National Handbook of Recommended Methods for Water Data Acquisition

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11.H. IRRIGATION

Irrigation water use is by far the largest use of water diverted from streams or withdrawn from aquifers in the western United States (Solley and others, 1990). Total annual irrigation water use can vary depending on many factors including climate, foreign trade, commodity prices, production costs, cost efficiency of irrigation, and changes in irrigation technology. Modern irrigation practices began to develop with the settlement of the arid West where precipitation generally is insufficient for crop production. In addition, some irrigation has long been practiced in the humid eastern States to supplement precipitation in order to increase the number of plantings per year and yield per acre, and to supplement a lack of precipitation during droughts (Solley and others, 1988). A history and summary of irrigation in the United States is presented by the U.S. Department of the Interior and others in Irrigation Water Use and Management (1979), an interagency task force report on irrigation efficiencies.

Irrigation water-use data are used to manage finite ground-water supplies and often over-appropriated surface-water supplies. For example, Congress mandated*1. a study of the High Plains aquifer in the central United States to determine if it is being depleted. Also, the U.S. Bureau of Reclamation is required (Public Law 90-537) to monitor consumptive uses and losses of the much-used water resources in the Colorado River Basin (U.S. Bureau of Reclamation, 1981). In addition, many states have established various kinds of water-management districts to manage specific water sources that have been identified as critical.

11.H.1. Description

Irrigation water use includes all water artificially applied to farm, orchard, pasture, and horticultural crops (fig. 8). In addition to normal plant growth, irrigation water may be used for germination, frost and freeze protection, chemical application, crop cooling, harvesting, or dust suppression. Irrigation also includes water used to irrigate public (SIC code 7992) and private (SIC code 7997) golf courses. Irrigation water can be self-supplied or purchased from an irrigation company, irrigation district, or other supplier.

Figure 8. Diagram of irrigation water use.

Water used for irrigation is diverted or withdrawn from natural stream flow, aquifers, and springs. Much of this withdrawn water is stored in open reservoirs that also serve other uses such as recreation, flood protection, flow regulation, and hydropower generation and allow managers to deliver water at times of need. Surface-water-delivery systems include natural and man-made channels and pipelines. Reservoirs, unlined ditches, and canals have significant consumptive use through evaporation, bank storage, and return flow to ground water through leaky structures and porous soils. Ground water is used where surface supply is not economically or physically available or when better water quality is required. The costs associated with locating aquifers, drilling wells, and pumping may make ground water more expensive. Thus, ground-water-delivery systems are designed to minimize losses through closed pipeline systems.

Four irrigation methods are used throughout the United States including surface, sprinkler, micro, and subsurface. The most comprehensive reference recently published is the Management of Farm Irrigation Systems, ASAE Monograph (Hoffman, Howell, Solomon, 1990). Reports by Jensen (1983), and Withers and Vipond (1980) are just a few of the references that describe some of the many types of irrigation systems. The U.S. Bureau of the Census (1982, 1990) periodically surveys irrigation methods used throughout the nation.

Consumptive use of irrigation water occurs as (1) evaporation from open reservoirs and conveyances and during application to plants, (2) evapotranspiration during plant growth, and (3) product incorporation. Because total consumptive use in the irrigation category is larger than any other category, it is important to obtain or estimate accurate consumptive-use information when withdrawal and diversion data are collected or estimated.

11.H.2. Sources of irrigation water-use information

Sources of irrigation water-use information are: (1) Agricultural Extension agents, Universities, and Colleges of Agriculture, (2) the U.S. Bureau of the Census, Agricultural Census and Farm and Ranch Survey; (3) Federal or State Crop Reporting Service; (4) Department of Agriculture, National Resource Conservation Service (NRCS); (5) Irrigation equipment dealers; (6) State agency permitting or allocating the withdrawal of water resources; and (7) U.S. Bureau of Reclamation.

Agricultural extension agents should be able to provide information on the types of irrigation systems and irrigated crops in the area. They may be able to estimate irrigated acreage and irrigation methods and assist in the development of a crop calendar. A crop calendar includes information on the types of irrigated crops, planting and harvesting dates, and periods of plant growth. It is used for inventorying irrigated-crop acreages and monitoring irrigation-system use by providing a timetable for scheduling data collection during the growing season. This information also can be obtained from county agents and State agricultural agencies. Researchers at Universities and Colleges of Agriculture, especially land-grant universities, and Agricultural research stations can provide assistance and answer any questions dealing with irrigation including crop-water demand figures, soil information, and water-use information.

