Computer aided evaluation of the value of water for irrigation
by William Glen Greiman

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Agricultural Engineering
Montana State University

Abstract:
A method of determining a site specific value of water for irrigation is presented. The method presented uses designer interactive computer programs, which incorporate computer aided design (CAD) and spreadsheet software, to aid in the design and economic evaluation of an irrigation system. The value of water is found by budgeting all the costs and benefits of a farming operation before and after irrigation development and comparing them. The difference between the farm's before-and after-development return to land is attributed to the value of the irrigation water.

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William Glen Greiman

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ABSTRACT

A method of determining a site specific value of water for irrigation is presented. The method presented uses designer interactive computer programs, which incorporate computer aided design (CAD) and spreadsheet software, to aid in the design and economic evaluation of an irrigation system. The value of water is found by budgeting all the costs and benefits of a farming operation before and after irrigation development and comparing them. The difference between the farm's before-and after-development return to land is attributed to the value of the irrigation water.

CHAPTER 1

INTRODUCTION

"Nature never gives anything to anyone: everything is sold. It is only in the abstraction of ideals that choice comes without consequences." Ralph Waldo Emerson.

Throughout our country's history, water has been, for the most part, perceived as an abundant resource. Water shortage problems have been in distribution rather than in actual water scarcity. This abundance of water has fostered a social and political attitude that demands an adequate supply of good quality water. The high demand for water has spurred the development of large government-subsidized water projects, such as massive dams and water distribution systems in the water-short Southwest. Although multipurpose, water from these projects was primarily allocated to irrigation. Recent droughts and an ever increasing demand for water has focused attention on present and possible future areas of water scarcity.

Today, however, concern for the environment and government spending are making the development of new capital-intensive water projects more and more difficult. Past water projects have already claimed the most socially, economically, and environmentally acceptable sites. Also, increasing environmental concerns have raised legal questions of minimum stream flows and water quality.

Complicating the problem is our country's antiquated method of water allocation. In the west water has been allocated by the legal doctrines of "first in time first in right" and "beneficial use". In other words, a user can acquire the right to use water for almost any purpose and that use has a priority date based on when the right was acquired. As a result, the early mining and agricultural needs have priority over growing municipal and industrial needs.

All these factors, combined with the recent droughts and ever-increasing water demand, have focused attention on the problem of water scarcity and water allocation. The cost of water has been associated with the cost of development, delivery, and treatment with no value placed on the water itself. The growing demand for water has been accompanied by the realization that water is a natural resource and does have economic value. In many areas, conflicts are developing over competing uses for a limited supply of usable water. There are conflicts between states and among water users. One such conflict is between the allocated rights of irrigation and other water uses in already over-allocated areas. Another conflict is arising over which uses should have priority in future allocation of limited water supplies.

Future allocation or reallocation of water will have to be based on some evaluation of the competing uses. This thesis presents a method of using computers to determine the average, farm specific value of water for irrigation so that farmers and water planners can objectively evaluate alternatives.

A basic economic maxim is that the marginal value of a limited resource should be equal among competing uses in order to obtain maximum economic efficiency. Marginal value of a resource is the change in benefit realized by the last increment of the resource developed. If economic efficiency is to be the measure of conflicting water uses, the marginal value of these uses must be determined. In a purely competitive market the price for a resource tends toward this equal marginal value. However, water is almost never purchased in a free market situation.

The marginal value of water has been estimated in a number of ways. An analytical approach relates the volume of water, used or consumed, to the value of the end product with an empirical equation (Frank, 79). This demand curve can be differentiated to find water's marginal value, at any use level, and its optimal use level and value. This method is mathematically exact for the empirical function, but the function requires large amounts of information that must be carefully examined to obtain their proper relationships. Another approach budgets all the cost and incomes in an enterprise, including management costs, and attributes the balance to the value of water (Lacewell, 1974). This would give the average value of water for that situation, or an approximation of marginal value in a rational free market. Budgeting, however, is time consuming and requires that all resource and product prices, other than water, be known or estimated.

