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Cache County Water Demand/Supply Model

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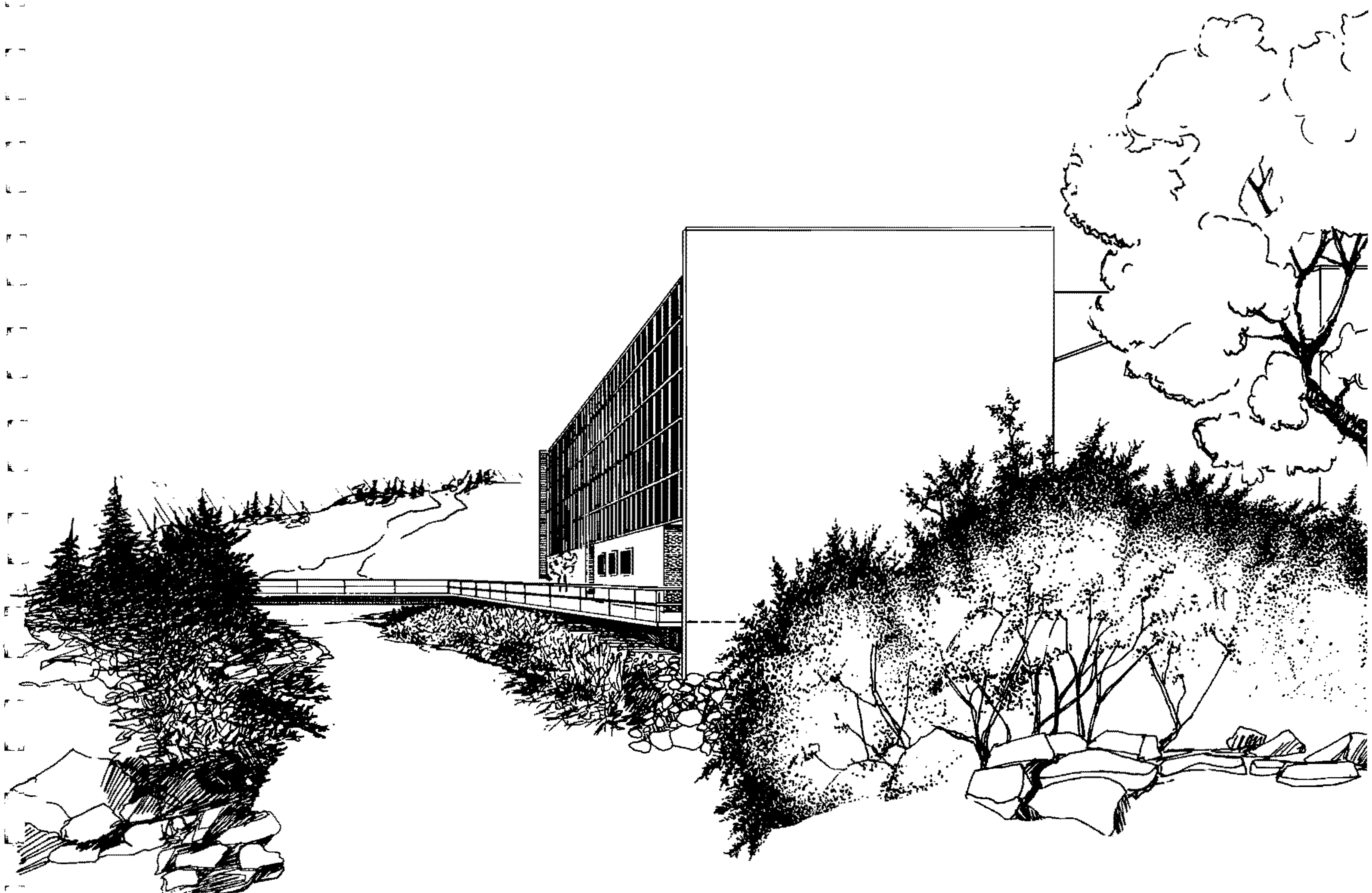

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CACHE COUNTY WATER DEMAND/SUPPLY MODEL

Final Report to
Utah Division of Water Resources,

U. S. Bureau of Reclamation
and

Cache County

by

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ABSTRACT

This report describes a municipal water demand forecasting model for use in areas of mixed rural and urban housing types. A series of residential demand functions were derived which forecast water demand based on the type and density of housing and season. Micro sampling techniques were used to correlate water use data and explanatory variable data for low, medium, and high density housing. The demand functions were incorporated into a geographic information system (GIS) platform consisting of a desk-top mapping program, MapInfo, coupled with a user interface program written in Visual Basic. The GIS-based model analyzes water demand at the census block level and aggregates the block level demands to a total city residential water demand. Averaged values of explanatory variables for each block are derived using the spacial relations of the block to map objects which have as attributes the various explanatory variable data. The model was applied to each of 23 community water systems in Cache County, Utah. The model projects future demands to the year 2020 based upon the individual community growth rate estimates produced by the Utah state demographers. In addition to projecting future demands, the model includes a supply allocation module which matches each system's demand with individual water supply sources.

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INTRODUCTION

Background

In 1993, a major effort related to projecting municipal water demand in Utah was completed. The Wasatch Front Water Demand Supply Model (WFWDSM) was applied to the four urban counties south of Cache Valley (Weber, Davis, Salt Lake, and Utah counties). When a Cache County water demand model project was initiated at the request of the Cache County Water Policy Advisory Board, a decision was required regarding whether to simply apply the WFWDSM model to Cache County or to develop a new model. The latter course was selected for several reasons:

- The socio-economic parameters which determine water use in Cache County are very different than in the more urban Wasatch Front counties. Of the 23 separate public water systems in Cache County, most are rural in nature with large numbers of both dairies and cattle feed lots and other stock water uses. These uses have an important influence on water use that was essentially missing in the WFWDSM demand functions.

- The largest city in the county, Logan, has very different characteristics than the urban cities in the previous model due to the dominating influence of Utah State University. Logan has the largest fraction of population in multi-family dwellings in the state, and, also, a much larger number of persons per household (PPH) in these apartments than other cities (with the possible exception of Provo).

- The GIS software used for the Wasatch Front model was purchased in 1986, and therefore lacks many of the technology improvements made during the last decade. For example, Tiger file maps are now commercially available at very low cost, and are provided with demographic data already included. Their use eliminates the need to develop special GIS imagery of each community to be modeled.

For these reasons, an entirely new model was produced for this study. It will be referred to as the Cache Valley Water Demand\Supply Model (CWDSM). Cache County includes 23 separate domestic water systems as shown in Figure 1 (19 municipal and 4 smaller non-municipal systems).

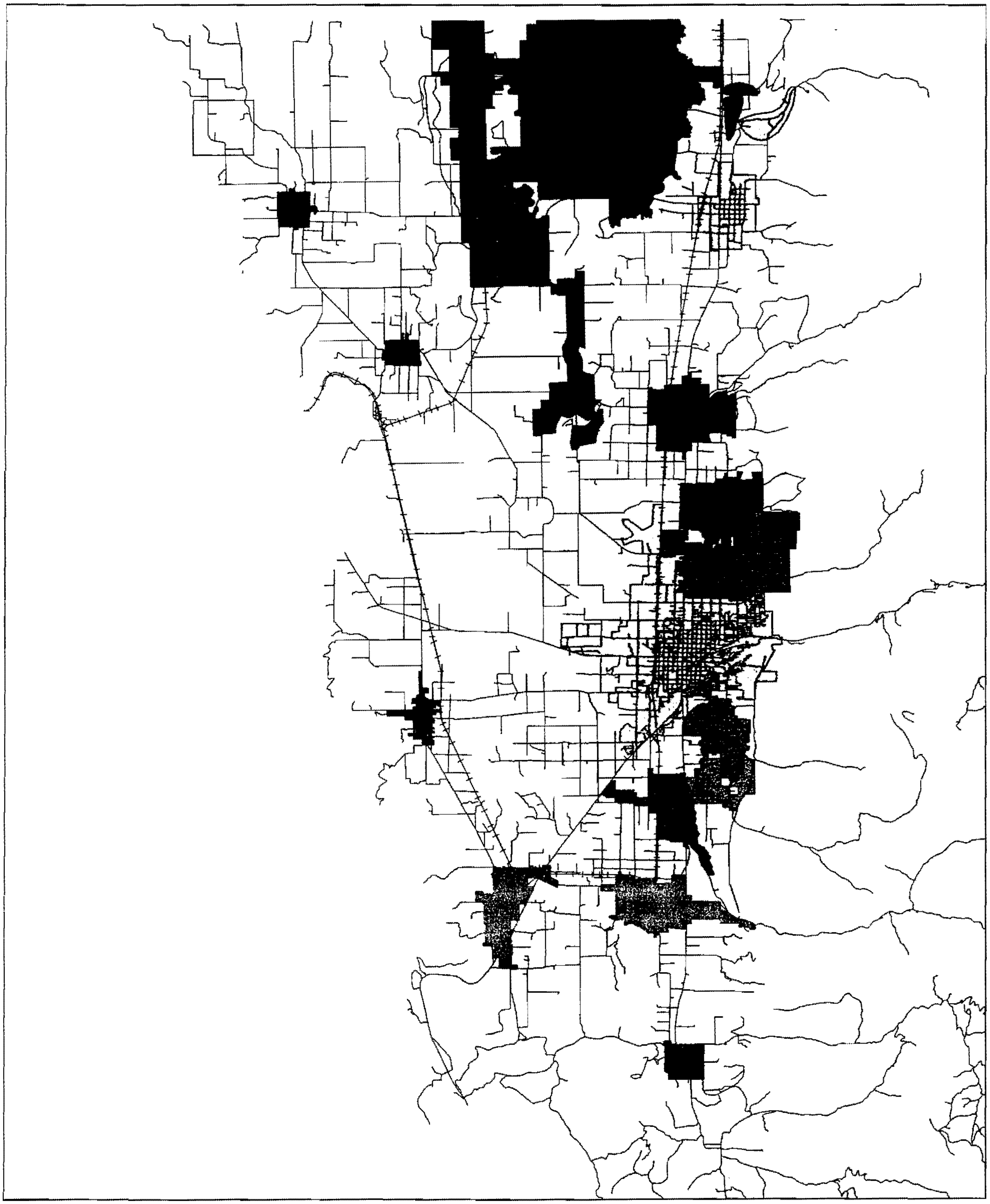


Figure 1. Cache County domestic water system boundaries.

Scope of Report

The real product of this study is the model itself which will be operating in both the Cache County Planner's office and the Utah Division of Water Resources office. The CWDSM should be useful in answering questions regarding future proposals for changes in land use and their impact on individual water systems. The purpose of this report is to describe the model structure, and to display examples of the current projections of future water demand and the ability of existing supply sources to meet those demands. The growth estimates will, of course, change over time and the model should be updated to reflect these better estimates.

Revisions to the 1990 census data provided with the Tiger file maps and the related population projections made by the Governor's office for Cache County have already been incorporated into the model. The basis for these revisions are the 1995 population estimates developed by the Cache County Planner using building permit data. Because of very rapid growth in some Cache Valley cities during the 1990 to 1995 period, the 1995 populations have already exceeded the year 2000 projections. The annual growth rates for each community produced by the State demographers in their 1994 report are still used, but the populations have been corrected to the 1995 Cache County planner's numbers. This increased future projections for many towns and decreased a few others. In the year 2020, for example, the estimate of county total population is increased from 116,636 to 141,889.

A detailed description of the Cache County water demand functions is given in Greg Norby's M.S. Thesis (Norby, 1996) and will only be summarized here.

OVERVIEW OF MODEL STRUCTURE

CWDSM is a multi-criteria type model which uses two types of seasonal water demand functions--one set for rural type communities, and one for more urban type systems. Development of the urban type functions required particular attention to (and a separate micro sample of) the large number of multi-family units in Logan City.

Tasks

The modeling process included the following sequence of tasks:

1. Gather three micro samples for development of residential water demand functions, including single family rural (using Nibley data), single family urban (using Logan data), and multi-family urban (using Logan data).

2. Perform regression analysis after separating the samples into seasonal components to develop the possible forms of water demand functions.

3. Gather data on total metered water use from all 23 M&I water systems in Cache County, separated by type of use for 1994 and 1995.

4. Develop necessary software and apply the demand functions to the near current years for each city, and verify the model by comparing model predictions to the metered water sales.

5. Develop a procedure for adding both commercial and industrial (C&I) water use and unmetered use to the model.

6. Add the population prediction data base to the model and project future water use to the year 2020.

7. Gather data on both legal and physical capacity of each water source to the model.

8. Develop software necessary to simulate future allocation of water demand estimates among the supply sources of each community; and project future supply shortages for winter and summer seasons, and for peak month.

