhode Island's water-supply infrastructure. This report documents the design and implementation of the WSSMP database. All WSSMP information in the database is, ultimately, linked to the individual water suppliers and to a WSSMP "cycle" (which is currently a 5-year planning cycle for compiling WSSMP information). The database file contains 172 tables—47 data tables, 61 association tables, 61 domain tables, and 3 example import-link tables. This database is currently implemented in the Microsoft Access database software because it is widely used within and outside of government and is familiar to many existing and potential customers.

Design documentation facilitates current use and potential modification for future use of the database. Information within the structure of the WSSMP database file (WSSMPv01.mdb), a data dictionary file (WSSMPDD1.pdf), a detailed database-design diagram (WSSMPPL1.pdf), and this database-design report (OFR2004-1231.pdf) documents the design of the database. This report includes a discussion of each WSSMP data structure with an accompanying database-design diagram. Appendix 1 of this report is an index of the diagrams in the report and on the plate; this index is organized by table name in alphabetical order. Each of these products is included in digital format on the enclosed CD-ROM to facilitate use or modification of the database.

Introduction

In Rhode Island, systematic management of the State's water resources would help to ensure that existing and potential water supplies are properly protected, conserved, developed, and utilized on a continuing and sustainable basis (Rhode Island Water Resources Board, 1998). The State of Rhode Island faces increased and competing demands for its ground-water and surface-water resources. The availability of water of sufficient quality and quantity to meet current and future needs is vital to life and the State's economy (McGreavy, 1998). During the past 34 years, Rhode Island has implemented a number of laws, policies, and plans to protect the State's waters as a natural resource, to promote economic development, and to protect current and future water supplies. In 1969, Rhode Island adopted its first water-supply policy, Element 721, of the State Guide Plan (Rhode Island Department of Administration, 1997a). The Rhode Island Public Drinking Water Supply System Protection Act of 1997 defines water as an invaluable natural resource and recognizes the need to protect current and future water supplies (Rhode Island General Assembly, 1997).

By law (Rhode Island General Assembly, 1997), all municipalities subject to the Comprehensive Planning and Land Use Regulation Act (Rhode Island General Assembly, 1988) and all water suppliers (including municipalities, municipal departments, agencies, districts, authorities, or other entities) which obtain, transport, purchase, or sell more than 50 million gallons of water per year are required to prepare, maintain and carry out a Water Supply System Management Plan (WSSMP). Arthur D. Little, Inc. (1990), estimated that the 30 major water suppliers that were required to maintain and submit WSSMPs supplied about 90 percent of the population, and that their distribution networks covered about 50 percent of the land area of Rhode Island in 1990. Currently (2004), 31 water suppliers are required to submit WSSMPs (C.L. McGreavy, Rhode Island Water Resources Board, written commun., 2003).

WSSMPs are intended to define the current condition of each major water supplier and to act as planning documents that can be used to project future water-supply demands and to develop strategies for controlling demands in order to enable continual growth and conservation of the water supply (McGreavy, 1998). WSSMPs are used to describe the infrastructure of the water-supply systems, provide information that can be used to assess the adequacy of the system for meeting current demands, and to estimate the adequacy to meet future demands (Rhode Island Water Resources Board, 1998). Each WSSMP must include a statement of goals; a description of the water system(s), related geographic information, demand-management measures, system-management measures, supply-management measures, emergency-management measures, and water-supply-coordination measures; identification of individuals responsible for implementing management measures; documentation of the efficiency of management measures; water-quality information; and leak-detection and -repair information. By law, water suppliers are required to review, amend (or replace), and file a WSSMP with the Rhode Island Water Resources Board (RIWRB) at least once every 5 years; this time period is commonly defined as the WSSMP "cycle." WSSMP specifications also include a requirement that spatial data are designed for compatibility with Rhode Island Geographic Information System (RIGIS) standards. The RIWRB has the responsibility to provide an opportunity for public review and to ensure expeditious review of these plans in conjunction with the Rhode Island Department of Environmental Management (RIDEM), the Department of Health (RIDOH), the Division of Planning of the Rhode Island Department of Administration (RIDOA), and the Division of Public Utilities and Carriers (RIPUC). Rhode Island State law and planning policies (Rhode Island General Assembly, 1997, Rhode Island Water Resources Board, 1998), therefore, define the content and format of the WSSMPs.

In 1992, the RIDEM Division of Water Supply Management designed and implemented a prototype WSSMP plan format and an associated database (Charpentier and others, 1992; Fly, 1992; Elizabeth Scott, Deputy Chief, Rhode Island Department of Environmental Management, Office of Water Resources, Surface Water Protection Section, written commun., 2002). The RIDEM WSSMP methods included 38 worksheets to facilitate WSSMP development efforts and to help standardize input for use in a relational database system. In the RIDEM implementation, the database was administered and populated entirely by personnel from the RIDEM Division of Water Supply Management. Water suppliers submitted WSSMPs to the RIDEM in paper format, and the information on the worksheet was then entered into the database. This database-design effort was not fully implemented and was abandoned when the RIDEM Division of Water Supply Management was eliminated (Elizabeth Scott, Deputy Chief, Rhode Island Department of Environmental Management, Office of Water Resources, Surface Water Protection Section, written commun., 2002). This database is not available because the electronic files were not formally published (McGreavy, 1998).

Currently (2004), inconsistencies in the content and format of WSSMP information submitted by different water suppliers complicates local, regional, or statewide review and analysis of this data (C.L. McGreavy, Rhode Island Water Resources Board, written commun., 2003). Differences in interpretation of the rules and procedures for WSSMPs (Rhode Island Water Resources Board, 1998) by the water suppliers that submit plans lead to inconsistencies in the content of information in different plans. Furthermore, water suppliers develop and submit WSSMPs in several formats, including paper forms, word-processing documents, text files, and electronic spreadsheets, which complicates efforts to integrate and interpret information among the various plans. Therefore, the RIWRB and other State agencies responsible for water-resources management in Rhode Island recognize the need for implementation of a database that can facilitate compilation, examination, and interpretation of WSSMP information.

Some information relevant to the water-resources-management process is captured and documented by the U.S. Geological Survey (USGS) water-use program (U.S. Geological Survey 2003b). Cooperative studies between the USGS and the RIWRB are currently (2004) documenting water use in Rhode Island with the New England Water-Use Data System (NEWUDS) developed by the USGS (Tessler, 2002). The NEWUDS is a conveyance-based data model rather than a site-based data model because it is designed to document water-use transactions that occur between water-use facilities (Tessler, 2002), rather than the engineering specifications and logistical data that are the focus of the WSSMP database. State and local water-use agencies in Rhode Island need water-supply-production and -distribution information that is not included in the NEWUDS design. Information about the infrastructure is important because the availability of water in a developing area may be limited by available water-supply infrastructure and resources available for system maintenance rather than by current water use or availability in a given basin. For example, low-capacity pumps, leaking water mains, or insufficient storage capacity to meet daily peaks in demand may limit water use or economic development in an area with an excess in available water resources. Furthermore, the national and State water summaries developed by the USGS in cooperation with different State agencies are meant to provide basic data and information for the public domain, whereas the detailed WSSMP information is, by law (Rhode Island General Assembly, 2002), confidential information to promote water-supply-system security.

The RIWRB, recognizing the earlier successes and limitations of the RIDEM WSSMP database efforts and subsequent improvements in computer technology, determined that a system of integrated water-use and water-supply databases would help planners direct resources and conservation efforts to ensure adequate water supplies. The USGS, in cooperation with the RIWRB, developed a WSSMP database during 2002–04 designed to be separate from, but compatible with NEWUDS, RIGIS, the USGS National Water Information System (NWIS), and, potentially, other State and Federal databases.

A relational data model that accurately describes the structure of a set of data is a precursor to any correctly designed database (Fleming and von Halle, 1989). Logical modeling is the process of analyzing and reducing a set of data to its separate components, establishing the nature and direction of relationships between those components, and thereby building a structure for the data that automatically enforces the business rules that are needed to maintain data integrity and provide easy access to all of the information stored in the database. A properly designed logical data model provides for change in the data-management process. A logical data model should, therefore, represent a straightforward generic structure that easily allows for later corrections and extensions without affecting the integrity of data already in the database (Granato and Tessler, 2001; Tessler, 2002).

This report provides basic information that will help the RIWRB assess the design, functionality, and potential uses of the WSSMP database. The report describes the WSSMP database's logical data model and its implementation as a Microsoft (MS) Access database for knowledgeable users who may need to do one or more of the following:

- examine the data model,
- evaluate the storage structure for a specific use,
- customize their own version of the database,
- link this database to other types of databases such as geographic information systems (GIS), and
- build software applications for data entry, analysis, and reporting.

Some basic information about database design and implementation in MS Access is provided to make the discussion intelligible, but the report was written with the assumption that the intended audience for this document has a working knowledge of MS Access and some background in the design or use of relational databases. Information and training on the use of MS Access is widely available and can be located on the Internet. Information about data models and relational database-design concepts are available in many books (for example, Fleming and von Halle, 1989; Hernandez, 1997; Roman, 1997), and in the Federal data-modeling standard document FIPS 184 (National Institute of Standards and Technology, 1993) for potential users who may need to become acquainted with these topics. Tessler (2002) and Horn (2002) describe the design and use of the NEWUDS database, respectively.

The WSSMP database design includes all the elements necessary to record WSSMP information and is based on the original RIDEM worksheet structure. During the study period, concerns about the potential safety and security of large water systems (Rhode Island General Assembly, 2002) changed the scope of the intended application from an open internet-based system to a closed confidential system that may be used to provide summary information to the public. Therefore, the scope of the design effort included the following factors:

- this version of the database is a preliminary design intended for evaluation and testing by the RIWRB,
- the database design is published with contact information for the water suppliers that submit WSSMPs and standard lists of WSSMP options, but the database is not published with actual WSSMP data, and
- this database design has not been developed into a full MS Access application with a graphical user interface.

Full implementation of a WSSMP database is planned after the RIWRB has evaluated the design of the current version from the perspective of an experienced user (C.L. McGreavy, Rhode Island Water Resources Board, written commun., 2002).

The author thanks Connie L. McGreavy of the RIWRB for guidance on WSSMP specifications and potential uses of the WSSMP database. Elizabeth Scott of the RIDEM provided information on the original WSSMP database application. Steven Tessler of the USGS designed the NEWUDS database (Tessler, 2002) and developed or applied a number of relational database standards, tools, and software applications for the design and documentation of water-resources databases. Steven Tessler provided information and advice for this effort on several occasions. Lora Barlow and Emily Wild of the USGS provided water-use specialists' perspectives on WSSMP information and on implementation of the NEWUDS database design. Todd W. Augenstein, information specialist and author of the National USGS Site Specific Water-Use Database (SWUDS), and Peter Church, a USGS hydrologist, provided detailed technical reviews of the WSSMP database and database documentation.

Database Specifications

The main objective guiding the WSSMP database-design process is the need to store large amounts of information in one data structure, thereby allowing Rhode Island State agencies and water suppliers to enter, explore, synthesize, and review WSSMP data efficiently. A data model is the blueprint from which a database is constructed. A well constructed data model is a normalized relational design that underlies the physical database as implemented within a specific database software application. Therefore, specifications for a successful database include a well-designed data-model and careful selection of the database software that will be used to implement the data model.

Data-Model Specifications

Information about data and user requirements is a necessary prerequisite for any database-development effort. This information is used to clarify the purpose and scope of the database, to guide the development of the database structure, and to serve as a final checkpoint for the end product. The WSSMP database is designed to meet the need for improved information exchange by providing a database structure that

- is focused on the description of the water-supply system infrastructure (such as the reservoirs, wells, treatment systems, transmission lines, distribution systems and other facilities that are used to obtain, treat, and supply water),
- records the data following Section 8 of the RIWRB (1998) rules and procedures for WSSMPs,
- can be adopted by water suppliers who are familiar with existing WSSMP worksheet formats,
- promotes completion and standardization of the required elements of the WSSMP,
- provides a mechanism for recording and tracking confidential WSSMP data,
- is compatible with RIGIS data standards,
- is compatible with the USGS NEWUDS system,
- is compatible with water-quality data maintained by the RIDOH,
- is compatible with other potential sources of water-resources data, and
- can be expanded in the future.

Data modeling is a method that is used to define real-world objects (such as a well) and information (such as the well's production volumes) as data entities and to define relationships among these data entities. A relational database model defines each entity in a data set with a table or tables that define or document characteristics of each entity in the data set. Relationships among these tables define or document the relationships between different data entities in the database.

Normalization is the process of creating a data model in which data elements are separated into their component parts. Normalization reduces redundancy and therefore maximizes storage efficiency of a given data model. A normalized relational model will organize a data set in a manner that will efficiently store information for retrieval and synthesis (Granato and Tessler 2001, Tessler, 2002). A high degree of normalization and the resultant gains in computer storage space are critical in large databases (those with millions of individual records). A highly normalized database, however, may have more tables and relations than an unnormalized database. Also, overnormalized databases can be difficult to use because of problems such as possible losses in information (when relations are not accurately defined in the model), possible losses in dependencies (when dependent fields are not defined in the model as dependencies), and difficulties in reconstitution of data entities from their normalized components (Roman, 1997). In the development of the WSSMP database, a relational model was specified, and database normalization was included as a design goal, but the degree of normalization was not specified. The WSSMP database design documented in this report is balanced between the benefits and liabilities of the normalization process.

Software Specifications

Many issues were considered by the USGS in choosing database software, including import and export capabilities in different formats, reasonable purchase price, prospects for continued availability, software capabilities, ease of use, and vendor support. A primary consideration is to have software that is user-friendly with an interface that would be familiar or easy to use for many potential customers. Import and export capabilities, including the ability to read and write text and data in space-delimited or tab-delimited ASCII formats, are important to facilitate information transfer between text files, word processors, spreadsheets, and other database applications. The interface must support input, output, and queries through standard forms for use by report reviewers and database users. It is important to be able to exchange data and information with GIS software to facilitate geographic data analysis. Logistically, it is also important to select database software that

- can be published on CD-ROM with a low or no royalty run-time version for basic use by people who do not own a particular database-software package;
- has a reasonable purchase price for advanced users who may not own the software;
- is available for computers that use a MS operating system, which is commonly available to local, State and Federal agencies concerned with water-supply information; and
- has vendor support from a company that has a reasonable chance for continued viability over the next 5 to 20 years.

MS Access was chosen by the USGS because it best fit these software specifications and because it is the same software that is being used to support the database for other water-use studies in Rhode Island (NEWUDS).

Database-Design Concepts

The WSSMP database is designed to rigidly protect the integrity of the data once entered, yet be flexible enough to store variable data, allow extension and customization, and provide linkages to other databases. This section discusses the general database design concepts that were used to design and construct the WSSMP database. Specific examples are provided to explain these concepts but this section is not a detailed description of the entire database design. The following section "Database Contents" is a detailed description of each section of the database. The data dictionary (provided in the file titled "WSSMPDD1.pdf" on the accompanying CD-ROM) documents all table and field definitions.

Table Design in a Relational Database

Each table in the relational database is designed to characterize a data entity in the WSSMP. Examples of unique data elements include water suppliers, reservoirs, and supply wells. One or more tables are created for each unique entity. Tables consist of one or more fields (columns) that define the characteristics of the entity. Each unique entity (commonly referred to as an entity instance) in a table is defined within a record (row). The data in each field (column) in the record (row) documents one of the unique characteristics of the entity instance. In the relational database design, each row is a unique record because each row must have a combination of field values that define a unique entity instance. For example, a table may be used in a relational database to provide a standard list of materials used for construction of water-storage tanks. At a minimum, a table characterizing the storage-tank materials should contain two fields, an index number and a description of the material. If, however, the RIWRB and the water suppliers decided to categorize material types, then at least one extra field would be needed to uniquely characterize each new category of construction materials while maintaining a unique index number and definition for each material in the respective fields. In this case, the category definition would be repeated for each material in the category and each type of material could be identified by index number, by category, or by the description of the material.

The power of a relational database lies in the ability to compartmentalize each unique data entity in the WSSMP plans into one or more individual tables that characterize the data entity without duplicating or losing the information that describes the relationship between individual entities. For example, worksheet 1 of the WSSMP reports identifies each surface-water supply and the physical, hydrological and chemical characteristics associated with each surface-water-supply. Theoretically, each water-supplier may own or administer one or more surface-water supply sources. It would not be efficient to repeat all the water supplier identification information with the data for each surface-water-supply source. Therefore, identification information for water suppliers is stored in (at least) one table and data associated with surface-water supplies is stored in (at least) one other table. Once entered in a relational database, this information may be used in many different ways. For example, a water supplier may examine trends through time in the total storage capacity of its surface-water supplies. In another example, State or regional officials can use this relational database to identify and aggregate data for all surface-water supplies in a region by location (irrespective of supplier) almost instantly if an emergency, such as a large-scale forest fire, creates an immediate need.

The relational model provides a way to extract data from any two or more tables in any combination desired, if an unambiguous pathway of relationships exists between them. In the WSSMP database, "Keys" are the numerical identification tags that provide the unambiguous pathways that bind different data entities together in a relational database. The key structure consists of primary keys (PKs) and foreign keys (FKs). A unique PK value is a number that identifies each record in a table. The PK and its value in one table (a parent table) can be used to identify the records in other subordinate tables (or child tables) that have related information. When a PK from one table is used to identify related information in other tables, the PK from the parent table is the FK in the child, or receiving table. In some cases, a complex key consisting of two or more FK fields derived from other tables can be used as the PK in a given table. In the relational model each table stores information dependent on one or more key fields; each datum or descriptive entity is recorded in only one location. Relational keys to the data stored in one table are dispersed among other tables as surrogates for the detail data. All information in the database is accessible from anywhere else through the use of the key relational structure. Therefore, links established between tables by means of the PK/FK fields identify relationships between individual records in the two or more source tables that may be used to view the data from different tables as if it were in a single table. For example, the supplier-identification number is the key that identifies each water supplier in the database; this key identifies all information in the database that is associated with any given water supplier. All WSSMP data in the database is ultimately associated with one or more water suppliers through relationships based on the PK/FK number fields. The result of this is that queries (data structures within MS Access that collect and combine data) can create the illusion of a flat file (or spreadsheet) view that combines many separate, but related, tables at once.

MS Access has a number of built-in features for implementation of the relational data model while maintaining referential integrity of the data. MS Access provides direct protection of the keys throughout the tables in the database, and does not allow the key structure or defined relationships to be corrupted or compromised. The MS Access database software protects PK fields in two ways: (1) it requires that the PK field always be filled whenever new rows are added, and (2) it prevents the PK field value from being duplicated in rows of the table (each PK value within a table is unique). The MS Access database software enforces the defined-relationship properties. To protect the integrity of the keys among tables, referential integrity constraints are placed on the keys through the relation. All relationships in the WSSMP database have common settings to protect the keys. No keys are optional; each record in each table must be identified by a key value. A cascade update applies when a PK value is changed; all occurrences of that value in the related FK in other tables have their values automatically updated. A restricted delete applies when a record is being deleted from a table and prompts a warning when children of the record (holding that FK value) are present in other tables, thus preventing related records from becoming orphaned. MS Access issues this warning automatically once the relationship is established. Relationship rules can be adjusted as needed after one has experience with the WSSMP database, but adjustment of these rules might compromise the referential integrity of the database.

Limiting the complexity of key fields that identify related data stored in different tables controls the integrity of data identified in a key structure when it is viewed or combined with data from other parts of the database (Granato and Tessler 2001, Tessler, 2002). Information-rich keys (fields that have apparently unique values and could serve to identify data rows, such as a water-supplier's alphanumeric code name for a water-supply well) are not used as key fields in the WSSMP database because such code names could be changed. Such a change would corrupt relationships between data in associated tables. Therefore, information-neutral numeric keys are used to identify all data entities within the WSSMP database.

The WSSMP system is based on multiagency review of plans submitted by multiple water departments on a regular schedule of WSSMP cycles (Rhode Island General Assembly, 1997; Rhode Island Water Resources Board, 1998). Therefore, the PK/FK system in the WSSMP database is primarily built on a numeric key identifying each water supplier and a numeric key identifying each WSSMP cycle. Depending on RIWRB requirements, either the water supplier or both the water supplier and the WSSMP cycle keys are used to identify data. For example, interpretation of future water-use projections is heavily dependent on the water supplier and on WSSMP cycle in which they were made, so both keys are used. Individual suppliers may use past estimates to refine future estimates and the RIWRB may, in the future, use this information to compare the accuracy of forecasting methods used by different water suppliers. Conversely, the RIWRB decided that only the current supplier owning a facility and current emergency contacts should be included in the active WSSMP database and that these contacts should always be current, correct, and complete, irrespective of the five-year plan cycle. Therefore, the supplier and their contact information is identified through the supplier key, but is not identified using the WSSMP cycle key. When necessary, historical records of ownership by suppliers and historical contact information may be retrieved from earlier copies of the WSSMP database that are recorded on durable backup media.

The relational database structure also promotes data integrity by implementation of standardized lists of choices that are used to populate different data elements in the WSSMP database. Tables that provide standardized lists are known as domain tables because each provides specific information about a particular subject domain (Granato and Tessler 2001, Tessler, 2002). Domain tables also are known as lookup or reference tables. Domain tables increase data integrity in several ways. Logical errors caused by nonstandard use of abbreviations (for example Rhode Island, R.I., or RI), differing scope (for example, a surface-water reservoir on the Congdon River may be correctly identified in a text field as being in the Pawtuxet River, the Big River, or the Congdon River Basin), or typographic and spelling errors are prevented by proper use of domain tables. Because domain tables compartmentalize data, they reduce redundancy and improve normalization of the data structure. In tables that supply lists of choices, the PK is simply an integer, which represents each row of data in the domain table. One or more data tables use this inherited key as a surrogate for the detailed data provided by the domain list. A relationship with a domain table can provide many different pieces of information that can be used to sort or group data through the single value of the inherited key field. Domain tables provide considerable flexibility to the WSSMP database because they can be extended as needed to account for new WSSMP data requirements without affecting the rest of the database design. MS Access promotes referential integrity by linking information in different tables by key, which appears as a list of standard choices to the database user rather than as a meaningless integer. About 35 percent of the 172 tables in the WSSMP database are domain tables.

Naming Conventions

Naming conventions are necessary to communicate the identity and contents of database entities unambiguously. Consistent use of a standard naming convention facilitates an understanding of design elements and relationships in the design of the database. A standard naming convention can be used as a documentation tool in development and use of the database because the user can interpret the purpose and scope of each database object by examination of its name. In the WSSMP database, naming conventions apply to tables and fields within tables. Naming conventions should also be applied to any queries, forms, reports, web pages, macros, or modules developed for implementation of the WSSMP database. The naming conventions used in the WSSMP database correlate with naming conventions used in the NEWUDS database to facilitate integration of information among these databases.

Naming conventions generally are designed around use of a few standard prefixes that define the object type and a meaningful name structure that identifies the content and purpose for the database object. Common prefixes are tbl, qry, frm, rpt, web, mac, and mod for tables, queries, forms, reports, web pages, macros, and modules, respectively. Naming conventions are especially important when designing and building an interface. These prefixes may be further customized to define subcategories within each object (for example, the prefix qrymt may be used for a make-table query). Naming conventions allow the designer (and ultimately the user) to identify the components of the database, which are integrated into the user interface. Knowledge of the naming conventions used in the WSSMP database provides the user with information about the function of each object in the database and relations between different objects. The following naming conventions should be used in the creation of new objects and the modification of existing objects to ensure uniform communication about the functional properties of all items in the database.

General Naming Conventions

Objects in the database are identified by three general naming conventions.

1. Name-phrases are constructed by using whole words or simple acronyms to readily identify the contents or purpose of the named object.

   For example the table name "tblSupplier" indicates that this object is a table that holds basic information about the major water suppliers. Similarly, this table's primary key "Supplier_ID" is identified by name as an identification field for each supplier; this field uniquely identifies each supplier throughout the database. The table tblSupplier also contains information fields such as "SupplierName" and "SupplierWebPage" that can be identified by name. Names can also include abbreviations. For example, the primary field for the ground-water index table (tblGWIndex) is GroundWater_ID, but related field names such as GWName are abbreviated. Commonly accepted acronyms or abbreviations also are used in names, (for example, NEWUDSSite_ID, RIGISCoverageName, or DOHSampleSite).

2. The first letter of each word in the name-phrase is capitalized to facilitate name recognition.

   For example, the table name "tblGWAquiferTest" indicates that the object is a table (tbl) containing ground water information (GW), which includes aquifer-test data. Similarly, the related field name AquiferTest_ID defines the primary key of this table.

3. Name-phrases do not include numerals, punctuation, or other special characters (such as spaces or dashes).

   Names do not contain numerals, punctuation, or other special characters (such as spaces or dashes) because these characters may cause programming errors when the objects are queried by using the MS Access structured query-language (SQL) operators or manipulated by using MS Visual Basic for Applications (VBA) code. The only exception to this "special character" convention is the use of the underscore "_" character to build key names in the database. Such names consist of a root-table name (without the prefix) and an _ID suffix (for example, "Supplier_ID" in "tblSupplier"). The _ID suffix convention for key fields identifies key fields among the non-key (data) fields. If the _ID key convention is used on non-PK fields in a table, the indicated field is related to data in a separate table with the root name of the _ID field. For example, in the table tblSupplier, the non-PK field SupplierType_ID provides a relationship with the domain table tdsSupplierType, which provides a list that describes the type of water supplier.

Table-Name Prefix Conventions

Table names in the WSSMP database consist of a three-letter functional prefix and a definitive table name. The table-name prefixes are intended to facilitate determination of the function of each table in the database (Granato and Tessler 2001; Tessler, 2002). The individual table names are meant to convey the contents of each table and the relationships between tables.

Seven different types of tables are defined by a three-letter table-name prefix system used throughout the WSSMP database (fig. 1). The table-name prefixes are typed in lower-case letters to distinguish tables from field names, which start with upper-case letters. The table-name prefixes in the WSSMP are similar to the prefixes used in the NEWUDS database (Tessler, 2002) to facilitate integration of these databases. The WSSMP database utilizes additional prefixes to identify "link tables" and recursive domain tables. Table prefixes for the WSSMP are as follows:

tbl—data table, for example tblSupplier (fig. 1). Data tables hold primary data that is entered into the WSSMP worksheets. Data tables include two main subtypes, index tables and descriptive tables. Index tables are designed to identify information that is expected to be consistent regardless of date or WSSMP cycle. Descriptive tables are designed to identify information that is expected to change from cycle to cycle. For example, the table tblTFIndex contains the name and location of each treatment facility, whereas the table tblTFProcess contains information about the treatment process such as the process name, type, and flow specifications, which could conceivably change from cycle to cycle. Index data tables have a single PK field, which is an AutoNumber field in MS Access (a unique integer automatically incremented for each new record by MS Access). Descriptive tables have a PK field and one or more FK fields from index tables; the FK fields help identify and describe the subject entity. Also, data tables typically contain one or more nonkey fields that are FKs from domain tables, and thus inherit data elements from other tables as their own extended attributes.

tas—association table, for example tasGWProduction (fig. 1). Association tables are used to resolve many-to-many relations between other tables and are composed of only the FK fields from each linked table. Association tables have a complex PK composed solely of the FKs of each table involved in the association; no other fields are present in tas tables. The association table name is a phrased combination of the identifying elements from the parent table names sharing in the association. For example, the table tasGWProduction contains the GroundWater_ID field (from table tblGWIndex) and the ProductionVolume_ID field (from tblProductionVolume). This combination of keys associates water-production volume information with each water-supply well. The PKs in association tables generally are assigned by choosing relevant records from the parent tables in the desired combinations. MS Access maintains the integrity of each relation in the association table by allowing each combination only once.

FUNCTIONAL TABLE PREFIX DEFINITION	DIAGRAM DISPLAY FORMAT
tbl -- basic data table yellow display color rectangle	**tblSupplier** Supplier_ID: Long Integer Owner_ID: Long Integer SupplierType_ID: Long Integer (FK) SupplierName: Text(100) SupplierWebPage: Text(50) SupplierMemo: Memo WSMIS_ID: Text(50) SupplierParent_ID: Long Integer
tas -- association, simple white display color rectangle with rounded corners	**tasGWProduction** GroundWater_ID: Long Integer (FK) ProductionVolume_ID: Long Integer (FK)
tad -- association, with data green display color rectangle with rounded corners	**tadGWIndexRIGIS** GroundWater_ID: Long Integer (FK) RIGISCoverage_ID: Long Integer (FK) RIGISFieldName: Text(50) RIGISFieldValue: Text(50)
tds -- domain, static blue display color rectangle	**tdsStageUnits** StageUnits_ID: AutoNumber StageUnits: Text(50)
tdx -- domain, user-extendable gray display color rectangle	**tdxWellDriller** WellDriller_ID: AutoNumber WellDriller: Text(50) WellDrillerContact: Memo
tdr -- domain, recursive purple display color rectangle	**tdrConstituent** Constituent_ID: Integer ConstituentParent_ID: Integer ConstituentName: Text(75) ConstituentLevel: Integer
til -- import-link data table tan display color rectangle	**tilUSGSStreamGage** StreamGage_ID: AutoNumber SiteNumber: Text(255) StationName: Text(255) DLatitude: Double DLongitude: Double DCoordinateDatum: Text(255) MapName: Text(255) Altitude: Single AltitudeDatum: Text(255) HUC-08Digit: Text(255) DrainageArea: Single ContinuousGage: Yes/No NWISWEB_ID: Memo

Figure 1. Examples of tables with functional prefixes and their diagram display formats. Each table has several fields to represent entity attributes in the database. Fields above the line in the table form the key that uniquely identifies each record.

tad—association table with data, for example, tadGWIndexRIGIS (fig. 1). The association tables with data are similar to association tables. Association tables also store data that describes some property unique to the combination of key values forming the PK. For example, tadGWIndexRIGIS combines the ground-water identification number (from table tblGWIndex) with a particular RIGIS-coverage identification number (from table tblRIGISCoverageIndex) to form its PK. This allows an individual public-supply well to be associated with one or more RIGIS coverages and each RIGIS coverage to be associated with one or more wells. This table also includes the RIGIS field name, used to identify well names in the RIGIS coverage, and the RIGIS field value used to identify a specific well. Thus, tad tables provide many-to-many relations and also store data that are unique to a specific association of items from different tables and that may not be stored efficiently in a separate location.

tds—static domain table, for example tdsStageUnits (fig. 1). Static domain tables provide a list of classification or descriptive items that are used by other tables; the list of choices is considered static because these tables are used to provide standard choices which are used to populate the WSSMPs (for example, the tdsStageUnits table is fully populated with records describing standard units that are commonly used to describe reservoir water levels in a WSSMP). The tds tables have a single PK field. The PK field is an AutoNumber field (automatically incremented integer) for all static domain tables. Two tables in the WSSMP database, tdsAddressOrder and tdsMonthName, do not have AutoNumber fields because the key codes in these two tables may be construed as meaningful numbers namely, the priority address order or the month number, respectively.

tdx—user-extendable domain table, for example tdxWellDriller (fig. 1). User-extendable domain tables provide a list to which the database user can add fields and records as needed. The tdx tables are for lists that are expected to be expanded as the WSSMP database is populated. For example, the tdxWellDriller table provides a place for the RIWRB and(or) water suppliers to record information about contractors who drill water-supply wells. Users may add additional well drillers as the database is populated. Users also may expand the tdx tables by adding additional fields to record more detailed information. For example, the table tdxWellDriller could be expanded to provide additional contact information and information about the capabilities of each driller. The table could be used as a catalog of available public-supply well drillers in Rhode Island. The tdx tables have a single PK field, which is an AutoNumber field (automatically incremented integer).

tdr—recursive domain table, for example tdrConstituent (fig. 1). These tables also are domain tables in that they hold a list of classification or descriptive items that are used by other tables to provide a list of choices. These tables, however, provide the given choices within an organizational hierarchy by recursive association. For example, tdrConstituent recursively defines each constituent within the hierarchy of the water-quality-constituent classification system described by Dionne and others (1999). The relations between constituent and constituent classes are defined in the table in a manner that facilitates data manipulation in the MS Access environment. In the table tdrConstituent, the water-quality constituent "Nitrate" has a Constituent_ID of 194 and a ConstituentParent_ID of 18. This ConstituentParent_ID is the Constituent_ID of the class "Nutrients" within the table; this association identifies Nitrate as a Nutrient. Similarly, the class "Nutrients" has a ConstituentParent_ID of 3, which identifies all nutrients as "Inorganic Constituents." The ability to group members of a domain table by these recursive relations is identified by the tdr preface and denoted by the information loop on database design diagrams.

til—import-link table, for example tilUSGSStreamGage (fig. 1). Import-link tables are one way of making the WSSMP database compatible with other potential sources of water-resources data. The import-link table provide links to available on-line data sources. For example, the table tilUSGSStreamGage provides basic information about USGS streamflow-gaging stations in Rhode Island and a hyperlink to the USGS NWIS web page that allows a user access to current and historical streamflow measurements, streamflow statistics, water-quality measurements, and other data that are available to the public. As an example, the streamflow-gaging station information is linked to surface-water supplies (tblSWIndex) through an association table (tasSWUSGSStreamGage). Similarly, these streamflow-gaging stations may be linked to public-supply wells that may cause streamflow depletion. The amount of depletion may be quantifiable by use of data collected at the station.

