Benchmarking Irrigation System Performance Using Water Measurement and Water Balances

San Luis Obispo
March 10-13, 1999

Opening Session

ABSTRACT

Water balances are essential for making wise decisions regarding water conservation and water management. The paper defines the essential ingredients of water balances, and distinguishes between farm and district-level balances. An example of a hypothetical district-level balance is provided. The importance of listing confidence intervals is highlighted. Classic errors in water balance determination are noted.

ABSTRACT

A large irrigation project in the western United States has a hydrogeologic structure such that only small amounts of deep percolation leave the project directly as subsurface flows. This hydrogeology provides for relatively accurate application of a surface water balance so that crop evapotranspiration (ET_c) can be determined as a residual of inflows and outflows. This ability to calculate ET_c from discharge measurements has provided the opportunity to assess the accuracy and consistency of an independently applied crop coefficient – reference evapotranspiration (K_c ET_o) procedure. K_c ET_o calculations were based on the newly revised FAO-56 "dual" crop coefficient approach and included separate calculation of evaporation from precipitation and irrigation events. Grass reference ET_o was computed using the CIMIS Penman equation. ET_c was computed for over 30 crop types. On average, K_cET_o computations exceeded the water-balance determined ET_c ($ET_{c\ WB}$) by 8% on an annual basis over a seven year period. The accuracy of $ET_{c\ WB}$ was ±5% at the 95% confidence level. The primary cause of the 8% overprediction is that values used for K_c represent potential and pristine growing conditions, whereas crops in the study project were not in fully pristine condition due to various water and agronomic stresses. A 6% reduction was applied to calculated K_cET_o for all crops, and a further 2% reduction was applied to lower value crops. The standard error of estimate (SEE) for the average

ABSTRACT

Leaching for salt removal is the most significant beneficial use of non-consumed water. This paper discusses common equations for both maintenance and reclamation leaching, and applies them to the case of a series of crops in rotation. It is shown that the most water efficient leaching strategy is to keep the root zone ECe at, or just slightly above, the threshold value for the most salt sensitive crop in the rotation. In particular, letting soil salinity rise during the growth of a salt tolerant crop may not save as much leaching water as the subsequent leaching requires to bring the root zone salinity back down to the point needed by the most salt sensitive crop in the rotation.

ABSTRACT

Irrigation water, once applied, becomes part of the hydrologic system and is difficult to trace. When determining irrigation performance, it is usually necessary to make assumptions about what happened to all the applied water. While surface waters are relatively easy to measure, evapotranspiration and deep percolation are extremely difficult to accurately measure, particularly at a project scale. Standard statistical methods can be adapted for use in determining the accuracy of irrigation performance parameters, such as irrigation efficiency, based on the accuracy of the measured components (i.e., values that make up the numerator and denominator in the efficiency equation). The are particularly useful when using a water balance approach since there are often components of a water balance that are inaccurately known. The statistics also provide insight into which quantities have the most influence on the accuracy of a performance parameter for a particular situation. These procedures can be applied to performance at any scale, e.g. an

individual field or an irrigation district. The water-balance approach can be applied to subsystems within a project to infer the quality of internal operations. Long-standing terms, particularly irrigation efficiency, still do not have universally agreed upon definitions, which complicates their use. Published estimates of irrigation performance parameters should include estimates of accuracy because they may be less accurate than previously expected.

ABSTRACT

The Concept of hydronomic zones (hydro-water, nomus-management), based primarily on consideration of return flows is introduced to provide a simple framework for interpreting water balance based performance measures and for formulation of effective, site specific, water management strategies.

The paper defines hydronomic zones, identifies various conditions that may occur within zones, then reviews basin development concepts pertinent to performance assessment. Water balance considerations are described relevant to zones, and generic means of improving performance within zones are presented. To illustrate, an example of hydromonic zones from Sri Lanka is presented.