The U.S. Bureau of the Census is authorized by Congress (Title 13 of the United States Code--section 182) to conduct surveys deemed necessary to furnish annual or other data on the subject covered by the census. Selected irrigation data for on-farm irrigation have been collected in the census of agriculture since 1890. A census of farms reporting irrigation in the 1900 Census of Agriculture was authorized by Congress. Surveys of irrigation in humid areas were taken in connection with the 1954 and 1959 censuses. The 1988 Farm and Ranch Irrigation Survey (US Bureau of the Census, 1990) is the third survey devoted entirely to the collection of on-farm irrigation for the conterminous United States. The 1979, 1984, and 1988 Farm and Ranch Irrigation Surveys collected similar data using similar methods and procedures of data collection and processing.

The NRCS assists farmers with their irrigation problems through about 2,500 field offices. They work with about 278,000 farmers making on-farm irrigation evaluations including estimates of water use. The National Agricultural Statistical Service (NASS), in cooperation with the Department of Agriculture in each State, also collects annual crop and livestock statistics and irrigated-land crop data for many of the states where irrigation is used extensively.

Irrigation equipment dealers can provide information about the types of systems they sell and the types that are used regionally. Dealers are a valuable source of information, since they can describe the actual systems that are seen in the field. They can determine equipment design specifications such as the capacities of certain center pivot systems. These specifications are needed for analyzing inventory data. Many types of irrigation systems can be inspected at the dealerships. U.S. Bureau of Reclamation publication Summary Statistics: Water, Land, and Related Data is also useful source of agriculture data.

11.H.3. Measurement, estimation, and data-collection methods for irrigation water use

Measurement of irrigation water use consists primarily of measuring surface-water withdrawals from rivers, lakes, and streams; ground-water withdrawals; and diversions and conveyance losses in surface-water-delivery systems. However, determining irrigation water use over large areas, which may include hundreds or thousands of irrigation systems, requires reliance on data from other sources, or developing methods to derive irrigation water-use values from coefficients related to power consumption, or estimating water use through irrigated acreage and crop consumption coefficients. Irrigation consumptive use and ground-water return flow usually are estimated.

11.H.3.a. Primary data acquisition

Measurements of irrigation water use focus on determining withdrawals from surface and ground water, deliveries from surface-water-delivery systems, conveyance losses through the surface-water delivery systems (evaporation and seepage), and return flow through ground water and surface water. Consumptive use during application and use of water by the plants usually are estimated. It's important to determine which water-use processes are critical to the objectives of the study particularly where surface-water-delivery systems are used. Withdrawals may be considered to have occurred when the water leaves a reservoir, with delivery occurring when water is diverted from the canal into the irrigation field. Conveyance losses (evaporation and canal seepage), as opposed to the volume of water applied to the field, can be a major component of the withdrawals, especially in arid areas and areas with low water tables and porous surficial material. In other areas, surface-water withdrawals may be considered to occur as the water is diverted from the canals adjacent to the fields so that conveyance losses are negligible. Similarly, withdrawals can be from rivers, streams, or wells adjacent to the irrigation field with negligible conveyance loss. To avoid confusion in this section, diversions from natural surface-water bodies and aquifers are considered withdrawals and diversions from canals are considered deliveries to the field.

Surface-water irrigation systems rely on water diverted or pumped from a river, stream, lake, or reservoir. Water pumped from a surface-water source can be measured using the methods described in Chapter 1 of this National Handbook of Recommended Methods. Surface-water withdrawals can be determined by measuring flow in the diversion (the point where water is withdrawn from the stream) or by measuring the flow upstream and downstream from the diversion when the diversion is a significant part of the flow. Similarly, return flow can be determined by measuring flow at the point of discharge into the stream or measuring the flow upstream and downstream of the discharge. The difference between withdrawals and return flow is consumptive use, which consists of evaporation, deep percolation, and evapotranspiration by and incorporation into the plant. Methods for measuring and estimating ground-water pumpage are discussed in Chapter 2 of this National Handbook of Recommended Methods for Water-Data Acquisition.

Conveyance loss (evaporation and seepage) can be measured after the return flow of one user and before the withdrawal of the next user. Conveyance loss also can be measured by determining the loss attributable to canal seepage and adding an estimate of evaporation. Several methods commonly are used to measure canal seepage. These include ponding tests, inflow-outflow studies, and seepage-meter studies.