Table- and Field-Definition Conventions

Table and field definitions provide descriptive information about each table and each field within a table. Table definitions are entered in the description-property window accessed by right-clicking the table and choosing the properties setting on the pop-up menu. The table definition is available to the database user in the table object window of the MS Access interface. The table definition may be retrieved by use of a macro or a Visual Basic module when a full MS Access application is developed from the database design. Similarly, a definition for each field within each table is entered in the table-design window. Once field definitions are entered, the definitions are available to the database user in the information bar in the lower left of the MS Access interface. MS Access automatically links these definitions when the table fields are utilized in MS Access queries or forms. The use of table and field definitions provides necessary metadata about each object for use or development of the database.

The conventions used for table and field definitions are not as rigorous as the table naming conventions, but the definitions are implemented systematically. Generally, table definitions indicate the type of table and the content of the table. For example, the definition for the table tadGWIndexRIGIS is "Association between ground-water wells and RIGIS coverage information." This definition identifies the table as an association table and describes the type of information in the association. Field definitions indicate the purpose and scope of each data field. For example, the table tadGWIndexRIGIS includes the identification field "GroundWater_ID" that has the definition "Key that uniquely identifies a ground-water (GW) supply.

Entity/Relationship Diagramming Conventions

Entity/Relation (E/R) diagrams are used to visualize database designs. Several different display and notation methods are in common use for E/R diagrams, but all share similar characteristics. The Information Engineering (IE) relation notation and style (National Institute of Standards and Technology, 1993) (enhanced by WSSMP naming standards) is used to document the database design. An E/R diagram that illustrates several diagramming conventions is shown in figure 2. In this E/R diagram, boxes are used to denote an entity, which is a single table in the physical database. Each entity box has its name at the top. Within the box are one or more entity attributes, which are fields in the physical database. Lines connecting entities represent their defined relationship.

In the E/R diagram, the PK for each entity (composed of one or more attributes) is listed at the top of the attribute list within the entity box and is separated from the other attributes by a horizontal line. When a PK from one table (the parent) is passed to another table (the child) through a relation, the corresponding FK in the child table is designated FK in the diagram. If the FK is part of the PK in the child table, the relation is said to be strong and the relation line is solid in the diagram (this will always be true for association tables). If the FK is an attribute of a child table, the relation is said to be weak and the line is dashed. To further help the user visualize table dependencies, tables in a strong relationship are shown with rounded corners (for example, tadSWDescription), whereas tables that do not have FK dependencies in their PK are shown with squared corners (for example tblSupplier).

Each relationship line has a direction and cardinality. The direction is recognized by the origin end (parent entity in the relation), which does not have a symbol or has an open diamond (when the relationship provides an optional FK value), whereas the target end (child entity in the relation) has a filled circle. These relation symbols, however, do not define cardinality of the relations. Cardinality defines how each record in the origin entity relates to records in the target entity. Relationships between entities may be defined as one-to-one or one-to-many. In a 1:1 relationship, each entity instance in the parent table may have zero or one match in the child table. In a 1:n relationship, each entity instance in the parent entity may have zero, one, or more matching instances in the child entity.

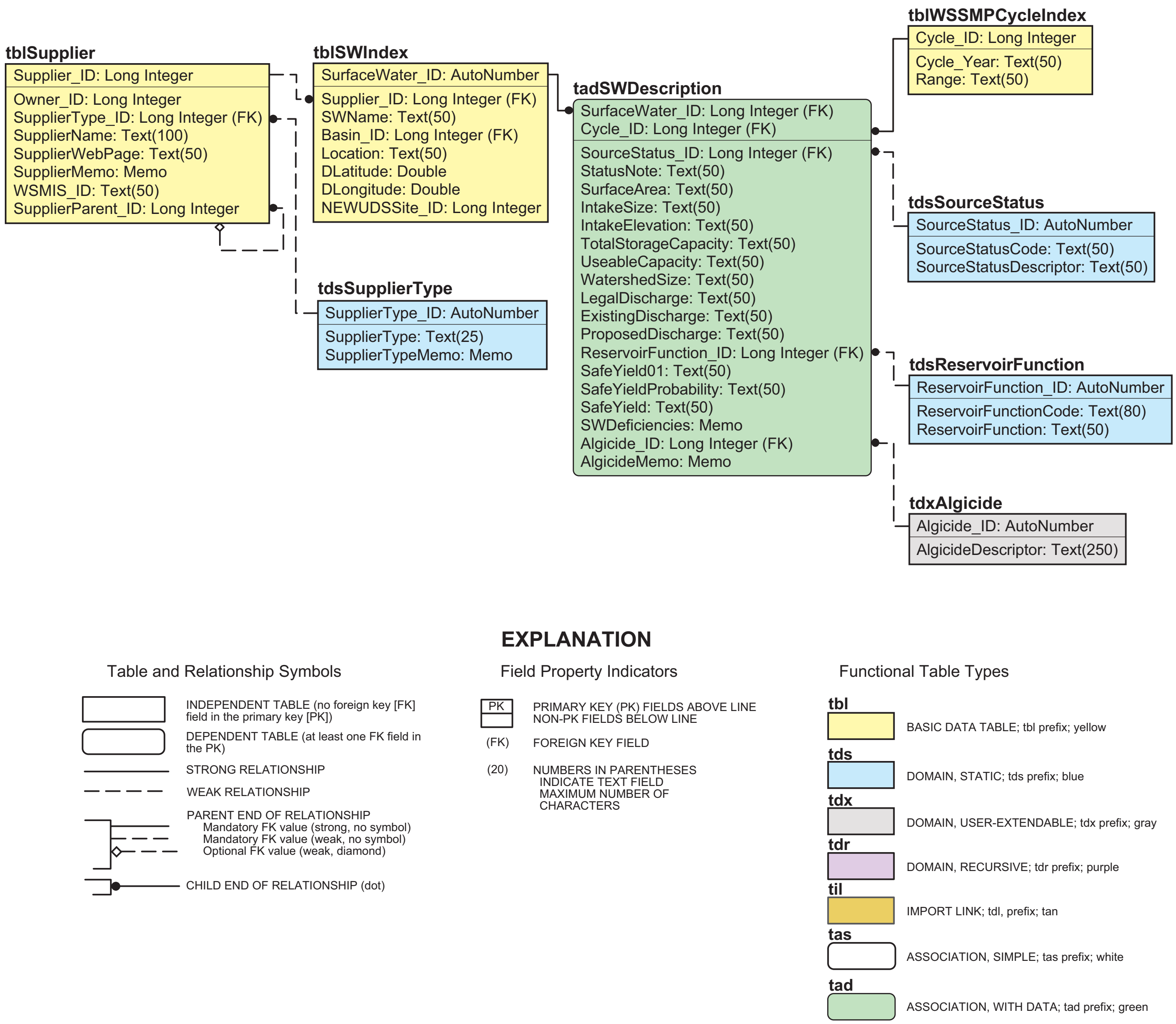

Figure 2. Entities, attributes, and relationships represented by an entity/relationship (E/R) diagram.

Almost all relationships in the WSSMP model are one-to-many (1:n). This type of relationship is used when each parent can have none, one, or more children, and each child must have a parent (the FK cannot be null). For example, in figure 2, the table tblSupplier has a parent-to-child relationship with tblSWIndex. Each Supplier_ID record can be used to identify zero, one, or more surface-water supplies, and each surface-water supply must be attributed to a supplier. The table tblSWIndex, however, is an independent table because a unique SurfaceWater_ID identifies each surface water supply. A one-to-zero relationship allows the user to create a record in a table that has no relationships in other tables. This type of relationship allows the user to populate a domain table with a list of all permissible values before other data are entered into a database. These values are not used until they are needed. For example, the table tdsSupplierType contains the standard descriptors that define the type of water supplier and the table tdsSourceStatus contains all the standard descriptors that define the current status of a surface-water supply. The contents of these domain tables are available for use as the database is populated.

In the WSSMP database, one-to-one relationships only occur when two tables share the same primary key(s). These one-to-one relationships are only used when there is a reason to divide information that could be stored as one entity. For example, emergency contact information (tblContactEmergency) could be included with other contact information in tblContact; these tables share the same primary key and could be merged into one table. The home address and phone number information in tblContactEmergency, however, is private information that should be segregated and made available only to certain users. As a result, the tables were kept separate.

The relationship from the table tblSupplier to itself is recursive and provides the means to identify a supplier (Supplier_ID) by a parent owner (SupplierParent_ID) that is also listed in the supplier table. This convention allows data to be analyzed for the individual water suppliers and allows the data from individual suppliers to be aggregated by parent owner. If there is no parent owner, the value in the field SupplierParent_ID equals the Supplier_ID value. This convention (and inclusion of the NEWUDS Owner_ID) was adopted to increase compatibility with NEWUDS, which was designed to provide for the situation in which one entity (for example, a corporation) owned or managed a number of individual water suppliers (Tessler, 2002).

Figure 2 presents a partial view of the surface-water-supply portion of the database and demonstrates many of the diagramming conventions mentioned. For example, the table tadSWDescription is a child (and therefore a dependent table) of tblSWIndex and tblWSSMPCycleIndex. There is a one-to-many relationship from each parent table because each surface-water supply has one description for each WSSMP cycle. SurfaceWater_ID is the FK that identifies each surface-water supply and Cycle_ID is the FK that identifies each WSSMP cycle. The table tdsSourceStatus, however, is an independent table supplying choices to tadSWDescription. This is a one-to-many relation (each status definition in tdsSourceStatus may be associated with many surface-water supplies in tadSWDescription) with tadSWDescription being a child (but nondependent) and receiving the FK SourceStatus_ID from tdsSourceStatus. The table tadSWDescription, however, is nondependent with respect to table tdsSourceStatus because SourceStaus_ID is not part of the PK of tadSWDescription.

Database-Design Documentation

Design documentation facilitates the current use and potential modification of the database for future use. The design of the database is fully documented on the enclosed CD-ROM in four ways, including

- documentation of the structure of the WSSMP database file,
- a data-dictionary file,
- a detailed database-design diagram, and
- this database-design report.

The WSSMP database contains three types of design documentation within the MS Access file: table definitions, table-design details, and database-relationship information. MS Access is an object-oriented application. Each object (such as a field, table, relationship or query) has standard properties that are documented. For example, each object has a description property that is used in the WSSMP design to describe the purpose and scope of each object. The documentation in MS Access is useful for examining individual objects, but it is not useful for providing an overview or for illustrating the overall design of the database.

Table names and descriptions identify the purpose and scope of each table. Table names and definitions are visible in the table object window when the "Details" view is selected. Alternatively, table definitions may be viewed and edited by right-clicking a table and choosing the "Properties" option, which activates the table-properties window.

Each table is composed of fields, which have names, descriptions, and other properties. Field names and descriptions identify the purpose and scope of each field. Each field description is visible in the status box at the lower left of the MS Access interface screen when the table is open in datasheet view and the field is active. Properties of each field, including

- the presence of keys as denoted by a key symbol,
- field names,
- data types,
- description, and
- specific field properties

are visible in the design view of each table. The table-design view allows the user to assess and manipulate field properties. The table-design view should be used carefully because changes in field properties may corrupt the database and its contents.

The relations between database tables may be viewed by using the tools menu and selecting the relationships option, which activates the Relationships window. The WSSMP database, however, is complex enough to limit the clarity of information available in this view if the entire database is viewed at once. To view individual subject areas, users may activate the MS Access relationships window, add the table(s) of interest with the "Show Table Button," and then click the "Show Direct Relationships" button on the tool bar to see all tables that have relationships with the table of interest.

A computerized data-dictionary file is provided to facilitate examination of the database design and to document the completed database. Complete documentation of the table names, table descriptions, and information about each of the fields in the database is provided in the data dictionary file, which is provided as an Adobe PDF file. The data-dictionary file is named WSSMPDD1.pdf, and this file also is available on the CD-ROM under database-documentation information (the folder "database"). This file provides summary information about the design and implementation of each table and is very useful for browsing the design of the database. The data-dictionary file, however, does not provide the overview needed to convey the overall design of the database.

A database-design diagram (pl. 1) is provided to document selected subject areas in the database and to illustrate relationships between database entities that may not be apparent from examination of the E/R diagrams in this report. This database-design diagram will help the user understand the existing structure and potentially modify the database. Plate 1 documents selected data structures that are organized into five subject areas: the water-supply-system infrastructure, emergency management and contact information, production and demand information, water-use and water-use projection information, and information about major users. These data structures were selected for inclusion on plate 1 to provide an integrated view of information in the individual E/R diagrams that are included in the following discussion of database contents. This poster-size diagram (36 by 42 inches) is included as file WSSMPPL1.pdf on the enclosed CD-ROM. Appendix 1 of this report is an alphabetical index of the tables included on plate 1 and in each figure of this report.

Database Contents

The RIWRB document defining rules and procedures for water-supply-system-management planning (Rhode Island Water Resources Board, 1998, 2001) describes the WSSMP process and requirements for information to be included in these plans. The RIDEM WSSMP database (Fly, 1992) focused on information (such as water-supply system infrastructure, water use, and water-conservation efforts) that would be useful if it was available in a searchable database format. This current (2004) version of the WSSMP database was developed as an initial test platform with the expectation that the design and its use would be refined by the RIWRB in conjunction with local and

State water-supply organizations. The database includes all WSSMP data entities that meet criteria identified during the database-design process. The primary criterion was that the information would be potentially useful for local, regional (by county, water-service area, or watershed), or State water-resources planning or management efforts. The secondary criterion was the suitability of information that can be stored, searched, and manipulated as plain text or numerical data. Therefore, WSSMP entities such as maps, schematic diagrams, or engineering drawings are not included in the database. (The location of some of these elements, however, may be identified in comment fields within the database, which may be expanded to include links to electronic files containing these elements if a standard file system is established for storing files containing maps, plans, diagrams and drawings.) The final criterion was to support links to information in other available Federal, State, and local databases rather than recreating this information within the WSSMP format.

The contents of the current WSSMP database are described in terms of Section 8 of the RIWRB document defining rules and procedures for water-supply-system-management planning (Rhode Island Water Resources Board, 1998) and are summarized in the WSSMP check list (Rhode Island Water Resources Board, 2001). Many of the water suppliers, however, are accustomed to the worksheet format originally designed by the RIDEM (C.L. Mc Greavy, Rhode Island Water Resources Board, written commun., 2002). Table 1, therefore, is a cross-reference that associates elements of the rules with information in the RIDEM worksheets. Table 1 also indicates which topics are included in the current WSSMP database.

WSSMP components were not included if they were not suitable for database manipulation. For example, narrative statements are not easily queried and compiled for meaningful synthesis of trends in water-supply-system infrastructure. Also, text manipulation capabilities of MS Access are rudimentary in comparison to capabilities of various word-processing software packages. Therefore, for example, elements such as the WSSMP Goals Statement are not included in the database structure. The graphics capabilities of MS Access do not support the drawing-file formats of many engineering drawing, drafting, and computer-aided-design software packages. Furthermore, MS Access may provide hydrologic data for watershed models, hydraulics programs, or geographic information systems, but MS Access will not run these programs without the design and construction of a custom interface. Therefore, WSSMP elements requiring data formats that are not native to MS Access are not currently in the WSSMP database design. MS Access, however, does support Object Linking and Embedding (OLE) and hyperlink fields so that a database can activate such computer-format files (if all files are copied to maintain the integrity of links and the appropriate software is available on the user's computer). Alternatively, other applications (for example geographic information system software) are able to use data in an Access database through an open-database-connectivity (ODBC) driver. Some preliminary efforts are made to use the hyperlink function to access external databases such as the USGS NWIS and the RIGIS web sites. Further development of this type of structure, however, would depend on standardization of file formats among water suppliers that file plans and the State agencies that may use the database information.

Identification fields designed for links to other databases (for example NEWUDS) are provided in the WSSMP database design but are not implemented as true foreign keys, so that the WSSMP database may be used as a stand-alone product. The user may enter these identification fields manually, or by linking the databases on a computer, which has copies of the respective databases. Therefore, identification fields (with the _ID) that do not appear on database-diagram figures as foreign fields (FK) exist to provide link information for external database fields.

The WSSMP database has nine general topic areas: descriptions of water-supply infrastructure, water production, water use, water-quality protection, supply management, demand management, system management, emergency management, and financial management (table 1). Most of the tables within the WSSMP database are used to define components of the water-supply infrastructure. The designs of the data structures for the various components of the water-supply infrastructure are similar in order to maintain consistency and facilitate understanding and use of the database.

Table 1. Rhode Island Water Resources Board Water Supply System Management Plan contents, legislative mandate, Rhode Island Department of Environmental Management worksheet designations, and current database status.

[**Current database status:** N, No (not included in the current database); Y, Yes (included in the current database). --, no independent RIDEM worksheet number; RIDEM, Rhode Island Department of Environmental Management; WSSMP, Water Supply System Management Plan]

WSSMP section	Section title	RIDEM worksheet number	Current data-base status
	Chapter of Rhode Island general laws: 46-15.3-5.1 (a)		
8.01	Goals Statement	--	N
	Chapter of Rhode Island general laws: 46-15.3-5.1 (b)		
8.02	Water-supply system description	--	Y
a)	Organization and legal structure	--	N
b)	System overview	--	N
c)	Supply sources	--	Y
1)	Surface-water sources	01	Y
2)	Ground-water sources	02	Y
d)	Infrastructure components	--	Y
1)	Treatment facilities	03	Y
2)	Storage facilities	04	Y
3)	Pump stations	05	Y
4)	Transmission facilities	06	Y
e)	Interconnections	07	Y
f)	Service area	08	Y
g)	Meters	09	Y
h)	System production data	12,13, 14–17	Y
i)	Water-use data	18-26	Y
j)	System deficiencies	--	N
	Chapter of Rhode Island general laws: 46-15.3-7.3		
8.03	Water-Quality Protection	--	Y
	Chapter of Rhode Island general laws: 46-15.3-5.1 (f)		
8.04	Supply Management	--	Y
a)	Anticipated Future Demands	26–28	Y
b)	Available Water	01, 29	Y
c)	Alternative Supply	--	N
d)	Supply Augmentation Studies	--	N
	Chapter of Rhode Island general laws: 46-15.3-5.1 (d)		
8.05	Demand Management	--	Y
a)	Residential-Retrofit Program	30	Y
b)	Major Users Technical Assistance Program	--	N
	Chapter of Rhode Island general laws: 46-15.3-5.1 (a–e)		
8.06	System Management	--	Y
a)	Metering	09–11	Y
b)	Leak-Detection and -Repair (LDR) Plan	31, 32	Y

Table 1. Rhode Island Water Resources Board Water Supply System Management Plan contents, legislative mandate, Rhode Island Department of Environmental Management worksheet designations, and current database status.—Continued

[**Current database status:** N, No (not included in the current database); Y, Yes (included in the current database). --, no independent RIDEM worksheet number; RIDEM, Rhode Island Department of Environmental Management; WSSMP, Water Supply System Management Plan]

WSSMP section	Section title	RIDEM worksheet number	Current data-base status
	Chapter of Rhode Island general laws: 46-15.3-5.1 (g)		
8.07	Emergency Management	33–37	Y
	Chapter of Rhode Island general laws: 46-15.3-5.1 (i)		
8.08	Implementation Schedule, Responsible Ethics, and Projected Costs	--	N
	Chapter of Rhode Island general laws: 46-15.3-5.1 (i)		
8.09	Financial Management	38	Y
	Chapter of Rhode Island general laws: 46-15.3-5.1 (h)		
8.10	Coordination	--	N
	Chapter of Rhode Island general laws: 46-15.3-5.1 (c)		
8.11	Rhode Island Geographic Information System Compatibility	--	Y

The discussion of each WSSMP data entity and the associated data structure focuses on the design of the database by topic. Each data structure is documented in an E/R diagram. Tables within each data structure are identified as appropriate. Detailed table and field definitions, however, are documented in the MS Access database and in the data dictionary on the enclosed CD-ROM. The underlying information about Rhode Island State laws, regulations, policies, and planning methods are not described for each data structure. Public documents available from Rhode Island State agencies that provide information relevant to the WSSMP database, however, are included on the enclosed CD-ROM to provide the reader with pertinent WSSMP background information and to document current (2004) WSSMP requirements that define the database design.

Plan-Summary and -Tracking Data Structure

Water-supply-management plans are reviewed by the RIWRB, the RIDEM, the RIDOH, the RIDOA, and the RIPUC. A summary of plan contents is included in the WSSMP database to provide an overview of the types of information and the number of water-supply facilities included in each WSSMP. Water suppliers and the reviewing agencies may use the plan-summary data to assess the contents and the degree of completion of each plan. Similarly, it may be used as the basis for comparisons among suppliers and between WSSMP cycles. The plan-tracking data structure may be used by the RIWRB and other State agencies to track the status of each plan as it is received and reviewed.

The plan-summary and -tracking data structures are not a formal part of the WSSMP format, but are described first as a simple introduction to the data structure used throughout the WSSMP database. Plan-summary information for each WSSMP cycle for each water supplier is recorded in the association table tadPlanSummary (fig. 3). Plan-summary information includes a yes/no field for each data type to indicate whether the plan contains that data and a number field to indicate the number of corresponding water-supply facilities described in the plan. For example, if a water supplier does not own any reservoirs then the field SurfaceWaterSites would be a "no" and SWNumber would be zero (fig. 3). The association table tadPlanSummary has two FKs, Cycle_ID and Supplier_ID, which associate each WSSMP with an individual WSSMP cycle date and an individual water supplier, respectively (fig. 3). WSSMP cycle dates are recorded in the table tblWSSMPCycleIndex. Identifying information about each water supplier is recorded in the table tblSupplier. There is a one-to-many relationship between tblWSSMPCycleIndex and tadPlanSummary because each WSSMP cycle date (for example, the year 2000) could have many entries (one for each water supplier that submits a WSSMP). Similarly, there is a one-to-many relationship between tblSupplier and tadPlanSummary because each water supplier that submits a WSSMP could have an entry for one or more WSSMP cycle dates. Therefore, each record in the table tadPlanSummary is identified by the unique combination of a water supplier (Supplier_ID) and a WSSMP cycle (Cycle_ID).

The plan-tracking information is recorded in the association table tadTrackingStatus (fig. 3), which includes date/time and memo fields to record review dates and detailed review comments from each State agency that reviews the plans. For example, the DEMAgencyDate and the DEMAgencyNote fields are used for review of the date and comments from the RIDEM. The association table tadTrackingStatus has the same two foreign keys (fig. 3) as the table tadPlanSummary, and thus is also identified by the unique combination of a water supplier (Supplier_ID) and a WSSMP cycle (Cycle_ID).

Surface-Water-Supply Data Structure

The RIWRB rules and procedures for WSSMPs (Rhode Island Water Resources Board, 1998, 2001) require that all surface-water supplies be inventoried, characterized, described, and mapped by the water suppliers. Surface-water-supply sources were described in Worksheet 1 of the original WSSMP format (Charpentier and others, 1992; Fly, 1992) and in Section 8.02c1 of the RIWRB (1998, 2001) planning documents (table 1). The surface-water-supply data structure provides a means for describing surface-water supplies. Rhode Island State law (Rhode Island Water Resources Board, 1998, 2001) requires that water-supply maps be created in a format compatible with RIGIS data standards. The WSSMP database structure provides for entry of location information. The section on the RIGIS Data Structure database also describes a method for links between surface water supply information and related RIGIS files.

Surface-water supplies (and other water-resources infrastructure facilities) are generally enduring facilities that may last for decades or longer. Information about these facilities such as the owner, the condition, and the status may change with time. Therefore, surface-water supplies are uniquely identified in the table tblSWIndex (fig. 4). The index table includes the surface-water-supply name (such as the name of a reservoir), location information (the decimal coordinates of the surface-water diversion point), and a link to the NEWUDS database (NEWUDSSite_ID). The associated supplier (tblSupplier) may change with time and the supply characteristics may change from cycle to cycle (tadSWDescription), but the index table provides the means to track facility status through time because the SurfaceWater_ID number should remain constant, even when the other information changes. Similar index structures are used to define most water-supply infrastructure components cataloged in the WSSMP database. The domain tables tdsSourceStatus, tdsReservoirFunction, and tdxAlgicide (fig. 4) provide standard lists of descriptors to characterize each surface-water supply. These descriptors help to ensure that all the plans are submitted or recorded in a consistent format. This format enables decisionmakers to use the relational database to interpret trends in the condition of the water-supply infrastructure.

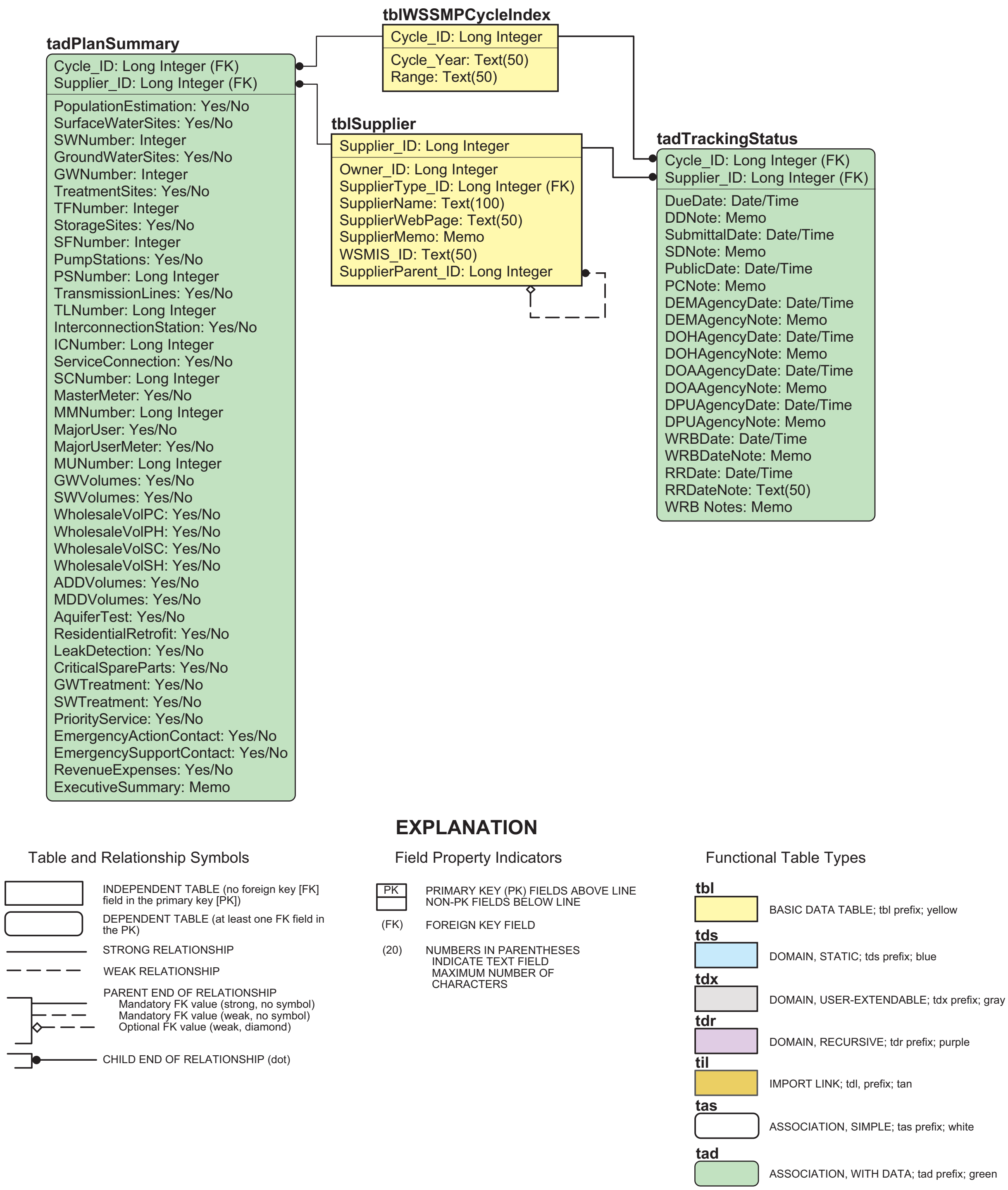

Figure 3. Plan-summary and tracking data structure tables, fields, and relationships.