Base Maps

Previous GIS approaches to M&I water demand models (such as the WFWDSM) required digitizing paper maps for use as the basic geographic representation of the region modeled. While some utilities in Cache Valley now have access to GIS systems developed specially for their city, most small communities do not. There is, however, one GIS format--the Tiger file maps which are commercially available at very small cost for every city in the U.S. These electronic maps include city boundaries, street maps, and water courses. They are already coupled to the most important data base for water demand--the census data. Tiger files, therefore, were selected for use in the CWDSM. The GIS software used to display the maps and query the related data bases is a low cost desk top type system called MAPINFO.

Disaggregation Level

A basic decision for any GIS system is what level of geographic disaggregation to select for making calculations. Most census data are available at several levels including blocks, traffic zones, and census tracts. Some information is not available at the block level. An example is estimated population growth rates, which are, however, available for Cache Valley at traffic zone level. Unfortunately, traffic zone boundaries do not coincide with city boundaries; and, therefore, traffic zone parameters cannot be aggregated to produce city boundary totals. The block level, therefore, was selected as the basic unit at which the water demand functions are applied. The growth rates for each block were assumed to be the same as the traffic zone which contains the block. This most detailed possible disaggregation level also provides much more accurate maps of lot size and dual system service areas. The individual census blocks for a portion of the valley are displayed in Figure 2.

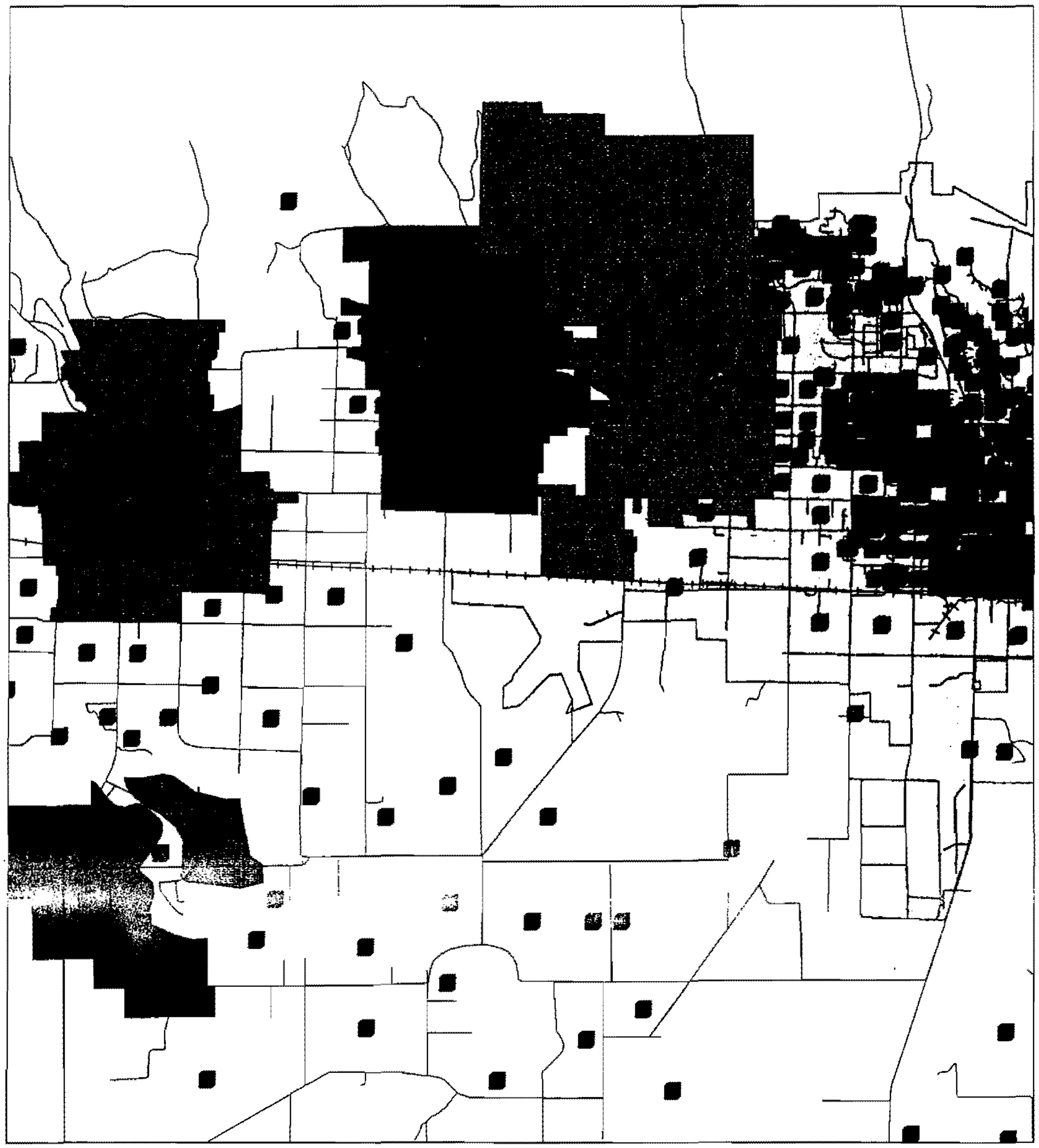


Figure 2. Example of census blocks.

STATISTICAL METHODS

Explanatory Variables

The selection of potential explanatory variables for this study was motivated by the goal of a practical and effective forecasting model, rather than exhaustive theoretical examination of potential explanatory variables. The objective was a model based on data which are readily available. The letters shown in parenthesis following the variables are abbreviations used later in this report.

Assessed Value(AV)

Income of the water user is often assumed to be correlated with water use. Assessed value of property is often also assumed to be a surrogate for income because it is more readily available than income data. This study collected data on both AV and income, though some survey respondents declined to provide income data; therefore, AV was used.

Persons Per Household (PPH)

The number of people living in a home is expected to be positively correlated with the *total* water use for the residence, due to increased showering, toilet flushing, cooking, and cleaning uses of water. However, the *water use per occupant* is expected to be negatively correlated with PPH due to "economies of scale" among such activities as dish and clothes washing, in which the addition of one occupant may not result in increased cycles of use for these appliances.

Climate

Climate data were not collected as part of the micro samples because the study area from which the cross-sectional data were collected was too small to exhibit significant climatic variability. However, variations in climatic parameters such as potential evapotranspiration (PET) and rainfall (RAIN) are expected to be strongly correlated with changes in residential outdoor water use (Wang, 1992). A probability distribution of historic Cache Valley data for these parameters was developed to allow simulation of demand during various future climate years.

Price(P)

Economic theory implies that demand for water is expected to have a negative correlation with price. For the purposes of this study, each city's marginal price is used as the P variable. For example, if a city charges \$10 for the first 10,000 gallons used, and then \$0.55/1000 gallons overage, the marginal price of \$0.55 will be used as the price for that city.

Lot Size(LOT)

The size of a residential lot is expected to be positively correlated with water use. However, this correlation decreases above a certain lot size as homeowners elect to limit the size of the irrigated areas around the home, or to obtain a different water source for large irrigated areas. Hughes(1996) found that water use from domestic water systems does not increase as lots exceed 0.44 acres.

Green Area(GA)

Green area is a variable whose value is derived from LOT, and represents the estimated irrigated area for a residential lot. A positive correlation is expected between GA and water use. Limaye, et al.(In review) and Hughes(1996) have shown that a strong positive linear relationship exists between the irrigated area of a home and LOT up to a certain value of LOT, beyond which GA remains relatively constant. The LOT data collected in this study were used to confirm this relationship, particularly in the rural study areas where larger lot sizes are more common than in urban areas. The equation used in this study is that derived by Hughes (1996), with LOT and GA measured in acres;

$$GA = 0.704*LOT, \text{ for } LOT \leq 0.44 \text{ acres}$$
$$GA = 0.31, \text{ for } LOT > 0.44 \text{ acres.}$$

Dual System Use

The use of a separate, non-culinary water source for irrigation is expected to have a strong negative correlation with culinary water demand during the summer season. Within Cache County, either an open ditch or pressurized pipe are used to supply dual systems. This study considered only those areas served by pressurized pipe dual systems to have dual system coverage.

Although there are extensive open-ditch secondary systems in many communities, it is assumed that these supply water primarily for uses such as pasture for livestock and watering large gardens; and homeowners in such areas generally use culinary water for irrigation of lawns, flower beds, and other decorative landscaping immediately adjacent to the home. This assumption is difficult to verify due to the high number of small local ditch systems and the lack of both maps and use data for the ditch systems.

Livestock

Within the rural study area, it was anticipated that keeping of non-commercial quantities of livestock (horses, cows, sheep, etc.) would have a positive correlation with water use. Data were collected regarding both the number of livestock kept and the seasonal sources of water for watering these animals.

Multi-family Housing Occupancy Rate(OCC)

Based on the study objective of differentiating single and multi-family homes, separate data were collected to examine multi-family housing water use. One of the distinctive factors in multi-family housing, particularly in cities with a university, is fluctuations in the occupancy rate. It was expected that OCC would have a positive correlation with water use.

Multi-family Housing Per Unit Green Area (PUGA)

This variable is similar to GA for single family homes. It is the ratio of irrigated area in an apartment complex to the total number of units in the complex. PUGA was expected to have a positive correlation with water use.

Summary of Statistical Analysis Procedure

The following steps summarize the statistical procedures used in this study. An EXCEL statistical analysis package was used to perform the calculations and create the associated graphs.

1. Compile data files with each record consisting of water use and the various explanatory variable values.

2. Run simple linear regression on each potential explanatory variable. Use scatter plots and residual plots to detect significant patterns in the relationship between water use and each variable. Compare results to expected trends and determine potential causes for unexpected trends.

3. Select variables for introduction to the multi-variate function, using steps outlined above. Evaluate the derived multi-variate function.

4. Use residual plots to identify outliers and influential data points. Remove outliers (> 3Â)and if possible identify factors causing the extreme values, such as service line leakage. Evaluate influential data points to identify possible extreme influences.

5. Verify the assumptions of standard normal distribution, equal variance, and linearity. If the assumptions are violated, examine log-linear or log-log transforms of values.

6. Repeat steps 3, 4, and 5 for transformed function.

MICRO SAMPLES

Data Collection and Refinement

For derivation of the demand functions, three separate data sets were generated for each of the three housing categories; single family rural housing (SFHR), single family urban housing (SFHU), and multi-family housing (MFH). In addition, a fourth data set was constructed which consisted of pooled data from both the SFHR and SFHU data sets. Table 1 summarizes the contents and source of data for each data set.

Table 1. Major data sets and information sources

Data Set	Contents	Source
SFHR SFHU MFH	Seasonal water use and explanatory variable values for each household	City water billing records and phone surveys, site visits to apartments
Municipal water use	Total annual and/or seasonal water use by user category	City water billing records
GIS mapping data	1990 census block and tract maps, city street and zoning maps, dual systems, county traffic zones	1990 census TIGER files, County Wide Planning and Development Office, various city offices

The selection of communities from which data were collected for deriving the demand functions was determined primarily by the type of housing and overall density of development within the community. The City of Logan was chosen for both the SFHU and MFHU data because it is the most urbanized area within Cache County and also contains most of the multi-family housing units within the county. The City of Nibley was selected for the SFHR data based on the low housing density and overall rural nature of the community.

Additional considerations included the quantity and quality of data available. The communities within the county vary greatly in the frequency of water meter reading, the level of disaggregation by user type, and the sophistication of record keeping. The communities which were selected had at least two years of water use data, a separate billing category for residential use, and storage of data in electronic format.

Single Family Housing Rural Data

For the SFHR data set, a customer list of 320 accounts was obtained from the Nibley water billing records. A random selection of 40 customer accounts was made. Water use data were obtained from monthly billing records for each of the 40 homes, from April 1994 to January 1996. Although each customer receives a bill monthly, the water meters are only read monthly from March to October. The winter billings are based on estimated use, and an adjusted bill is sent following the March meter readings.

A survey was conducted by phone to gather detailed information related to the type of housing, income, family size, and other variables. Appendix A contains a copy of the survey form used, and lists in detail the data collected. Of the 40 accounts in the initial list, 35 were able to provide adequate data for inclusion in the data set. Information on lot size, building size, and assessed property value was obtained from the Cache County tax assessor's office. The final data set for the SFHR demand functions consisted of 35 records, or data points. Each record contained the household's water use for the 6-month summer season (April 1994 to October 1994) and the 6-month winter season (October 1994 to March 1995), as well as each explanatory variable value. The meter reading cycle for Nibley matched the proposed model seasons, so that the summer water use was simply the sum of the April-September usage, and the winter use was taken from the March metered usage, which included all water use since the previous September. Table B.1 in Norby (1996) contains the SFHR data set.

Single Family Housing Urban Data

For the SFHU data set, a randomly generated list of 200 customers was obtained from the City of Logan's water billing records. The city also provided billing data for each of the 200 customers, from January 1993 to January 1996. However, the city's meter reading cycle did not correspond with the model's seasonal periods, as in Nibley. The residential meters in Logan are read between 2 and 4 times per year, generally between April and October, but with no set pattern. During the winter months, and in between meter readings, the customers are billed based on an estimated use, which is then adjusted following the next meter reading.