Also, since it only gives average values for a situation, an optimal value and level of use are difficult to find.

Optimal levels of water use can be determined at different water values by using the variable costs from the budgeting approach with linear programing methods. Linear programing optimizes the solution to a set of linear equations. For example, one can determine the production costs and values for various crops through budgeting. Then linear equations that describe the water cost, crop yield, and crop prices are established. Linear programing can use these equations, subject to the appropriate constraints, to find the optimal level of production for each crop. When this is done, with increasing price levels of water, crops will drop out of the solution until no irrigated crops remain in the optimal solution. The water price at which a crop drops out of the optimal solution is its "optimal marginal water value". Thus, marginal water value can be calculated and compared to the range of crops raised.

Most user water demand is inelastic (Gibbons, 86). This means that for a given change in price a user will use less water; in percentage terms, however, the change in use will be smaller than the change in price. Municipal water use provides a good example. In Colorado, where water is allowed to be traded freely, municipal water has a marginal value of $300/ac-ft (Gibbons, 86). Many industrial uses have threshold water price levels. For example, the cost of water would need to be $933 to $1300/ac-ft before a coal-fired power plant would change from once-through cooling to a dry cooling tower method (Gibbons, 86). In many industrial processes, water only contributes a small amount to the overall cost of the end product. In coal fired electrical production, for example, a $200/ac-ft water price increase would only raise the price of the electricity generated by 1-2% (Campbell, 85). The price of water to transport coal in coal slurry pipelines is estimated at $1600/ac-ft (Campbell, 85).

The demand for water in hydropower facilities is set by the load structure of the utilities. Utilities have the responsibility to meet consumer demand for electricity, which varies during the day and throughout the year. Established hydropower is generally the cheapest way to meet this demand in the Pacific Northwest, but the capacity is limited (Northwest Power Plan, 86). Most hydropower facilities have reservoirs that can store the water's potential energy, allowing power-generating levels to be quickly changed to meet varying load demands. Thus, hydropower is usually used to meet peaking loads, while thermal cycle power units are used to supply the base load. The value of water for hydropower electrical generation is therefore considered, by some, to be the cost at peak load demand. While the amount of power that can be generated by an acre-foot of water is easy to calculate, its value is subject to interpretation.

It is virtually impossible to place a dollar value on water for its environmental and aesthetic utility. Society is recognizing these uses by setting minimum allowable stream flow levels and reservoir draw down elevations, and by restricting water uses that degrade water quality. The value of water in these cases is considered to be zero as long as minimum flows and qualities are maintained. This is also the case with navigational uses of water. However, when minimum flow is not available, the loss of revenue to an economic system can be estimated for navigational uses of a river system. Alternatively, one can estimate the increased shipping tonnage that is gained by artificially maintaining a minimum required flow.

Irrigated agriculture has been and will continue to be the largest water consumer in the West. However, as water becomes increasingly scarce some reallocation of water from irrigation to other uses seems inevitable. This is important to both the farmer and the resource planner. The farmer needs to know the value of his irrigation water to make rational marketing decisions. Similarly, the resource planner needs to know the value of water for competing uses to make rational water allocation policies.

The value of water for irrigation is extremely variable and difficult to determine. Fluctuating product end prices, varying response characteristics, and operation-specific production costs can cause differing water values for similar crops in the same area. While statistical production functions can determine regional water values these values will at best be aggregate averages. They are of little value for estimating water values for specific situations (Young, 72). Many studies have used production functions to estimate regional water values for irrigation. Frank (1979) found that the value of water for agriculture varied from $27.79/ac-ft in California, to $1.71 in Idaho (based on a nine variable Cobb-Douglas production function derived from regional agricultural statistics). Other production functions have indicated a marginal value of $120 for the first acre-inch of water applied to corn in Oregon, and no value for water when over 18 inches is applied (Miller, 61).