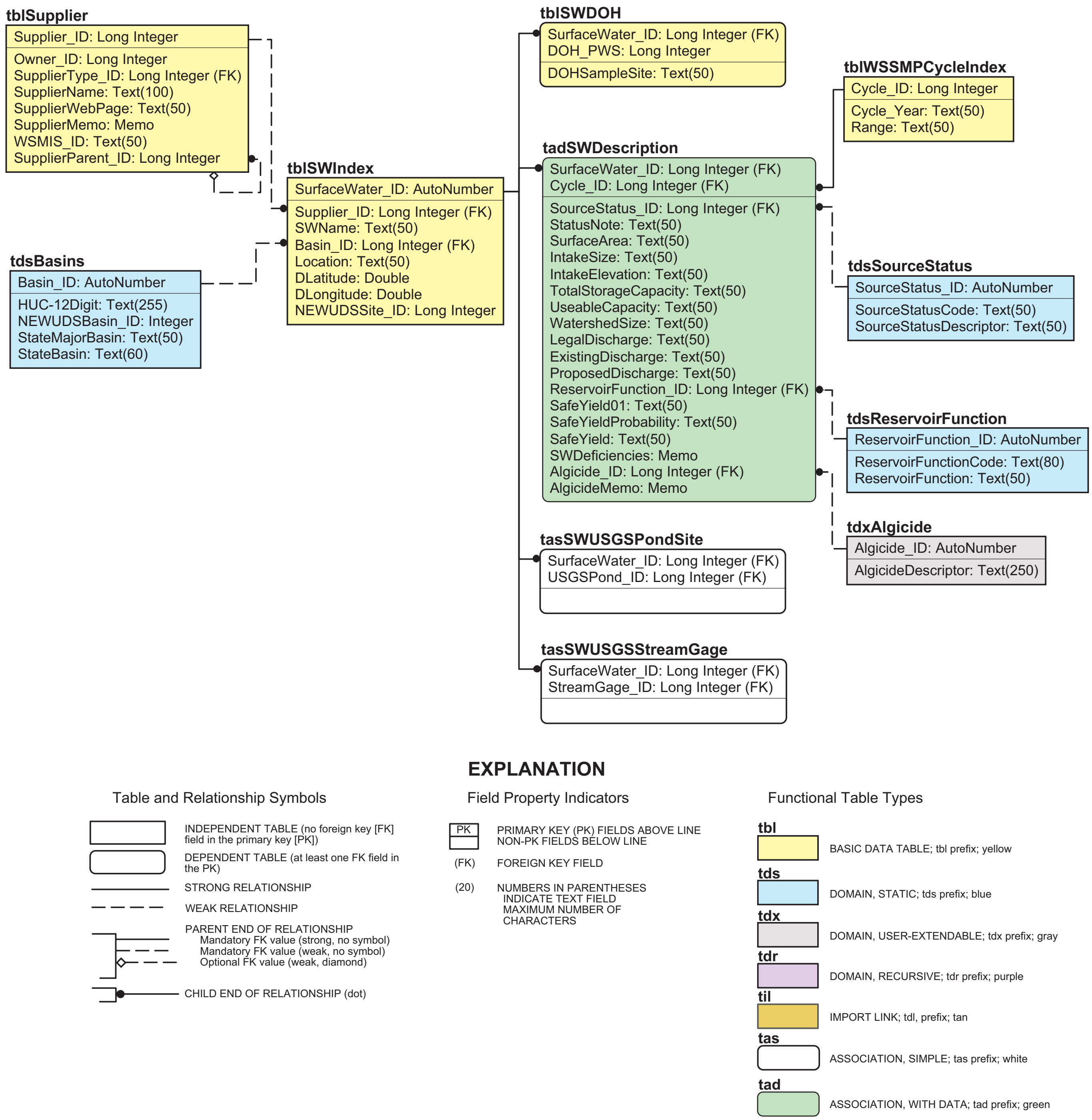

Figure 4. Surface-water-supply data structure tables, fields, and relationships.

The complete surface-water-supply data structure is illustrated on (fig. 4). Figure 4 contains all the entities in figure 2 and the remaining surface-water data entities. The table tblSWDOH identifies one or more RIDOH sampling sites within the surface-water supply basin. RIDOH sampling sites are not indexed by WSSMP cycle because the RIDOH identifiers are unique to the site and do not change with WSSMP cycle (Elizabeth Scott, Deputy Chief, Rhode Island Department of Environmental Management, Office of Water Resources, Surface Water Protection Section, oral commun., 2002). The domain table tdsBasins identifies the surface-water supply by basin. The tables tasSWUSGSPondSite and tasSWUSGSStreamGage identify USGS pond gages and stream gages, respectively. These sites in the USGS NWIS database may have water-level data, flow data, or water-quality data that is pertinent to the operation of surface-water supplies. These association tables also link to the import tables, which are not shown in figure 4, but are shown in figure 33 in the section on import tables, which is presented later in the report.

Ground-Water-Supply Data Structure

The RIWRB rules and procedures for WSSMPs (Rhode Island Water Resources Board, 1998, 2001) require that all ground-water supplies be inventoried, characterized, described, and mapped. Ground-water-supply sources were described in Worksheet 2 of the original WSSMP format (Charpentier and others, 1992; Fly, 1992) and in Section 8.02c2 of the RIWRB (1998, 2001) planning documents (table 1). The ground-water-supply data structure provides a means for describing ground-water supplies. Rhode Island State law (Rhode Island Water Resources Board, 1998, 2001) requires that water-supply maps be created in a format compatible with RIGIS data standards. The WSSMP database structure provides for entry of location information. The section on the RIGIS Data Structure describes links to RIGIS files.

Ground-water supplies are uniquely identified in the table tblGWIndex (fig. 5). The index table includes the well name, location information, and a link to the NEWUDS database (NEWUDSSite_ID). The table tadGWDescription and associated domain tables describe characteristics of each supply well and the surrounding aquifer. The domain tables tdsSourceStatus, tdxWellType, tdxWellDrillMethod, tdxWellDriller and tdxPumpType (fig. 5) provide standard lists of descriptors to ensure that this data in the plans are submitted or recorded in a consistent format. This information may be used to improve coordination among water suppliers and State water-resource agencies. For example, the table tdxWellDriller could be used as a standard list of certified well drillers. Similarly, technical information on ground-water pumps may be useful to suppliers who are looking for a new well pump.

Other tables in figure 5 provide related information. The table tblGWDOH identifies one or more RIDOH sampling sites within the ground-water-supply contributing area. This table also provides the field DEMWHPA_ID that defines the RIDEM well-head-protection area (WHPA) identification number, which in turn is used to identify the estimated contributing area to the well (DeSimone and Ostiguy, 1999). The domain table tdsBasins identifies the surface-water basin (watershed) where the ground-water-supply well is located. The association table tasGWUSGSWell lists wells in the USGS NWIS database with associated water levels, water-quality data, or hydrogeologic information pertinent to the operation of ground-water supplies. These association tables also link to the import tables, which are not shown in figure 5, but these links are shown in figure 33 in the section on import tables, which is presented later in the report.

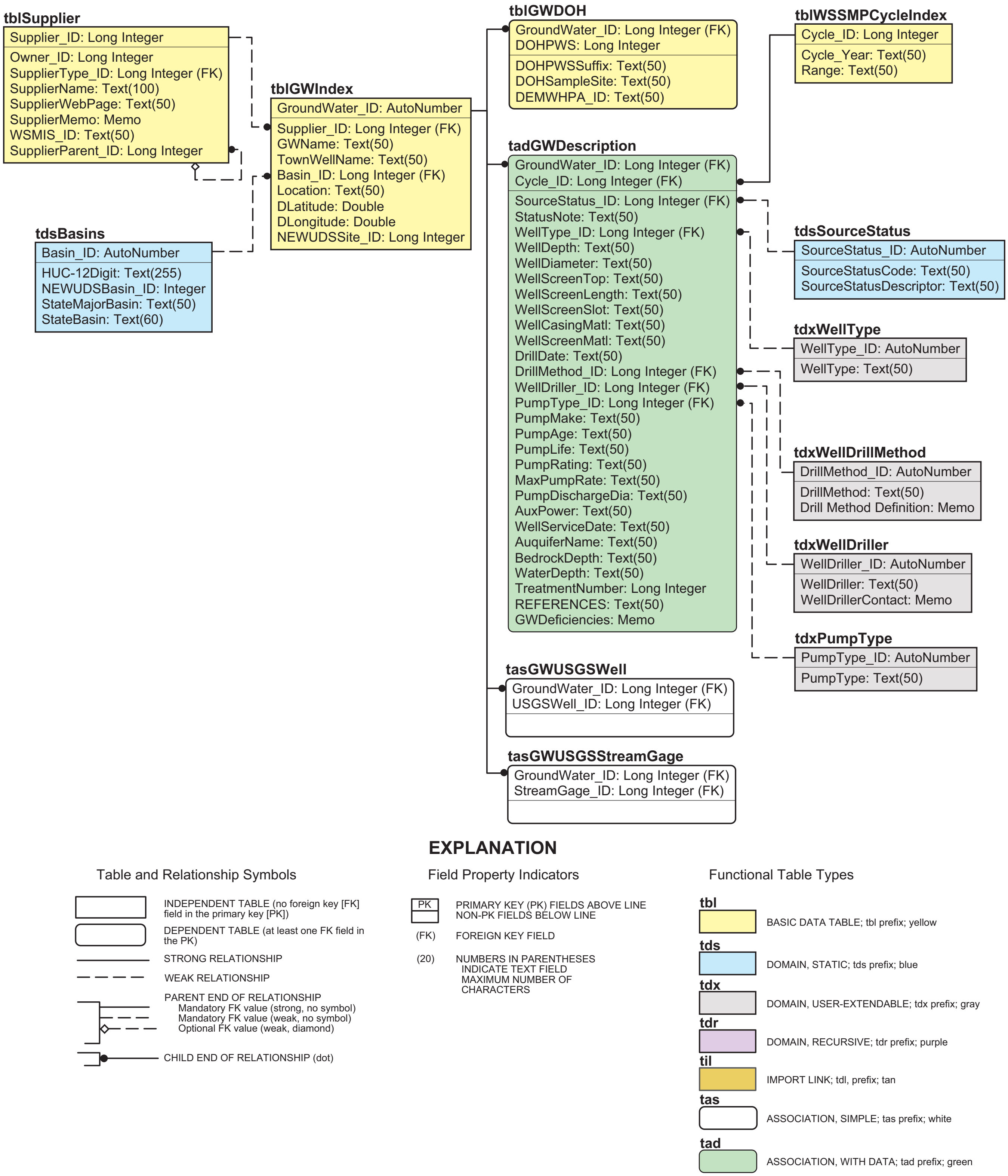

Figure 5. Ground-water-supply data structure tables, fields, and relationships.

Treatment-Facility Data Structure

The RIWRB rules and procedures for WSSMPs (Rhode Island Water Resources Board, 1998, 2001) require that all treatment facilities be inventoried, characterized, described, and mapped. Information about treatment facilities is described in Worksheet 3 of the original WSSMP format (Charpentier and others, 1992; Fly, 1992) and in Section 8.02d1 of the RIWRB (1998, 2001) planning documents (table 1). The treatment-facility data structure provides a means for describing treatment facilities and individual treatment processes within each facility. The section on the RIGIS Data Structure describes links to RIGIS files that may be used to locate treatment facilities.

Treatment facilities are uniquely identified in the table tblTFIndex (fig. 6). The index table includes the name, location information, and a link to the NEWUDS database (NEWUDSSite_ID). The table tadTFDescription describes characteristics of each treatment facility. The table tblTFProcess and the associated domain tables are used to describe characteristics of each treatment process within a treatment facility. The field treatmentf_ID is a FK in tblTFProcess so that one or more processes may be associated with each facility. This means, however, that process information must be repeated for each facility even if identical processes are used in different treatment facilities. The domain tables tdsTreatmentType and tdsTreatmentStatus (fig. 6) provide standard lists of descriptors to help ensure that all the plans are submitted or recorded in a consistent format. The association tables tasTreatmentTankSludge and tasTreatmentFilterBackwash link to the data tables tblTFTankSludge and tblTFFilterBackwash, respectively (fig. 6). These two data structures define relationships among treatment processes and treatment-waste repositories. For example, the sediment from a clarifying tank may go to one or more landfills and each landfill may accept sediment from one or more treatment facilities (and one or more water suppliers). Treatment-process information and treatment-facility information is entered for each WSSMP cycle as indicated by the relationships to the table tblWSSMPCycleIndex (fig. 6).

Relationships between treatment processes and water-supply sources are shown in figure 7. The association tables tadTreatmentGW and tadTreatmentSW provide the link necessary to associate each water supply with one or more treatment processes in one or more treatment plants. For example, water pumped from a well may go through an initial pH buffering process at the wellhead (process 1 at facility 1). This water may be piped to a central treatment facility with water from one or more other wells (process 1 at facilities 2 through "n"), which is then chlorinated (process 2 at facility n+1). Each of these relationships leads through the index tables to tblSupplier; therefore, this data structure can be used to trace the source of treated water, even when a treatment facility receives water from a number of sources and a number of suppliers.

Storage-Facility Data Structure

The RIWRB rules and procedures for WSSMPs (Rhode Island Water Resources Board, 1998, 2001) require that all storage facilities be inventoried, characterized, described, and mapped. Information about storage facilities are described in Worksheet 4 of the original WSSMP format (Charpentier and others, 1992; Fly, 1992) and in Section 8.02d2 of the RIWRB (1998, 2001) planning documents (table 1). The section on the RIGIS Data Structure describes links to RIGIS files that may be used to locate storage facilities.

Storage facilities are uniquely identified in the table tblSFIndex (fig. 8). The index table includes the name, location information, the type of storage facility, and a link to the NEWUDS database (NEWUDSSite_ID). The domain table tdsSFFacilityType is linked to tblSFIndex and provides standard lists of descriptors for the storage-facility type. The table tadSFDescription describes characteristics of each storage facility. The domain tables tdsFacilityCondition and tdsSFConstructionMaterial (fig. 8) provide standard lists of descriptors to help ensure that all the plans are submitted or recorded in a consistent format. Storage-facility-description information is entered for each WSSMP cycle as indicated by the relationship to the table tblWSSMPCycleIndex (fig. 8).

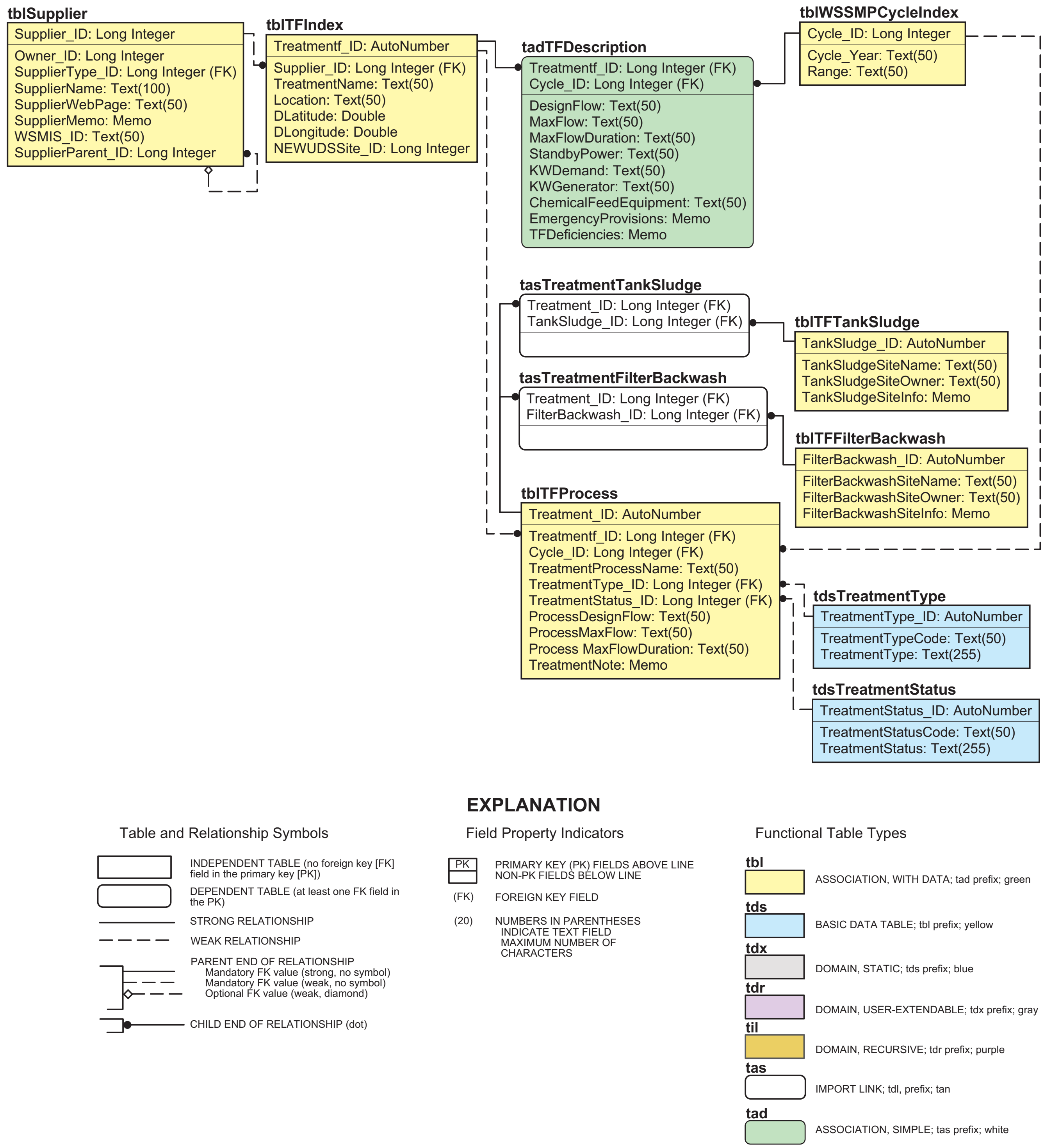

Figure 6. Treatment-facility data structure tables, fields, and relationships.

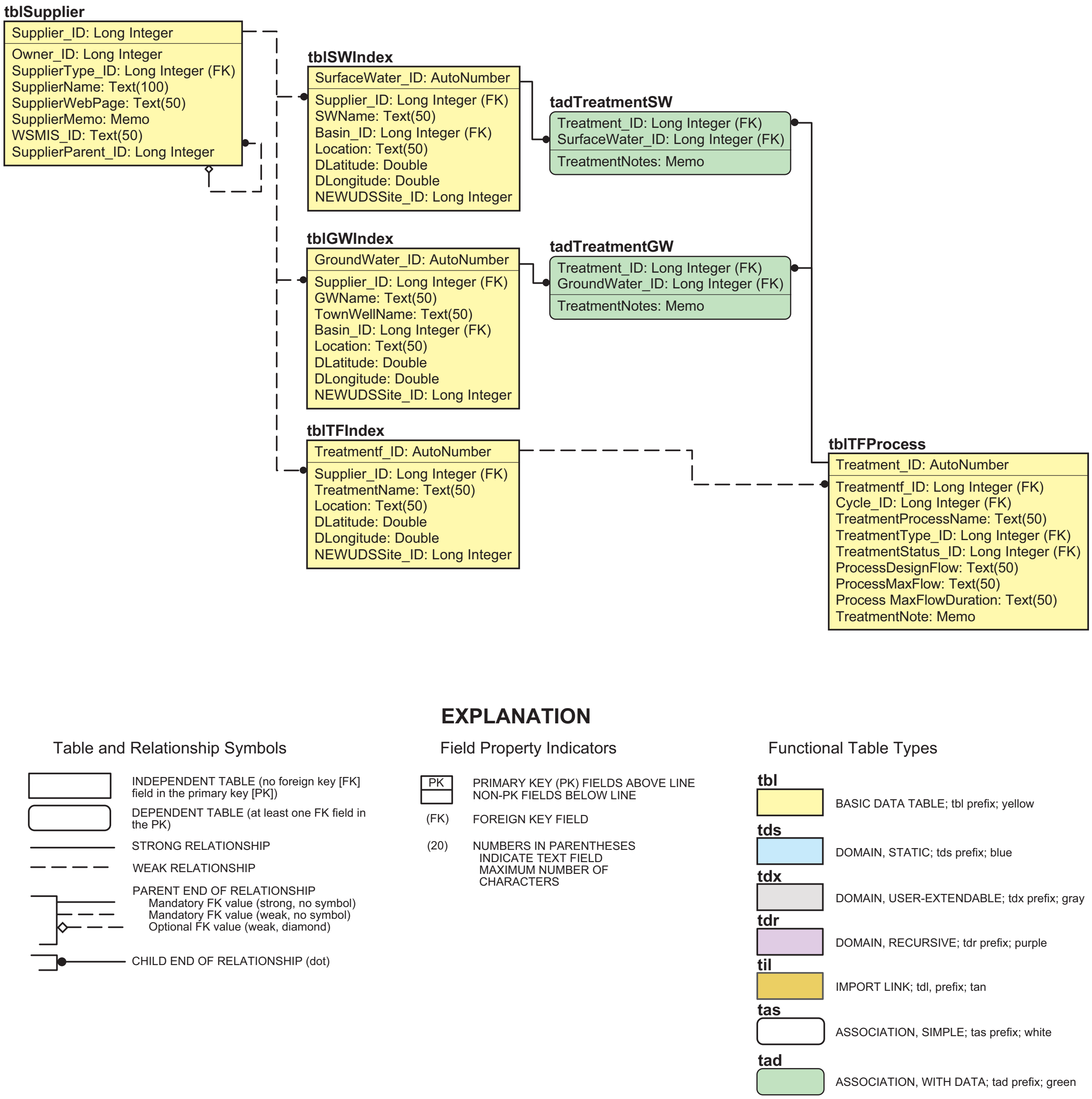

Figure 7. Treatment facilities, processes, and water-supply sources tables, fields, and relationships.

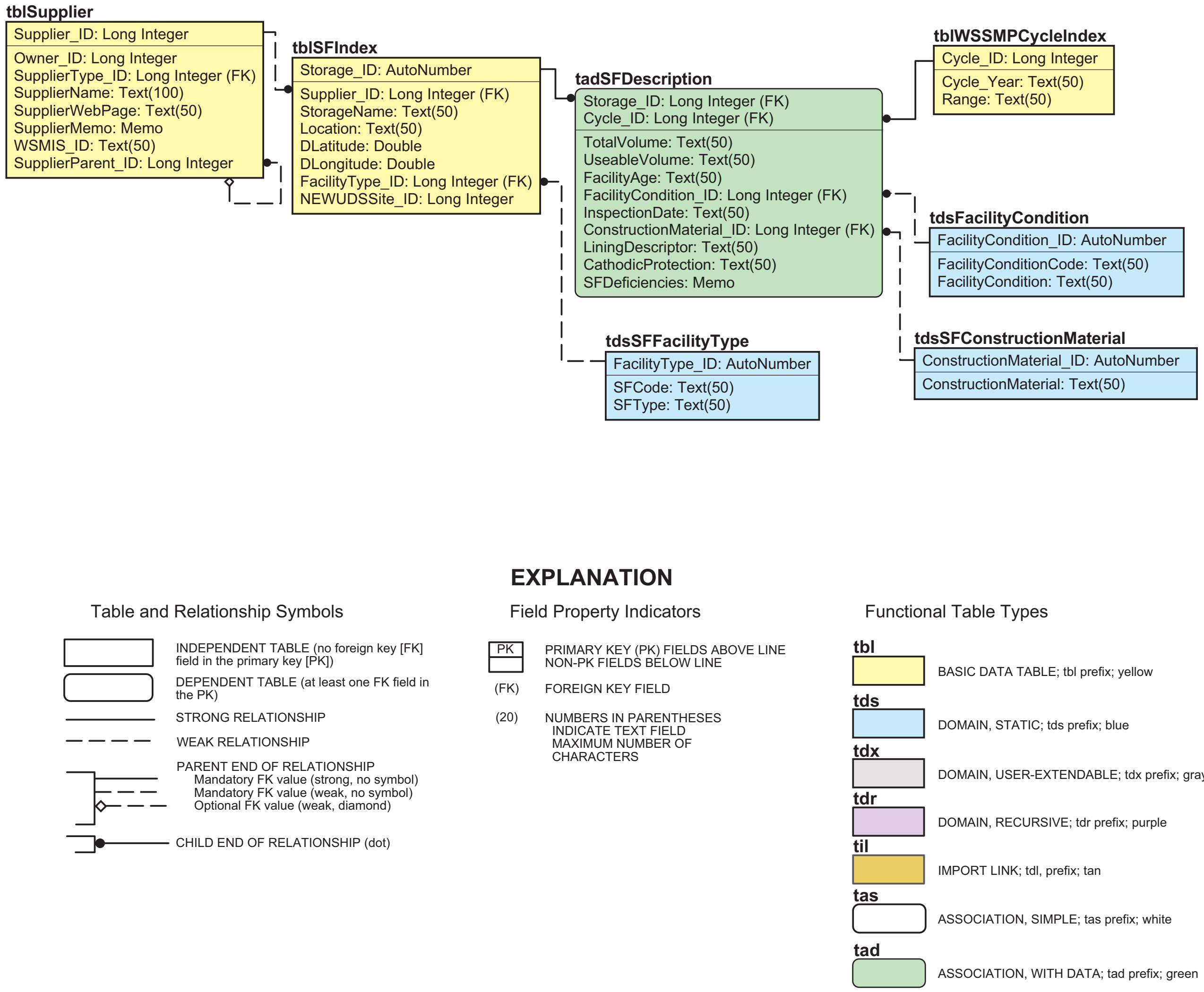

Figure 8. Storage-facility data structure tables, fields, and relationships.

Pump-Station Data Structure

The RIWRB rules and procedures for WSSMPs (Rhode Island Water Resources Board, 1998, 2001) require that all pump stations be inventoried, characterized, described, and mapped. Information about pump stations is described in Worksheet 5 of the original WSSMP format (Charpentier and others, 1992; Fly, 1992) and in Section 8.02d3 of the RIWRB (1998, 2001) planning documents (table 1). The pump-station data structure provides a means for describing pump stations and individual pumps within each station. The section on the RIGIS Data Structure describes links to RIGIS files that may be used to locate pump stations.

Pump stations are uniquely identified in the table tblPSIndex (fig. 9). The index table includes the station name, location information, and a link to the NEWUDS database (NEWUDSSite_ID). The table tblPSPumps describes characteristics of each pump at each pump station. The table tadPSDescription describes characteristics of each pump station. The domain table tdsPumpStation (fig. 9) provides standard lists of descriptors to help ensure that all the plans are submitted or recorded in a consistent format. Pump information and pump-station information is entered for each WSSMP cycle as indicated by the relationships to the table tblWSSMPCycleIndex.

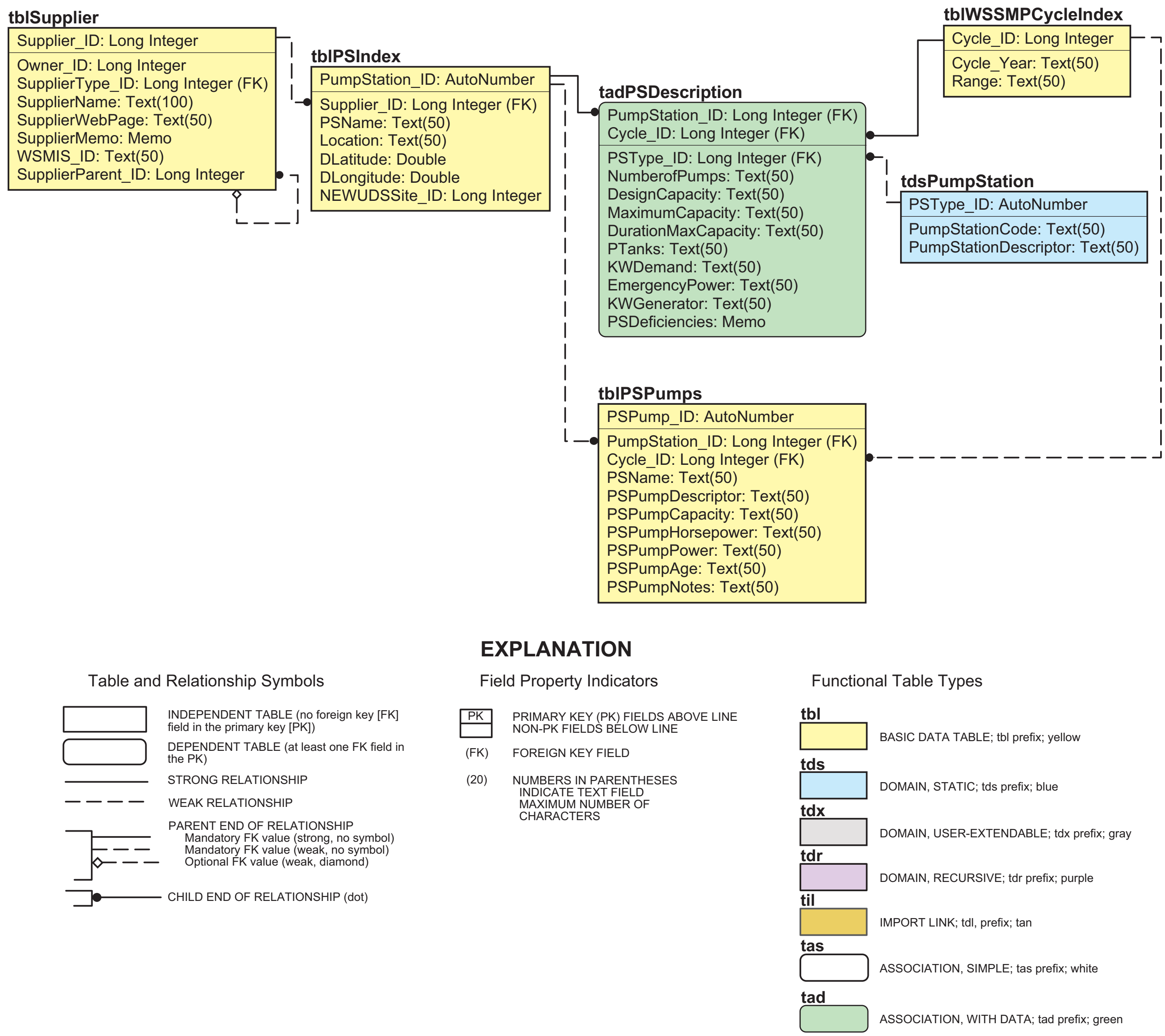

Figure 9. Pump-station data structure tables, fields, and relationships.

Transmission-Facility Data Structure

The RIWRB (1998) defines transmission facilities as the pipes, pumping stations, and storage facilities that carry high volumes of water from one water-supply-system facility to another and from these facilities to distribution areas, and specifies that transmission facilities do not include distribution facilities. The RIWRB rules and procedures for WSSMPs (Rhode Island Water Resources Board, 1998, 2001) require that all transmission facilities be inventoried, characterized, described, and mapped. Information about transmission facilities is described in Worksheet 6 of the original WSSMP format (Charpentier and others, 1992; Fly, 1992) and in Section 8.02d4 of the RIWRB (1998, 2001) planning documents (table 1). The transmission-facility data structure provides a means for describing the pipes that are used as transmission facilities and provides links to information about the water-supply sources, pumping stations, storage facilities, interconnections, and distribution areas that complete the transmission-facility infrastructure. The section on the RIGIS Data Structure describes links to RIGIS files that may be used to locate map-distribution facilities.

Transmission facilities are uniquely identified in the table tblTLIndex (fig. 10). The index table includes the facility name and location information. The association table tasTransmissionConveyance includes the Conveyance_ID number, which is the link to the NEWUDS database. This direct link to a NEWUDS ID number is included because NEWUDS is a conveyance-based design (Tessler, 2002), whereas the WSSMP database is primarily designed to document the characteristics of water-supply infrastructure and associated facilities. The association table implements a data structure in which each transmission line may be associated with one or more NEWUDS conveyances and each NEWUDS conveyance may be linked to one or more transmission lines (fig. 10). The table tadTLDescription is used to describe the characteristics of each transmission line. The domain tables tdsTransmissionLineMaterial and tdsFacilityCondition (fig. 10) provide standard lists of descriptors to define pipe materials and the condition of the line, respectively. Transmission-facility information is entered for each WSSMP cycle as indicated by the relationships to the table tblWSSMPCycleIndex. The association table tasTLNodes defines the relationship between each transmission line (tblTLIndex) and one or more transmission-line nodes (tblTLNode). The table tblTLNode records the position (latitude and longitude) and type (provided in a standard list—tdsTLNode) of each node. The node-based data structure requires at least two nodes (the starting point and endpoint of each line), but water suppliers and State agencies must decide if this schematic representation is sufficient or if each segment along the entire transmission line must be delineated by additional nodes. Each node is associated with a supplier so that ownership of transmission lines between systems can be properly defined.

Relationships between transmission-line nodes and the facilities they connect are shown in figure 11. Association tables are used to define relations between one or more transmission-line nodes and one or more supply-system facilities. For example, the table tasTLNodeSurfaceWater (fig. 11) is used to associate transmission-line nodes (table tblTLNode) with surface-water-supply sources (tblSWIndex). The current (2003) WSSMP database design is based on the assumption that transmission lines between facilities are part of the permanent infrastructure and therefore these relationships will not change substantially from cycle to cycle. If cycle information is later found to be necessary, adding the Cycle_ID as a key to the association tables and establishing the relationship in MS Access will accomplish this modification.