Due to this meter reading schedule, the City of Logan's original data set consisted of both actual and "estimated" use, on a monthly basis for each account. The original data file contained over 10,000 records, most of which were not for actual meter readings. These data were refined in a two-step procedure to allow allocation of the recorded water use into the model's two seasonal periods. The objective of the procedure was to obtain for each account a summer season and winter season water use value, which then became the dependent variable for the regression analysis.

In the first step, a FORTRAN program (LGNSFH.FOR) was written to sort through the initial file and eliminate the "estimate" data and sum up water use for each account between actual meter readings. The refined file consisted of sorted records with the customer number, the "begin" and "end" dates for each actual meter reading, and the quantity of use for that period. This code is included in Appendix C of Norby (1996)

The time periods for the blocks of water use in the output file from LGNSFH.FOR had a fairly random distribution, and in many cases overlapped the model's seasonal periods. A second FORTRAN program (SUMWIN.FOR) was written to allocate these randomly distributed blocks of use into the model seasons. The distribution algorithm used relied on two primary assumptions. First, winter season use per household was assumed to consist entirely of indoor uses, and to be a function only of the persons per household. This assumption appears reasonable based on the results of previous demand studies (WFWDSM, 1993) and the normal winter season climate of Cache Valley. An average value of indoor water use was derived based on the Nibley winter season data and average winter indoor use per person data from other communities in the county. The assumed indoor use for Logan was 96 gallons per person per day.

The second assumption was that the summer season outdoor portion of use had a time-distribution similar to the summer season PET. For example, if 22% of the total summer season PET occurred in August, then approximately 22% of the total seasonal outdoor water use occurred in August as well. This assumption was verified using the Nibley data. Additional details and the program code for SUMWIN.FOR are contained in Appendix C of Norby (1996).

The end result of this two-step refinement was a data file with estimated summer season (April to September 1994) and winter season (September 1994 to March 1995) use for each of the 200 household accounts. A phone survey of the households was conducted to gather data on explanatory variables, using the same questionnaire as the Nibley survey with minor changes such as deleting questions relating to livestock. Of the 200 accounts in the initial list, 98 were able to provide adequate data for inclusion in the data set. Data on lot size, building size, and assessed property value were obtained from the Cache County tax assessor's office. Table B.2 in Appendix B of Norby (1996) contains the SFHU data set.

Multi-Family Housing Data

For the MFH data set, the City of Logan provided a randomly generated list of 20 apartment complexes. Each complex is served by a single master meter. The number of units in the complexes ranged from 4 to 24 units. Water billing data from January 1993 to January 1996 were obtained for each complex. Because the apartment meter data was similar to the SFHU data in terms of the irregularity of meter reading periods, the same refinement steps were used on the MFH billing data as described for the SFHU data.

Each unit within a complex has a City of Logan utility account. Whenever a unit had an active account, the unit was assumed to be occupied. Thus, the city's active account data provided a proxy for occupancy without requiring the individual property managers to sort through occupancy records for each of their apartment units. Site visits were made to each complex to gather data on irrigated area, number of units, number of bedrooms and bathrooms, and number of washing machines. Estimates were made for the average persons per unit, based on site visits and discussions with property managers regarding their leasing policies. The final data set consisted of 17 apartment complexes, with 145 total housing units. Table B.3 in Norby (1996) contains the final data set.

Total Metered Residential Water Use Records

In addition to the individual customer water use data collected for the micro sample data sets discussed previously, total residential water use data were collected for each community. The length of record available, the frequency of meter reading, and the accuracy and detail of the data varied for each community. Most communities retain no more than two years of billing data, which limits the opportunity for verifying model results using a series of past annual data, as has been done in previous studies.

GIS MAP DATA

Several sources of mappable data were used to construct the GIS data base. Some of the data were directly imported to the GIS, such as the United States Census Bureau TIGER maps. Other maps were digitized into the GIS from paper copies.

Lot Size Maps

City boundary maps were included with the Tiger file maps. Lot size maps were developed by overlaying city boundary maps with the Tiger File street maps and correlating with city zoning maps. The city boundary is the area to which demand is aggregated for analysis in the GIS model.

Census Bureau Maps (TIGER Files)

These maps which include both city boundaries and street maps were directly imported to the GIS. They contain data from the 1990 federal census. The census data are organized into a sequence of increasing geographic levels, from block to block group to tract. The census block is the smallest geographic division, with each block representing roughly one physical city block in an urban area. The census block level data provided population, the total number of housing units, the average persons per household, and the land area represented by each block.

Cache County 1995 Surveillance Study Map

This map contains data from the Cache County Planning Office's survey of housing and population changes since the 1990 census. The data is organized at the traffic zone level, and includes total traffic zone population, average PPH, and the number of housing units, both single and multifamily.

Transfer of Traffic Zone Data to Census Blocks

The area represented by a traffic zone typically encompasses several census blocks, but is smaller than a block group. For this reason, the 1995 surveillance data were used to update the 1990 census population data at the census block level and to estimate the number of multi-family and single family housing units in each census block. The data adjustment was made in the following manner.

The Cache County Planner has updated the population estimates within each traffic zone by using information from building permits issued within each city. By knowing the number of new housing units constructed within each traffic zone and the average PPH for the zone (PPH_{Zavg}), the increase in population for the zone is estimated as the product of these two values.

The distribution was based on the idea that new growth would tend to take place in areas of lower population density, as this is where land is assumed to be most affordable and available for new construction. Population density for each block in 1990 is known from the census data, taken as;

$PD_{Bi90} = POP_{Bi}/Area_{Bi}$, where
POP_{Bi90} = 1990 population for census block *I*
$Area_{Bi}$ = land area within census block *I*, in acres
PD_{Bi90} = 1990 population density for block *I*, in persons/acre

The growth distribution algorithm developed in this study uses the maximum 1990 population density within a traffic zone, PD_{Zmax}, as a target which other blocks in the zone will seek as overall population density within the zone seeks equilibrium. The maximum theoretical population change for a given block, POP_{Bimax}, is given by;

$$\Delta POP_{Bimax} = Area_{Bi}*PD_{Zmax} - PD_{Bi90}$$

This is the population increase each block would need in order to achieve a PD value equal to PD_{Zmax}. The total population change for the zone, ΔPOP_{ZONE}, is then allocated using the ratio of each census block's ΔPOP_{Bimax} to the sum of the ΔPOP_{Bimax} values for all the blocks within the zone ($\Sigma\Delta POP_{Bimax}$), as;

$$\Delta POP_{Bi} = (\Delta POP_{Bimax})/\Sigma\Delta POP_{Bimax}*\Delta POP_{ZONE}$$

Finally, the 1995 population for each block, POP_{Bi95}, is given by;

$$POP_{Bi95} = POP_{Bi90} + POP_{Bi}$$

Because the water demand model treats multi-family and single family housing separately at the block level, the adjusted 1995 population for each block needed to be apportioned into an estimated population for each housing type, for each block. The census data only provides a count of *total* HU's at the block level, but gives separate numbers for single family HU's (SFU) and multi-family HU's (MFU) at the traffic zone level. An estimate of the population living in SFU's (POP_{SFUBi}) and MFU's (POP_{MFUBi}) within each block was made using the ratio of MFU/SFU at the traffic zone level $(MFU/SFU)_{Zk}$ and the average PPH (PPH_{avgBi}) at the block level. This estimate assumes that the ratio of SFU/MFU for the traffic zone is approximately the same for the blocks within each zone. The block level populations for each housing type were then estimated by

$$POP_{MFUBi} = PPH_{avgBi}*(MFU/SFU)_{Zk}$$
$$POP_{SFUBi} = PPH_{avgBi}*(1-(MFU/SFU)_{Zi})$$

During the Wasatch Front model development, the PPH for single families was much greater than that for apartment dwellers; however, in Cache Valley that is not the case. Because of the practice of placing several students in a single apartment, there does not appear to be a significant difference in PPH between single and multi-families. Therefore, it was assumed that average PPH *within the traffic zone* is not significantly different between single and multifamily housing. This assumption was verified in two ways. First, an average value of PPH for the MFH survey data set was calculated as 3.01, compared to 3.5 and 3.6 for the urban and rural single family housing survey data sets. Second, traffic zone level data were used to look at the relationship between PPH_{Zavg} and the ratio of single to multi-family housing, or SFU/MFU_{Zk}. If PPH varies significantly as a function of the type of housing, there should be strong correlation between PPH_{Zavg} and SFU/MFU_{Zk}. However, correlation was quite weak (R^2= 0.227), indicating that while there may be some slight difference in average PPH between the two housing types overall, it should not introduce significant error in the model over any single traffic zone.

Piped Secondary Irrigation System Maps

These maps were digitized into the GIS to show the areas which have access to pressurized pipe secondary irrigation systems. The completeness and accuracy of these maps vary between systems. In cases where good maps were not available, it was assumed that the city boundary approximated the dual system service area boundary. This was done for the dual systems in Millville, Paradise, Mendon, Richmond, Nibley, and Newton.

County Assessor's Data

For each community, the average assessed value for all residential lots was obtained from the county assessor's office. The average was based on the combined value of all residential property in the community divided by the total number of residential lots.

Geographic Information System Software Description

GIS Software Selection

The GIS is the platform which provides integration of the water demand functions and the many different types and sources of data into an efficient and flexible forecasting tool. This study used GIS software in combination with a user interface to facilitate operation of the water demand model. The GIS system chosen was MapInfo, a GIS produced by MapInfo Corporation of Troy, New York. The system requirements for MapInfo are such that it can be run on almost any newer desk-top or portable lap-top computer. The system requirements are 4 MEG RAM (8 MEG recommended), 4.5 MEG for storage on a hard drive, a VGA monitor, and Microsofts' Windows 3.1 operating system.

Key features of MapInfo include the following. Data can be directly imported from and/or exported to most common database and spreadsheet software, such as D-Base, FoxPro, Excel, Lotus 123, and generic ASCII files. Both raster and vector images can be used in MapInfo. Figures and maps created using common CAD or GIS software can be imported for use in MapInfo. Data can be viewed and analyzed using tables, graphs, and maps. Extensive data analysis capabilities make use of both data base record-attribute relationships and spacial relationships based on the data's geographic location and properties.

Model Interface with MapInfo

A user interface program was created to allow use of the model without requiring working knowledge of MapInfo, and also to automate execution of the analytic tools within the GIS needed to run the model. Microsoft's Visual Basic programming language was selected for this shell. The interface program is a critical part of the model, as it essentially translates the analytic methodology into actual computer operations in the GIS.

The interface program provides the model user with an easily navigated menu of preselected options related to execution of the model and modification of the input data. The user can change the demand functions assigned to a given city, modify the mathematical form of the demand functions, change reference values for price and climate, select a future year for which water demand is to be projected based on given population growth rates, and select the level of aggregation of the model results. With some working knowledge of MapInfo, a user can also access the maps and data tables stored in MapInfo to modify the various input data for communities, such as lot sizes or the boundaries for a dual water system.

A user's manual for CWDSM is included in Appendix A.

RESIDENTIAL WATER DEMAND PROJECTION

Overview

Residential water demand functions, explanatory variable data sources, and analytic methods are brought together within the GIS model to estimate the total residential water demand for a community. The model works by estimating residential water demand at the census block level as follows. The population within the block is known, and the fractions of the population within the block living in single and multi-family housing are estimated from the traffic zone data. Average values for each explanatory variable are determined using the various mapped data sources and the spacial relationship of the block to each mapped layer of data. Figure 2 is a sample of the mapped data for a portion of North Logan, showing census blocks, and dual system boundaries.

The appropriate demand function is selected based on the community type (rural or urban), housing type (single or multi-family), the presence or lack of a dual water system, and season (winter or summer). The demand function uses the averaged values of the appropriate explanatory variables to estimate the average daily water use per person, or Q_{gppd}. This is done for both the single and multi-family housing populations within the block. For both populations, the estimated average water use per person is then multiplied by each associated population and the number of days in the season to get the total seasonal water demand for the block. The block level water use is aggregated to a city-wide total use, which is then adjusted for price and climate variables. The following section describes each of these steps in greater detail.

Unit of Analysis

This model uses the census block as the basic level of analysis for application of the demand functions. A census block represents a specific population group, and is physically represented on a map by a symbol at the geographic centroid of the area within which the population lives. In an urban area, a census block typically represents one physical city block. In a rural area, a census block may represent a much larger land area, up to several square miles. In Figure 2 each small square symbol is a census block.