Lacewell, Sproutt, and Beattie (1974) used the Texas Agricultural Extension Service budget generator to show the value of water for several crops at differing yields and prices. This study shows a water value of $92/ac-ft for corn (@ 120 bu/ac yield and $3/bu) and $61/ac-ft for wheat (@50 bu/ac yield and $3.50/bu). Willitt, Hathorn, and Roberts (1975) used crop budgets to find water values that ranged from $7/ac-ft for grain sorghum to $67/ac-ft for sugarbeets. Using linear programing methods, Condra, Lacewell, and Sproutt (1975) found water values that varied from $8/ac-ft for wheat to $72/ac-ft for soybeans in the Texas High Plains. In another linear programing analysis Martin and Snyder (1979) showed irrigation water values varying from $23/ac-ft for grain sorghum to $990/ac-ft for dry onions in Arizona.

Griffin (1976) used linear programing methods to show that the value of water ranged from $17.09 to $94.62 per acre-foot for crops in Southwestern North Dakota. Anderson (1961) analyzed the active water market in Colorado to determine a value of $3.50/ac-ft for agricultural water. Young and Gray (1972) concluded that the value of water for irrigation ranged from $5 to $25 /ac-ft, with an average value of $10/ac-ft, for unsubsidized agriculture.

Due to the variability of crops, prices, productivity, and methods of analysis, Young and Gray (1972) questioned the advisability of using regional water values for irrigation. Clearly, a standardized site-specific method of evaluating irrigation water value is needed.

Such a method would require extensive farm budgeting and yield data for each site analyzed.

A method is presented in this thesis that incorporates computer aided design (CAD) and spreadsheet software programs to quickly estimate a site specific value of irrigation water. There are other methods that can be used to determine all the costs for an irrigation development. For example the SCS has developed a FORTRAN program call "IRRISYS" (SCS, 79) that designs distribution systems and calculates the water requirements for a large irrigation development. However, this program doesn't determine the infield system design or costs such as pivot and wheel lines. These costs are entered by the user. King, Sauer, and Busch have developed a comprehensive FORTRAN program on irrigation system programing (King, 87). This program does determine irrigation development costs and system requirements but requires extensive user input for each component in the irrigation system (ex. length and location). Licht has developed a method of using CAD to draft an irrigation design and determine system lengths and areas (Licht, 87). Licht's method doesn't design system components within the CAD program, leaving the designer to manipulate the information (in a spreadsheet) to determine system requirements and costs.

The Cooperative Extension Service at Montana State University uses a computer program that determines the cost of owning and operating farm machinery (Johnson, 84). The purpose of the program is to aid farmers in making machinery management decisions. While this program determines machinery ownership costs, it is not set up to easily determine the total equipment costs for each crop raised on a specific farm. Washington State University has developed a similar program (Mohasci, 84). The Cooperative Extension Service also produces enterprise cost studies that budget all the costs and revenues of selected farming scenarios (Fogle, 80)

These components can be used to budget the costs and revenues of an irrigation development. However, the process would be cumbersome and time consuming. This thesis presents a method for quickly generating site specific farm budgets. The costs of new irrigation developments are accounted for, including annual irrigation costs. Using the computer aided irrigation design and economic analysis method developed and explained in the following text, the task of evaluating the value of water for irrigation is both less difficult and more accurate. Both farmers and water resource planners will gain by the ability to obtain more site-specific irrigation water values.