Interconnection-Facility Data Structure

The RIWRB rules and procedures for WSSMPs (Rhode Island Water Resources Board, 1998, 2001) require that all interconnections be inventoried, characterized, described, and mapped. Information about interconnections is described in Worksheet 7 of the original WSSMP format (Charpentier and others, 1992; Fly, 1992) and in section 8.02e of the RIWRB (1998, 2001) planning documents (table 1). The interconnection-facility data structure provides a means for describing interconnections and individual valves within an interconnection facility. The section on the RIGIS Data Structure describes links to RIGIS files that may be used to locate interconnections.

Interconnections are different from other components of the water-supply infrastructure in that one or more water suppliers may own each facility. Therefore, interconnection facilities need to be described in terms of the wholesale transactions between water suppliers that may occur at these facilities. The table tadTransactionOwnerDirection is an association table with data that defines the relationship between suppliers (tblSupplier) and their transactions (tblICTransactionDescription), which are further defined by the domain table tdsICFlowDirection (fig. 12). The domain tables tdsICFeedDescription and tdsICTransactionFrequency define the type of transaction feed (for example gravity or pressure feed) and the transaction frequency (for example daily, monthly, or annually), respectively. The tables tblICIndex and tadICDescription define and describe the interconnection facility where the interconnection transactions take place. The index table includes the facility name, location, and a link to the NEWUDS database (NEWUDSSite_ID). The domain tables tdsICtype and tdsFacilityCondition (fig. 12) provide standard lists of descriptors to help ensure that all the plans are submitted or recorded in a consistent format. The information on transactions and the interconnection facility descriptions are entered for each WSSMP cycle as indicated by the relationships to the table tblWSSMPCycleIndex.

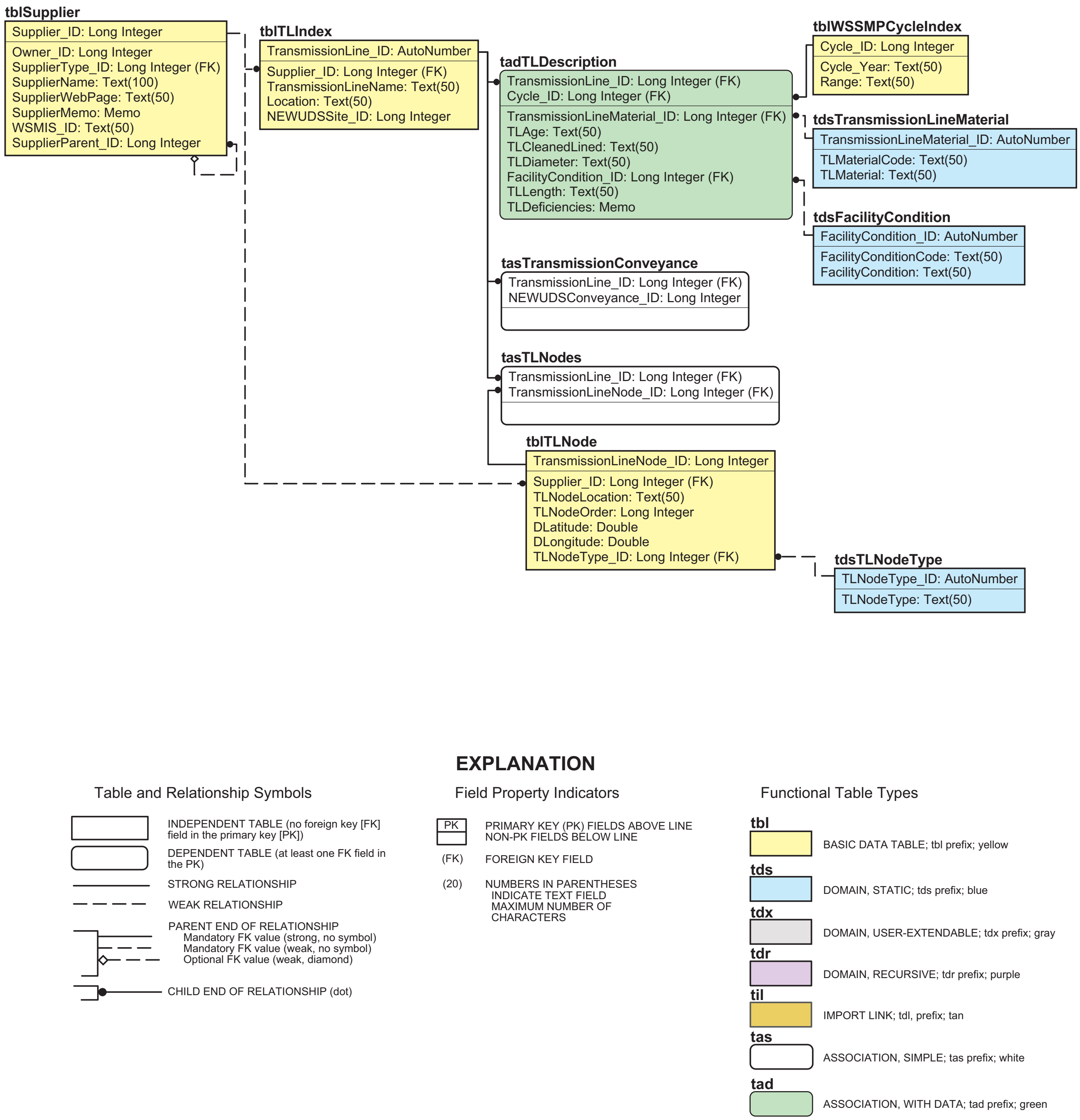

Figure 10. Transmission-facility data structure tables, fields, and relationships.

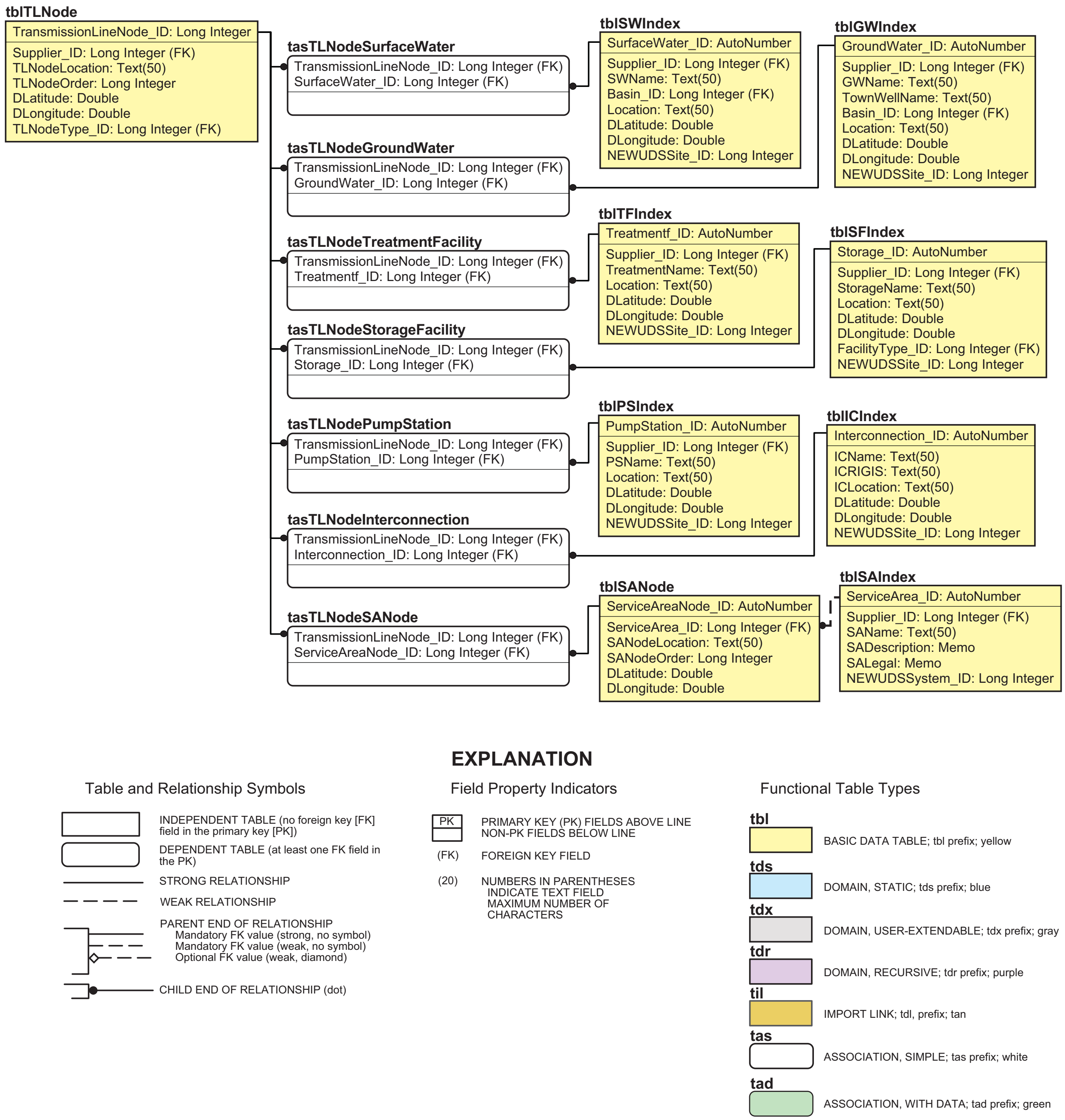

Figure 11. Transmission-line-node data structure tables, fields, and relationships.

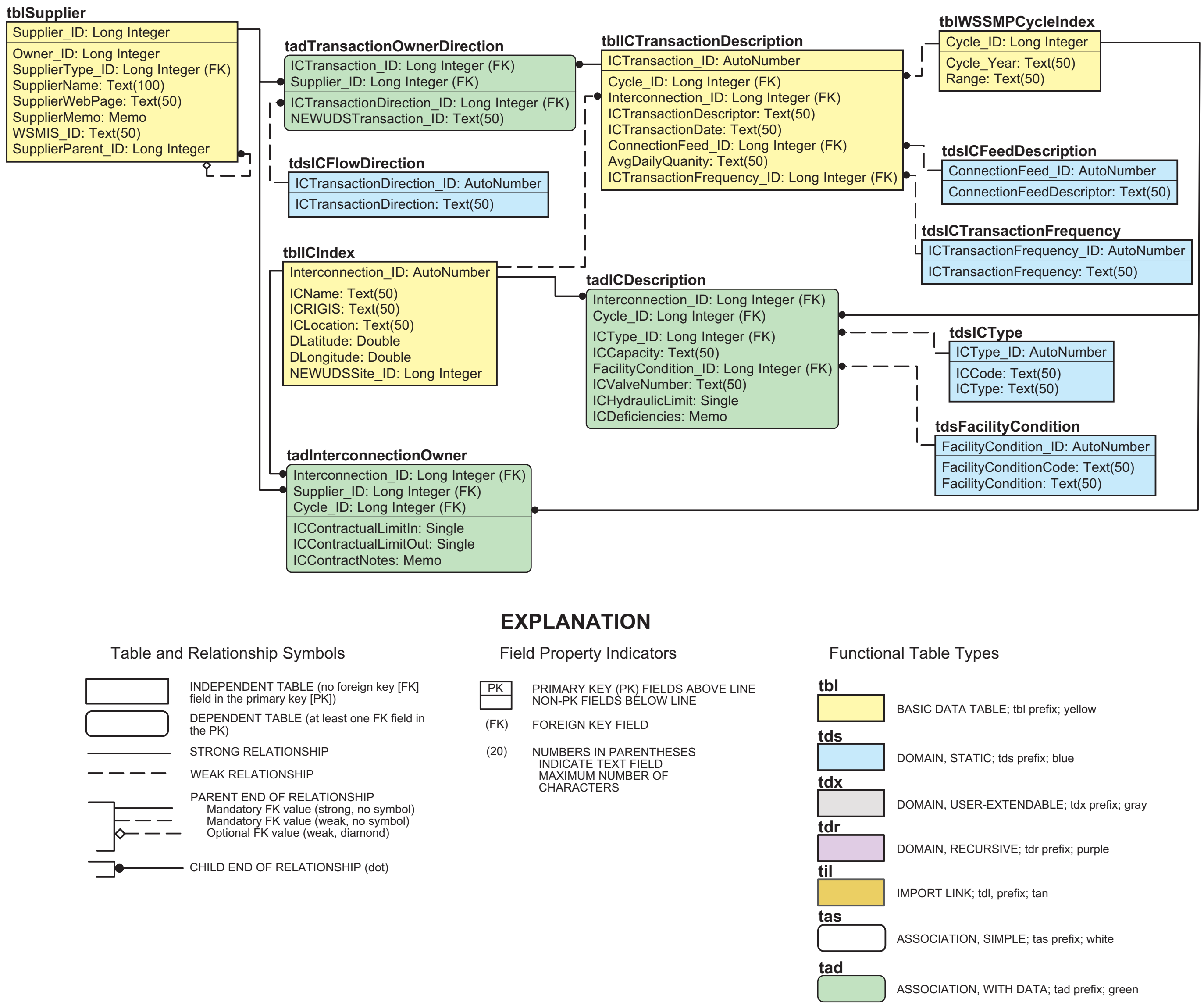

Figure 12. Interconnection-facility data structure tables, fields, and relationships.

Interconnection valves are uniquely identified in the table tblICValveIndex (fig. 13). The table tadICValveDescription is used to describe characteristics of each valve. The domain table tdsValveStatus (fig. 13) provides standard lists of descriptors to help ensure that all the plans are submitted or recorded in a consistent format. Interconnection-valve information is entered for each WSSMP cycle as indicated by the relationship from the table tadICValveDescription to the table tblWSSMPCycleIndex. Figure 13 also shows the relationship between interconnection facilities (tblICIndex) and associated pump stations (tblPSIndex) through the association table tasInterconnectionPumpStation.

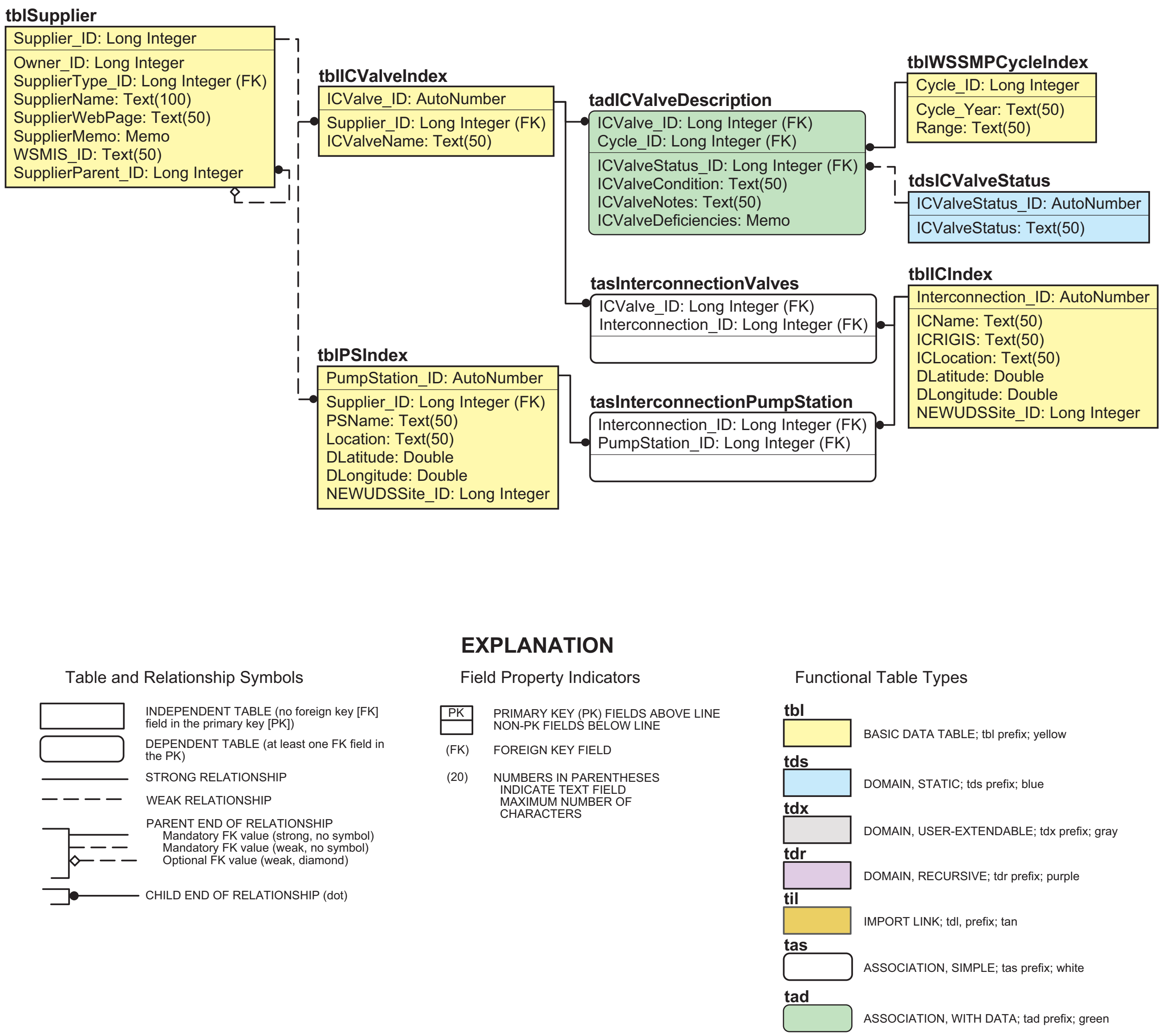

Figure 13. Interconnection-valve data structure tables, fields, and relationships.

Service-Area Data Structure

The RIWRB rules and procedures for WSSMPs (Rhode Island Water Resources Board, 1998, 2001) require that the geographic boundaries of service areas (areas in which water suppliers currently serve and areas that are eligible to be served) be described and that the service areas be inventoried, characterized, and mapped. Information about service area is described in Worksheet 8 of the original WSSMP format (Charpentier and others, 1992; Fly, 1992) and in Section 8.02f of the RIWRB (1998, 2001) planning documents (table 1). The service-area data structure provides a means for describing the boundaries and the populations of service areas. The geographic areas eligible to be served are considered legal boundaries for each water district and RIGIS files defining service areas will be developed (C.L. McGreavy, Rhode Island Water Resources Board, written commun., 2003). The section on the RIGIS Data Structure describes links to RIGIS files that may be used to locate service areas after these GIS files have been developed.

Service areas are uniquely identified in the table tblSAIndex (fig. 14). The index table includes the service-area name, a description, and a legal definition of each service area. Service areas are linked to the NEWUDS database-system area by the field NEWUDSSystem_ID because the NEWUDS system area is used in water-use studies to aggregate water-use transactions (such as the annual water use by all residents of a town) into a single transaction (Tessler, 2002). The current and projected population of a service area is of primary importance because water use is generally proportional to the population served. The population associated with each service area is recorded in the table tblSAPopulationEstimates. Population estimates are entered for each WSSMP cycle as indicated by the relationships to the table tblWSSMPCycleIndex. Annual population estimates or data (if Federal, State, or town census data is available) may be entered each year (or in any year) in the table tblSAPopulationEntries (as indicated by the relationship to the table tdxAnnual Date). The number and types of connections are recorded in the table tblSAConnectionDescription. This data may be entered in each cycle (as indicated by the relationships to the table tblWSSMPCycleIndex) and in each year within the cycle (as indicated by the relationship to the table tdxAnnual Date). The geographic boundary of the service area may be described by entering geographic coordinates for points along the perimeter in the table tblSANode (fig. 14).

The node-based data structure allows the user to define each linear segment of the service area boundary and requires at least three or four nodes to define a closed polygon, but water suppliers and State agencies must decide if a schematic representation is sufficient or if each segment along the entire geographic boundary must be described in detail. Theoretically, each pipe and service connection in a service area could be defined as a node in tblSANode, but the complexity of the distribution system limits the potential benefits from the considerable effort that would be required. The relationship between each service area and a specified transmission-line node can be used to associate each service area with all the other components of the water-supply infrastructure (fig. 11).

Master-Meter Data Structure

The RIWRB rules and procedures for WSSMPs (Rhode Island Water Resources Board, 1998, 2001) require that the extent of source and distribution metering and programs for meter reading, testing, calibration, and repair or replacement be described. In particular, each master meter (a meter that measures water from a source of supply or from other water suppliers) must be described and mapped. Information about master meters is described in Worksheet 9 of the original WSSMP format (Charpentier and others, 1992; Fly, 1992) and in Section 8.02g of the RIWRB (1998, 2001) planning documents (table 1). The section on the RIGIS Data Structure describes links to RIGIS files that may be used to locate master meters.

Master meters are uniquely identified in the table tblMMeterIndex (fig. 15). The index table includes the meter name, location information, and a link to the NEWUDS database (NEWUDSSite_ID). The table tadMMeterDescription is used to describe each master meter. The domain tables tdsMeterType, tdsMeterReadingFrequency, tdsMeterRegister, tdsMeterUnits, tdsMeterTime, tdsMeterMultiplier, and tdsMeterTestingFrequency provide standard lists of descriptors to ensure that all the plans are submitted or recorded in a consistent format. Master-meter information is entered for each WSSMP cycle as indicated by the relationships to the table tblWSSMPCycleIndex. The association tables tasSWMMeter, tasGWMMeter, and tasMMeterInterconnection describe relationships between each meter and one or more surface-water sources, ground-water sources, or interconnection sources, respectively (fig. 15).

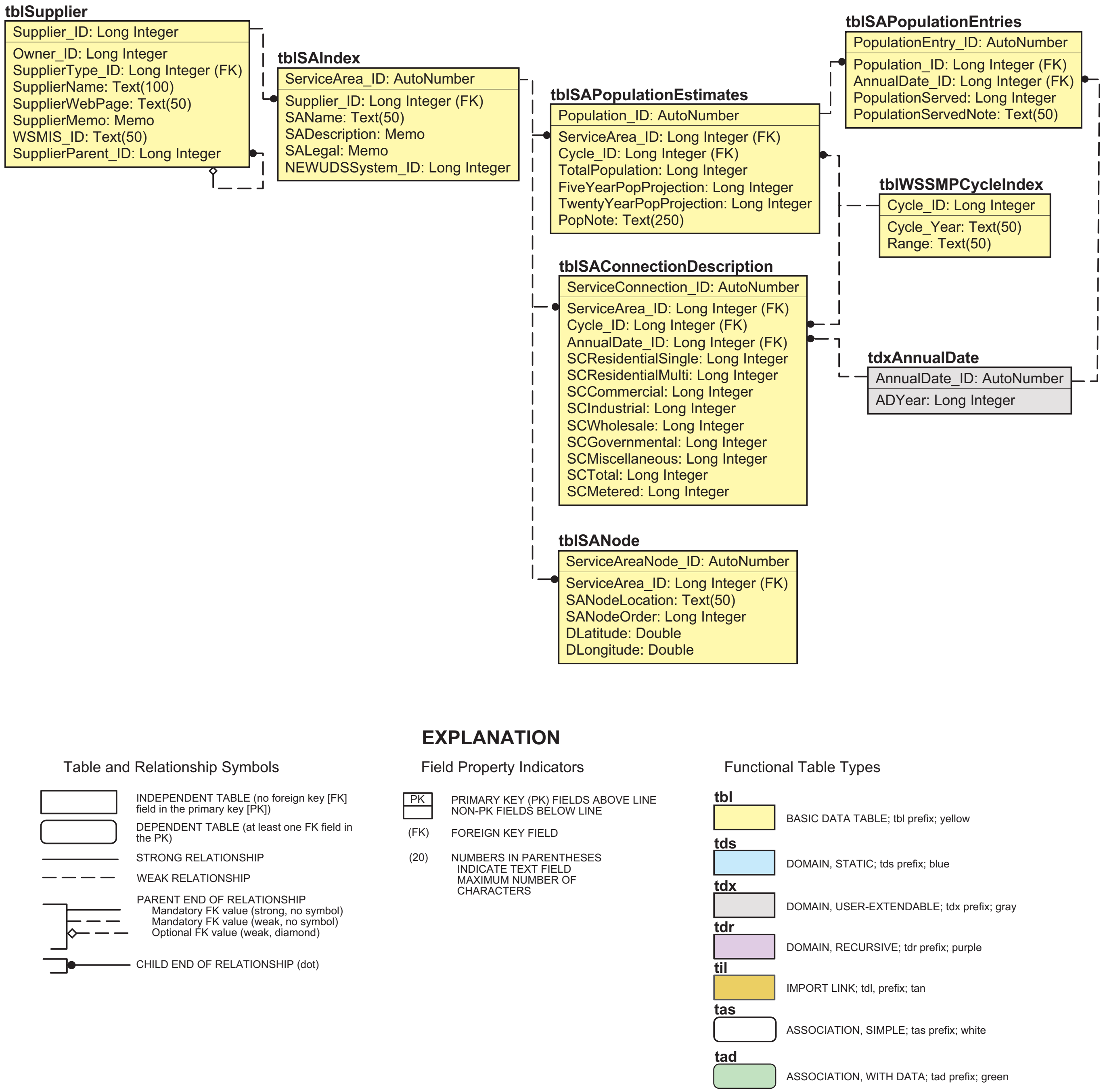

Figure 14. Service-area data structure tables, fields, and relationships.

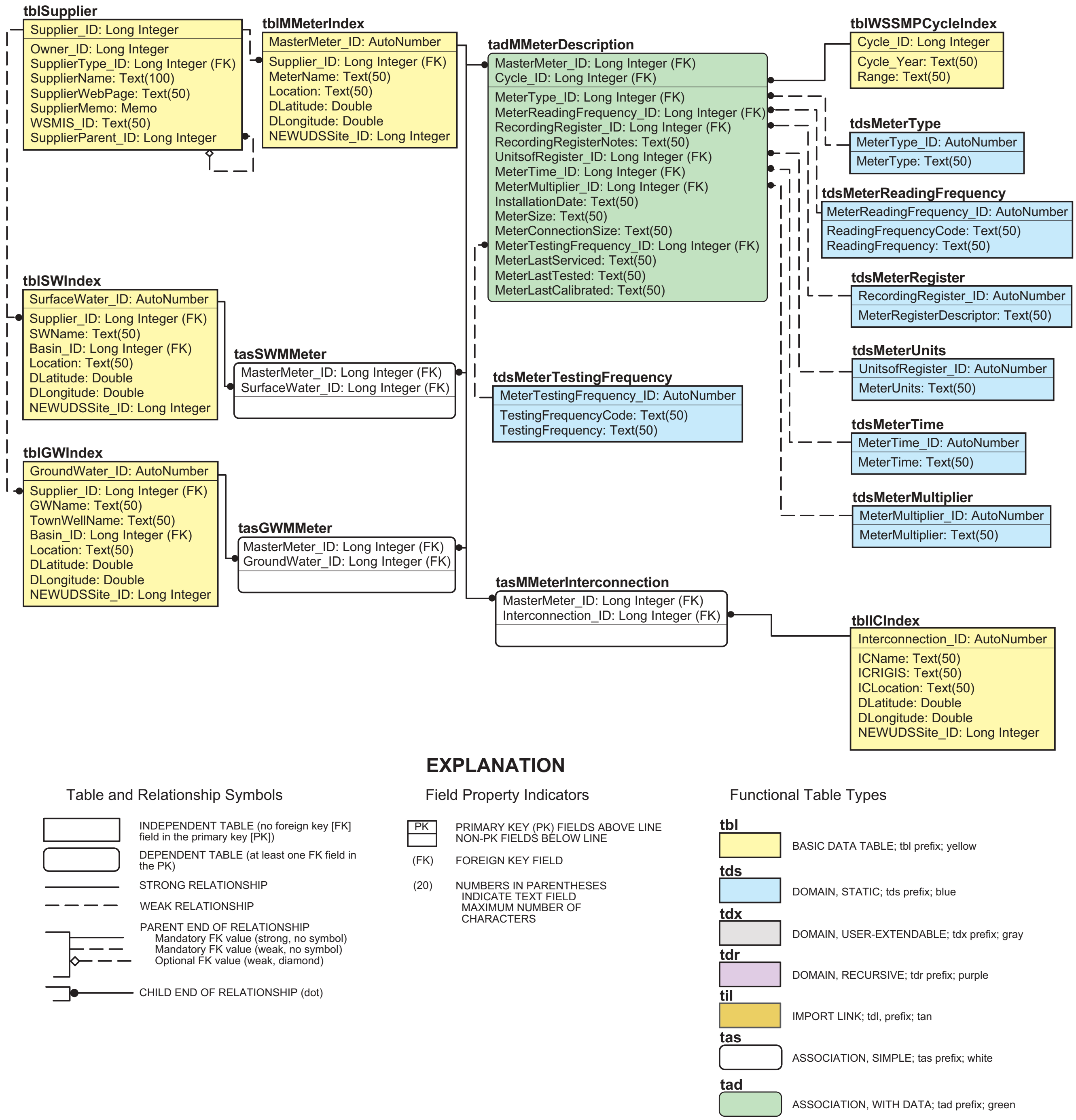

Figure 15. Master-meter data structure tables, fields, and relationships.

System-Production Data Structure

The RIWRB rules and procedures for WSSMPs (Rhode Island Water Resources Board, 1998, 2001) require that system-production data be documented in the plan. Information about production data is described in Worksheets 12 and 13 of the original WSSMP format (Charpentier and others, 1992; Fly, 1992) and in Section 8.02h of the RIWRB (1998, 2001) planning documents (table 1). The original WSSMP format had data structures for surface-water (Worksheet 12) and ground-water withdrawals (Worksheet 13). Examination of historical WSSMP documents indicates that different suppliers provided production data in different formats, on different time scales (daily, weekly, monthly or annually), and with different multipliers (for example, in gallons per day, thousands of gallons per day or in millions of gallons per day). Therefore, the system-production data structure is designed to characterize the differences and allow for standardization of values by computation in queries that convert varied input format to a standard output format (for example, annual production values in millions of gallons per day). Production and demand data structures are integrated in a diagram on plate 1.

Production data entries are uniquely identified in the tables tblProductionVolume and tblProductionVolumeEntry (fig. 16). The table tblProductionVolume identifies a unique set of production volume data by WSSMP cycle (through a relationship with tblWSSMPCycleIndex) and by annual date (defined in the domain table tdxAnnualDate). The table tblProductionVolume documents the frequency of measurements (defined in the domain table tdsReportingFrequency), units (defined in the domain table tdsMeterUnits), the unit rate (defined in the domain table tdsMeterTime), the meter multiplier (defined in the domain table tdsMeterMultiplier), and the source type (defined in the domain table tdsProductionSourceType).

The domain table tdxAnnualDate provides a list of annual dates, which are used to define a set of water-use entries. The three "Meter" tables are used in conjunction with one another to provide different flow-rate units. For example, the domain table tdsMeterUnits defines the water-use units (for example gallons), the domain table tdsMeterTime the rate (for example per day) and table tdsMeterMultiplier the water-use multiplier (for example one million). The combination of these examples yields the flow-rate units millions of gallons per day. The data-source type may be defined as surface-water-production data, ground-water-production data, or as an interconnection purchase or sale by selecting a choice from the domain table tdsProductionSourceType. The structure of table tblProductionVolume allows the user to define the characteristics of a set of production volumes once (for example, monthly production volumes from a well for a given year) so that the individual entries can be made in table tblProductionVolumeEntry without repeating the supporting information. Each entry may be associated with a NEWUDS transaction with the NEWUDSTransaction_ID field in the table tblProductionVolumeEntry. The source of a given production volume may be identified by using the association tables tasSWProduction and tasGWProduction, which are related to the tables tblSWIndex and tblGWIndex, respectively (fig. 16).