For each census block, the following housing and population values are known or estimated; total population, population living in SFH's (POP_{SFH}), number of SFH's, population living in MFH's (POP_{MFU}), and the number of MFH's. The model analyzes water demand for each housing sector within the block and then sums the results to obtain the total residential water demand for the census block. For example, the SFH water demand in gallons per person per day (gppd) is given by some SFHU summer demand function as;

$$Q_{SFH} = \beta_o + B_1{*}PPH + B_2{*}LOT + B_3{*}AV$$

The total daily SFH water demand for the block is then;

$$Q_{SFHTOT} = Q_{SFH}{*}POP_{SFH}$$

Similarly, the MFH water demand in gppd is given by some MFH summer demand function as;

$$Q_{MFH} = \beta_o + B_1{*}PPH + B_2{*}OCC + B_3{*}PUGA$$

The total daily MFH water demand for the block is then;

$$Q_{MFHTOT} = Q_{MFH}{*}POP_{MFH}$$

The summer season total residential demand for the block is then given by;

$$Q_{SUMTOT} = (Q_{SFHTOT} + Q_{MFHTOT}){*}182.5$$

Q_{SUMTOT} = summer season residential demand in gallons

182.5 = days in a six-month summer season

The winter season residential demand for the block is obtained in the same manner, except the winter season demand functions are used. The above demand function forms are examples only. The demand functions selected for use in the model are presented later in this section. Which demand function is used is determined by the season (summer-winter), the type of community (rural-urban), the housing type (single or multi-family), and the presence or lack of a dual water system.

Explanatory Variable Values

Values for the explanatory variables such as LOT and AV are derived in the GIS using the spacial relation of the census block to the other data maps. For example, one map layer contains the zoning map and associated lot size data for North Logan. Which housing zone a census block is located in is used to assign an average value of LOT in the demand function. Similarly, the areas of dual system irrigation are contained on a separate map layer, so census blocks within these areas are assumed to have dual system access, and blocks outside the area do not.

The variables used in the demand functions are "attributes" associated with various map objects in the GIS. For example, the population and housing variables are attributes of each census block. LOT values are attributes of land use zones. AV is an average value attribute for a city. Table 2 summarizes the level at which each variable is assigned as an attribute for a map object.

Table 2. Map object attributes

Map Object	Variables
Census Block	Adjusted POP_{Bi}, SFU_{Bi}, MFU_{Bi}
Traffic Zone	1995 Pop_{Zk}, SFU_{Zk}, MFU_{Zi}
Dual System Boundary	% of use (k-factor)
Land Use Zone	LOT, GA
City	AV, P, OCC, PUGA

Adjustment for Dual System Areas

Within dual system areas, outdoor use is expected to be much lower than in non-dual areas. However, some level of outdoor use is expected within dual system areas because customers may choose to utilize their culinary water source for outdoor use for reasons of convenience or concerns regarding water quality in the dual system. For this reason, an adjustment factor (k) is used to account for the estimated percentage of homes within a dual system area which actually use the dual system for all outdoor water use.

For each block located in a dual system area, the total block population is split into a dual use population and non-dual use population, as $k*POP_{Bi}$ and $(1-k)*POP_{Bi}$, respectively. The per capita daily water demand for each population is then calculated using the appropriate demand functions, with outdoor use variables in the demand functions such as GA and LOT set equal to 0 for the dual areas.

Aggregation to Total City Demand

The model is intended to estimate total residential water use for a city. Each city's total population and housing sectors are represented by the census blocks contained within the mapped boundary of the city. The GIS model obtains the total city residential water demand by simply summing up the estimated water demand for each census block. Again, the GIS uses spacial relations of mapped data to do this by recognizing which census blocks are contained within each city's boundary.

COMMERCIAL AND INDUSTRIAL WATER DEMAND

One way to project future C&I water use is to develop regression equations for each Standard Industrial Code (SIC) and to assume that this sector increases in proportion to employment projections. This was not possible for Cache Valley systems because future employment projections are not yet available. Also, the amount of C&I users in each SIC in this valley represent an inadequate sample for useful statistical analysis.

C&I water use was, therefore, divided into two categories with different growth rates as follows: The non-agricultural use is assumed to increase at the same rate as population. The most important agricultural use served from the domestic water systems in Cache Valley is the cattle industry (principally dairies, but also some beef cattle feed lots). Because of recent policies related to decreasing dairy surpluses and changing habits related to beef demand, the water use of these businesses is not expected to grow at the same rate as population. This category was, therefore, separated and given a growth rate of zero (but this could be changed by the user to any other growth rate).

CORRECTION FOR PRICE AND CLIMATE

The estimated water demand obtained from the above steps is based on demand functions which were derived under a fixed set of price and climate conditions, referred to as "reference conditions." Both price and climate variables are known to have significant effects on water demand, so adjustments to the estimated demand must be made for price and climate conditions different from the above reference conditions. Both adjustments are made using estimated elasticity values for these factors; η_p, η_{PET}, and η_{RAIN} for price, PET, and RAIN, respectively. Because two separate data sets were used to derive the rural and urban demand functions, there are two sets of reference conditions, depending on which category of demand functions is used.

The urban demand functions were derived with data from the City of Logan from October 1993 to October 1994. Therefore the reference climate conditions are for summer, 1994. The total summer season PET and RAIN for 1994 were 38.34 inches and 3.0 inches, respectively. No reference climate conditions are necessary for the winter demand functions because these functions do not utilize any climatic variables. The reference price for the urban demand functions is $0.45/1k gallons.

The rural demand functions were derived with data from the City of Nibley from October 1994 to October 1995. Therefore the reference climate conditions are for summer, 1995. The total summer season PET and RAIN for 1995 were 33.61 inches and 9.67 inches, respectively. The reference price for the rural demand functions is $0.55/1k gallons.

The initial water demand value is first adjusted for price, based on the season and the presence or lack of a dual system. Winter season η_p is 0.10. Summer season η_p is 0.417 for non-dual areas and 0.10 for dual areas. The different η_p values are based on the idea that indoor water use is much less responsive to changes in P. The summer season, non-dual η_p of 0.417 is based on previous studies by Erickson (1991) and Hansen (1981). The price-adjusted water demand, Q_{padj}, is given by

$Q_{padj} = Q_{npa} * \eta_p *(P-P')/P' + Q_{npa}$, where
P = new price
P' = reference price
Q_{npa} = non-price adjusted water demand

The price adjusted water demand, Q_{padj}, is then adjusted for climate conditions. Thirty years of daily summer season PET and RAIN values for the Logan area were used to establish the probability distribution for these variables. The model can then examine the effect of climate conditions with probabilities ranging from 0.01 to 0.99. The seasonal totals of PET and RAIN for the KVNU weather station in Logan were used to derive these functions. The values of η_{PET} (0.633) and η_{RAIN} (-0.069) are based on the results of Wang's (1992) study for the Salt Lake City area. Q_{pa} is then adjusted for the new climate conditions as

$$Q_{cpa} = [\eta_{RAIN} *(R-R')/R' + \eta_{PET} *(PET-PET')/PET']*Q_{pa} + Q_{pa}$$

where

Q_{cpa} = the new climate and price adjusted water demand
PET', RAIN' = reference values of PET and RAIN
PET, RAIN = new values of PET and RAIN

WATER DEMAND FUNCTIONS

Regression Analysis Results

A primary objective of this study was to examine possible differences in water demand between three major housing types; single family rural (SFHR), single family urban (SFHU), and multifamily housing (MFH). The following sections present separate summer and winter season water demand functions for each of the housing types. Statistical parameters for each function are presented. Significant findings regarding water demand in each sector are discussed. Table 3 summarizes the demand functions and the primary statistical variables for each. Detailed statistical results are given in Appendix 4 of Norby (1996) including graphs for verification of assumptions regarding residual distribution, variance, and linearity. Water demand (Q) is in units of gallons per person per day (gppd). The notation for the dependent variable (Q) indicates the housing sector and the season. For example, the SFHR summer water demand is symbolized by $Q_{SFHRsum}$ and the MFH winter demand is symbolized by Q_{MFHwin}.

Equations derived using linear regression lose accuracy outside of the range of variable values used in the regression analysis. This was the case for several of the equations used in this study. When tested under the range of independent variable values, the equations yielded obviously erroneous values of water demand. The solution to this problem was to use transforms of the equations which may have only slightly weaker statistical parameters but which are more robust under the range of variable values. Such cases are noted below. The equations presented in Table 3 are the final forms used in the demand model.

Rural Housing Demand Functions

Summer Season SFHR

For the rural housing sector, summer season, the hypothesized explanatory variables included PPH, LOT, GA, LVSTK, INC, and AV. The variables found to be significant were PPH and GA. The following equation form had the best statistical parameters;

$$Q_{SFHRsum} = 644.180-367.439*Ln(PPH)+1096.820*GA$$

$R^2 = 0.581$

$F = 20.073.$

Table 3. Summary of residential water demand functions

Housing Sector	Season	Function Form	Variables	Coeff.	R^2	F
SFHR	Summer	Log-Linear	Constant PPH GA	395.440 0.808 23.86	0.420	10.88
	Winter	Linear	Constant PPH	181.548 -22.075	0.393	18.70
SFHU	Summer	Log-Linear	Constant PPH LOT A V	351.426 0.768 1.412 1.006	0.525	30.259
	Winter	na	na	na	na	na
Pooled SFH	Summer	Linear-Mixed	Constant Ln (PPH) GA	607.828 -305.153 603.079	0.453	46.450
	Winter	na	na	na	na	na
MFH	Summer	Log-Log	Constant PPH OCC PUGA	5.263 -1.000 1.521 0.185	0.647	32.358
	Winter	Log-Log	Constant PPH OCC	6.130 -1.457 1.312	0.694	87.355

However, the following transform generally provided more accurate estimates of water use in those communities classified as rural;

$\log(Q_{SFHRsum}) = 2.598 - 0.0926*PPH + 1.378*GA$
$R^2 = 0.420$, $F = 10.880$

Or, expressing $Q_{SFHRsum}$ directly;

$Q_{SFHRsum} = 395.440*(0.808)^{PPH}*(23.86)^{GA}$

Significant findings from this data set were as follows. LVSTK was not found to be significantly correlated with Q, contrary to the initial hypothesis. Although it seems reasonable to assume that increased LVSTCK values would result in increased water use, the data set was not able to demonstrate this for two possible reasons. First, there were fewer than anticipated households in the micro sample in Nibley which had LVSTCK. Second, several homes with LVSTK used shallow wells or ditch water rather than culinary water for the stock, so no increase in culinary use could be documented due to LVSTCK. However, the water demand in Cache Valley is in general greater per person than in the WFWDSM systems, and this may well be due to the prevalance of livestock in many of the rural communities.

There are major demands from dairies and feed lots in some rural communities, but they are categorized as C&I connections. The discussion of LVSTCK above refers only to residential connections which also serve a small number of livestock on the same lot.

Regression analysis of AV against INC showed that AV is not a strong indicator of income in rural areas. The R^2 value from regression is 0.078. This appears to contradict the assumptions made in some past studies regarding the use of AV as a proxy for INC data. This result does not by itself indicate that water use is not related to INC, only that use of AV as a surrogate for INC may not be accurate in rural settings. One hypothesis for this is that AV in rural areas is influenced by the larger land holdings, as opposed to building values. These lands may be held by families whose income is modest relative to the increasing values of their land holdings.

Water use is poorly correlated with LOT in rural areas. Initial regression of Q against LOT showed a negative correlation, contrary to expectations from past studies. This is most likely due to the larger LOT sizes common in rural areas. Examination of the original data set showed that several influential data points with large values of LOT were distorting the regression results. When the data were limited to LOT values less than 0.5 acres, the correlation was positive, although still weak. These results confirm similar trends for rural Utah communities noted by Hughes(1996).

Water use is strongly correlated with irrigated area as measured by the GA function, which limits the estimated irrigated area to 0.301 acres beyond LOT values of 0.44 acres. These results indicate that use of GA instead of LOT in areas with LOT values over approximately 0.5 acres will provide more accurate water demand estimates.

Winter Season SFHR

For the rural housing sector, winter season, the hypothesized explanatory variables included PPH, LVSTK, INC, and AV. The only significant variable was PPH. The demand function is;

$$Q_{SFHRwin} = 181.54-22.07*PPH$$
$$R^2 = 0.393, F = 18.70$$

Significant findings from this data set were as follows. LVSTK was not found to be significantly correlated with water use, contrary to the hypothesis. Possible reasons for this lack of correlation are discussed above. AV and INC were not found to be significantly correlated with water use, similar to the summer season results. Because winter season use is primarily for indoor uses, PPH was expected to be the most significant variable, and the results confirm this expectation. Similar results were obtained for the WFWDSM(1993), with a nearly identical resultant demand function given as;

$$Q = 168-21.59*PPH$$

Urban Housing Demand Functions

Summer Season SFHU

For the urban housing sector, summer season, the hypothesized explanatory variables included PPH, LOT, GA, INC, and AV. The variables found to be significant were PPH, LOT, and AV. The demand function form which provided the best statistical results with all significant variables at a P value of < 0.05 was;

$$Q_{SFHUsum} = 465.638-87.997*PPH+1.546*AV+176.310*LOT$$
$$R^2 = 0.453, F = 22.343$$

However, a log-transform of Q yielded a much more stable equation over the range of variable values. In the log-linear form, the significance of LOT decreased to 0.85%, while PPH and AV retained significance levels > 95%. The resulting equation as used in the model is;

$$Q_{SFHUsum} = 351.426*(0.768)^{PPH}*(1.006)^{AV}*(1.412)^{LOT}$$
$$R^2 = 0.525, F = 30.259$$

Significant findings from this data set were as follows. The explanatory variables for urban residential water demand in Cache County agree with the findings of the WFWDSM study, which used data from the Salt Lake City urban area. The correlation between water demand and both LOT and AV was much stronger than in the rural housing area. Again, this is most likely due to the smaller range of LOT values for the urban area.