CHAPTER 2

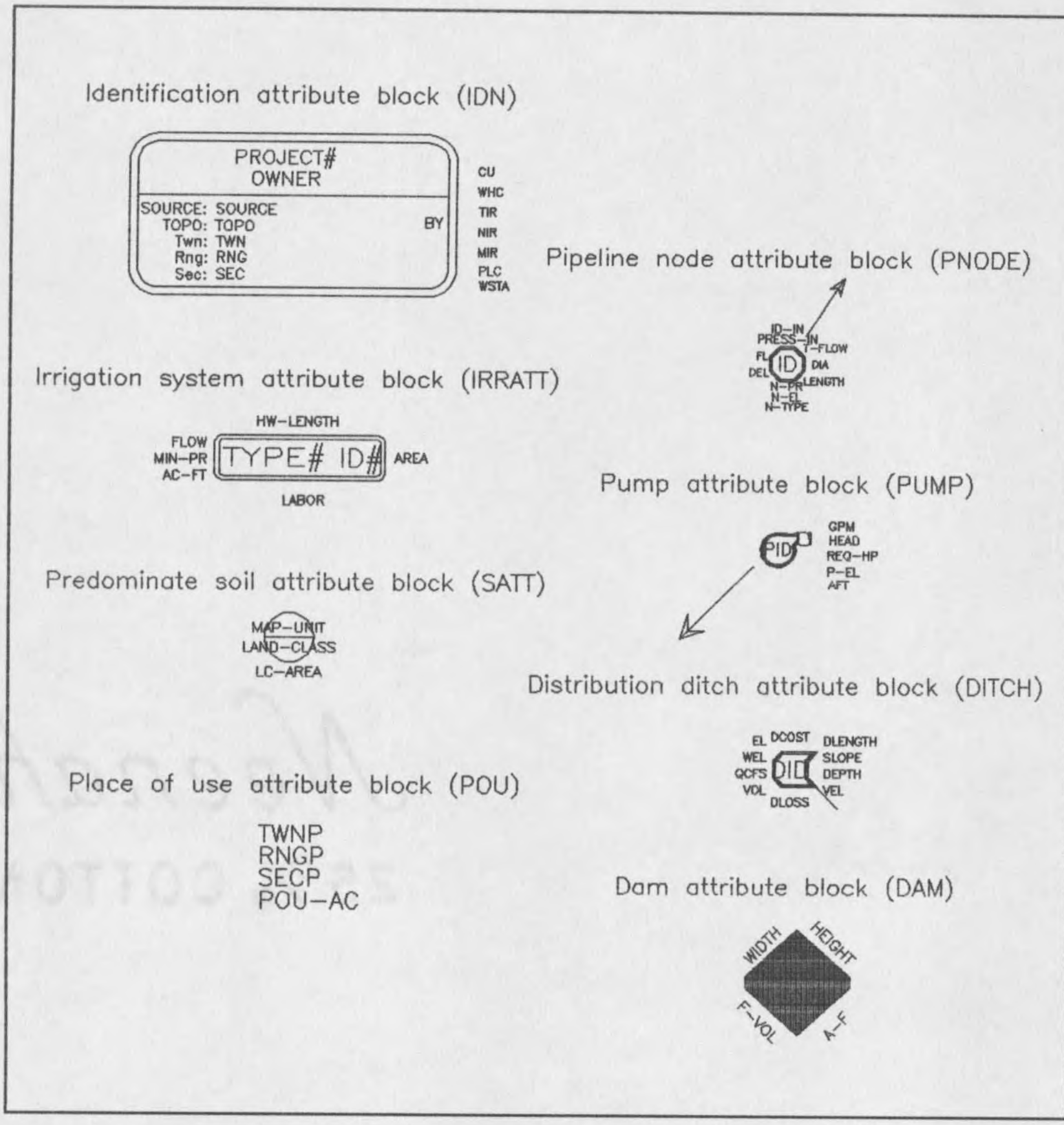
GENERAL COMPUTER SOFTWARE DESCRIPTION

The method of determining the value of water for irrigation developed in this thesis uses commercially available computer aided design and spreadsheet software programs: specifically, AutoCAD computer aided drafting and design (AutoCAD rel. 9.0, 1987) and Lotus computer spreadsheet (Lotus 123 rel 2.01, 1987) software along with a graphics-capable computer. This chapter introduces the basic concepts and nomenclature of these software programs.