The relationship between tdsReportingFrequency and tdsWaterVolumeDate defines the appropriate water-volume dates (entered in tblProductionVolumeEntry) for the reporting frequencies (entered in tblProductionVolume) (fig. 16). For example, if quarterly reporting frequencies are defined in tblProductionVolume (through tdsReportingFrequency), then the associated choices from tdsWaterVolumeDate would be Q1, Q2, Q3, or Q4. Similarly, if a monthly reporting frequency is selected, then there should be a production-volume entry for each month. This relationship can be used to build a user interface that will limit the available choices by the reporting-frequency field, and require the appropriate number of entries for the report frequency selected. For example, if a policy requires monthly production data, then the interface can be programmed to accept only the monthly option and to require one value for each month of each year.

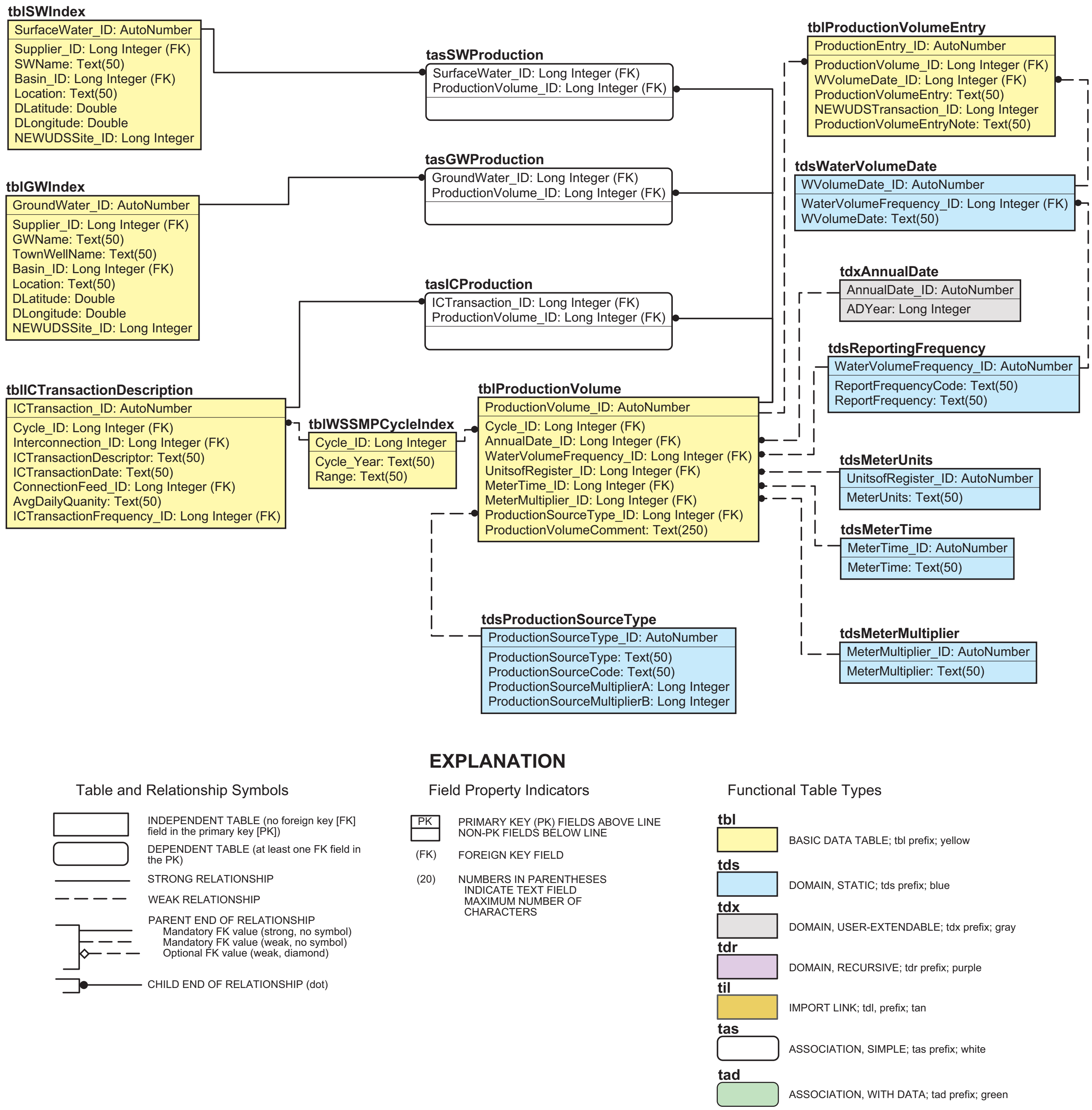

Figure 16. System-production data structure tables, fields, and relationships.

The RIWRB rules and procedures for WSSMPs (Rhode Island Water Resources Board, 1998, 2001) specify that that water bought from or sold to another water supplier (wholesale water sales) be reported with production data. The RIDEM format (Charpentier and others, 1992; Fly, 1992), however, had separate worksheets (numbers 14–17) for current and historic wholesale water transactions (table 1). Purchases and sales from other water suppliers are defined by links from tblProductionVolume through the association table tasICProduction to tblICTransactionDescription (fig. 16). This link is necessary because wholesale transactions are also characterized in tblICTransactionDescription in the interconnection-data structure (fig. 12).

Assessing the magnitude and direction of water bought from or sold to another water supplier can be confusing; water that is produced by one supplier can be double counted with water that is bought or sold from another supplier. The table tdsProductionSourceType (fig. 16) was designed to describe production data by source and so includes the choices surface water, ground water, purchases, and sales to account for differences between production and use. The field ProductionSourceMultiplierA may be used to indicate flow direction by sign. A positive multiplier designates production values and purchases, and a negative multiplier designates sales. The field ProductionSourceMultiplierB may be used to null purchases and sales so that actual production data may be summed separately from interconnection values in a query.

Water-Use Data Structures

The RIWRB rules and procedures for WSSMPs (Rhode Island Water Resources Board, 1998, 2001) require that historic, current, and projected water-use data be documented in the plan. Information about water-use data is described in Worksheets 18 through 26 of the original WSSMP format (Charpentier and others, 1992; Fly, 1992) and in Section 8.02i of the RIWRB (1998, 2001) planning documents (table 1). Water-use data structures include tables to define system-wide and per-capita uses by daily demand (worksheets 18, 19, and 22), water-use by category and subcategory (worksheets 20 and 21), water use by major users, (worksheets 23 and 24), and firefighting and non-account use (worksheets 25 and 26). Similar data structures and common domain tables are used to document each of these different types of water-use data. The WSSMP specifications, however, require different formats for each of these types of water-use data. The NEWUDS database (Tessler, 2002) is designed to store water-use data as transactions, but is not explicitly designed to segregate these different types of water-use data according to the WSSMP formats. All of the water-use data structures include the field NEWUDSTransaction_ID, which may be used to link the WSSMP water-use data with individual NEWUDS transactions. After a unified NEWUDS database has been integrated for Rhode Island, the WSSMP database can be configured to work directly with NEWUDS by use of the MSAccess linked table manager.

The same domain tables that are used to define system-production volumes also are used to define water-use volumes. As with the production data, different suppliers have, historically, provided water-use data in different formats, on different time scales (daily, weekly, monthly or annually), and with different multipliers (for example, in gallons per day, thousands of gallons per day or in millions of gallons per day). Therefore, the domain tables tdxAnnualDate, tdsReportingFrequency, tdsWaterVolumeDate, tdsMeterUnits, tdsMeterTime, and tdsMeterMultiplier provide lists of standard choices that define water-use volumes.

Daily Demand

The daily demand is defined as the total volume of water supplied to the system, including changes in storage, during a representative period divided by the number of days in that period. WSSMP rules and procedures require the current and historic average daily demand by month, the maximum daily demand, and the peak-hour demand during the period. These water-use data, in terms of the daily demands, are uniquely identified in the tables tblDemandVolumes and tblDemandVolumeEntry (fig. 17). The table tblDemandVolumes identifies a unique set of demand-volume data (for example, average daily demand by system) by WSSMP cycle (through a relationship with tblWSSMPCycleIndex) and by annual date (defined in the domain table tdxAnnualDate). The table tblDemandVolumes provides the frequency and units of measurement. The structure of tblDemandVolumes allows the user to define the characteristics of a set of demand volumes (for example the average daily demand by month for a given year) once, so that the individual entries can be made in tblDemandVolumeEntry without repeating this supporting information. Demand volumes are not associated with a NEWUDS transaction because they are, by definition, a summary of individual transactions in a system. If, however, all transactions are entered in NEWUDS, then demand volumes could be calculated in NEWUDS by using one or more summation queries. Per-capita water-use demands may be calculated through relationships with the supplier and the population (by service area) for each supplier (fig. 14). Implementation of calculated fields in example queries is discussed in the section Operational Issues and Procedures. Production and demand data structures are integrated in a diagram on plate 1.

Water Use by Category

Water use by category provides information about the pattern of use for each supplier. Categories include single-family residential use, multi-residential use, commercial uses, industrial uses, institutional uses and government water use (for example, firefighting). The data structure for the water use by category (fig. 18) is similar to the daily-demand structure (fig. 17) in that water-use volumes are listed in an identifying table (tblWaterUse) and individual entries are identified in an entry table (tblWaterUseEntry). The water use by category structure, however, includes a relationship from the field UserCategory_ID in tblWaterUse to the domain table tdsUserCategory, which supplies a standard list of water-use categories.

Water Use by Major User

The RIWRB defines a major user as any water customer that uses more than 3 million gallons per year and requires detailed water-use records in the WSSMP for such users (Rhode Island Water Resources Board, 1998, 2001). The RIWRB, however, also allows individual water suppliers to use a threshold that is less than 3 million gallons per year in the designation of major users. The data structure for documenting water use by major users is similar to the other water-use data structures except that the water-volume tables tblMUWaterUse and tblMUWaterUseEntry are related to tblMUIndex, which identifies major water users, rather than to suppliers in tblSupplier (fig. 19). Data structures defining major users are integrated in a diagram on plate 1.

Major water users are identified and characterized in the major-user data structure (fig. 20). As indicated in figure 20, major users are identified for each supplier in table tblMUIndex. The relationship between tblSupplier and tblMUIndex associates each major user with a supplier. Major users are further defined in table tblMUIndex by one or more RIWRB categories by association with categories in tdsUserCategory through the table tasMUUserCategory. One or more addresses may be identified for each major user through the relationship between association table tadMajorUserAddress and the table tblAddress. The table tadMUDescription provides the structure to define characteristics of each major user in each WSSMP cycle. This information includes the meter-reading frequency (tdsMeterReadingFrequency), the meter units (tdsMeterUnits) and the meter-testing frequency (tdsMeterTestingFrequency). Each major user may be associated with a NEWUDS site by identification with the field NEWUDSSite_ID in tblMUIndex (fig. 20).

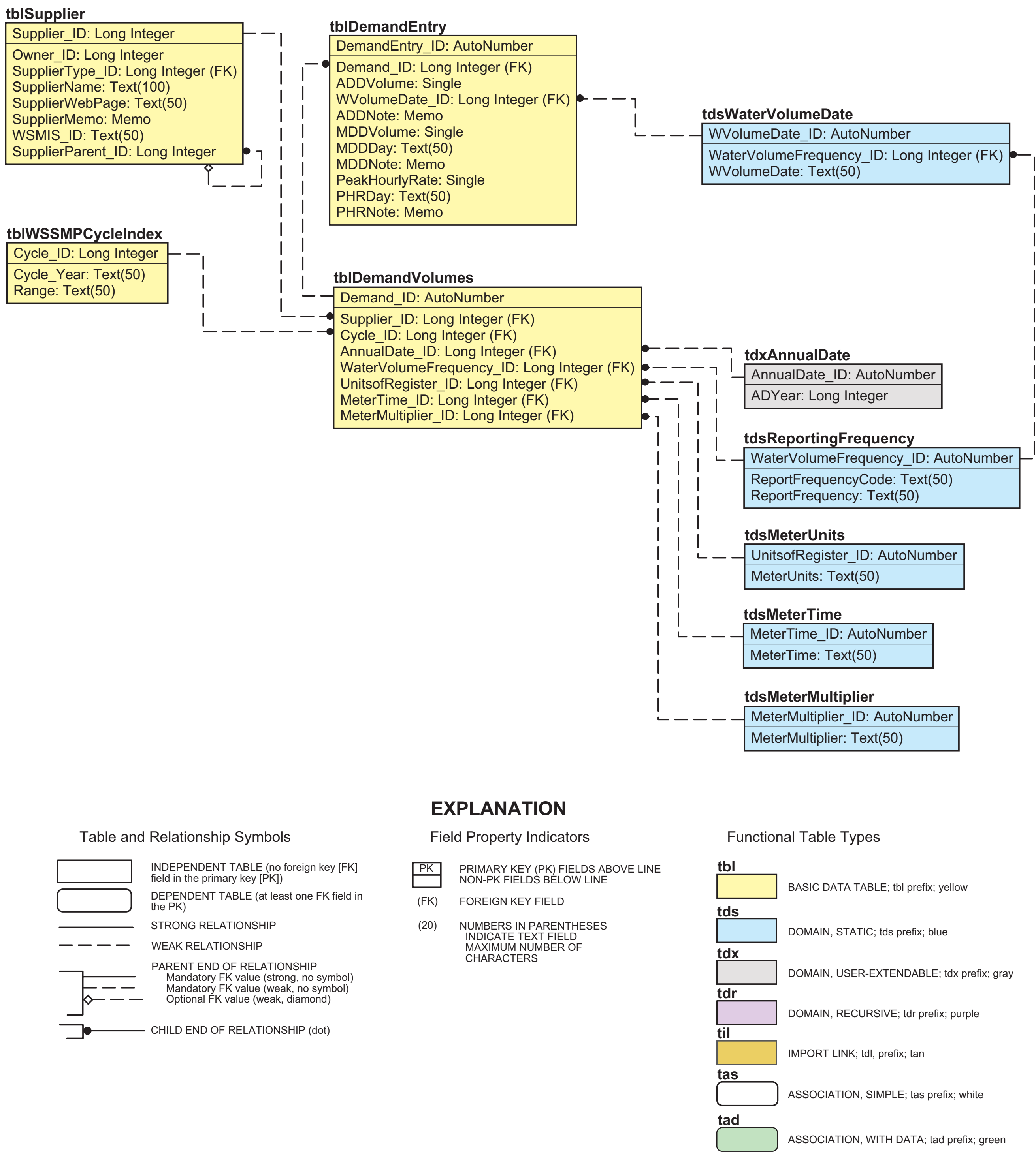

Figure 17. Daily-demand tables, fields, and relationships.

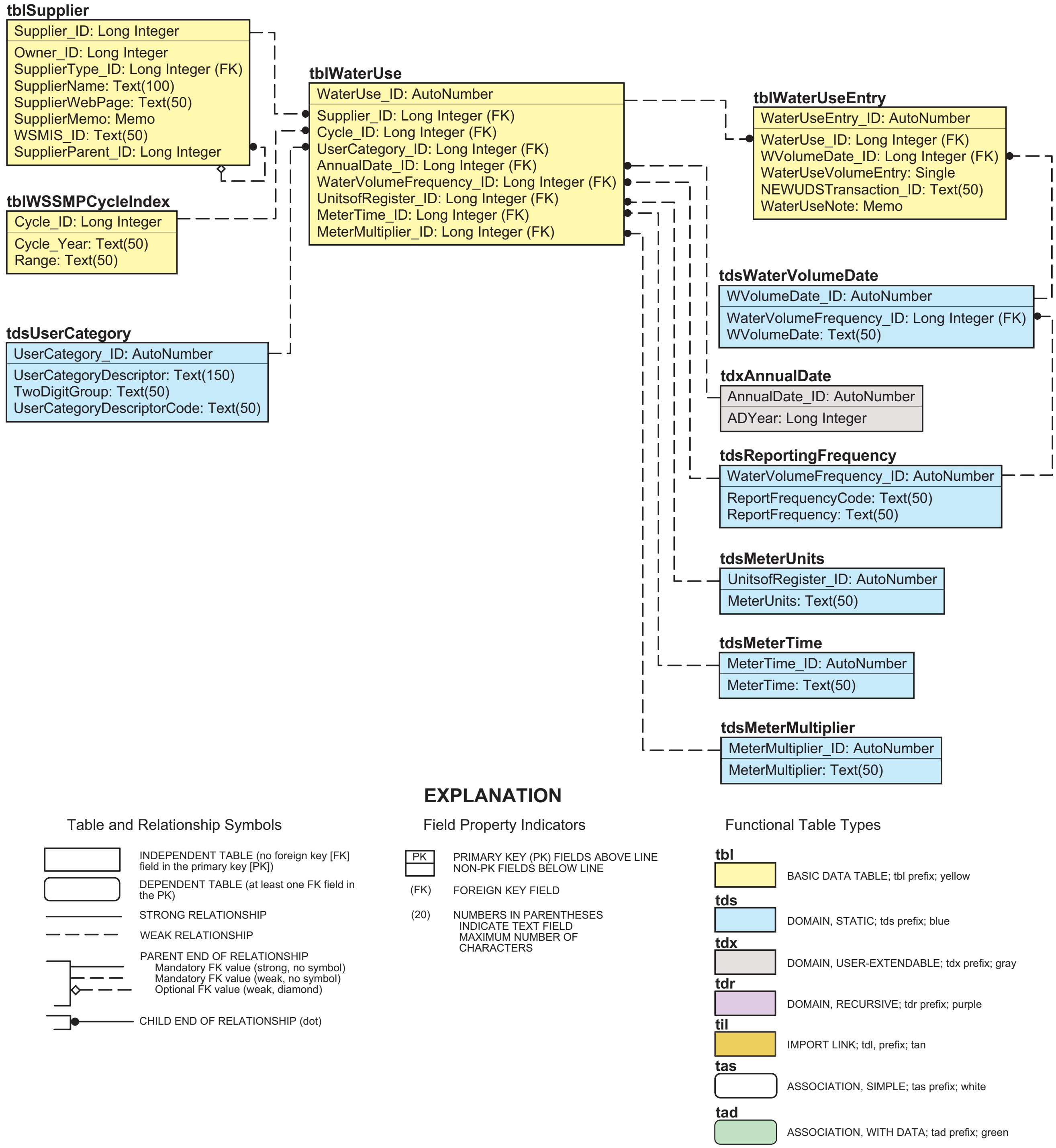

Figure 18. Water use by category tables, fields, and relationships.

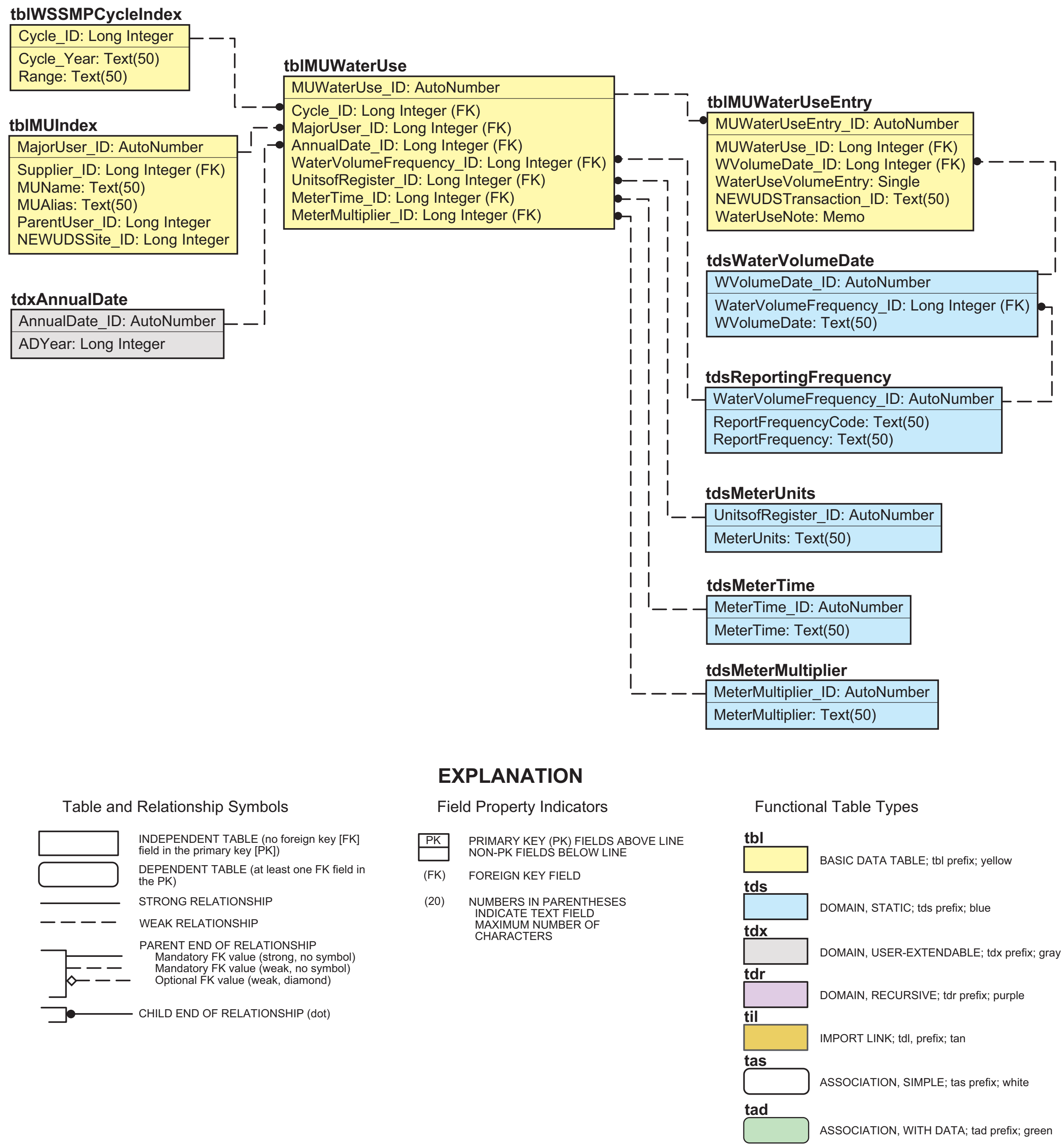

Figure 19. Water use by major user tables, fields, and relationships.

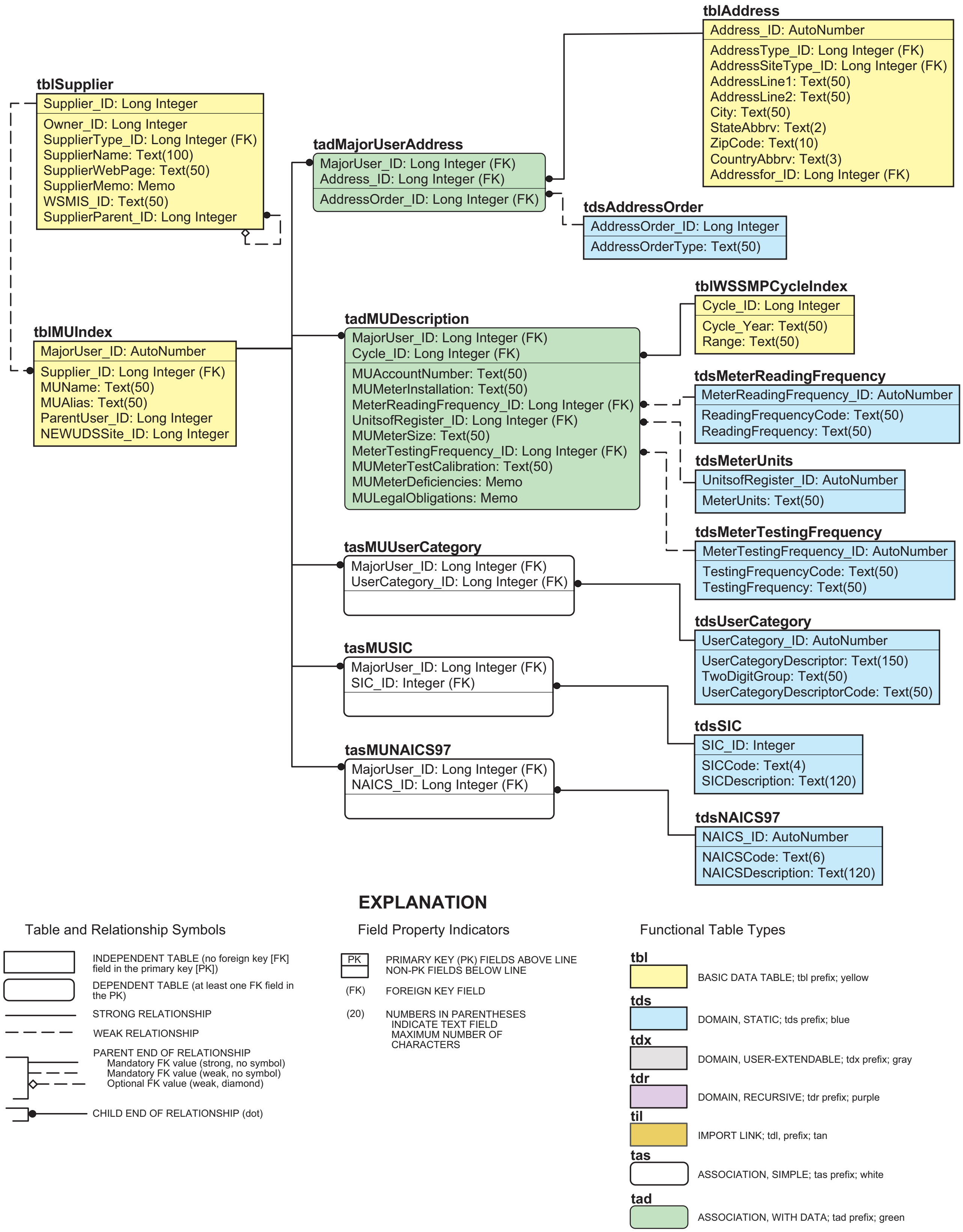

Figure 20. Major-user data structure tables, fields, and relationships.

Major users are also identified by two Census Bureau classification codes. Classification of users by one or more official US Census Bureau (USCB) Standard Industrial Classification (SIC) system codes (Office of Management and Budget, 1987) may be established through the association table tasMUSIC with tdsSIC (fig. 20). Similarly, classification of users by one or more USCB North American Industrial Classification System (NAICS) codes (Office of Management and Budget, 1997) may be established through the association table tasMUNAISC97 with tdsNAICS97 (fig. 20). SIC codes are included so that the WSSMP database will be compatible with plans submitted for the 2000 WSSMP cycle (Rhode Island Water Resources Board, 1998); the 1997 NAICS codes are included so that the WSSMP database will be compatible with NEWUDS (Tessler, 2002) and plans submitted under the new RIWRB guidelines (Rhode Island Water Resources Board, 2002). The Office of Management and Budget updated the NAICS codes again in 2002 and plans to update the codes every five years thereafter (Office of Management and Budget, 2002). Therefore, the WSSMP cycle will perpetually be out of phase with the NAICS cycles, and it was decided to identify major users with the 1997 standard to preclude continued version-control problems among current and future plans. The RIWRB may, however, wish to resolve potential problems with the use of these codes in future versions of the WSSMP database (C.L. McGreavey, Rhode Island Water Resources Board, written commun., December 5, 2003).

Water-Quality-Protection Data Structures

Suppliers that sell more than 50 million gallons per year are required to complete the water-quality protection component of the WSSMPs as defined by the RIWRB (1998, 2001). Information about water quality is described in section 8.03 of the RIWRB (1998, 2001) planning documents (table 1), but was not included in the worksheets of the original WSSMP format (Charpentier and others, 1992; Fly, 1992). The water-quality protection component of the WSSMP includes delineation of source-water-protection areas, an inventory of potential sources of contaminants in each source-water-protection area, a determination of source-water susceptibility, a description of efforts to protect water quality, and identification of source-water-protection strategies. Delineation of source-water-protection areas must be created in a format compatible with RIGIS data standards (Rhode Island Water Resources Board, 1998, 2001). The section on the RIGIS Data Structure describes links to RIGIS files that may be used to locate and describe source-water-protection areas.

Information about potential sources of contaminants, source-water susceptibility, and water-quality-management measures may be recorded in the surface-water quality (fig. 21) or the ground-water-quality (fig. 22) data structures. A list of potential constituents of concern is listed in the recursive domain table tdrConstituent, which is used in both the surface-water-quality and the ground-water-quality data structures. Relationships between water supplies and contaminants are only made when there is a known, potential, or suspected water-quality problem (Rhode Island Water Resources Board, 1998, 2001). To define the status, each constituent of concern can be defined as a "known contaminant," a "potential contaminant," or a "suspected contaminant" for each water supply by use of the relationship with the domain table tdsKnownPotential.

The water-quality-protection data structure is not designed to be a water-quality-sample database. Results of analysis of individual water-quality samples are not currently specified in the WSSMP requirements (Rhode Island Water Resources Board, 1998, 2001). A number of technical issues limit the potential efficacy of water-quality data in this WSSMP database. For example, the RIDOH collected and analyzed 28,744 water-quality samples in 2001 as part of its mission to protect public health (Rhode Island Department of Health, 2001). Water-quality data is available, on request, from the RIDOH (2003) database. Similarly, water-quality data collected by the USGS is available on line from the NWIS database (U.S. Geological Survey, 2003a). The WSSMP database does not include original water-quality data because this would be a duplication of effort. Also, there are many technical factors including sample collection, handling, and analysis methods, which are documented by the RIDOH and the USGS, that are necessary to determine the potential suitability and comparability of individual water-quality measurements for a given purpose. Water-quality data are collected by the RIDOH for regulatory purposes, whereas water-quality data collected by the USGS are for research and resource characterization.