Winter Season SFHU

A separate demand function for winter season residential use for single family homes was not obtained for the following reasons. The data intended for use in deriving the function were that obtained from the City of Logan Utility Department. Due to the lack of winter season meter readings and the generally arbitrary pattern of the summer season meter readings, it was not possible to separate out the winter season water use for the 200 billing records obtained for the study.

However, based on the above comparison between the WFWDSM results and the Nibley sample results, it appears reasonable that the winter use function derived for the rural areas is equally applicable to the urban areas of Cache County. For this reason, the same winter season use function was used in both rural and urban communities.

Combined Data Set Summer Season

The rural and urban single family housing, summer season, data sets were pooled into a single data set for analysis. The purpose of analyzing this pooled data set was to derive functions which may work well in areas of mixed urban and rural housing types. No specific hypothesis was made, although it was expected that the resulting functions would reflect some combination of the influences of the two housing types. Because the urban housing data set (86 points) was more than twice the size of the rural data set (33 points), it was expected that the urban factors might be most significant in the pooled data analysis. This was not the case. The significant explanatory variables are PPH and GA, similar to the SFHU summer function. The function is;

$Q_{pooled\text{-}sum} = 607.828+603.079*GA-305.153*Ln(PPH)$
$R^2 = 0.453, F = 46.450$

Multi-Family Housing Demand Functions

MFH Summer

The significant variables for the selected demand function form (water use per person) were PPH, PUGA, and OCC. The demand function with the best statistical parameters is;

$Q_{MFHsum} = 515.455+0.330*PUGA-545.099*Ln(PPH)+272.656*Ln(OCC)$
$R^2 = 0.807, F = 73.660$

However, a log-log transform of the variables yielded a more stable function, as;

$Ln(Q_{MFHsum}) = 5.263+1.521*Ln(OCC)-1.00*Ln(PPH)+0.185*Ln(PUGA)$
$R^2 = 0.647, F = 32.358$

Significant findings for this data set are as follows. MFH water use is influenced by factors similar to those for SFH. Indoor use is strongly determined by household size, with decreasing water use per person as PPH increases. Outdoor use, as indicated by the PUGA value, is strongly influenced by the design of the apartment complex in terms of the amount of vegetated open space per unit. The average value of PUGA for the data set was 300 ft^2.

The occupancy rate, OCC, has a strong influence on MFH water use, as hypothesized. The significance of this variable is likely to be greatest in areas with large transient populations, such as university neighborhoods or seasonal worker housing. OCC may also prove significant in modeling changes in water demands resulting from alternating cycles of overbuilding and restrictive multi-family housing markets, which are common to communities experiencing rapid economic and/or population growth.

MFH Winter

For the MFH data set, winter season, the hypothesized explanatory variables were the same as for the MFH, summer season, data set except for the PUGA. The variables found to be significant were PPH and OCC. The demand function with the best statistical parameters is;

$Q_{MFHwin} = 230.066+121.937*OCC-203.351*Ln(PPH)$
$R^2 = 0.740, F = 109.635$

Again, a log-log transform yielded a more stable function;

$Ln(Q) = 6.130+1.312*Ln(OCC)-1.457*Ln(PPH)$
$R^2 = 0.694, F = 87.355$

As with SFH, winter season, the water demand for MFH in winter is largely determined by household size, with the additional influence of changes in OCC. The significance of OCC for the winter season is based on the same factors discussed above for the summer season.

Peak Month Demand

There is essentially no long-term (seasonal) storage for Cache County water systems, and all sources are either spring flow or deep wells. It is, therefore, inadequate to plan future supply capacities to meet average summer demands. Peak month demands were, therefore, estimated and added to the demand allocation module. Peak month demands were estimated by developing a monthly fraction of annual demand using data from Cache Valley systems as follows:

Month	Percent
Jan	4
Feb	4

Mar	4
Apr	6
May	11
Jun	15
Jul	18
Aug	17
Sep	9
Oct	4
Nov	4
Dec	4

The peak month for residential use (with no dual service) is, therefore, estimated as 1.54 times summer season average as follows: 18/11.7 = 1.54 (where 11.7 is the average of May through October). Residential connections served by dual systems are assumed to have no increase above summer average for peak month (the dual system experiences the peak). C&I demand has a much smaller summer peak because of the much smaller fraction of outdoor use. A 10% increase over summer average for C&I demand is, therefore, assumed for peak month. Unmetered demand is assumed to be equal to its summer average.

MODEL VERIFICATION

Scope of Test

The CWDSM calibration was tested by applying it to nine communities in Cache County. The communities were selected to provide a full cross-section of the factors which influence water use in the county, but the cities selected were also those which had the more reliable meter data for comparison with model predictions. The communities range from small rural farm towns to large urban communities. Table 4 summarizes key features of each community.

Each type of demand function was tested on each community to determine which function best modeled the community's water use. Because of the lack of separate multi-family water use data in most of the communities, the same MFH demand functions were used in all cases. The model results were then compared to metered water use data to determine the accuracy of the model.

The value of findings from comparison between modeled and metered demand is heavily dependent on the quality of the data provided by the cities regarding their metered water use. The term "quality" of the data refers specifically to the following aspects. Is residential usage strictly separated from commercial, agricultural, institutional, and other use categories? Is there a regular meter reading cycle which allows seasonal disaggregation of use? What fraction of homes make regular use of ditch systems for outdoor water use? Are household meters and production meters serviced on a regular basis to minimize incorrect meter data? The selected test communities generally had adequate to very good data, with adjustments required to data in some cases for seasonal overlap of meter reading schedules or to remove non-residential use.

Table 4. Test community descriptions

City	Population (1995)	SFU	MFU	Lot[a]	Dual Sys.	Water Rates
Cornish	220	72	2	0.75	None	$0.60/lk
Hyrum	5203	1179	211	0.26	90% Pipe	$0.45/lk
Logan	38,793	6150	7396	0.10	None	$0.45/lk
Mendon	733	203	21	1.0	80% Pipe	$0.30/lk
Nibley	1651	411	39	0.71	30% Ditch	$0.55/lk
North Logan	4472	998	171	0.64	60% Pipe	$1.20/lk
Providence	3911	1024	25	0.27	None[b]	$0.40/lk
Wellsville	2585	705	32	0.48	None[b]	$0.40/lk

Notes:
[a]Lot sizes are population weighted averages.
[b]Providence and Wellsville both have ditch irrigation systems. However, both were modeled as having no dual systems for seasons listed below.

Model Test Results

The results for the nine test communities are summarized in Table 5. Due to the data problems for the City of Logan's water use and the obviously extreme error between the model and the city's metered data, the following conclusions are presented exclusive of the model results for Logan. The "error" is the difference between the predicted and metered water use, expressed as a percentage of the metered water use. Because the nine communities vary significantly in population, the average errors are weighted by population in order to provide an indication of the model's accuracy for the region as a whole. Non-weighted averages are listed in parentheses following the weighted averages.

The results for the test communities indicate that the model does an effective job of projecting residential water use. The average annual error, excluding the City of Logan, is -2.1%(-3.9%). The average summer season and winter season errors are -0.7%(+0.9%) and +7.2%(+7.1%), respectively. The seasonal accuracy varies, but appears to be quite good for communities with well delineated areas of dual system coverage such as Wellsville, Hyrum, and North Logan. There are no apparent patterns of consistent under- or over-estimation for either winter or summer season use.

Table 5. Metered and predicted residential water use

City	Demand Function	Winter Water Use (mgal)			Summer Water Use (mgal)			Annual Water Use (mgal)		
		Meter	Model	% Δ	Meter	Model	% Δ	Meter	Model	% Δ
Cornish	Rural	5.2[a]	4.6	-11.5%	10.6[a]	9.7	-8.5%	15.8[a]	13.91	-12.0%
Hyrum	Urban	87.7	86.1	-1.8%	110.6	119.3	+7.9%	198.3	205.4	-3.6
Logan	Urban	411[b]	792	+92.7%	872[b]	1600	+83.5%	1284[b]	2392	+86.3%[b]
Mendon	Urban	11.2	13.5	+20.5%	18.5	18.7	+1.1%	33.4[3]	33.4	<1.0%
Nibley	Rural	27.4	23.4	-14.6%	64.3	84.1	+23.5%	91.7	107.5	-17.2%
North Logan	Urban	63.95	73.66	+15.2%	141.6	131.3	-7.3%	205.5	204.9	<1.0%
Providence	Rural	92.2	69.6	-24.5%	181.6	242.6	+33.6%	273.8	312.2	+14%
Smithfield	Urban	116	121	+4.3%	208	176	-15.4%	324	307	-5.2%
Wellsville	Urban	25.4	43	+69.3%	93.9	67.9	-27.7%	119.3	111.0	-7.0%
		Average %Δ =		+7.1%		+0.9%		-3.9%		
		Pop. Wt Qvg =		+7.2		-0.7%		-2.1%		

[a]Q_{sum} = 19.8 -(7.02 + 2.16), where 7.02 is dairy use, 2.16 is city park and cemetery. Q_{win} = 11.53-7.02.

[b]City of Logan billing and operation reports indicate 49% difference between production and billed municipal water use. Given the data discrepancies, no meaningful comparisons can be made between "metered" and modeled water demand.

The model appears to have the most difficulty in areas with ditch secondary systems used for outdoor watering in the summer. The summer season results for Nibley, Providence, and Wellsville are examples of this effect. Summer use is overestimated in Providence and Nibley, and underestimated in Wellsville.

Firm conclusions cannot be made as to the effectiveness of the multi-family housing functions, beyond the statistical results already presented. Unfortunately, the City of Logan contains the majority of multi-family housing units in Cache Valley, but cannot provide separate, reliable data for their water use on a city-wide basis. The results for North Logan, which has approximately 15% multi-family housing, provide some indication that the multi-family housing functions are reasonably accurate.

Those communities with the best quality data (Hyrum, Nibley, North Logan, and Smithfield) have a non-weighted average annual error of only 6.5%. Again, the quality of the water use data provided by the cities is crucial to evaluating the effectiveness of the model. Factors such as lack of seasonal and use sector disaggregation in reporting, poor maintenance of distribution piping and meters, and lack of good estimates for use of ditch systems cannot be accounted for in any model.

The classification of communities as either rural or urban is very subjective. However, it appears that the type of demand function used in each community (rural or urban function) matches what are likely to be common labels of "urban" or "rural" for these communities, with the possible exceptions of Wellsville and Mendon.

Model Results Using the WFWDSM Functions

The WFWDSM residential water demand functions were incorporated into the model in order to compare the results between the functions derived in this study and those used by the WFWDSM. The results are discussed in detail by Norby (1996), and only summarized here. The WFWDSM functions generally predict somewhat lower water use than the functions developed for Cache Valley, and the match with metered data is not as good as with the Cache Valley functions.

WATER DEMAND PROJECTIONS FOR CACHE COUNTY

The demand model results for each system in Cache County plus an estimate of the use by families with private water sources (unincorporated) are given in Table 6 for 1995, Table 7 for 2010, and Table 8 for 2020. Four of the systems shown are small private systems, and the rest are municipal systems.