AutoCAD

AutoCAD is an open architecture graphics software program that allows the user to modify the program for a specific purpose. In this case, AutoCAD was used to design irrigation systems. With AutoCAD the user can draw points, lines, geometric objects, and perform freehand traces. These drawing components, or "entities" are drafted onto the computer screen using an input device (similar to a keyboard) called a "digitizing tablet". The digitizing tablet can be calibrated to any map scale. Using a digitizing tablet and a printer or plotter, these entities can be drafted and reproduced on a map at any desired scale.

Figure 1. Attribute blocks used in AutoCAD irrigation designs.



AutoCAD also allows the user to enter information or "attributes" associated with each drawing entity. Together, the entities and their attributes are referred to as "blocks". The information in each block can be written to an ASCI file for use in Lotus 123 spreadsheets. Finally, AutoCAD allows the user to write interactive LISP programs. These programs can draw and manipulate entities and query the user for information used in entities' attributed blocks. There are eight attributed blocks used in the irrigation design process (Figure 1).

Lotus 123

A spreadsheet is a computer program that allows the user to manipulate discrete units of information. It consists of numbered rows and alphabetically headed columns, where each cell has a unique "address" (e.g. A11, Z182 ..). A cell can contain either an alpha-numeric label, a single number, or a mathematical formula. A cell formula can contain numbers, cell addresses, mathematical operators, or functions. The spreadsheet performs formula calculations, using values from other cells where indicated, and stores the result in that cell. The following is a list of mathematical operators in order of precedence:

^	exponentiation
*	multiplication
/	division
+	addition
-	subtraction
=	equal
<	less than
>	greater than

A function enables the user to perform more complex mathematical manipulations. Functions are indicated by the character @ followed by an "argument", or list of values (e.g. @SUM(A1...A10)). The most commonly used spreadsheet functions are @SUM and @IF. The @SUM function totals the cell values contained within the "range", or group of cell addresses, specified in the argument. The @IF function is a logic statement that evaluates an argument. If the condition is true the spreadsheet calculates the value of the first argument; if it is false, it calculates the last argument. In the example @IF(A1<10,B15,0), if the value in cell A1 is less than 10, the resulting value will be that of B15; but if the value of cell A1 is equal to or greater than 10, the resulting value will be 0. (A listing of functions and their arguments can be found in LOTUS 123 manuals.)

In the spreadsheets developed in this thesis, "label cells" explain parts of the spreadsheet, designate units, or head columns and rows of data. Labels at the head of a row or column describe the data in that column or row. Cell values can be user input variables, standard parameters, calculated data, or summary result data. The spreadsheet is "protected" so that the only easily altered cells are user input variable cells. The spreadsheet is "menu" driven to make it more user friendly. The menu allows the user to view parts of the spreadsheet, change user input variables, and print sections of the spreadsheet without directly accessing the entire spreadsheet.