Ponding tests give the most reliable results. To conduct a ponding test (Rohwer, 1948), a section of canal is blocked off with dams at each end and filled with water to, or slightly higher than, the level at which it usually flows during the irrigation season. As the water level in the canal section declines, the time is recorded and a seepage rate determined. Necessary corrections for temperature and evaporation are made and the seepage loss-rate computed. Ponding tests are usually conducted during the nonirrigation season, and are applied in a nonflow situation in which actual flow conditions are not being met. This is discussed in more detail by Rohwer (1948).

Inflow-outflow studies are conducted using long reaches of the canal and require the least extrapolation of the three methods. However, the inaccuracy of an inflow-outflow measurement is proportionate to the total flow in the canal, and can be a much larger value than the amount of seepage that occurs in a reach that has little seepage. Inflow-outflow studies using discharge measurements are described in detail by Rantz and others (1982). One of the major advantages of using the inflow-outflow method is that it can be applied during the irrigation season.

Seepage meters sometimes are used to determine seepage rates at certain locations on the canal. Obtaining a tight seal on the canal bottom or sides, however, is a problem; therefore, the use of seepage meters is not appropriate in canals with rocky or rubbly perimeters or in canals with flow velocities faster than 2 feet per second. Because seepage rates may vary considerably from point to point, many measurements need to be made throughout the length of the canal to achieve an acceptable average value. Seepage meters probably are most helpful in determining rates at specific locations along the canal, and in determining relative seepage rates at different locations. Seepage meters probably are best used while the canal is in operation. However, because of variable and sometimes erratic values obtained in measurements using the seepage meters, they are seldom used.

In order to extrapolate seepage measurements throughout the evaluation area, the canal system needs to be adequately described. Reaches need to be classified by soil type, conveyance properties (mean flow, wetted perimeter, and slope), and geohydrologic setting. Generally, soil type and conveyance properties are known, but the geohydrologic-setting analysis commonly is inadequate. The hydraulic conditions under which canal seepage occurs needs to be specifically determined for test reaches, and at least qualitatively estimated for the remainder of the canal system. Basically, two hydraulic conditions may be present in the canal system: (1) If the water table intersects the canal prism, the pore water in the bank material of the canal will be under positive pressure (greater than atmospheric), and the seepage rate will be controlled by the rate of water flowing in the saturated part of the aquifer; and (2) if the pore water in the bank material of the canal is under atmospheric or negative pressure, the seepage rate will be controlled by the hydraulic properties of the bank material and the gradient underlying the canal. Because the transmissivity of the bank material is greater than the transmissivity of the aquifer, seepage will be greater for the bank material than for the water-table condition. The geohydrologic setting can be determined by use of transects of piezometers or wells or both. If the geohydrologic setting is not the same during the seepage test as during normal operation of the canal, use of test results to estimate annual seepage loss is not appropriate.

11.H.3.b. Secondary data acquisition

States that have allocation permits may have a reliable data base on irrigation withdrawals. Data reported to these agencies needs to be carefully examined to evaluate the reliability of the method used to determine the reported withdrawals. Some withdrawals may be metered, but frequently are estimated from pumping rates and measurement or recollection of pump time duration, or may even reflect permitted volumes. Estimates made from pumping rates may be too high if the pumping rate used is the design pumping rate and not a measure of the current rate.

11.H.3.c. Derived data

For large areas and for areas where measurements cannot be made, irrigation withdrawals can be estimated from coefficients that relate (1) irrigated acreage to water applied or (2) power used to pump ground water to ground-water withdrawals. Land-use mapping and remote sensing may be used to determine irrigated acreage with statistical sampling used to develop coefficients for application rate and power consumption. An approach can be developed that is tailored to meet the objectives of the study and available data after review of information on local cultivation and irrigation practices, crop types, farm sizes and numbers, types of irrigation systems being used, local geography, and water-supply sources.

Maps for use in determining irrigated acres can be obtained from State agencies (such as the Department of Agriculture, Department of Natural Resources, Department of Transportation or Topographic Offices) and the U.S. Geological Survey. Parcels of land and their owners are recorded in plat books that can be obtained from county agencies. Aerial photographs may be available from numerous sources including State agencies, the NRCS, the U.S. Agricultural Stabilization and Conservation Service, the National Aeronautics and Space Administration, and local colleges or universities.