Table 6. Model projection of demand for 1995

Cache County Water Demand Model Results : 1995

Climate Probability = 0.5
Summer Totals of Rain Potential ET in inches
Year Forecast 7.65 34.13
Average Year 7.65 34.13

Note : All Units are in Acre Feet

City	Estimated Population	WINTER Demand				SUMMER Demand				TOTAL ANNUAL DEMAND
		Residential	Industrial/ Commercial	Unmetered	Total	Residential	Industrial/ Commercial	Unmetered	Total	
Amalga	370	23	117	61	201	134	117	132	382	584
Benson	423	26	22	2	49	58	22	3	83	132
Clarkston	647	40	1	4	45	195	2	9	205	250
Cornish	218	14	12	3	29	57	12	4	74	103
Goaslind	48	3	2	0	5	8	2	0	10	14
High Creek	62	3	1	0	5	17	1	0	18	23
Hyde Park	2,660	137	2	14	152	212	8	28	241	393
Hyrum	4,986	264	417	31	712	386	310	40	843	1,556
Lewiston	1,564	99	33	11	143	557	73	25	615	757
Logan	38,659	2,431	1,452	274	4,156	3,893	2,058	274	5,619	9,775
Mendon	684	41	3	4	48	67	6	9	78	127
Millville	1,385	70	57	3	130	116	65	3	177	307
Newton	659	40	10	5	54	93	18	11	114	168
Nibley	1,310	72	5	20	97	280	15	20	305	402
North Logan	5,224	226	34	12	273	320	106	25	379	651
Paradise	580	28	0	0	29	61	0	1	62	90
Providence	3,809	214	7	22	242	794	58	56	857	1,099
Richmond	1,968	111	36	13	160	285	66	32	353	513
River Heights	1,361	86	0	11	98	168	0	11	179	277
Riverside	53	3	2	0	5	17	2	0	19	24
Smithfield	6,445	371	154	31	556	606	218	64	823	1,379
South Cove	102	6	2	1	9	12	2	1	15	25
Trenton	478	29	2	2	33	138	13	2	142	175
Unincorporated	6,387	405	0	0	405	2,175	0	0	2,175	2,580
Wellsville	2,224	132	31	15	179	220	115	39	290	469
County Total	82,306	4,876	2,401	539	7,816	10,867	3,287	788	14,057	21,873

Table 7. Model projection of demand for 2010

Cache County Water Demand Model Results: 2010

Climate Probability	=	0.5
Summer Totals of	Rain	Potential ET in inches
Year Forecast	7.65	34.13
Average Year	7.65	34.13

Note: All Units are in Acre Feet

City	Estimated Population	WINTER Demand				SUMMER Demand				TOTAL ANNUAL DEMAND
		Residential	Industrial/ Commercial	Unmetered	Total	Residential	Industrial/ Commercial	Unmetered	Total	
Amalga	491	31	150	81	263	177	150	175	503	765
Benson	493	30	23	2	55	68	23	4	94	149
Clarkston	813	50	1	5	56	245	3	11	258	314
Cornish	252	16	12	3	31	66	12	5	83	115
Goaslind	56	3	2	1	5	9	2	1	11	16
High Creek	71	4	1	1	5	19	1	1	20	26
Hyde Park	3,766	193	2	20	215	300	11	39	342	557
Hyrum	7,031	373	588	43	1,004	544	437	56	1,189	2,193
Lewiston	1,817	115	36	12	164	647	80	29	712	876
Logan	47,510	2,987	1,784	336	5,108	4,785	2,529	336	6,905	12,013
Mendon	976	59	3	6	68	96	7	12	112	180
Millville	2,205	112	91	5	207	185	103	5	281	488
Newton	817	49	10	6	65	116	19	13	139	204
Nibley	2,473	136	9	37	183	528	22	37	575	757
North Logan	8,172	354	53	19	426	500	165	38	591	1,018
Paradise	706	34	0	0	35	74	0	1	75	110
Providence	5,372	301	9	31	341	1,120	80	79	1,208	1,549
Richmond	2,730	154	44	18	216	395	86	44	483	699
River Heights	1,596	101	0	13	115	196	0	13	210	324
Riverside	70	4	2	1	6	22	2	1	24	31
Smithfield	8,335	480	193	40	713	783	273	82	1,059	1,771
South Cove	119	7	2	1	10	14	2	1	18	28
Trenton	552	34	2	2	38	159	13	2	164	202
Unincorporated	7,426	470	0	0	470	2,529	0	0	2,529	2,999
Wellsville	2,931	174	41	20	235	290	152	51	382	617
County Total	106,780	6,274	3,059	703	10,036	13,868	4,172	1,038	17,965	28,001

Table 8. Model projection of demand for 2020

Cache County Water Demand Model Results : 2020

Climate Probability = 0.5
Summer Totals of Rain Potential ET in inches
Year Forecast 7.65 34.13
Average Year 7.65 34.13

Note : All Units are in Acre Feet

City	Estimated Population	WINTER Demand				SUMMER Demand				TOTAL ANNUAL DEMAND
		Residential	Industrial/ Commercial	Unmetered	Total	Residential	Industrial/ Commercial	Unmetered	Total	
Amalga	653	41	195	108	345	236	195	233	664	1,009
Benson	564	34	24	2	60	77	24	4	105	165
Clarkston	1,003	62	1	6	70	303	3	14	318	388
Cornish	283	18	12	3	34	74	12	5	92	126
Goaslind	64	4	2	1	6	10	2	1	12	18
High Creek	83	5	1	1	6	22	1	1	24	30
Hyde Park	5,486	282	3	28	314	438	16	57	498	811
Hyrum	10,196	540	854	63	1,457	790	634	82	1,725	3,182
Lewiston	2,088	133	39	14	186	743	88	34	816	1,002
Logan	57,732	3,630	2,168	409	6,207	5,814	3,073	409	8,391	14,599
Mendon	1,442	87	4	9	101	142	10	18	164	265
Millville	3,854	196	159	8	362	323	181	9	491	854
Newton	1,008	61	10	8	78	143	20	16	169	247
Nibley	5,720	314	21	86	421	1,221	41	86	1,328	1,749
North Logan	13,867	600	90	33	722	848	279	65	1,003	1,725
Paradise	850	41	0	0	42	89	0	1	90	132
Providence	7,804	438	12	45	495	1,627	115	115	1,754	2,249
Richmond	3,866	218	55	25	299	560	116	63	678	977
River Heights	1,850	117	0	15	133	228	0	15	243	376
Riverside	94	6	2	1	8	30	2	1	32	40
Smithfield	10,767	620	244	51	915	1,012	345	106	1,362	2,277
South Cove	136	8	2	1	12	16	2	1	20	31
Trenton	630	39	2	2	43	182	14	2	187	230
Unincorporated	8,538	541	0	0	541	2,908	0	0	2,908	3,449
Wellsville	3,875	230	54	27	311	383	201	68	505	816
County Total	142,453	8,266	3,955	947	13,168	18,218	5,374	1,407	23,579	36,747

ALLOCATION OF DEMAND

Source Capacities

After projecting future water demands, the question which concerns each system manager is--how will these quantities be supplied? To provide a quantitative answer to this question, it is necessary to inventory the capacities of existing and proposed supply sources and to compare them with projected demands in a way that identifies potential shortages.
This is not so trivial an exercise as it might seem because of the way in which some water rights are structured. For example, a large fraction of supply sources for many Cache Valley cities consist of spring flows; and some large springs are shared by two or more cities. To determine source capacity, it is necessary to examine both the hydraulic (pipe or pump capacity), the hydrologic (watershed or aquifer capacity), and the water right (legal capacity). In a surprisingly large number of cases, for Cache Valley systems, both the hydraulic and hydrologic capacities are only roughly approximated from spot measurements. Therefore, in the allocation portion of the model, hydrologic and hydraulic capacities are not differentiated; but the estimate of minimum physical capacity is labeled hydraulic capacity.

The State Division of Water Rights has now made water right data available on the Internet; therefore, the data used as legal capacity were taken from this source. In a few cases, some data were missing; and, therefore, is shown with a -1 symbol (to prevent it from being treated as zero quantity).

In general, the intent was to select the minimum of the hydraulic and legal capacities for any particular source as the quantity used to allocate demand; however, in some cases, this does not reflect reality. For example, the Division of Water Rights has agreed, in some cases, to allow cities to move a diversion right from one well to another since they both pump from the same aquifer. In such cases, even though the legal capacity is less than the hydraulic capacity for a single well, the hydraulic capacity may be the proper limit because additional right is available from another source. Therefore, the legal right should be limiting only in terms of the total system rather than an individual source.

Wholesale Suppliers

In Cache County, there are no domestic water wholesalers. There are a few cases where adjacent cities have the physical capability to sell water to each other. However, these arrangements consist of a single pipe with a normally closed valve, and are mostly used only in emergency situations. For long-term planning purposes, such connections were, therefore, not included in the model.

Structure of Allocation Module

The allocation module screen allows two geographic levels of allocation report, and also allocation at two separate time increments--seasonal and peak month. The latter will be discussed first. For purposes of projecting future demands on the groundwater aquifer, seasonal volumes, aggregated to annual quantities, are useful. However, because there are no seasonal storage reservoirs for Cache Valley municipal supplies, a shorter time increment analysis is also needed. Allocation of peak month demands are, therefore, also provided.

City Level

This report gives the hydraulic and legal capacities of individual sources existing (or nearing completion) for a selected utility. The seasonal demands are shown, and the assumed allocation of demands to each source is also shown. The determination of which sources are used first are based on a simple priority number which matches the operating rule described by the system operator. Table 9 displays an example of this report for a single system. The associated demand is identified both by year and type of climate.

County Level

If the county level is selected, a summary of quantities for winter, summer, and annual demand and allocations from the total of all sources for each system (plus the county total) are given. Tables 10, 11, and 12 display this type of report for years 1995, 2010, and 2020, respectively. For the domestic users in unincorporated areas, there is no assumed limit to the source (several hundred individual wells or springs); and, therefore, no city level report exists. However, for the county level report, supply allocation is assumed to equal demand--this allows the county total demand and allocation to be consistent.

CONSUMPTIVE USE OF M&I DIVERSIONS

A separate study at the Utah Water Research Laboratory (Hughes, 1996) recently developed a method for estimating consumptive use in municipal systems in Utah. That method has been applied to each of the water systems in Cache County, and the results for 1995 are displayed in Table 13.

Whether or not the loss from sewage treatment plants should be added to the depletion quantity is subject to how one defines depletion. Since the areas now covered by oxidation lagoons were previously either pasture or wetlands, the related rate of *increase* in consumptive use may be quite small; and therefore, depletion above the lagoons may be the more accurate estimate of depletion. The averages shown at the bottom of Table 13 (39 percent depletion above the sewage treatment)

Table 9. Example of single city sources and demand allocation

Supply Allocation Summary for Clarkston **1995**

Climate Probability	=	0.5	
Summer Totals of	Rain	Potential ET	in inches
Year Forecast	7.65	34.13	
Average Year	7.65	34.13	

Total Demand in Kgal

Summer	Winter	Peak Month
66,890	14,630	16,951

Source Name	Legal Capacity in gpm		Hydraulic Capacity in gpm		Sequence	Allocation in Kgal			Shortage in Kgal		
	Summer	Winter	Summer	Winter	Number	Summer	Winter	Peak Month	Summer	Winter	Peak Month
Little Birch Spring	229	229	220	220	1	57,816	14,630	9,504	0	0	0
Big Birch Spring	1,347	1,347	140	140	2	9,074	0	6,048	0	0	0
City Creek Spring	225	225	60	60	3	0	0	1,399	0	0	0
Total						66,890	14,630	16,951	0	0	0

Note : -1.00 indicates that Legal Capacity was unavailable

Table 10. Supply allocation for 1995 (average climate)

Supply Allocation Summary for entire County : 1995

Climate Probability = 0.5
Summer Totals of Rain Potential ET in inches
Year Forecast 7.65 34.13
Average Year 7.65 34.13

Note : All Units are in Acre Feet

CITY NAME	Total Demand			Allocation			Shortage		
	Summer	Winter	Peak Month	Summer	Winter	Peak Month	Summer	Winter	Peak Month
Amalga	382	201	110	382	201	84	0	0	26
Benson	83	49	19	83	49	19	0	0	0
Clarkston	205	45	52	205	45	52	0	0	0
Cornish	74	29	18	74	29	18	0	0	0
Goaslind	10	5	2	10	5	2	0	0	0
High Creek	18	5	4	18	5	4	0	0	1
Hyde Park	241	152	60	241	152	60	0	0	0
Hyrum	843	712	163	843	712	163	0	0	0
Lewiston	615	143	161	615	143	161	0	0	0
Logan	5,619	4,156	1,522	5,619	4,156	1,522	0	0	0
Mendon	78	48	20	78	48	20	0	0	0
Millville	177	130	42	177	130	42	0	0	0
Newton	114	54	29	114	54	29	0	0	0
Nibley	305	97	78	305	97	78	0	0	0
North Logan	379	273	106	379	273	106	0	0	0
Paradise	62	29	16	62	29	16	0	0	0
Providence	857	242	224	857	242	224	0	0	0
Richmond	353	160	91	353	160	91	0	0	0
River Heights	179	98	45	179	98	45	0	0	0
Riverside	19	5	5	19	5	5	0	0	0
Smithfield	823	556	206	823	556	206	0	0	0
South Cove	15	9	4	15	9	3	0	0	1
Trenton	142	33	38	142	33	29	0	0	10
Wellsville	290	179	84	290	179	84	0	0	0

Table 11. Supply allocation for 2010 (average climate)

Supply Allocation Summary for entire County : 2010

Climate Probability = 0.5
Summer Totals of Rain Potential ET in inches
Year Forecast 7.65 34.13
Average Year 7.65 34.13