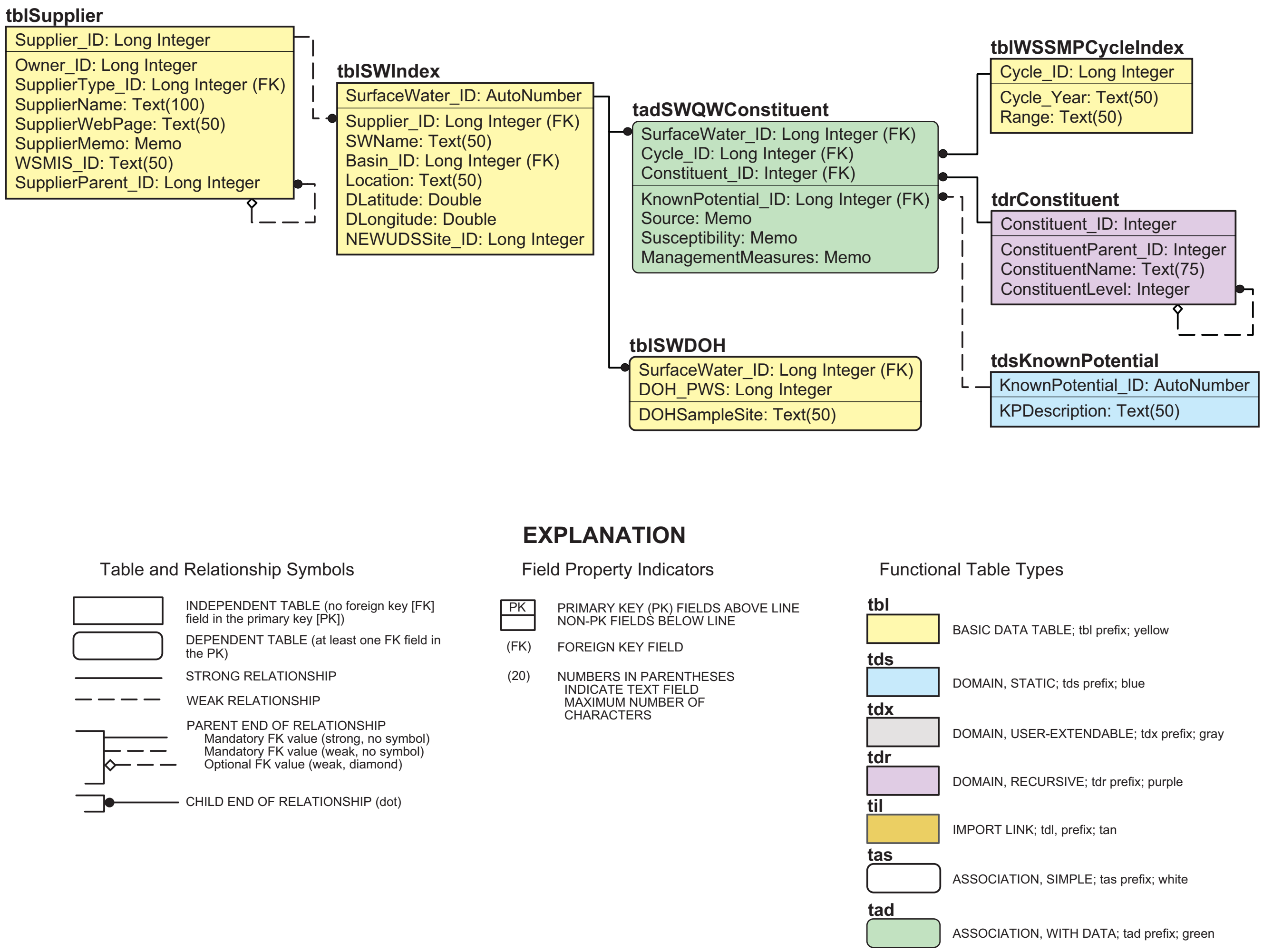

Figure 21. Surface-water-quality data structure tables, fields, and relationships.

Surface-Water-Quality Data Structure

The structure for documenting surface-water-quality data provides information about contaminants of concern for each surface-water source (fig. 21). Information about water-quality constituents of concern is defined in the association table tadSWQWConstituent. Relationships from tblSupplier and tblSWIndex define the water supplier and the surface-water source, respectively. Water-quality information is identified by WSSMP cycle through the relationship with table tblWSSMPCycle. Water-quality data for surface-water supplies may be obtained by selecting sampling sites identified by the RIDOH (tblSWDOH) or by relationships with on-line water-quality data from USGS pond sites (tasSWUSGSPondSite) or streamflow-gaging stations (tasSWUSGSStreamGage) as described in the section on import tables.

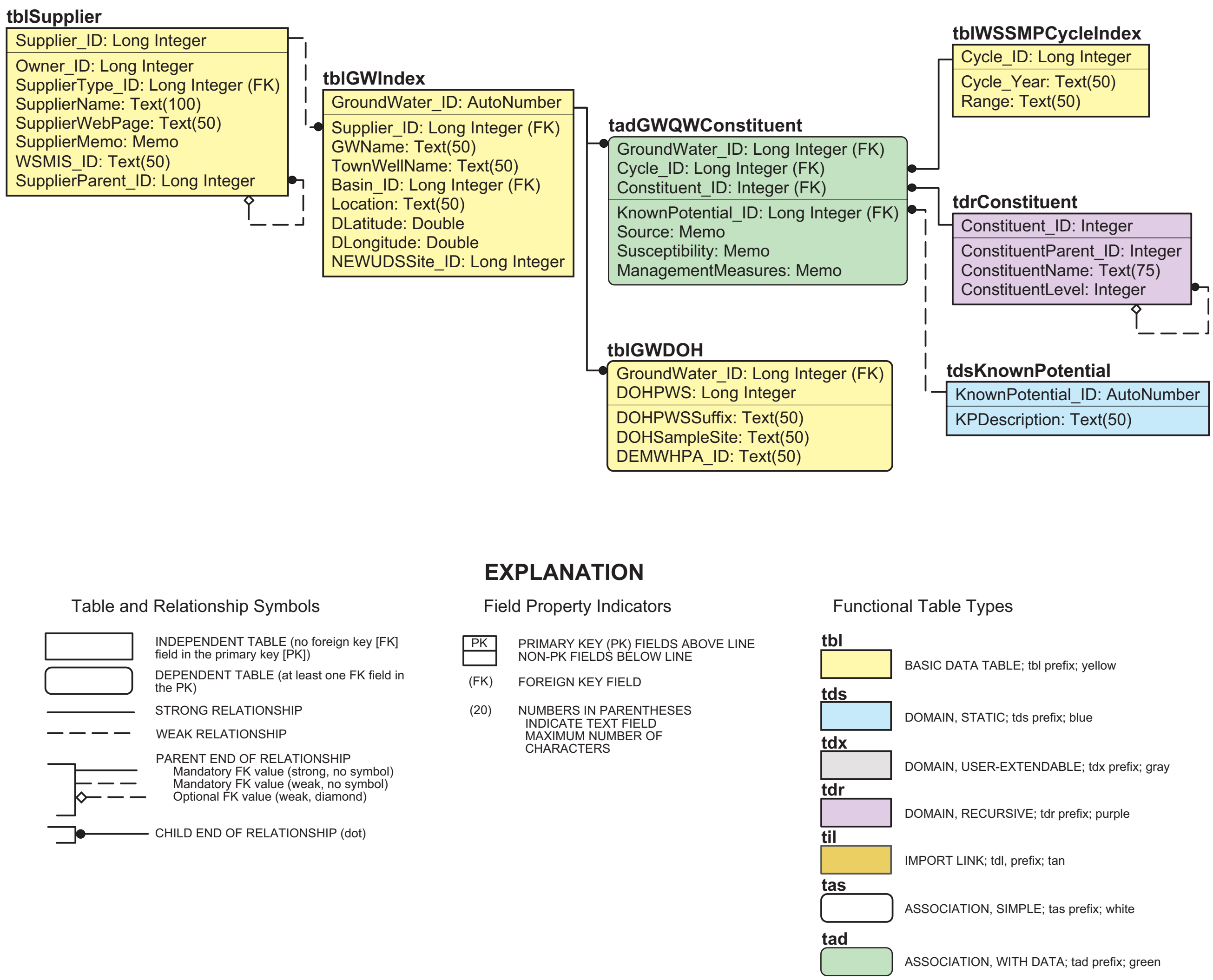

Figure 22. Ground-water-quality data structure tables, fields, and relationships.

Ground-Water-Quality Data Structure

The structure for documenting the ground-water-quality data provides information about contaminants of concern for each ground-water source (fig. 22). Information about water-quality constituents of concern is defined in the association table tadGWQWConstituent. Relationships from tblSupplier and tblGWIndex define the water supplier and the ground-water source, respectively. Water-quality information is identified by WSSMP cycle through the relationship with table tblWSSMPCycle. Water-quality data for ground-water supplies may be obtained by selecting sampling sites identified by the RIDOH (tblGWDOH) or by relationships with on-line water-quality data from USGS wells (tasGWUSGSWell) as described in the section on import tables.

Projected Water-Use Data Structures

The RIWRB rules and procedures for WSSMPs (Rhode Island Water Resources Board, 1998, 2001) require that water suppliers develop water-use projections for 5-year and 20-year planning periods during each WSSMP cycle as part of the supply-management process. Information about water-use projections is described in Worksheets 26 through 28 of the original WSSMP format (Charpentier and others, 1992; Fly, 1992) and in Section 8.04a of the RIWRB (1998, 2001) planning documents (table 1). These projections are done by category and subcategory (worksheet 27), including firefighting and non-account uses (worksheet 26) (Rhode Island Water Resources Board, 1998, 2001). Suppliers are also required to make projections for the 5-year and 20-year planning periods for each major user (worksheet 28). Similar data structures and common domain tables are used to document each type of water-use projection, but the WSSMP specifications require different formats for each projection type. The NEWUDS database (Tessler, 2002) could be used to store projection data as a water-use transaction, but is not explicitly designed to segregate actual water-use data from the projections in the WSSMP database.

Many of the same domain tables that are used to define production volumes and water-use volumes also are used to define projected water-use volumes. Historically, different suppliers have provided water-use projections in different formats, on different time scales (daily, weekly, monthly or annually), and with different multipliers (for example, in gallons per day, thousands of gallons per day or in millions of gallons per day). The domain tables tdsMeterUnits, tdsMeterTime, and tdsMeterMultiplier provide lists of choices for these quantities that standardize the projected water-use volumes. Additionally, the domain table tdsProjectionHorizon defines the projection horizon (a 5- , 10- , or 20-year cycle). The relationship with tblWSSMPCycleIndex provides the plan date from which the projections are based. Unlike the projections for water-use data, the projections do not include multiple entries. Comparisons between structures for water-use data and water-use projections can be made by use of the water-use area on plate 1.

Projected Water Use by Category

The data structure for documenting the projected water use by category provides information about anticipated future water-use patterns for each supplier. Categories include single-family residential use, multi-family residential use, commercial uses, industrial uses, and water used for firefighting purposes. The data structure for the projected water use by category (fig. 23) is similar to that for the water use by category in that the projections are identified by supplier (tblSupplier) and WSSMP cycle (tblWSSMPCycle Index). The data structure for the projected water use by category utilizes a link from the field UserCategory_ID in tblProjectionbyUse to the domain table tdsUserCategory. The table, tdsUserCategory, supplies a standard list of water-use categories.

Projected Water Use by Major User

The data structure for documenting the projected water use by major users is similar to the water use by major-user data structure in that the water-volume table (in this case tblProjectionbyMU) is related to tblMUIndex, which identifies major water users, rather than being directly related to suppliers in tblSupplier (fig. 24). Information about major water users is identified and characterized in the major-user data structure described previously (fig. 20).

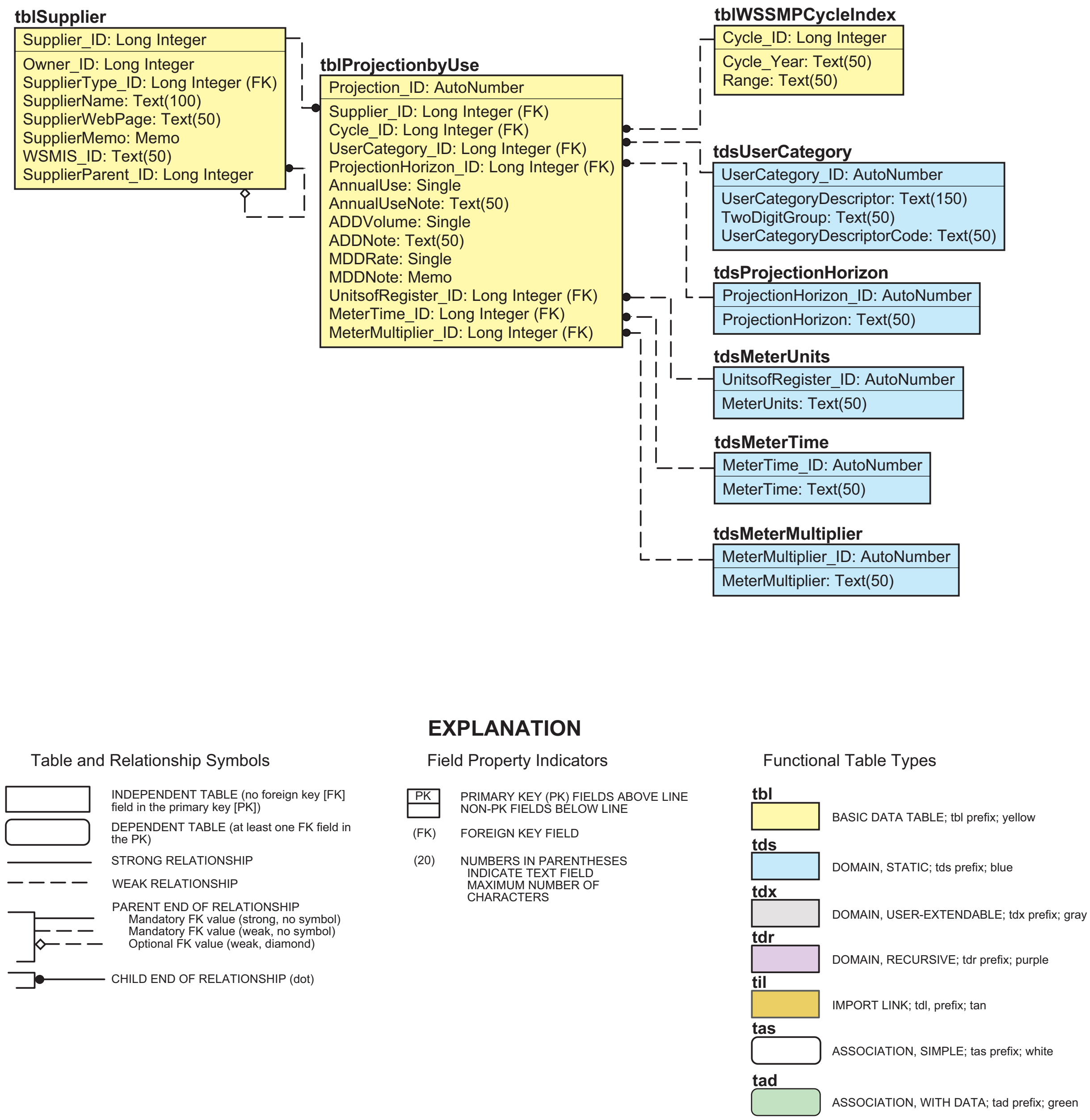

Figure 23. Projected water use by category tables, fields, and relationships.

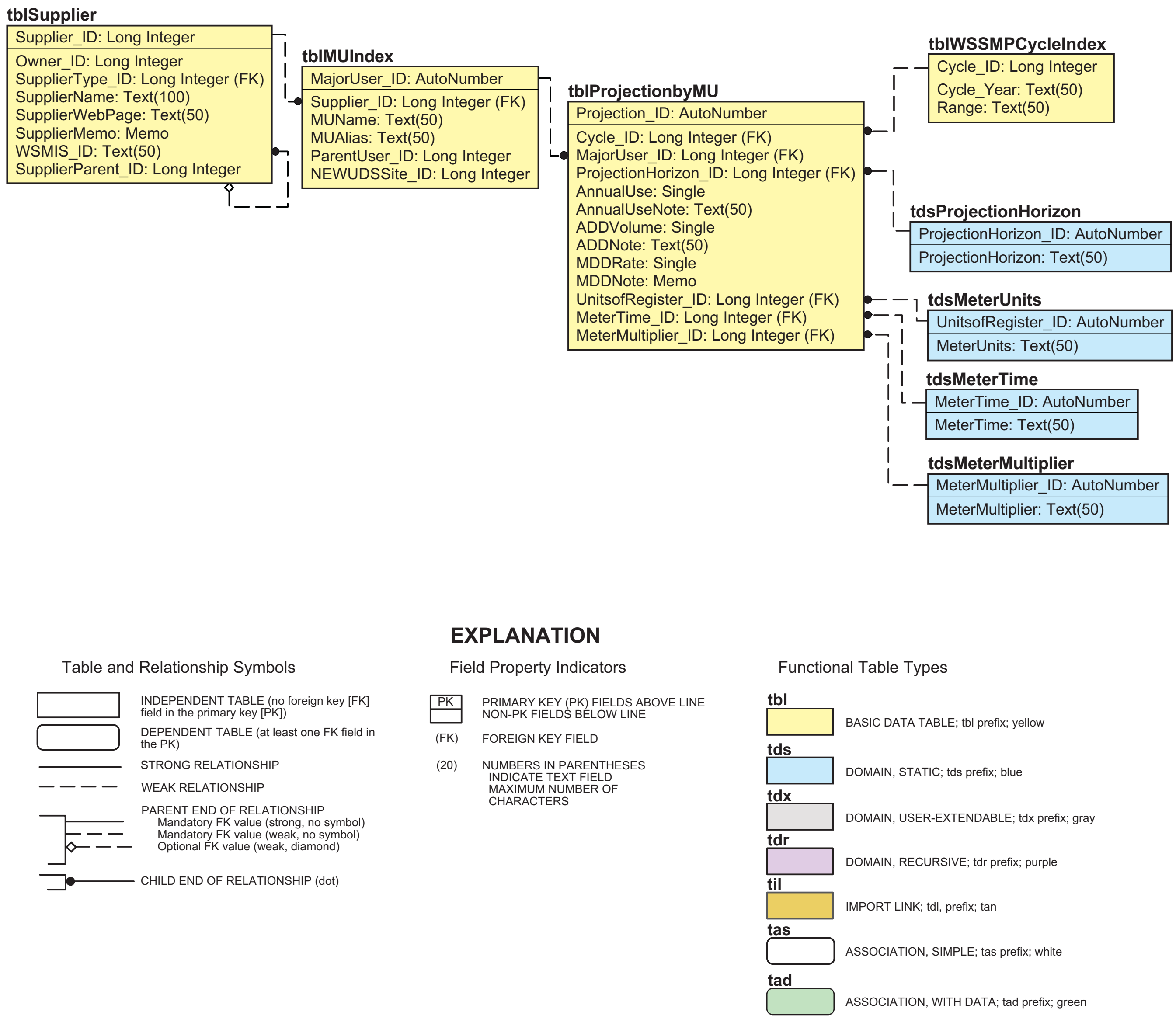

Figure 24. Projected water use by major user tables, fields, and relationships.

Water-Availability Data Structures

The RIWRB rules and procedures for WSSMPs (Rhode Island Water Resources Board, 1998, 2001) require that water suppliers develop information about the water available from different sources as part of the supply-management process. Information about water availability is described in Worksheets 1 and 29 of the original WSSMP format (Charpentier and others, 1992; Fly, 1992) and in Section 8.04b of the RIWRB (1998, 2001) planning documents (table 1). Water availability defines the amount of water that can dependably be supplied and includes estimates of the safe yield of surface reservoirs and the well capacity of ground-water sources.

Surface-Water-Availability Data Structure

The structure for documenting surface-water-availability data provides information defining the stage-storage relation for each surface-water source (fig. 25). Information about the stage-storage relation for each surface-water source is recorded in the table tblSWStageStorage. Relationships from tblSupplier and tblSWIndex define the water supplier and the surface-water source, respectively. The stage-storage relationship may change because of work on impoundment structures, sedimentation in the reservoir, or by dredging operations, and is identified by WSSMP cycle through the relationship with table tblWSSMPCycle. Safe-yield information is included in the table tadSWDescription (fig. 4). Surface-water stage and flow data may be obtained from USGS pond sites (tasSWUSGSPondSite) or streamflow-gaging stations (tasSWUSGSStreamGage) in the basin as described in the section on import tables.

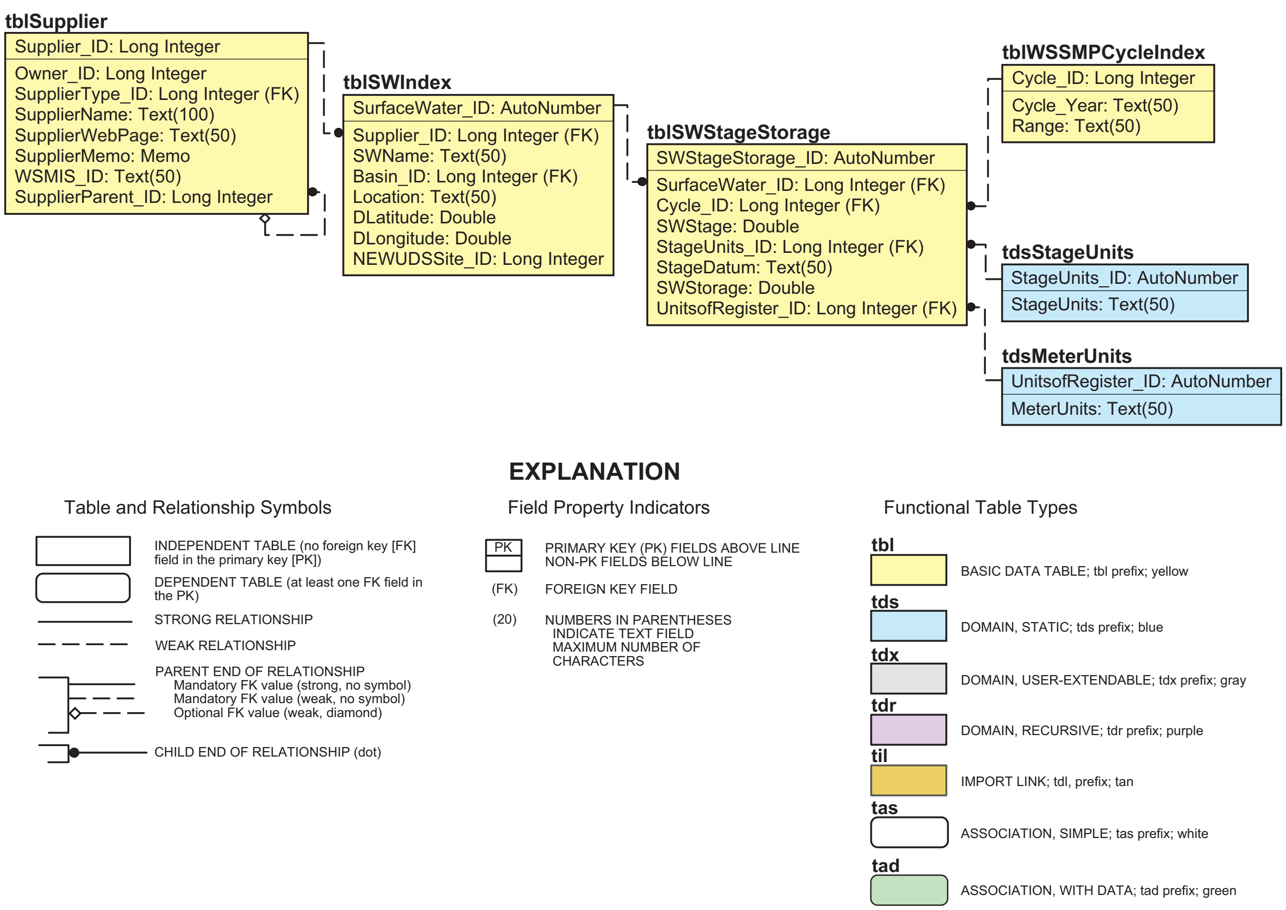

Figure 25. Surface-water-availability data structure tables, fields, and relationships.

Ground-Water-Availability Data Structure

The structure for documenting ground-water-availability data provides information defining aquifer-test results (fig. 26). Information about aquifer-test results is recorded in the table tblGWAquiferTest. One or more aquifer-test data sets may be identified by year (tdxAnnualDate) and entered for each monitoring well in the table tblGWAquiferTest. Aquifer tests, however, are not identified by WSSMP cycle because the need for such tests is relatively infrequent. Relationships from tblSupplier and tblSWIndex define the water supplier and the ground-water source, respectively. Ground-water data may be obtained from USGS monitoring wells (tasGWUSGSWells) in each basin as described in the section on import tables.

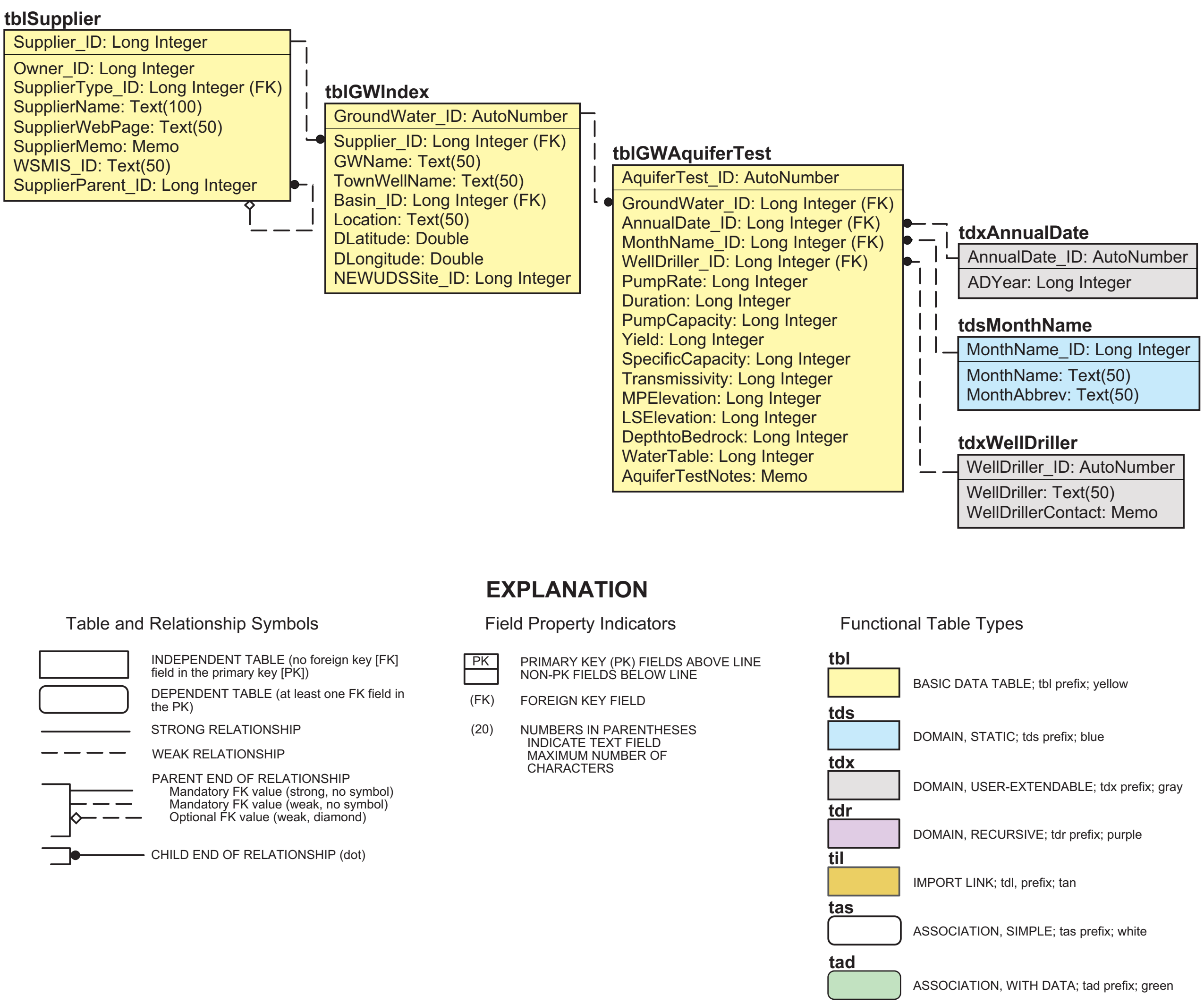

Figure 26. Ground-water-availability data structure tables, fields, and relationships.

Residential-Retrofit-Program Data Structure

The RIWRB rules and procedures for WSSMPs require that water suppliers implement and document a program to retrofit existing water-use devices that are not in conformance with the 1990 RI State building-code and plumbing-code regulations for water-saving plumbing equipment as part of their demand-management efforts (Rhode Island Water Resources Board, 1998, 2001). Residential retrofit programs include the distribution of retrofit kits that utilize water-saving plumbing equipment to reduce household water use. Information about retrofit programs is described in Worksheet 30 of the original WSSMP format (Charpentier and others, 1992; Fly, 1992) and in Section 8.05a of the RIWRB (1998, 2001) planning documents (table 1).

This data structure provides a standard method to identify and describe components of the residential retrofit program (fig. 27). The table tblRetrofitDone defines each retrofit program and identifies the program by supplier (tblSupplier), WSSMP cycle (tblWSSMPCycle) and year of implementation (tdxAnnualDate). Standard residential retrofit program descriptors are provided through relationships from nine domain tables to tblRetrofitDone (fig. 27). One or more retrofit-kit components may be identified through a relationship with the association table tadRetrofitKit and the table tblRetrofitKitComponents. This table is not a domain table because each supplier may use any of the available components; a standardized domain may be perceived as a product endorsement. One or more retrofit reminder notices may be defined through a relationship with the association table tadRetrofitReminder and the domain table tdsRetrofitReminders. One or more performance measures for residential retrofit programs may be defined through a relationship with the association table tadRetrofitInformation and the domain table tdsRetrofitInformation.

Leak-Detection and -Repair Data Structure

The RIWRB rules and procedures for WSSMPs require that water suppliers implement and document a program for leak detection and repair as part of their system-management efforts (Rhode Island Water Resources Board, 1998, 2001). Leak-detection and -repair programs are mandated to maintain nonaccount water at or below 15 percent of total metered supply, to require comprehensive leak-detection surveys on a periodic basis, and to trigger leak-detection surveys when losses exceed 15 percent of total metered supply. Information about leak-detection and -repair programs is described in Worksheet 31 and 32 of the original WSSMP format (Charpentier and others, 1992; Fly, 1992) and in Section 8.06b of the RIWRB (1998, 2001) planning documents (table 1).

The leak-detection and -repair data structure provides a standard method to identify and describe these efforts to meet system-management requirements (fig. 28). The table tblLeakDetection describes leak-detection and -repair efforts by each supplier (tblSupplier) during each WSSMP cycle (tblWSSMPCycle).

Emergency-Management Data Structures

The RIWRB rules and procedures for WSSMPs (Rhode Island Water Resources Board, 1998, 2001) require that water suppliers develop and document emergency-management plans that assess system risks, response capabilities, and describe contingency plans for water-supply emergencies. Information about emergency management is described in Worksheets 33–37 of the original WSSMP format (Charpentier and others, 1992; Fly, 1992) and in Section 8.07 of the RIWRB (1998, 2001) planning documents (table 1). The RIWRB rules and procedures for WSSMPs (Rhode Island Water Resources Board, 1998, 2001) include information that is necessary to address RIDOA emergency-management plans (Rhode Island Department of Administration, 1993, 1997a, b). The WSSMP database also includes elements of the RIDOA (2002) drought-management plan. Emergency-management information includes the contact-information data structure (fig. 29) and the emergency-response data structure (fig. 30). Data structures defining all the information pertinent to emergency management are integrated in a diagram on plate 1.