Field-specific irrigated acres by crop type are more difficult to obtain. Many government agencies may keep records of irrigated acres by county, or by grower (for various purposes) but field-level data may be less frequently available. Federal, State, and local agencies including the U.S. Bureau of the Census, the National Resource Conservation Service, the U.S. Agricultural Research Service, State agencies (engineers, water, agriculture, natural resources, and environmental departments), county assessors, and the County Extension Service are all potential sources of irrigated acreage information.

Irrigated acreage usually is estimated through a sample survey or complete census. Estimates of irrigated acreage can vary significantly, depending on the method used to collect the data and the purpose for which the information is needed. For example, one value may be reported to the State engineer for water-rights purposes and another value may be reported to the county assessor for tax purposes. A third value may be determined for a Federally sponsored farm subsidy program, and the local county extension agent may estimate an entirely different number. Thus, agency totals generally do not match. To overcome this problem, some States have formed water-use data work groups. These work groups compare estimates of irrigated acreages and attempt to resolve the differences. An additional benefit of forming work groups is for the establishment of statewide, or basinwide, computerized data bases. Irrigated acres and irrigable acres can be mapped and stored in geographic information system (GIS) data bases. The data base can be developed, updated, and accessed by all agencies requiring the information. All updates can be coordinated through and certified by the work group.

Remote sensing can be used to estimate irrigated acres. Remote sensing includes high- or low-altitude aerial photography or satellite imagery. Timing of the photographs or images is critical in determining actual acres irrigated. If taken too early, areas affected by shallow ground water from spring runoff are difficult to separate from areas where irrigation water is applied. If taken late in the season, harvesting may have been completed for some crops. In areas where successive crops are grown on the same land, more than one set of images may be needed. In some areas, cloud cover also may be a problem. Identification of specific crops from imagery is often uncertain and field surveys may be required to verify the accuracy of crop determination. Uncertainty in crop determination is frequent in areas where a large variety (more than 200) crops are grown that may appear similar in aerial photographs. Reliability in the use of aerial photography is increased in areas where crop variations are minimal, or if these tools are only used to determined general cropped or irrigated acreages. In general, use of computer-processed Landsat data to identify irrigated crop types and estimate crop acreage is more successful in arid and semiarid lands where crop diversity is minimal, dryland crop production is minimal, soils are warm and well drained, crop calendars are more diverse temporally, and fields are planted entirely and with one crop type (Kolm, 1985).

The U.S. Bureau of Reclamation in Denver, Colorado developed techniques for monitoring of irrigated lands using combined remote sensing and GIS programs. To develop accurate, annual irrigation information, field boundaries were determined at the 1:24,000 scale through manual photo-interpretation of infrared high-altitude photography. Irrigation status also was determined through manual photointerpretation. The information was determined to be accurate at a level of 99.99 percent through random field checking. Irrigated acreage was updated from year to year by overlaying the field-boundary maps with current Landsat Thematic Mapper imagery. This method provided an inexpensive, annual updating of the data base while retaining the accuracy of acreage estimates inherent in the large-scale field-boundary maps. This information was then incorporated into a GIS for use as a management tool (Verdin and others, 1986). Field boundaries and 1987 irrigation status were transferred into ARCINFO (a proprietary geographic information system) for further processing. Additional data layers for the elevation, crops, precipitation, and temperature were added to allow calculation of irrigation-water requirements using the modified Blaney-Criddle method (U.S. Department of Agriculture, 1967). Additional water-use data bases (water rights, ditch withdrawal points, streams, and reservoirs) also were linked to the ARCINFO database to provide water managers with a geographically referenced management tool.

After the number of irrigated acres has been determined by crop type, a value for the volume of water applied per acres is required. Development of an application rate incorporates crop water consumption, precipitation rates, and local irrigation practices. Local universities and county extension agents may have good estimates for crop water consumption. The U.S. Department of Agriculture (1976) published a report that provides consumptive irrigation requirements by crop type and by subareas within each state. The NRCS in 1994 published the National Engineering Handbook, Part 623, Chapter 2- "Irrigation Water Requirements". It describes the use of four methods for estimating crop consumptive use, depending on availability of data and geographic and climatic conditions. It also includes the modified Blaney-Criddle method in the appendix. Water application rates and crop consumption also can be developed through field work.

Development of an irrigation water application coefficient may begin with an irrigation survey, possibly coordinated with an interested State or local agency. After assimilating and evaluating all of the background information, a plan is developed for grouping irrigation sites by common characteristics, determining (1) the sample size for each group or strata, (2) what data to collect, and (3) the instrumentation for measuring flow or pumping rate and duration. The plan is based on the background information plus the availability of funding and the size of the work force.