Note : All Units are in Acre Feet

CITY NAME	Total Demand			Allocation			Shortage		
	Summer	Winter	Peak Month	Summer	Winter	Peak Month	Summer	Winter	Peak Month
Amalga	503	263	134	503	263	84	0	0	51
Benson	94	55	22	94	55	22	0	0	0
Clarkston	258	56	65	258	56	56	0	0	10
Cornish	83	31	20	83	31	20	0	0	0
Goaslind	11	5	3	11	5	3	0	0	0
High Creek	20	5	5	20	5	4	0	0	1
Hyde Park	342	215	86	342	215	86	0	0	0
Hyrum	1,189	1,004	229	1,189	1,004	229	0	0	0
Lewiston	712	164	186	712	164	186	0	0	0
Logan	6,905	5,108	1,848	6,905	5,108	1,848	0	0	0
Mendon	112	68	28	112	68	28	0	0	0
Millville	281	207	67	281	207	67	0	0	0
Newton	139	65	35	139	65	35	0	0	0
Nibley	575	183	146	523	183	86	51	0	60
North Logan	592	426	165	592	426	165	0	0	0
Paradise	75	35	19	75	35	19	0	0	0
Providence	1,208	341	315	1,208	341	315	0	0	0
Richmond	483	216	124	483	216	124	0	0	0
River Heights	210	115	53	210	115	53	0	0	0
Riverside	24	6	6	24	6	6	0	0	0
Smithfield	1,059	713	265	1,059	713	265	0	0	0
South Cove	18	10	4	18	10	3	0	0	1
Trenton	164	38	44	164	38	29	0	0	15
Wellsville	382	235	111	382	235	111	0	0	0

Table 12. Supply allocation for 2020 (average climate)

Supply Allocation Summary for entire County : 2020

Climate Probability = 0.5
Summer Totals of Rain Potential ET in inches
Year Forecast 7.65 34.13
Average Year 7.65 34.13

Note : All Units are in Acre Feet

CITY NAME	Total Demand			Allocation			Shortage		
	Summer	Winter	Peak Month	Summer	Winter	Peak Month	Summer	Winter	Peak Month
Amalga	664	345	167	508	345	84	156	0	84
Benson	105	60	25	105	60	25	0	0	0
Clarkston	318	70	81	318	70	56	0	0	25
Cornish	92	34	22	92	34	22	0	0	0
Goaslind	12	6	3	12	6	3	0	0	0
High Creek	24	6	6	24	6	4	0	0	2
Hyde Park	498	314	125	498	314	125	0	0	0
Hyrum	1,725	1,457	332	1,725	1,457	332	0	0	0
Lewiston	816	186	213	816	186	213	0	0	0
Logan	8,391	6,207	2,224	8,391	6,207	2,084	0	0	140
Mendon	164	101	41	164	101	41	0	0	0
Millville	491	362	118	491	362	81	0	0	37
Newton	169	78	43	169	78	39	0	0	4
Nibley	1,328	421	335	523	421	86	805	0	249
North Logan	1,003	722	280	1,003	722	280	0	0	0
Paradise	90	42	23	90	42	23	0	0	0
Providence	1,754	495	458	1,754	495	400	0	0	58
Richmond	678	299	175	678	299	145	0	0	30
River Heights	243	133	61	243	133	61	0	0	0
Riverside	32	8	8	32	8	8	0	0	0
Smithfield	1,362	915	341	1,362	915	341	0	0	0
South Cove	20	12	5	18	12	3	2	0	2
Trenton	187	43	50	173	43	29	13	0	21
Wellsville	505	311	146	505	311	146	0	0	0

Table 13. Cache County consumptive use estimate

CITY	PPH	Net ET	Dual System Fraction	Over Irrigation fraction	LOT acres	Green Area acres	Winter Demand g/p/d	Indoor Summer g/p/d	Outdoor Summer g/p/d	Winter Depletion Fraction	Summer Depletion Fraction	Annual Depletion Above Sewer Treatment	Additional Loss in Treatment Fraction	Annual Depletion Including Sewer Tr.
Amalga	3.24	1.25	0	0.24	0.45	0.31	113	122	265	0.15	0.60	0.50	0	0.50
Benson	3.16	1.25	0.85	0.24	0.45	0.31	113	122	41	0.15	0.31	0.25	0	0.25
Clarkston	3.22	1.25	0	0.24	0.45	0.31	110	119	266	0.15	0.60	0.50	0	0.50
Cornish	2.95	1.25	0	0.24	0.45	0.31	114	124	291	0.15	0.61	0.51	0	0.51
Hyrum	3.77	1.25	0.9	0.24	0.26	0.18	95	102	13	0.15	0.23	0.19	0	0.19
Lewiston	3.2	1.25	0	0.24	0.45	0.31	113	123	268	0.15	0.60	0.50	1	1.00
Mendon	3.41	1.25	0.7	0.24	0.45	0.31	108	117	75	0.15	0.41	0.32	0	0.32
Newton	3.45	1.25	0.76	0.24	0.45	0.31	107	116	60	0.15	0.37	0.29	0	0.29
Nibley	3.8	1.25	0.3	0.24	0.44	0.31	98	106	158	0.15	0.54	0.44	0	0.44
Paradise	3.58	1.25	0.8	0.24	0.45	0.31	87	94	48	0.15	0.37	0.29	0	0.29
Providence	3.77	1.25	0	0.24	0.27	0.189	100	108	139	0.15	0.52	0.41	0.22	0.54
Richmond	3.37	1.25	0.54	0.24	0.29	0.203	101	109	77	0.15	0.42	0.33	0.2	0.46
River Heights	3.24	1.25	0	0.24	0.21	0.147	113	122	126	0.15	0.48	0.38	0.22	0.51
Smithfield	3.47	1.25	0.76	0.24	0.28	0.196	103	111	38	0.15	0.32	0.25	0.22	0.41
Trenton	3.12	1.25	0	0.24	0.45	0.31	116	125	275	0.15	0.60	0.50	0	0.50
Wellsville	3.43	1.25	0	0.24	0.34	0.238	106	115	192	0.15	0.56	0.46	0.2	0.56
North Logan	3.86	1.25	0.41	0.24	0.32	0.224	77	83	95	0.15	0.50	0.39	0.22	0.53
Hyde Park	3.88	1.25	0.78	0.24	0.45	0.31	92	99	49	0.15	0.37	0.28	0.22	0.44
Logan	3.03	1.25	0	0.24	0.12	0.084	112	121	77	0.15	0.40	0.31	0.22	0.46
Millville	4.2	1.25	0.2	0.24	0.45	0.31	91	98	163	0.15	0.56	0.45	0	0.45
Goaslind	3.39	1.25	0	0.24	0.45	0.31	104	112	253	0.15	0.60	0.50	0	0.50
South Cove	3.27	1.25	0.67	0.24	0.45	0.31	107	116	87	0.15	0.43	0.33	0	0.33
High Creek	3.45	1.25	0	0.24	0.45	0.31	100	108	249	0.15	0.61	0.51	0	0.51
Riverside	3.31	1.25	0	0.24	0.45	0.31	107	116	259	0.15	0.60	0.50	0	0.50
Unincorporated	3.16	1.25	0.5	0.24	0.45	0.31	113	122	136	0.15	0.50	0.39	0	0.39
									Averages	0.15	0.48	0.39	0	0.47

are not weighted for volume of use. A weighted average for this quantity is 33 percent. The Utah Division of Water Resources and the Division of Water Rights have agreed to use 33 percent as the best estimate of depletion for the Cache valley region.

CONCLUSIONS

Total water diversions for use in municipal type systems in Cache County in 1995 were approximately 7,082 million gallons (21,735 acre feet). The 1995 population of 81,883 is expected to increases by 73% to 141,889 in 2020. The CWDSM projects a related increase in these water diversions to 11,918 million gallons (36,580 acre feet); an increase of 68% during this 25-year period.

In terms of average rates of use, the figures above represent diversions of 30 cubic feet per second (cfs) in 1995 and 50.6 cfs in 2020. Of these amounts, 33% is estimated to be lost from the hydrologic system by evaporation. The balance is returned either directly to surface streams, or to groundwater. The 20.6 cfs increase in estimated diversions from 1995 to 2020 will result in an increased depletion from the Bear River Basin of about 6.8 cfs.

Not all of the increase in diversions will require new water rights. A significant fraction of the increased demand will be provided from higher use rates on existing wells. However, as shown in the demand allocation summaries for years 2010 and 2020 (Tables 11 and 12), an increasing number of systems will experience shortages unless new supplies are developed.

The groundwater aquifer in Cache Valley stores an enormous quantity of water relative to both current and future projected demands. Therefore, it is reasonable to assume that groundwater represents the most economical; and, therefore, the most probable source for new water development. An exception may be in the northwest region of the county where wells are less productive.

LITERATURE CITED

Erickson, C.R., 1991, The Effect of Dual Systems on Price Elasticity of Residential Water Demand. M.S. Thesis, Utah State University, Logan, UT.

Hansen, R.D. and R. Narayana, 1981. A Monthly Time-Series Model of Municipal Water Demand. Water Resources Bulletin, 17(4):578-585.

Hughes, Trevor C., 1996, Consumptive Use of Municipal Water Supply, Report to the Utah State Water Resources Department.

Limaye, Umesh S., et al., unpublished, Analysis of Water Demanding Landscapes Using Multisprectral Videography, American Water Resources Association (in review).

Norby, Gregory, 1996, Residential Water Demand Projection in Cache County, M.S. Thesis, Utah State University, Logan, Utah.

Wang, Yu Min, 1992, Modelling of Climate Change on Urban Water Demand. PhD Dissertation, Utah State University, Logan, Utah.

Wasatch Front Water Demand/Supply Model, 1993, Joint publication from Utah State University, Utah Division of Water Resources, US Department of the Interior, and US Bureau of Reclamation.

APPENDIX A

User's Manual

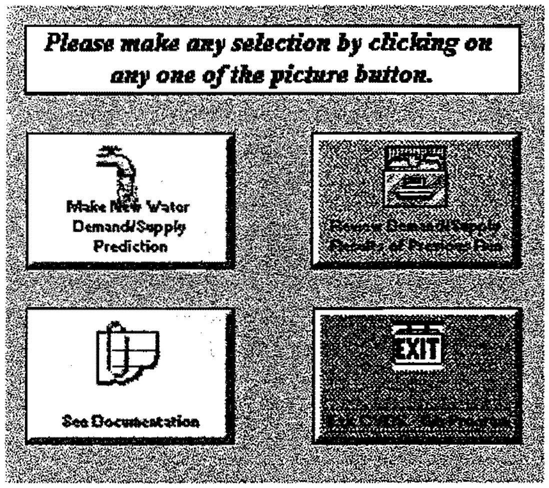
CACHE WATER DEMAND & SUPPLY MODEL

USER MANUAL

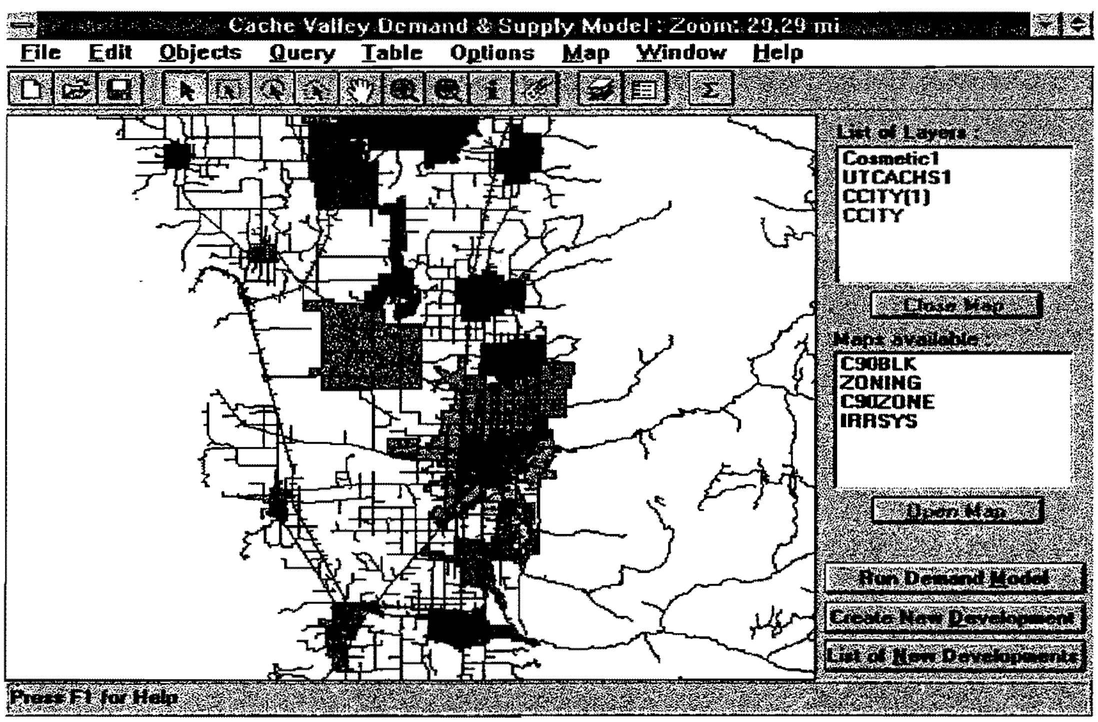
Utah State University
1997

The model is a GIS based platform which uses MAPINFO format for the maps (which are Tiger Files). Microsoft's Visual Basic programming language was used to develop the shell which interfaces the GIS maps and census data with the other modules and data. Use of the model is quite easy and mostly intuitive. The information which follows is therefore a brief explanation of the definitions, language, and tasks which the user will encounter on each screen while using the model. A more detailed description of the demand function parameters and map layers is given in the body of the project report or in the M.S. Thesis of Greg Norby.