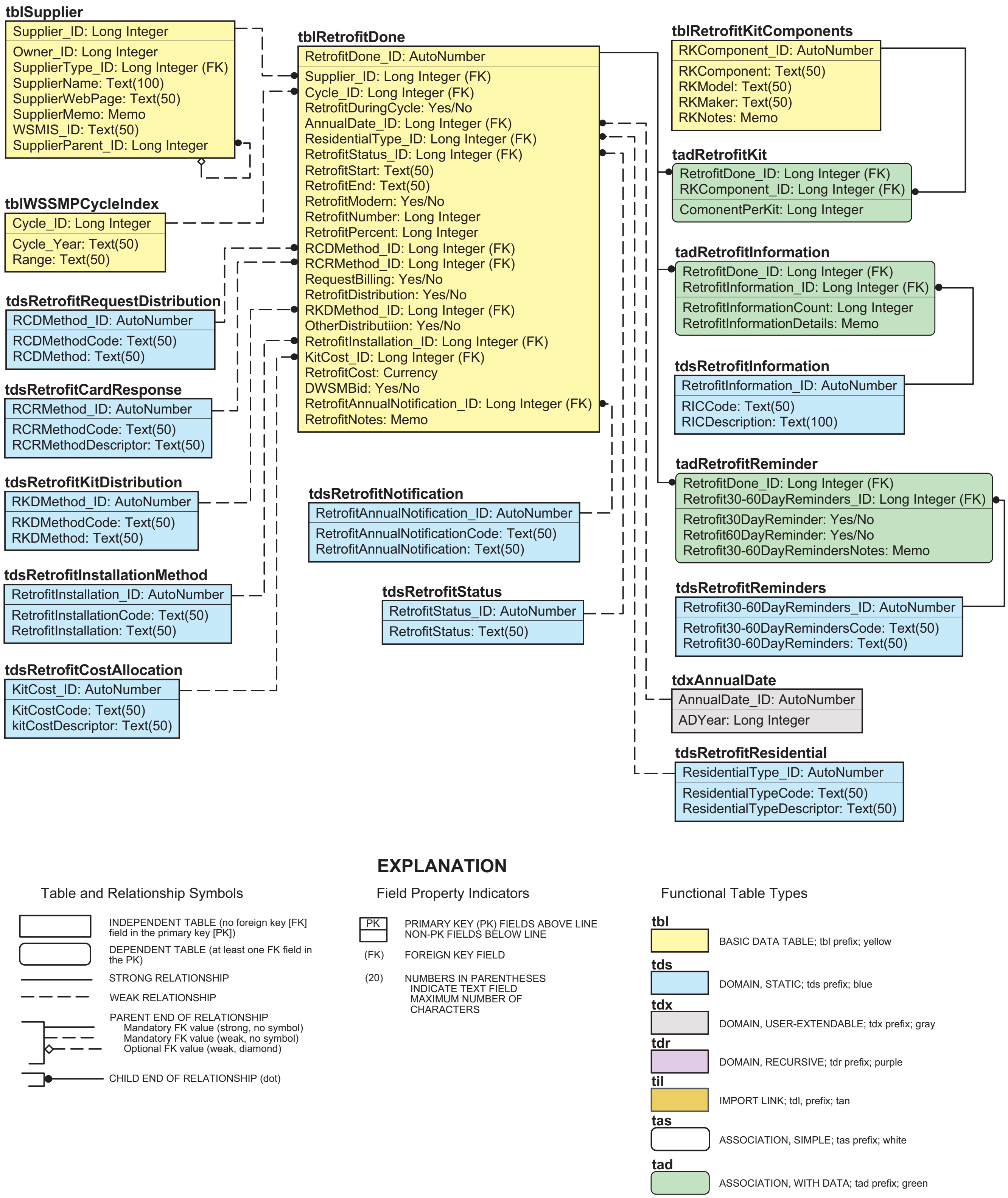

Figure 27. Residential-retrofit-program data structure tables, fields, and relationships.

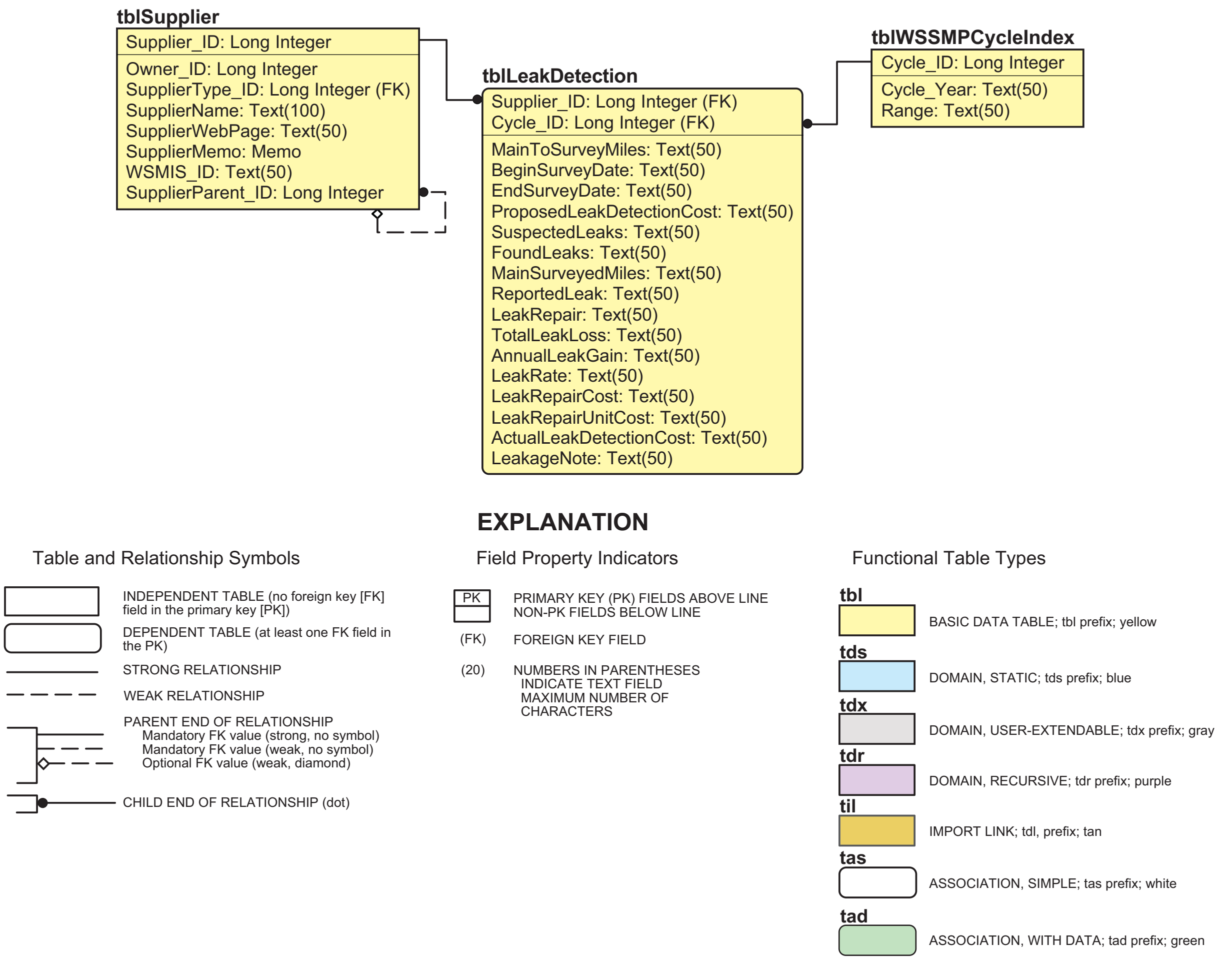

Figure 28. Leak-detection and -repair data structure tables, fields, and relationships.

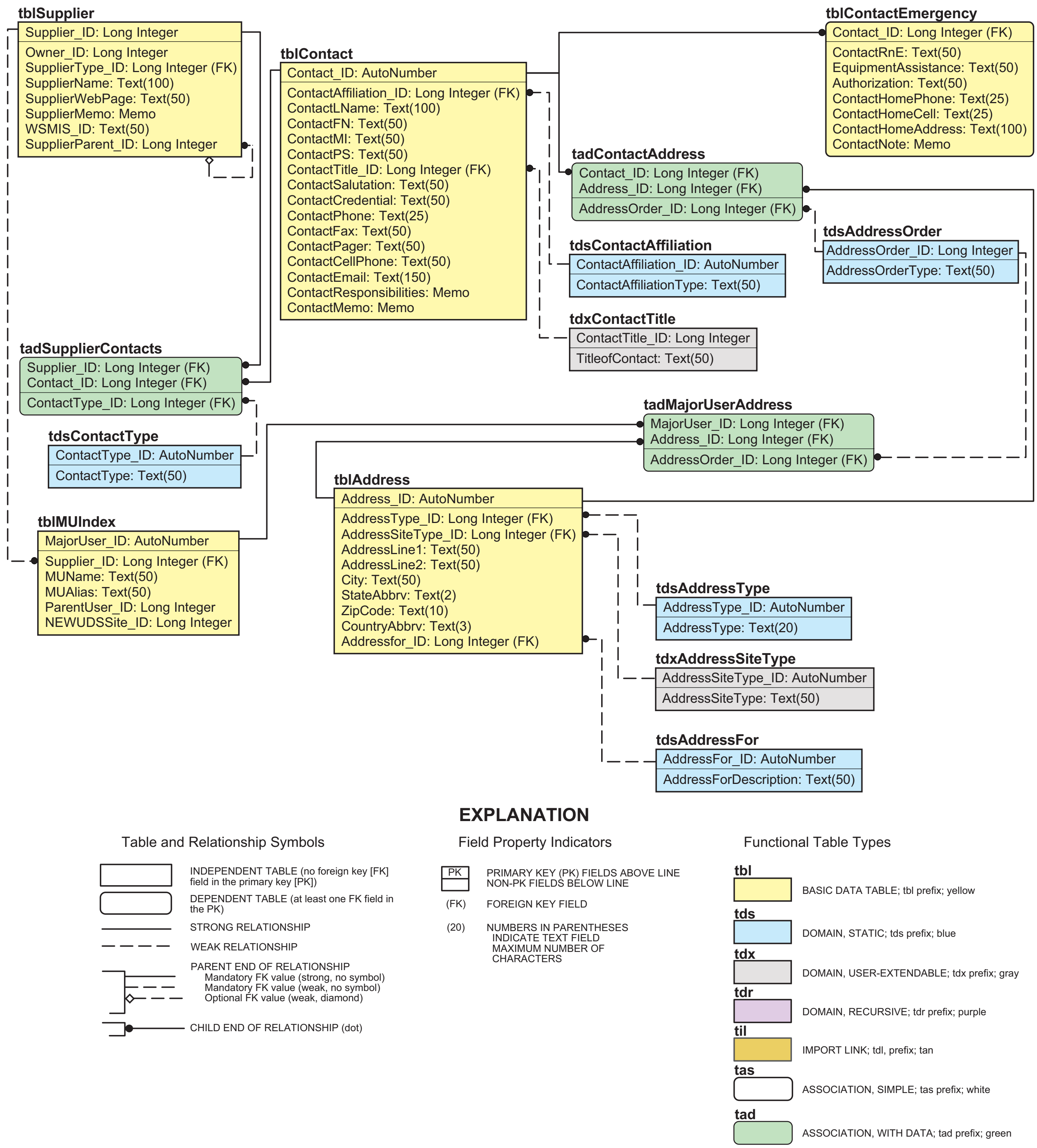

Figure 29. Contact-information data structure tables, fields, and relationships.

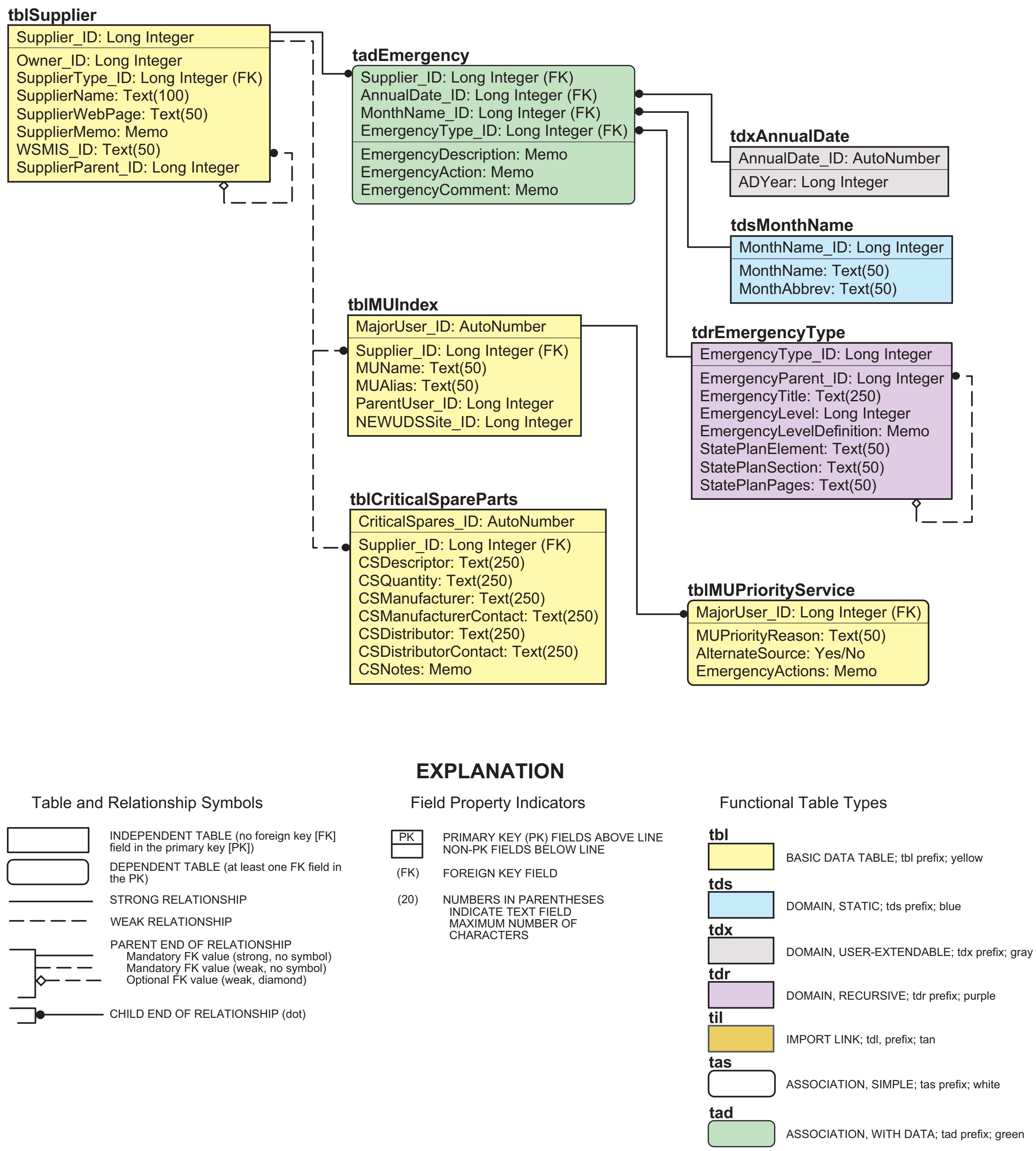

Figure 30. Emergency-response data structure tables, fields, and relationships.

Contact-Information Data Structure

The contact-information data structure includes normal contact and address information for water suppliers and their major users and a separate emergency-contact information table (fig. 29). All contact information is identified by supplier (tblSupplier). Contact information, however, is not identified by date or WSSMP cycle because this information, which may be necessary in an emergency, should be current at all times. The relationship between the association table tadSupplierContacts and the domain table tdsContactType provides the structure necessary to identify one or more people in the water-supplier's organization by one or more roles. All water-supply-system contacts are identified in the contact table (tblContact). The relationship from tblContact through the association table tadContactAddress to the address table tblAddress allows each contact to have one or more addresses and each address to apply to one or more contacts.

The table tblContactEmergency holds the emergency-contact information that may be confidential (such as authorization information) or private (such as home telephone numbers or home addresses). The table tblContactEmergency has a one-to-one relationship with tblContact. The data in tblContactEmergency, however, is separate so that this data can be provided or withheld on a need-to-know basis (fig. 29). Access to the information may be controlled by hiding the table, by deleting the table from versions of the database released by the RIWRB, or by setting password access in the database.

The address table tblAddress may also contain basic-contact information for each supplier's major users. The association table tadMajorUserAddress is associated with the address table (tblAddress) and the major-user index (tblMUIndex), which identifies major users by supplier (fig. 29).

Emergency-Response Data Structure

The emergency-response data structure includes tables to document water-supply emergencies, priority-service information for major users, and an inventory of critical spare parts. The association table tadEmergency may be used to document a water-supply emergency, to describe the event, and any actions the water supplier took to mitigate the emergency (fig. 30). Emergencies are identified by supplier (tblSupplier), by year (tdxAnnualDate), by month (tdsMonthName), and by type of emergency (tdrEmergencyType). The recursive domain structure in table tdrEmergencyType describes each type of emergency by definition and level of severity as defined in the State Plan elements 723 and 724 (Rhode Island Department of Administration, 1993; 2002). In the future, suppliers and State agencies may use emergency-response data to refine emergency-management plans.

In a water-supply emergency, some major users, such as hospitals or other medical care facilities, may require priority service. Priority-service information is identified by supplier (tblSupplier) through a link from the major-user-index table (tblMUIndex) to the priority-service table (tblMUPriorityService). Priority-service information, such as the reason for priority service, and any planned alternative sources and emergency actions are defined in the table tblMUPriorityService (fig. 30). The relationship between tblMUIndex and tblPriorityService is a one-to-one relationship; the tables are separate to help secure this confidential information.

Information about critical spare parts (or emergency-response equipment) is necessary for a response to a water-supply emergency caused by a mechanical failure or a disaster. Information about critical spare parts is identified by supplier (tblSupplier) in the table tblCriticalSpareParts.

Financial-Management Data Structure

The RIWRB rules and procedures for WSSMPs (Rhode Island Water Resources Board, 1998, 2001) require that water suppliers maintain and report financial-management information so that State agencies may ensure that each water supplier will continue to operate in a financially self-supporting manner. Financial-management information is described in Worksheet 38 of the original WSSMP format (Charpentier and others, 1992; Fly, 1992) and in Section 8.09 of the RIWRB (1998, 2001) planning documents (table 1). The financial-management data structure is designed as a simple summary of monthly revenue and expenses (fig. 31). Financial information is identified in the table (tblFinancial) by supplier (tblSupplier), by year (tdxAnnual Date), and by month (tdsMonthName). The type of rate structure used by each water supplier is identified in the domain table tdsRateStructure.

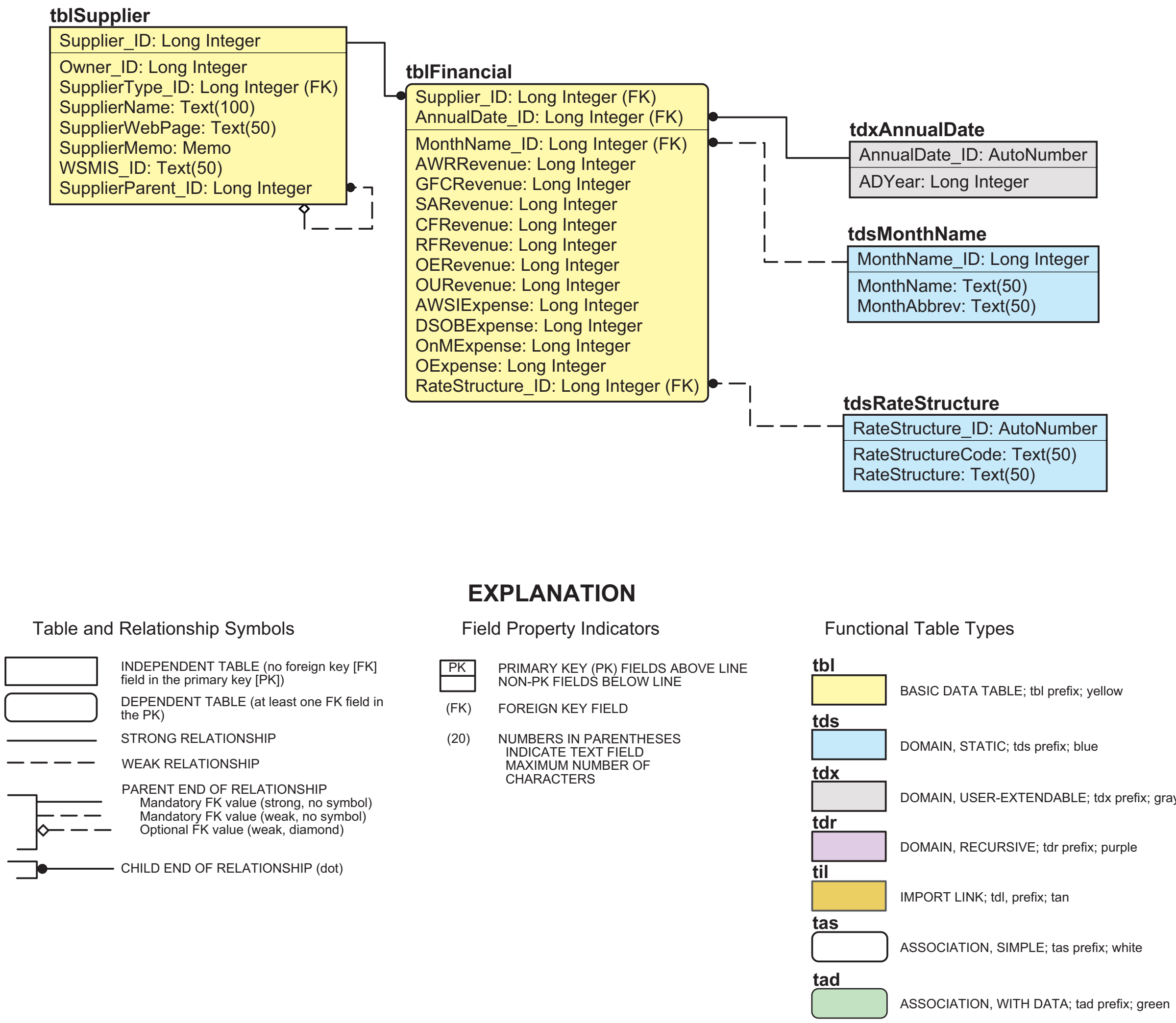

Figure 31. Financial-management data structure tables, fields, and relationships.

RIGIS Data Structure

The RIWRB rules and procedures for WSSMPs (Rhode Island Water Resources Board, 1998, 2001) require that all geographic data prepared as part of the WSSMP process should be transferable directly into the RIGIS. GIS files created for Federal or State distribution need to meet the metadata standards (Federal Geographic Data Committee, 1998). The RIGIS has a many GIS coverages, such as the public water-supply basins coverage and the wellhead-protection coverage, that are relevant to the WSSMP process. The table tblRIGISCoverage is a list of coverages that are currently (2004) available on the Internet from RIGIS. These coverages are defined by the RIGIS categories with the domain table tdsRIGISCovCat. The table tblRIGISCoverage includes the coverage name and the RIGIS data-set catalog-identification code. A series of association tables with data are used to establish the relationships between components of the water-supply infrastructure such as surface-water supplies (tblSWIndex), ground-water supplies (tblGWIndex), or treatment facilities (tblTFIndex) and the RIGIS coverages (tblRIGISCoverage) (fig. 32). The tad tables also are used to document the appropriate RIGIS field name and RIGIS field value so that these RIGIS database features can be used to identify pertinent information in the WSSMP database and to transfer information between the WSSMP database and the GIS systems that are used to manipulate RIGIS data. The field RIGISWEBDIR in table tdsRIGISCovCat is used to record the Internet directories for different types of RIGIS coverages. The query qryMakelink combines this information and the coverage name from the table tblRIGISCoverage to make a web link that may be used to access the metadata for each coverage of interest.

Import-Table Data Structure

The WSSMP database was designed with an import-table data structure to meet the RIWRB objective to make the database compatible with other potential sources of water-resources data. For example, surface-water, ground-water, and water-quality data are available on-line from the USGS NWIS Web (U.S. Geological Survey, 2003a). It would be imprudent to include all the NWIS data for Rhode Island in the WSSMP database because this would be an unnecessary duplication and because NWIS Web is continuously being updated. By use of a connection to the Internet, the import-table data structure provides access to historical, current, and in some cases, real-time water-levels, flow, and water-quality information that may be used to assess the quantity and quality of available water supplies.

Examples of import-table data structures are displayed in figure 33. The table tilUSGSStreamGage provides basic information about USGS streamflow-gaging stations in Rhode Island and a hyperlink to the USGS NWIS Web page interface that allows a user to access current and historical streamflow measurements, streamflow statistics, water-quality measurements, and other data that are available to the public. Within the WSSMP database, streamflow-gaging-station information is linked to surface-water supplies (tblSWIndex) through an association table (tasSWUSGSStreamGage). Pond-gage information is linked to surface-water sources by the relationships from table tilUSGSLakes through tasSWUSGSPondSite shown in figure 33. Similarly, streamflow-gaging-station information may be linked to one or more public-supply wells in the same basin using the relationship between tblGWIndex, tasGWUSGSStreamGage, and tilUSGSStreamGage (fig. 33). Monitoring-well information is linked to ground-water sources by the relationships from table tilUSGSWell through tasGWUSGSWell.

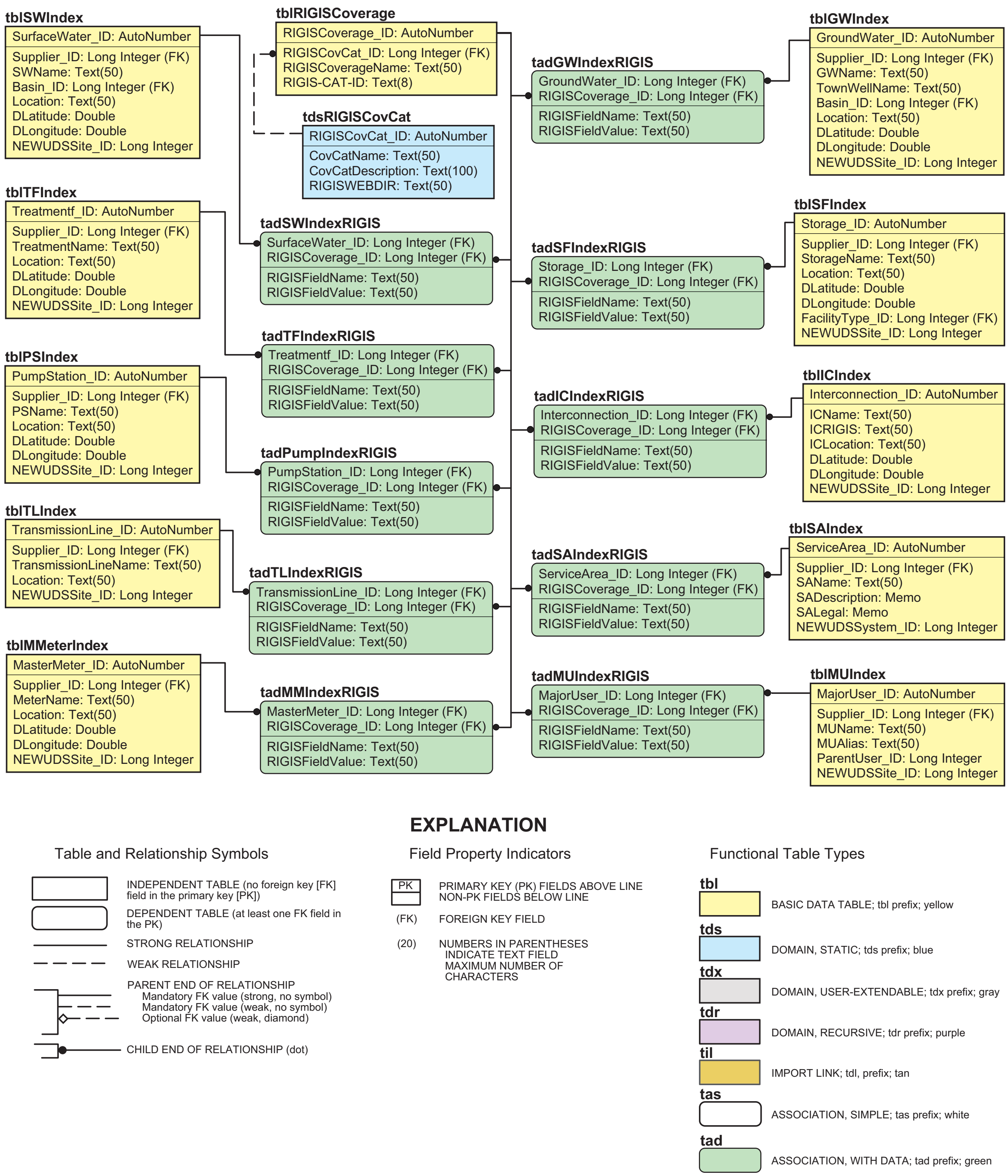

Figure 32. Rhode Island Geographic Information System data structure tables, fields, and relationships.

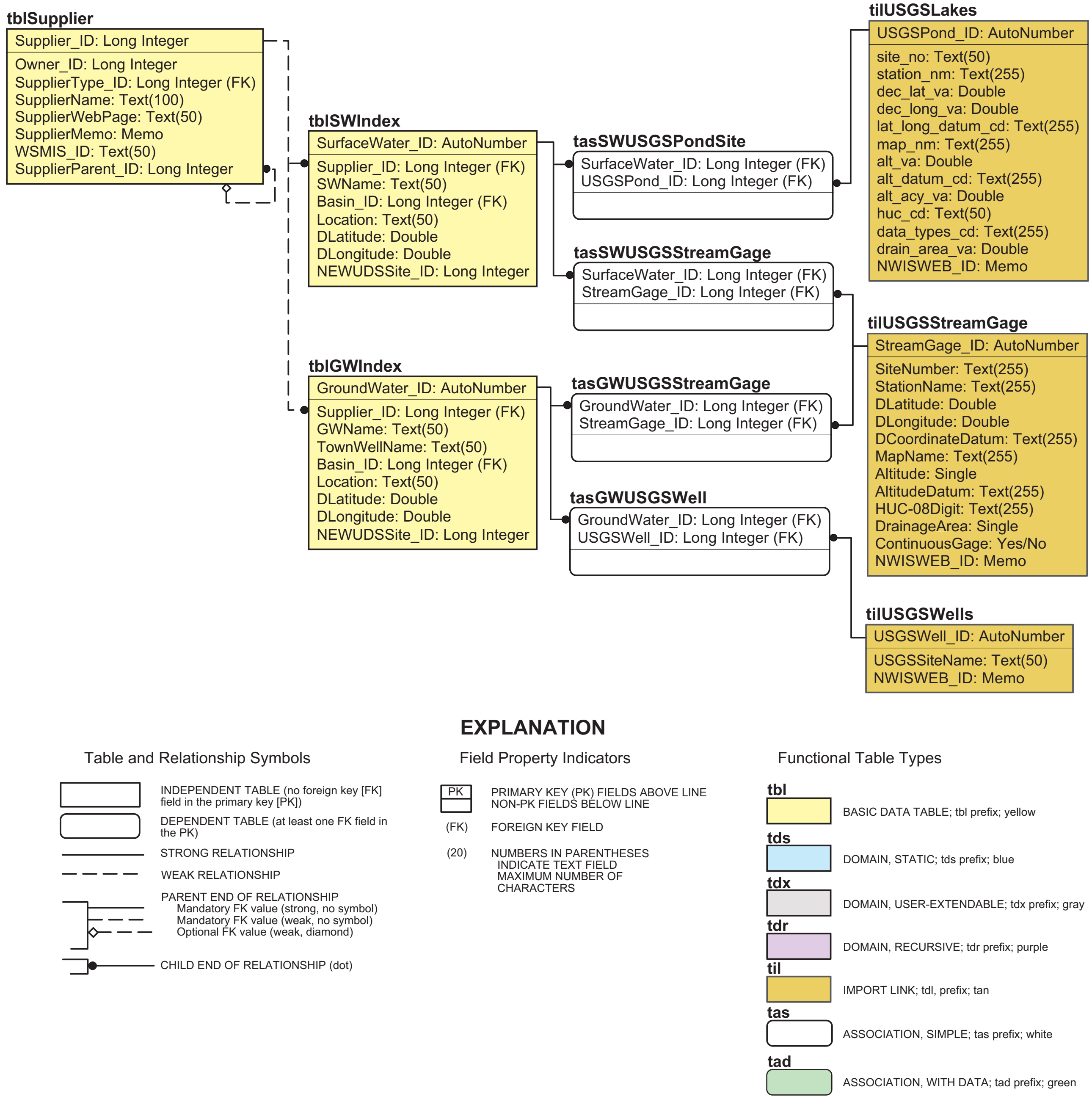

Figure 33. Import-table data structure tables, fields, and relationships.