After the plan is developed, individual landowners and farmers are randomly selected and contact to obtain permission to collect the necessary information. During the initial contact, farmers can be interviewed to obtain answers to questions on the inventory form. The farmer usually is the best source of information for the inventory. See Shoemyen (1979) for suggestions. An inventory form is developed to collect the necessary water-use information and provides the format for the data storage and retrieval system. Shoemyen (1979) provides guidance in developing an inventory form. The form needs to include information on crop types, irrigation systems, and owners of the systems. The rate of return for the forms depends on the publicity associated with the survey and the consequences of noncompliance. Accuracy of the information supplied on the survey forms also may vary, depending upon the equipment that is available to the farmers and the record-keeping practices of each farmer. Rate of return and accuracy can be increased by follow-up visits to or telephone contacts with the farmers.

Irrigation water use or water application coefficient can be estimated from the power used during pumping by use of data on total power consumption and an estimate for the average number of kilowatt hours required to pump an acre-foot of water (unit power consumption). In a pilot study designed to explore costs and procedures for calculating ground-water pumpage, Ogilbee (1966, p. 17-31) compared nine variations of three basic approaches for estimating irrigation water use. He concluded that the most convenient and reliable technique is to use total power consumption and annual mean unit power consumption to compute estimates of pumpage. Sandburg (1966) and Hurr and Litke (1989) used this approach for areas where it is impractical or too costly to equip all wells with totalizer flow meters; for these areas, the total volume of ground water withdrawn may be determined by use of energy-consumption data. In this approach, pumping-plant installations are grouped or stratified according to area, aquifer, irrigation method, crop type, and availability of surface water, and then the pumping-plant installations are sampled. Data on power consumption and pumping rate and duration are collected for each of the installations in the sample. Power consumption data were obtained through reading energy meters. At pumping plants powered by electricity, the calculations were modified if transformers were present. At pumping plants powered by natural gas, the effects of the pressure-correction factor were included in the calculations. At pumping plants powered by gasoline, diesel oil, or liquid petroleum gas, the geometry of storage tanks were analyzed as part of the calculation. The power consumption and pumping rate and duration were used to determine the power consumption coefficient that will convert the volume of the energy consumed by that installation into the equivalent volume of water pumped during a given period. This is done for each of the installations in the sample. A mean conversion factor is then calculated for each group. The total power use for all users in each group is obtained from the power company and then multiplied by the conversion factor developed for that group to determine an irrigation water-use estimate. Where equipment and hydrologic conditions are stable, this coefficient were applied to total energy consumption at a site to estimate total ground-water withdrawals. Random sampling of power-consumption coefficients was used to estimate area-wide ground-water withdrawals.

A water application coefficient should be developed for each group or strata of irrigators. Important variables, such as crop type, system type, and precipitation, as well as slope and soil type, should be analyzed to determine their significance to the application rate. The water application rate can be adjusted to variations in crop type and precipitation rates for future irrigation estimates.

In general, the difference between withdrawals and return flow equals consumptive use. In irrigation water use, return flow has a surface water (including overland flow to the stream) and a ground-water component. Irrigation water returning via canal or ditch to the surface-water system can be measured using standard methods. Irrigation water returning to the ground-water system and through the soil to the surface-water system, such as through canal seepage, excess water applied to the field, is much more difficult to quantify. Intensive ground-water studies or water-balance studies may be needed to accurately estimate ground-water return flows.

Nationally, conveyance losses and consumptive use in irrigation account for 76 percent of irrigation withdrawals (Solley and others, 1993); therefore, estimates of conveyance losses and consumptive use are important. Estimating conveyance loss and consumptive use incorporates the following relations:

> Theoretical CU requirement (plant ET and PI) - precipitation = crop irrigation requirement. (3)

> Crop irrigation requirement + irrigation efficiency (AL and RF) = irrigation water

requirement (4)

Irrigation water requirement + conveyance losses (evaporation and seepage) = withdrawals (5)

where CU is consumptive use, ET is evapotranspiration, PI is product incorporation, AL is application losses, and RF is return flow.

11.H.3.d. Quality assurance

As in quality assurance procedures for other uses, irrigation quality assurance depends on using corroborative data. Reliable estimates of irrigation water use depends on (1) a thorough understanding of all the water-use processes involved, (2) use of corroborative data on irrigated acreage, and (3) incorporating all the water-use processes in a water balance equation, as in Equations 3, 4, and 5, in the previous section.

11.D.4. Irrigation selected references

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