CHAPTER 3

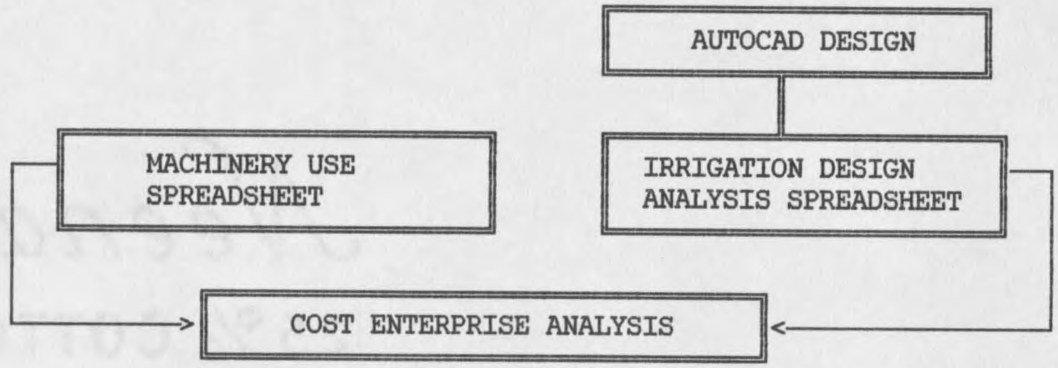
METHODOLOGY

To evaluate the economic feasibility of an irrigation development, one must analyze and compare before- and after-development scenarios. This analysis is done with the Farm Enterprise Analysis spreadsheet. The spreadsheet requires economic input data on crops raised (acres, yield, and prices), chemical use, irrigation costs, and machinery costs. The output to be compared is the farm's return to land, including the break-even price and yield for each crop.

The Machinery Use spreadsheet calculates the costs of owning and operating machinery. This spreadsheet computes for each scenario the fixed and variable costs of machinery ownership based on input variables on acres of crops raised, interest rate parameters, equipment used, number of annual equipment operations, and annual truck use.

AutoCAD and the Irrigation Design Analysis (IDA) spreadsheet are used to determine the annual costs of the irrigation systems. The designer enters the system components while AutoCAD answers program queries about the irrigation development site, storing the information in attribute blocks that are then transferred to Lotus 123. These blocks include information on size of equipment, amount and diameter of pipeline, required flow, number and size of pumps, and total water required. The IDA spreadsheet then inserts this information into the appropriate spreadsheet location and calculates annual costs by summing annualized component costs. This information is then transferred to the Enterprise Cost Analysis spreadsheet to determine the farm's total budget. The value of water for that farm scenario is the difference in the net return to land from the before- and after-development scenarios. The flow chart in Figure 2 shows the interaction between the spreadsheets and AutoCAD.

Figure 2. Flow chart showing spreadsheet relationships.



This thesis presents and explains the development of these spreadsheets and the AutoCAD programs. The spreadsheets are presented in range sections following the order in which they are accessed within the spreadsheet. The ranges are then briefly explained in terms of the range's function and its relation to the rest of the spreadsheet. There are several levels of named ranges in the spreadsheet: large information blocks and calculating cells that are used to organize the spreadsheet, titled columns and rows that indicate similar types of cell information or calculations, and individual cells for addressable input or parameter values. These ranges are capitalized and abbreviated as they appear in the spreadsheet when referred to in the major range area explanations. Each range area explanation includes a table, which is a range printout followed by an explanation of calculating cell formulas. Many titled ranges contain similar formulas with addressed cells changing relative to the calculating cell's position, in which cases only the first cell formula in the range is listed and explained. A complete listing of cell formulas for each range presented is listed in Appendix B.

Chapter 8 demonstrates the method of determining the value of water for three irrigation development sites. Four example problems show the variability of irrigation water's value. The first example is for a large cattle ranch that develops a pivot close to the Missouri River. The second example is the same pivot irrigation system used in example one, developed by a dryland grain farming operation. The third example is a small farm-ranch developing two wheel lines on a high terrace of the Missouri river. The last example is for a dryland farm developing a large six pivot irrigation project on a terrace of Belt Creek in Chouteau county.

Each example problem description contains a summary of the machinery use and enterprise cost spreadsheets for the before development scenario. Next, the irrigation development drawing is presented along with its annualized cost summary. This information is then included in the after-development enterprise cost analysis along with the new machinery costs. The value of water for each irrigation development scenario is then found by subtracting the net return to land of the before-development from the after-development scenario. A more complete listing of each scenario's spreadsheet output is presented in Appendix B.

CHAPTER 4

IRRIGATION DESIGN AND ECONOMIC EVALUATION

To begin the design, the designer calibrates the digitizing tablet to a base map of the proposed irrigation site. Then, with the aid of the AutoCAD LISP programs, the appropriate information is entered. While these programs do not make design decisions, they do make the design process easier, quicker, and more accurate. Once the design is finished, the attribute information is transferred to a spreadsheet that performs the economic analysis and formats the information in a report-ready form.