Operational Issues and Procedures

The WSSMP database is designed so that State and local officials who are familiar with the existing WSSMP worksheets will easily make the transition to the new database. It is, however, necessary to understand the basic data model, details of the data entities, and the operational aspects of working with data in a relational database to make full use of the database design. Four main operational issues which need to be considered during use of the WSSMP database include (1) the need to standardize and control key assignments within the database structure, (2) the need to follow a predetermined table-loading order, (3) methods for customizing and extending the data architecture, and (4) simplification of multitable structures for handling and presenting data.

Key Assignments and Control

The WSSMP database uses AutoNumber fields for all key values. AutoNumber fields are integers that automatically are incremented by MS Access to ensure that each new record has a unique identifying key. The WSSMP database does not use information-rich keys (fields that have code names that may apparently provide unique values) because such keys could be reassigned in practice and would therefore corrupt associated data in other tables. Use of autonumber keys is recommended as a standard relational-database design practice (Tessler, 2002), but this design convention does have a potential liability. Most databases are designed for a specific user and are controlled and maintained by a single organization in a central location (for example, the USGS NWIS system). Alternatively, some databases are designed to convey information in a distributed format to many users. These databases are commonly provided as a tool to document results of a data-collection effort and are fully designed and populated when the data is distributed. Therefore, key assignments are not a factor in the distribution design. The method for population of and maintenance of the WSSMP database, however, has not been fully determined by the RIWRB. The RIWRB is currently (2004) implementing a recent law on the security of the WSSMP data (Rhode Island General Assembly, 2002) and will be determining the best course of action within the law as they implement the WSSMP database (C.L. McGreavy, Rhode Island Water Resources Board, written commun., 2003). Ultimately, water suppliers and State agencies will need to choose a centralized model, a distributed model, or an integrated model for database implementation.

In a centralized model, the RIWRB would host the only official version of the WSSMP database. In this model, RIWRB staff and (or) water suppliers would enter data on a RIWRB computer (either on the premises or through use of a secure modem or Internet connection). Key assignments and controls would not be a critical factor because each database entry would automatically generate a unique key-field value. The centralized model would allow for analysis of data from individual suppliers and for integration of information from different suppliers without duplication of effort in building data queries. Standard methods to enter, query, and report data would be easy to implement. Use of a centralized database, however, may not meet individual data needs beyond the information provided by a standardized statewide interface. The RIWRB would be responsible for the security of all WSSMP information in a centralized model.

In a distributed model, each water supplier would maintain and control their version of the WSSMP database. In this model, key assignments and controls would not be a critical factor because each copy of the database would contain unique and independent information. The power of the relational database could be used to examine information for each supplier through time, but State agencies would not be able to easily integrate and compare information among suppliers because each WSSMP would be in a different database file. The distributed model would also create situations where duplication of effort by different suppliers would be necessary to examine the data. Suppliers would be responsible for the security of their WSSMP information in the distributed model.

In an integrated model, each water supplier would maintain and control their version of the WSSMP database, but the different copies of the database would be integrated by appending each water supplier's information into a central copy of the database. In this model, water suppliers would enter data on their own computer systems and send a copy to the RIWRB for integration into the central version of the database. Key assignments and controls would be a critical implementation factor. Each copy of the database would be owned and operated by the water suppliers and would contain unique and independent information. The process of integrating individual copies of the database from each supplier into the central version, which is owned and operated by the RIWRB, could corrupt the database if autonumbers used in the individual copies overlap. To address a similar problem in the implementation of NEWUDS databases in each major river basin in Rhode Island, USGS staff implemented a system in which the autonumber key fields in each basin were defined in intervals of 1000 so that the autonumber increments from different basins would not overlap (L.K. Barlow, U.S. Geological Survey, written commun., 2003). An integrated model would allow the RIWRB, other State agencies, and individual water suppliers to utilize common queries and reports. It would also allow individual water suppliers to design and implement custom queries and reports for their own needs. In an integrated model, the RIWRB, other State agencies, and individual water suppliers would share responsibilities for the security of individual WSSMP databases and the central WSSMP database information.

Table Loading Order

The design and implementation of the WSSMP database makes it necessary to follow a predetermined loading order. The loading-order information is necessary for manual entry or automated entry of data and for design of a user interface. The loading order is determined by design factors such as the division of information among tables in each data structure, by implementation factors such as restrictions caused by data-protection settings, and by the use of foreign keys in association tables. The domain (tds, tdr, and tdx tables) tables are populated with the information that has been accepted as appropriate in existing WSSMP worksheets. The RIWRB will determine the standard choices for data entry available in these tables (C.L. McGreavy, Rhode Island Water Resources Board, written commun., 2003). Similarly, example import-link (til) tables are populated within the published version of the database and the contents of these tables will continue to be the responsibility of the RIWRB. The contents and key-number assignments will thus be standard for all versions of the database. The loading order of basic data (tbl) tables depends on the presence of foreign keys. Almost all information in the database is ultimately associated with a water supplier, and (or) a WSSMP cycle date. A list of suppliers and cycle dates has been provided in this preliminary database design, and like domain-table entries will be maintained by the RIWRB. To facilitate use of the WSSMP database during several WSSMP reporting cycles, each component of the water-supply infrastructure is identified in an index table (for example tblSWIndex) so that each resource can be uniquely identified through time, irrespective of changes in attributes or ownership. Therefore, the index tables within each data structure will be the first tables populated by the end user. Association tables (tas and tad) are dependent on foreign keys from basic data tables and domain tables, and therefore are commonly the last tables to be populated within each data structure.

The individual data-structure-design diagrams (figs. 3–33) map the design of the database and may be used to determine the proper table-loading order. Relationships in the WSSMP database are almost exclusively one-to-many relationships. Parent tables must be loaded first so that the parent information is available for selection in the child table. Appendix 1 is a table index listing each table in the database and all the data-structure-design diagrams in the report and on plate 1 in which the table appears. Therefore, a database user can determine the table-loading order by examining the appropriate design diagram(s) for each table and data structure.

The database is designed and implemented with MS Access "combo boxes," which provide a pull-down list of choices to populate information in a receiving table. These combo boxes provide a pull-down list of choices for each foreign-key field. If the desired choices are not available within a given combo box, the user is not following the optimal table-loading order. Other tables must be populated for the desired choices to appear in the combo box. If the appropriate selection is not available in the combo box, the user may consult the appropriate design diagram to follow the relations back to the parent table.

Customizing and Extending the Data Architecture

The WSSMP database was designed as a preliminary structure to provide a basis for collection and compilation of WSSMP data. The database was developed to provide an initial design that could be customized, extended, or even truncated as the RIWRB, other State agencies, and the water suppliers come to consensus on the type and format of data necessary to improve operations and the security of Rhode Island's water supply continually. The database may be extended by adding fields or by adding tables. To maintain data integrity, these extensions should be done by use of existing conventions that apply to normalization, keys and relationships, domain-table usage, and naming rules. If an individual water supplier or a State agency wishes to add auxiliary fields (for example, to record more detailed engineering information about the water-supply infrastructure), a new table that contains the new data fields in a one-to-one relationship with the parent table could be added. In this way, users can enter the desired information without compromising the ability to integrate data from different versions that may occur in distributed copies of the database. If the RIWRB determines that the new fields are useful to the majority of users and that other database users would utilize the new information, these new tables could be consolidated with existing tables in a future revision. Custom tables and fields should be distinguished with some form of unique identifier. For example, in the NEWUDS documentation, Tessler (2002) recommended that users designate custom accessory tables and fields by a prefix with the letter "z" or other unique indicator to distinguish them from the standard NEWUDS database objects. If items are removed from the WSSMP database, great care must be taken so that the database is not corrupted by loss of keys and relationships.

Simplification of Multi-Table Structures

The WSSMP database was designed with many tables and relationships to maximize data-integrity through normalization of information by water supplier and WSSMP cycle. The number of tables and the apparent complexity of relationships between the tables have the potential to confuse those not familiar with the design. For example, relationships between water suppliers, contact people working for each supplier, and address information is accomplished through use of four data tables, two association tables, and seven domain tables (fig. 29). At first, this may appear to be a complex design. Upon further consideration, however, it becomes apparent that each supplier may have one or more contact people (who may each have one or more roles in the organization), and each person may have one or more addresses (for example a mailing address and one or more site addresses). Furthermore, home-contact information may be necessary for emergency purposes, but this information is private and therefore should be restricted to emergency uses.

In practice, database users can build queries that combine information from multitable structures into a composite view of database contents. The resulting query can be manipulated and utilized like a single table in the database without duplication of information or loss of normalization. For example, the main mailing query (qryMainMailing) provides a mailing list of all water-supplier contacts at their physical or mailing address, whereas the emergency-contacts query (qryEmergencyContacts) provides the physical address and contact information for the designated emergency responders for each water supplier. The WSSMP database includes these two queries and a number of other example queries (table 2) that provide useful information, examples of data-aggregation techniques, and demonstration of methods for simplification of multitable structures by combining data from related tables. The queries, however, will not provide meaningful results until WSSMP data are entered in the database.

Table 2. List of example queries that demonstrate consolidation of many tables into a single view, queries that determine water rates from data inputs, and queries that can be used to link the Water Supply System Management Plan database to online USGS data.

[**Query types:** CQ, consolidation queries; WQ, water-rate calculation queries; LQ, Internet-link queries. ADD, average daily demand; ID, identification number; MDD, maximum daily demand; NWIS, National Water Information System; RIGIS, Rhode Island Geographic Information System; USGS, United States Geological Survey]

Query name	Query type	Explanation
qryEmergencyContacts	CQ	Example query that builds an emergency contact list.
qryMainMailing	CQ	Example query that builds a mailing list.
qryAvgADDVol	WQ	Example query to determine the average of ADD volume entries by water supplier, cycle, and year.
qryMaxOfMDDRate	WQ	Example query to select the maximum MDD rate by water supplier, cycle, and year.
qryPeakingFactor	WQ	Example query to determine the peaking factor (MDD/ADD) by water supplier, cycle, and year.
qryMakeLink	LQ	Example query to make RIGIS metadata links from the coverage type and coverage name.
qryNWISWEBPond	LQ	Example query retrieves pond-gage station IDs and NWIS WEB addresses.
qrySWNWISWEBPond	LQ	Example query that demonstrates the potential for linking reservoirs and pond-gage data.
qrySWNWISWEBGage	LQ	Example query that demonstrates the potential for linking reservoirs and stream-gage data.

Calculated Fields

The WSSMP database was designed to minimize repetition and reduce the chance for error by omitting calculated fields from the input data set. WSSMP data such as the annual average of average daily demands (AvgADD) and the peaking factor (which is the maximum daily demand divided by the AvgADD) are repetitious because they are based on other data within the database and can be incorrect because they are the result of manually selecting, sorting, and calculating many input values. These and similar operations are best handled by standard queries, macros, or modules within the database. It should be noted, however, that time-dependent calculated fields must be implemented with respect to the varying number of days per month or the days per quarter to produce correct values. The queries qryAvgADDVol and qryPeakingFactor are included with other similar queries (table 2) as examples to demonstrate methods necessary for calculating any value of interest to the water supplier or the State agencies responsible for the WSSMP system. For example, the query qryAvgADDVol groups the demand entries by supplier (tblSupplier), cycle (tblWSSMPCycleIndex), and year (tblDemandVolumes), and calculates the annual average of the average daily demands entered in tblDemandEntry. The structure of each query is documented in the design view and the SQL view of each query.

Conclusions

Information about available water resources, the water-supply infrastructure, and water-use patterns in terms of historical, current and future needs would help water suppliers, the Rhode Island Water Resources Board (RIWRB), and other State agencies responsible for the quality and quantity of water resources in Rhode Island. In 1997, the State of Rhode Island formalized a system of Water Supply System Management Plans (WSSMPs) to characterize and document relevant water-supply information. All major water suppliers (those that obtain, transport, purchase, or sell more than 50 million gallons of water per year) are required to prepare, maintain and carry out Water Supply System Management Plans (WSSMPs). An electronic database for this WSSMP information would allow for water suppliers and State agencies to document, maintain, and interpret the information in these plans. The need for public access to WSSMP information, however, must be balanced with security needs because some sections of the plans have been classified by law as confidential to protect the water-supply infrastructure from potential terrorist threats.

A WSSMP database was developed by the U.S. Geological Survey in cooperation with the RIWRB. The database was designed to catalog WSSMP information in a format that would facilitate analysis of Rhode Island's water-supply infrastructure. This report documents the design and implementation of the WSSMP database. The WSSMP database is a relational database, in that the information is linked to an individual water supplier and a WSSMP cycle. The database file contains 172 tables—47 data tables, 61 association tables, 61 domain tables, and 3 example import-link tables. The USGS selected the Microsoft (MS) Access database software because it is widely used within and outside of government, is familiar to many existing and potential users, and is used for the New England Water-Use Data System (NEWUDS).

Design documentation facilitates the current use and potential modification for future use of the database. The design of the database is fully documented in the structure of the WSSMP database file (WSSMPv01.mdb), a data-dictionary file (WSSMPDD1.pdf), a detailed database-design diagram (WSSMPPL1.pdf), and this database-design report (OFR2004-1231.pdf). Each of these products is included in digital format on the enclosed CD-ROM to facilitate use or modification of the database and the underlying design.

The U.S. Geological Survey, in cooperation with the RIWRB, has done several basin-wide water-use studies in Rhode Island. These water-use studies document water-use information with the USGS NEWUDS database, which is designed to document water-use transaction processes. Data entities in the WSSMP database structure are designed to characterize engineering characteristics of the water-supply-system infrastructure and the WSSMP database design is strictly aligned with State WSSMP regulations. Furthermore, widespread accessibility of the water-use and availability data stored in NEWUDS is necessary for public administration and planning purposes, whereas some of the WSSMP information must be kept confidential. Each database has a unique and defined role. Links between NEWUDS and the WSSMP may be managed to maintain information security while meeting information needs of the RIWRB, other State water-resource agencies, water suppliers, and the public.

References

Arthur D. Little, Inc., 1990, Water supply analysis for the State of Rhode Island: Final Report to Rhode Island Water Resources Coordinating Council—Summary, Reference 63851.

Charpentier, Michael, Gottlieb, Richard, Stone, Clare, and Whalen, Terence, 1992, Preparing water-supply management plans—A guidance document: Providence, RI, Division of Water Supply Management, Rhode Island Department of Environmental Management, 145 p.

DeSimone, L.A., and Ostiguy, L.J., 1999, A vulnerability assessment of public-supply wells in Rhode Island: U.S. Geological Survey Water-Resources Investigations Report 99-4160, 153 p.

Dionne, S.G., Granato, G.E., and Tana, C.K, 1999, Method for examination and documentation of basic information and metadata from published reports relevant to the study of stormwater runoff quality: U.S. Geological Survey Open-File Report 99-254, 156 p.

Federal Geographic Data Committee, 1998, Content standard for digital geospatial metadata: Federal Geographic Data Committee Report FGDC-STD-001-1998, 78 p., accessed on September 6, 2003, at URL http://www.fgdc.gov/metadata/contstan.html

Fleming, C.C. and von Halle, Barbara, 1989, Handbook of relational database design: Reading, MA, Addison-Wesley Publishing Company, 605 p.

Fly, Kathryn, 1992, Rhode Island water supply management information system: Providence, RI, Rhode Island Department of Environmental Management, Division of Water Supply Management, variously paged.

Granato, G.E., and Tessler, Steven, 2001, Data model and relational database design for highway runoff water-quality metadata: U.S. Geological Survey Open-File Report 00-480, 15 p.

Hernandez, M.J., 1997, Database design for mere mortals—A hands-on guide to relational database design: Reading, MA, Addison-Wesley Publishing Company, 480 p.

Horn, M.A., 2002, User's manual for the New England Water-Use Data System (NEWUDS): U.S. Geological Survey Open-File Report 01-328, 392 p.

McGreavy, C.L., 1998, Developing a water information system for the State of Rhode Island—A data management approach for government agencies: Providence, RI, Rhode Island State Library Report 333.91-M147, variously paged.

National Institute of Standards and Technology, 1993, Standard for integration definition for information modeling (IDEF1X): Federal Information Processing Standards Publication 184, 155 p.

Office of Management and Budget, 1987, Standard industrial classification (SIC) manual: Washington, DC, Executive Office of the President, Statistical Policy Division, 649 p.

Office of Management and Budget, 1997, North American industry classification system (NAICS) United States, 1997: Washington, DC, Executive Office of the President, Statistical Policy Division, 1,350 p.

Office of Management and Budget, 2002, North American industry classification system (NAICS) United States, 2002: Washington, DC, Executive Office of the President, Statistical Policy Division, 1,419 p.

Rhode Island Department of Administration, 1993, Water emergency response plan State guide plan element 723: Providence, RI, Department of Administration, Statewide Planning Program, 96 p.

Rhode Island Department of Administration, 1997a, Water supply policies for Rhode Island State guide plan element 721: Providence, RI, Department of Administration, Statewide Planning Program, Report No. 61, 86 p.

Rhode Island Department of Administration, 1997b, Water supply plan for Rhode Island, State guide plan element 722: Providence, RI, Department of Administration, Statewide Planning Program, 6 p.

Rhode Island Department of Administration, 2002, Rhode Island drought management plan State guide plan element 724: Providence, RI, Department of Administration, Statewide Planning Program, Report No. 104, 85 p.

Rhode Island Department of Health, 2001, Water-quality data and compliance report, 2001: Providence, RI, Rhode Island Department of Health, Office of Water Quality, 29 p.

Rhode Island Department of Health, 2003, Rhode Island Department of Health public drinking water, accessed on April, 5, 2003, at URL http://www.healthri.org/environment/dwq/Public.htm

Rhode Island General Assembly, 1988, Comprehensive Planning and Land Use Regulation Act, Chapter 45-22.2, *in* Towns and Cities, Rhode Island Title 45, Providence, Rhode Island, accessed on January 1, 2004, at URL http://www.rilin.state.ri.us/Statutes/TITLE45/INDEX.HTM

Rhode Island General Assembly, 1997, Public Drinking Water Supply System Protection, Chapter 46-15.3: in Waters and Navigation, Rhode Island Title 46, Providence, Rhode Island, accessed on January 1, 2004, at URL http://www.rilin.state.ri.us/Statutes/TITLE46/INDEX.HTM

Rhode Island General Assembly, 2002, An act relating to waters and navigation—Drinking water supply system protection, H 7211 LC02356, Providence, RI, 4 p., accessed on January 1, 2004, at URL http://www.rilin.state.ri.us/Billtext/BillText02/HouseText02/H7211.pdf

Rhode Island Water Resources Board, 1998, Rules and procedures for water supply system management planning: Providence, RI, Rhode Island Water Resources Board, 36 p.

Rhode Island Water Resources Board, 2001, Water supply system management plan check list: Providence, RI, Rhode Island Water Resources Board, 23 p.

Rhode Island Water Resources Board, 2002, Rules and procedures for water supply system management planning: Providence, RI, Rhode Island Water Resources Board, 39 p.

Roman, Steven, 1997, Access database design and programming: Sebastopol, CA, O'Reilly and Associates, 251 p.

Tessler, Steven, 2002, New England water-use data system (NEWUDS)—Data model and relational database design: U.S. Geological Survey Open-File Report 01-359, 70 p.

U.S. Geological Survey, 2003, National Water Information System (NWIS), accessed April 4, 2003, at URL http://waterdata.usgs.gov/nwis/.

U.S. Geological Survey, 2003, Water use in the United States, accessed on August 30, 2003, at URL http://water.usgs.gov/watuse/.

Appendix 1. Table Index By Figure.

Appendix 1. Table index by figure.

[This appendix is an alphabetical list of WSSMP tables and the figure numbers in which they appear (for example figure 1 is F01). The plate is referenced as follows: F34, Plate 01, Water supply system infrastructure; F35, Plate 01, Emergency management and contact information; F36, Plate 01, Production and demand information; F37, Plate 01, Water-use and water-use projection information; F38, Plate 01, Major-user information]

Table names	Figure numbers			
tadContactAddress	F29,	F35		
tadEmergency	F30,	F35		
tadGWDescription	F05,	F34		
tadGWIndexRIGIS	F01,	F32,	F34	
tadGWQWConstituent	F22,	F34		
tadICDescription	F12,	F34		
tadICIndexRIGIS	F32,	F34		
tadICValveDescription	F13,	F34		
tadInterconnectionOwner	F12,	F34		
tadMajorUserAddress	F20,	F29,	F35,	F38
tadMMeterDescription	F15,	F34		
tadMMIndexRIGIS	F32,	F34		
tadMUDescription	F20,	F38		
tadMUIndexRIGIS	F32,	F38		
tadPlanSummary	F03			
tadPSDescription	F09,	F34		
tadPumpIndexRIGIS	F32,	F34		
tadRetrofitInformation	F27			
tadRetrofitKit	F27			
tadRetrofitReminder	F27			
tadSAIndexRIGIS	F32,	F34		
tadSFDescription	F08,	F34		
tadSFIndexRIGIS	F32,	F34		
tadSupplierContacts	F29,	F35		
tadSWDescription	F02,	F04,	F34	
tadSWIndexRIGIS	F32,	F34		
tadSWQWConstituent	F21,	F34		
tadTFDescription	F06,	F34		
tadTFIndexRIGIS	F32,	F34		
tadTLDescription	F10,	F34		
tadTLIndexRIGIS	F32,	F34		
tadTrackingStatus	F03,			
tadTransactionOwnerDirection	F12,	F34,	F36	
tadTreatmentGW	F07,	F34		
tadTreatmentSW	F07,	F34		
tasGWMMeter	F15,	F34		
tasGWProduction	F01,	F16,	F36	
tasGWUSGSStreamGage	F05,	F33,	F34	
tasGWUSGSWell	F05,	F33,	F34	
tasICProduction	F16,	F36		

Appendix 1. Table index by figure.—Continued

[This appendix is an alphabetical list of WSSMP tables and the figure numbers in which they appear (for example figure 1 is F01). The plate is referenced as follows: F34, Plate 01, Water supply system infrastructure; F35, Plate 01, Emergency management and contact information; F36, Plate 01, Production and demand information; F37, Plate 01, Water-use and water-use projection information; F38, Plate 01, Major-user information]

Table names	Figure numbers					
tasInterconnectionPumpStation	F13,	F34				
tasInterconnectionValves	F13,	F34				
tasMMeterInterconnection	F15,	F34				
tasMUNAICS97	F20,	F38				
tasMUSIC	F20,	F38				
tasMUUserCategory	F20,	F38				
tasSWMMeter	F15,	F34				
tasSWProduction	F16,	F36				
tasSWUSGSPondSite	F04,	F33,	F34			
tasSWUSGSStreamGage	F04,	F33,	F34			
tasTLNodeGroundWater	F11,	F34				
tasTLNodeInterconnection	F11,	F34				
tasTLNodePumpStation	F11,	F34				
tasTLNodes	F10,	F34				
tasTLNodeSANode	F11,	F34				
tasTLNodeStorageFacility	F11,	F34				
tasTLNodeSurfaceWater	F11,	F34				
tasTLNodeTreatmentFacility	F11,	F34				
tasTransmissionConveyance	F10,	F34				
tasTreatmentFilterBackwash	F06,	F34				
tasTreatmentTankSludge	F06,	F34				
tblAddress	F20,	F29,	F35,	F38		
tblContact	F29,	F35				
tblContactEmergency	F29,	F35				
tblCriticalSpareParts	F30,	F35				
tblDemandEntry	F17,	F36				
tblDemandVolumes	F17,	F36				
tblFinancial	F31,					
tblGWAquiferTest	F26,	F34				
tblGWDOH	F05,	F22,	F34			
tblGWIndex	F05,	F07,	F11,	F15,	F16,	F22,
	F26,	F32,	F33,	F34,	F36	
tblICIndex	F11,	F12,	F13,	F15,	F32,	F34,
	F36					
tblICTransactionDescription	F12,	F16,	F34,	F36		
tblICValveIndex	F13,	F34,				
tblLeakDetection	F28					
tblMMeterIndex	F15,	F32,	F34			
tblMUIndex	F19,	F20,	F24,	F29,	F30,	F32,
	F35,	F38				
tblMUPriorityService	F30,	F35,	F38			
tblMUWaterUse	F19,	F38				
tblMUWaterUseEntry	F19,	F38				
tblProductionVolume	F16,	F36				

Appendix 1. Table index by figure.—Continued

[This appendix is an alphabetical list of WSSMP tables and the figure numbers in which they appear (for example figure 1 is F01). The plate is referenced as follows: F34, Plate 01, Water supply system infrastructure; F35, Plate 01, Emergency management and contact information; F36, Plate 01, Production and demand information; F37, Plate 01, Water-use and water-use projection information; F38, Plate 01, Major-user information]

Table names	Figure numbers					
tblProductionVolumeEntry	F16,	F36				
tblProjectionbyMU	F24,	F38				
tblProjectionbyUse	F23,	F37				
tblPSIndex	F09,	F11,	F13,	F32,	F34	
tblPSPumps	F09,	F34				
tblRetrofitDone	F27					
tblRetrofitKitComponents	F27					
tblRIGISCoverage	F32,	F34,	F38			
tblSAConnectionDescription	F14,	F34				
tblSAIndex	F11,	F14,	F32,	F34		
tblSANode	F11,	F14,	F34,			
tblSAPopulationEntries	F14,	F34				
tblSAPopulationEstimates	F14,	F34				
tblSFIndex	F08,	F11,	F32,	F34		
tblSupplier	F01,	F02,	F03,	F04,	F05,	F06,
	F07,	F08,	F09,	F10,	F12,	F13,
	F14,	F15,	F17,	F18,	F20,	F21,
	F22,	F23,	F24,	F25,	F26,	F27,
	F28,	F29,	F30,	F31,	F33,	F34,
	F35,	F36,	F37,	F38		
tblSWDOH	F04,	F21,	F34			
tblSWIndex	F02,	F04,	F07,	F11,	F15,	F16,
	F21,	F25,	F32,	F33,	F34,	F36
tblSWStageStorage	F25,	F34				
tblTFFilterBackwash	F06,	F34				
tblTFIndex	F06,	F07,	F11,	F32,	F34	
tblTFProcess	F06,	F07,	F34			
tblTFTankSludge	F06,	F34				
tblTLIndex	F10,	F32,	F34			
tblTLNode	F10,	F11,	F34			
tblWaterUse	F18,	F37				
tblWaterUseEntry	F18,	F37				
tblWSSMPCycleIndex	F02,	F03,	F04,	F05,	F06,	F08,
	F09,	F10,	F12,	F13,	F14,	F15,
	F16,	F17,	F18,	F19,	F20,	F21,
	F22,	F23,	F24,	F25,	F27,	F28,
	F34,	F36,	F37,	F38		
tdrConstituent	F01,	F21,	F22,	F34		
tdrEmergencyType	F30,	F35				
tdsAddressFor	F29,	F35,	F38			
tdsAddressOrder	F20,	F29,	F35,	F38		
tdsAddressType	F29,	F35,	F38			
tdsBasins	F04,	F05,	F34			
tdsContactAffiliation	F29,	F35				
tdsContactType	F29,	F35				

Appendix 1. Table index by figure.—Continued

[This appendix is an alphabetical list of WSSMP tables and the figure numbers in which they appear (for example figure 1 is F01). The plate is referenced as follows: F34, Plate 01, Water supply system infrastructure; F35, Plate 01, Emergency management and contact information; F36, Plate 01, Production and demand information; F37, Plate 01, Water-use and water-use projection information; F38, Plate 01, Major-user information]

Table names	Figure numbers					
tdsFacilityCondition	F08,	F10,	F12,	F34		
tdsICFeedDescription	F12,	F34				
tdsICFlowDirection	F12,	F34,	F36			
tdsICTransactionFrequency	F12,	F34				
tdsICType	F12,	F34				
tdsICValveStatus	F13,	F34				
tdsKnownPotential	F21,	F22,	F34			
tdsMeterMultiplier	F15,	F16,	F17,	F18,	F19,	F23,
	F24,	F34,	F36,	F37,	F38	
tdsMeterReadingFrequency	F15,	F20,	F34,	F38		
tdsMeterRegsiter	F15,	F34				
tdsMeterTestingFrequency	F15,	F20,	F34,	F38		
tdsMeterTime	F15,	F16,	F17,	F18,	F19,	F23,
	F24,	F34,	F36,	F37,	F38	
tdsMeterType	F15,	F34				
tdsMeterUnits	F15,	F16,	F17,	F18,	F19,	F20,
	F23,	F24,	F25,	F34,	F36,	F37,
	F38					
tdsMonthName	F26,	F30,	F31,	F34,	F35	
tdsNAICS97	F20,	F38				
tdsProductionSourceType	F16,	F36				
tdsProjectionHorizon	F23,	F24,	F37,	F38		
tdsPumpStation	F09,	F34				
tdsRateStructure	F31					
tdsReportingFrequency	F16,	F17,	F18,	F19,	F36,	F37,
	F38					
tdsReservoirFunction	F02,	F04,	F34			
tdsRetrofitCardResponse	F27					
tdsRetrofitCostAllocation	F27					
tdsRetrofitInformation	F27					
tdsRetrofitInstallationMethod	F27					
tdsRetrofitKitDistribution	F27					
tdsRetrofitNotification	F27					
tdsRetrofitReminders	F27					
tdsRetrofitRequestDistribution	F27					
tdsRetrofitResidential	F27					
tdsRetrofitStatus	F27					
tdsRIGISCovCat	F32,	F34,	F38			
tdsSFConstructionMaterial	F08,	F34				
tdsSFFacilityType	F08,	F34				
tdsSIC	F20,	F38				

Appendix 1. Table index by figure.—Continued

[This appendix is an alphabetical list of WSSMP tables and the figure numbers in which they appear (for example figure 1 is F01). The plate is referenced as follows: F34, Plate 01, Water supply system infrastructure; F35, Plate 01, Emergency management and contact information; F36, Plate 01, Production and demand information; F37, Plate 01, Water-use and water-use projection information; F38, Plate 01, Major-user information]

Table names	Figure numbers					
tdsSourceStatus	F02,	F04,	F05,	F34		
tdsStageUnits	F01,	F25,	F34,			
tdsSupplierType	F02,	F34,	F35,	F36,	F37,	F38
tdsTLNodeType	F10,	F34				
tdsTransmissionLineMaterial	F10,	F34				
tdsTreatmentStatus	F06,	F34				
tdsTreatmentType	F06,	F34				
tdsUserCategory	F18,	F20,	F23,	F37,	F38	
tdsWaterVolumeDate	F16,	F17,	F18,	F19,	F36,	F37,
	F38					
tdxAddressSiteType	F29,	F35,	F38			
tdxAlgicide	F02,	F04,	F34			
tdxAnnualDate	F14,	F16,	F17,	F18,	F19,	F26,
	F27,	F30,	F31,	F34,	F35,	F36,
	F37,	F38				
tdxContactTitle	F29,	F35,	F36			
tdxPumpType	F05,	F34,				
tdxWellDriller	F01,	F05,	F26,	F34		
tdxWellDrillMethod	F05,	F34				
tdxWellType	F05,	F34				
tilUSGSLakes	F33,	F34				
tilUSGSStreamGage	F01,	F33,	F34			
tilUSGSWells	F33,	F34				