Initial Screen



The first screen gives the user a choice of either running the demand model or reviewing the previous run. By clicking the *Make new prediction* button the following screen appears.

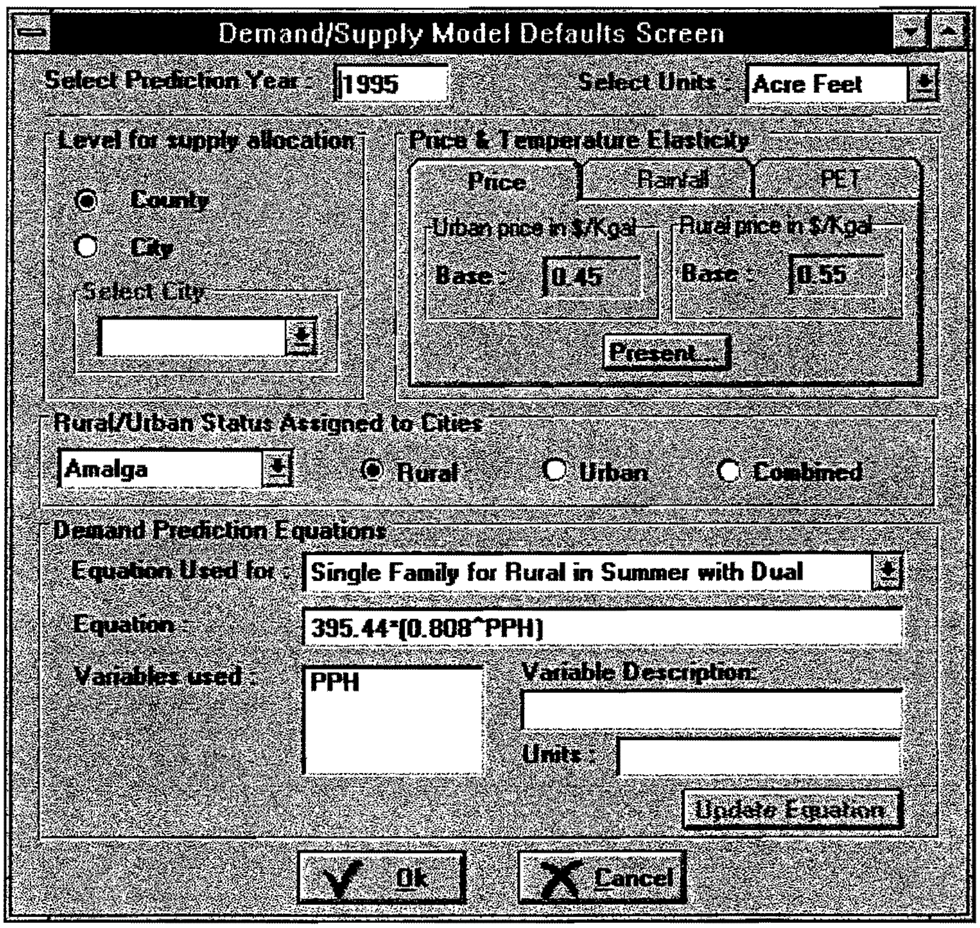


The screen above allows the user to either

- Make a new model run, or
- Create a new development (a new sub-division which did not exist when the model was calibrated), or
- View a list of proposed new developments (such as a proposed sub-division).

The row of icons across the top of the screen allows manipulation of the maps (such as zooming in to view more detail, identifying a particular system, editing a map layer, etc.). However, no such action is needed to run the current version of the model. These map tools provide MAPINFO functionality. The box labeled *List of Layers* names the map layers existing on the current screen. The box labeled *Maps available* lists the maps available but not currently displayed on the screen.

Demand/Supply Model Defaults Screen



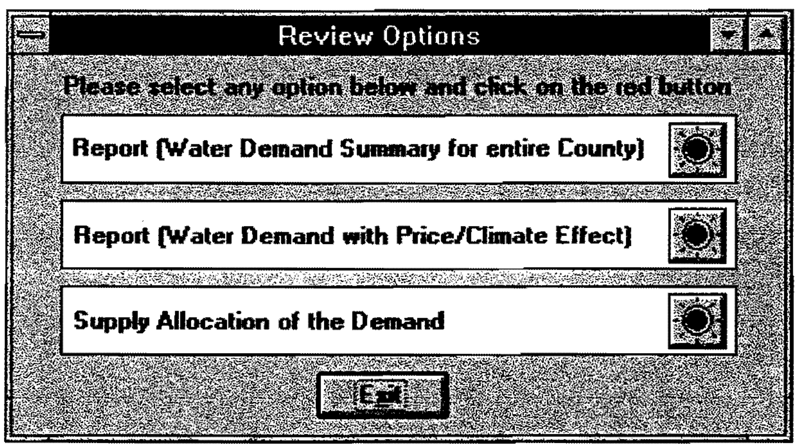
Clicking on *Run Demand Model* button displays the screen above which allows the user to change any of the demand and/or supply model parameters such as: selecting the year to be predicted; the dimensions of water volume (acre feet or thousands of gallons), marginal price each city charges for water; type of climate for the year predicted (average summer temperature and summer precipitation probability distribution).

The water demand report has two fixed formats (selected later); however, there are some options on this screen for the type of supply allocation report as follows: The box labeled *Level for supply allocation* allows the user to view a summary allocation report for all cities (County level); or for only a single city (city level). The *Select City* box also provides an option for obtaining a separate report for every city.

The model provides three possible types of demand functions — *rural, urban,* or *combined.* During the calibration process the best fit type has been selected and the related box simply displays the selected function. The user cannot now change these selections since this functionality has been disabled.

The Demand Prediction Equation box displays the various types of demand functions which are needed for different land uses, the actual equations, and the parameter included in each equation. These are not changeable by the user.

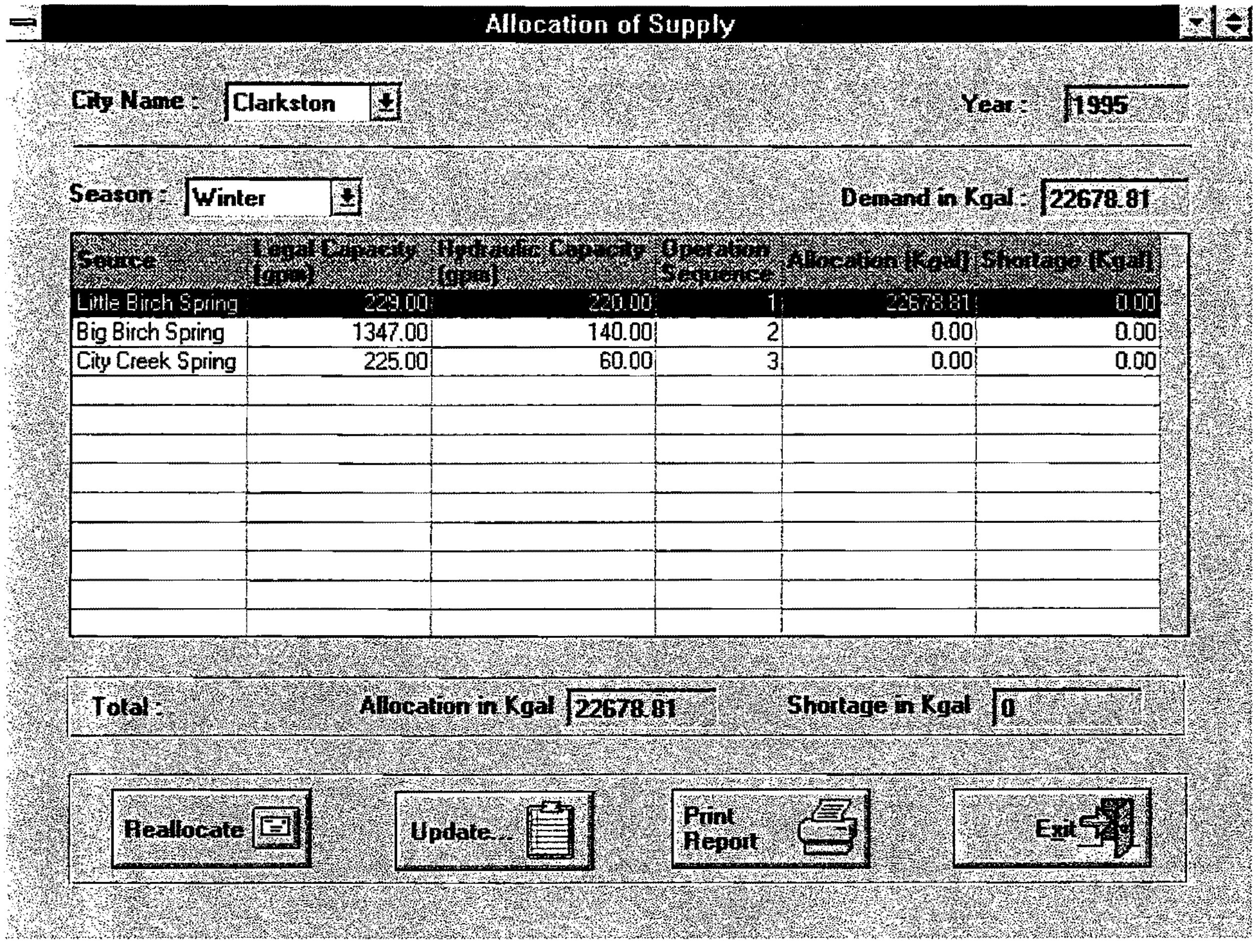
If the user accepts all of the default (previous run) parameter values, no action is required except clicking OK. Clicking OK displays a message box which allows either viewing a previous run or running a new one with revised parameters (such as climate or year). The user may, however, change either the allocation supply level or the water unit dimensions and without making a new run.



After making the selection the message box above will appear (several minutes later if a new run was selected). This box allows selection of the types of reports desired as follows:

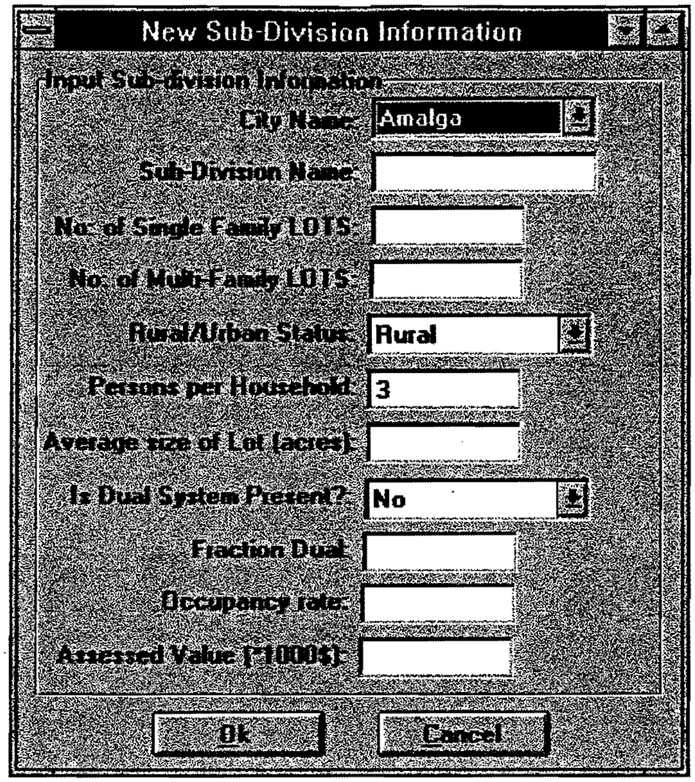
- The first box is the normal report desired for viewing water demand (all cities).
- The second box was provided for use during the model calibration procedure, since it displays the changes in demand related to either the price or climate selected. It is still available for the user's information.
- The third box performs the supply allocation level as previously selected.

Selection of the demand report displays the report on the screen and a row of icons on the bottom of the screen allows either printing the report, changing the report scale (the magnifying glass); or the report can be changed into any number of formats including spread sheets (the suitcase).



Selecting the *Supply Allocation* report displays the screen above, which gives (for the city last selected) the individual supply sources and the capacities (legal and hydraulic) of each. The city displayed can be changed by using the *City name* box. The total allocated and any shortage are also displayed.

The *Update* button allows the addition of a new source or modification of the existing source capacities. If such updates were performed the user should then use the *Reallocate* button. The *Print Report* button will print the level of report (all or a single city) as selected previously.



New Developments

Clicking the *Create New Development* button brings up the screen above. This requires the user to input each of the demand parameters required for the type of subdivision which is being proposed. Upon completing these data, and clicking OK, the summer and winter demand will be displayed. A message box then asks the user whether to make this development permanent, which will add the related volumes to that city's existing demand during any future runs.

The other button related to new developments will provide a list of all such developments previously made permanent (for all cities). That screen is editable (the development previously made "permanent" could now be deleted); and the report could be printed.