AutoCAD Irrigation Design Initialization

In order to run the initialization program (INT.lsp) - step one of the design process - the designer must gather basic information on the soils, climate, relief, and location of the project area. This information is obtained from topographic maps, soils maps, and the MT_TR21 consumptive use computer model (USDA 1987). The INT.lsp program asks the designer for site-specific design information and sets default variables for the rest of the design programs. The INT program displays the current values for **peak consumptive crop use** (PCU), **soil water holding capacity** (WHC), **total crop consumptive use** (TCU), **net irrigation requirement** (NIR), **maximum soil intake rate** (MIR), miles of required three-phase **powerline construction** (PLC), and weather station used (WSTA). The designer must verify and correct, where necessary, the values for WHC, MIR, PLC, and WSTA in response to the program's queries. The program determines the TCU, NIR, and PCU from preprogrammed weather station information and sets the default variables (Table 1). (The default variables can be changed by the designer at any time in the design process.)

Table 1. The default variable identification codes, values, and explanations used in the INT.lsp program.

MAD	0.5	*;max. % of allowable soil water deficit
Peff	0.75	;pivot efficiency
Weff	0.65	;line set efficiency
Feff	0.50	;flood efficiency
WLD	5	;whln dia. (inches) for friction loss calc.
FLF	0.37	;sprinkle lateral friction loss factor
MEP	23	;minimum pivot end pressure in feet
HFD	12	;hours of flooding per day
FDL	2	;hours of seasonal flood labor per acre
PVL	0.75	;hours of pivot seasonal labor/ac.
WSL	0.5	;hours of wheel line set labor/move
DSS	3	;Dam Side Slope ? to 1(vertical)
DTC	16	;Dam Top Crest width (ft)

*the semicolon in LISP separates active code from descriptive text

Next, the designer calibrates the digitizing tablet to correspond with a base map of the design area and digitizes the irrigable soils. Based on the type and size of irrigation system deemed suitable, the designer draws the appropriate geometric shape to depict pivots and wheel lines (circles and rectangles), flood systems, and hand line systems. The designer then inserts the irrigation attribute (IRRATT) blocks. The IRRATT blocks contain information on system type, identification number, insertion point, area, hardware length, required flow (gpm), minimum input pressure, and annual labor requirement. The designer may either enter this information directly, or use the developed LISP programs. The IRRATT insertion programs use the calculated and set variable from the INT.lsp program and user-queried information to calculate and enter the IRRATT attribute information.

The four IRRATT insertion programs developed for irrigation design are pivot (PIV), wheel line (WL), hand line (HL), and flood (FLOOD). The sample drawing in Figure 4 shows the different types of irrigation equipment, a distribution pipe line, and a storage reservoir (legend shown in Figure 3).

Pivot Design LISP Program (PIV.lsp)

The pivot program (Piv.lsp) queries the user for three points that determine the circumference of the pivot. These are found from the digitizing tablet map. From this circle, the **hardware length** (HWL) is found by subtracting 100′ (end gun radius) from the **radius** (R) of the circle. The **area** (A), in acres, is calculated from the circle's radius. The program also queries the user for the in-field elevation head and then calculates the annual **pivot labor** (PLB), pivot pipe diameter (PDIA), **flow** (GPM), **pivot friction loss** (PFL), and required **pivot pressure** (PPR) as follows:

PLB = A * PVL
GPM = 226 * PCU * A / (12.0 * PEFF)
PDIA= 6" if GPM < 750, 6.625" if 750> GPM < 1150, or 8"
PFL = 0.0007 * R * $GPM^{1.82}$ / $PDIA^{4.87}$
PPR = MEP + PFL + 22 + in-field elevation head

(All pressure rates are in feet of water head and all flows are gallons per minute unless otherwise indicated.)

Figure 3. Legend for AutoCAD irrigation design.