Flow Measurement for Water Balances

ABSTRACT

Water balance studies that involve knowledge of water inflows and outflows can be used to evaluate the nature and extent of water usage of crop production activities in an irrigated area. Part of a water balance study for any irrigated area obviously includes quantifying the water inflows and outflows in some manner. Surface water inflows and outflows are usually more assessable to direct measurement than deep seepage or evapotranspiration. Thus, their determination to a high accuracy aids evaluation of more difficult measurements. The type of data needed and the technology to acquire it often is controlled by the area being evaluated. For example, a large regional study is sometimes feasible because the inflows may be from a known reservoir supply and the surface flow exiting the region may be accumulated into a single surface stream, with the subsurface flows limited by an underlying geologically closed basin. Towards the smaller cropfield size, deep seepage can often be avoided or separately evaluated, and an assessment of irrigation techniques can be

ABSTRACT

Irrigation districts in southern Alberta are currently assessing the licensing of irrigated acreage and water requirements, with an eye to future expansion. The process yielded two key results: the development of the Irrigation District Model (IDM) of water supply and demand, and the establishment of irrigation block studies of operations and on-farm practices. This study concentrated on the K5 block, approximately 3000 acres of irrigated fields in the Bow River Irrigation District near Vauxhall, Alberta. The K5 block was monitored for a period of four years. Data were collected on crop type, irrigation method, field area, weather, canal capacity, as well as farm and other operations. Flow data were collected at 20 minute intervals from 49 locations, including turnouts, drains, farm spills and spillways. Inflow and outflow hydrographs were developed to evaluate the impact of various factors on return flow from an irrigated block, and to provide data to calibrate canal flow algorithms for modeling. The four years of collected data indicate return flow from canal operations is higher than expected, and on-farm operations significantly affect the rate and timing of return flow throughout the irrigation season. Base flow in the distribution system was higher than expected, and not constant throughout the season. The results were used to determine potential water savings from efficiency and management improvement scenarios.

ABSTRACT

Key to the successful management of water resources is accurate understanding of the flow quantity. Unfortunately, measurement of flow in an open channel is often costly, manpower intensive, and the performance limitations of the available technology may lead to inaccurate results. A new flow measurement approach, utilizing pulse Doppler signal processing, was developed to allow accurate measurement of flow rates in open channels and pipes even when the flows contain slow velocities or other complicated hydraulic conditions. The new meter derived from this technology is known as the ADFM Velocity Profiler™ (ADFM).

ABSTRACT

When daily flow is calculated from analog records such as Stevens Recorder charts, the average daily water elevations are often used. Such daily flow calculations, referred to herein as “hydrographer’s estimates”, are biased because the water elevation is generally raised to the 3/2 power in the flow equation. A relationship based on flow variability that can be used to adjust biased daily flow volumes to a more accurate daily volume without using such time consuming and costly methods as digitizing is needed.

An adjustment will be developed by comparing daily flow calculated from the average daily water elevation to daily flow calculated from digitized hourly flow data for a limited period of record. The adjustment will be tested by applying it to a second set of data for which both hydrographer’s estimates and digitized records exist. The check of the adjustment will be based on how well it reproduces the monthly flow volumes calculated from the digitized flow record. The results are anticipated to provide an acceptable method for adjusting daily flow records based on averaging heads to an unbiased daily flow record.

ABSTRACT

Correlation between accuracy of volume calculations and time interval selected for water elevation measurements is an important question in today’s digital world. Modern techniques for digital data acquisition can record water elevations at constant or varying time intervals. Recording water elevations at constant time intervals has the advantages of providing a predictable amount of data, allowing easier data filling for missing and out-of-range records, and permitting direct use of the average function. In addition, the constant time interval supports site maintenance because data collection cessation can easily be determined. Because of these advantages, a constant time interval is often chosen; however, the length of the time interval is usually selected based on equipment requirements rather than considerations about data accuracy.

The effect of constant and varying data recording intervals on calculated daily flow was investigated by analyzing an existing data set of digitized

Stevens Charts. The Stevens Chart record consists of a digitized point for each slope change in the recorded water surface level. For each site, eight sets of flow data (15-minute, hourly, every two hours, every four hours, every 6 six hours, every eight hours, every 12 hours, and once a day at 8 a.m.) were generated. The digitized data most closely matches the original, analog flow record, and thus, is the volume standard against which the calculated volumes from the other sets are compared.

Daily volumes were calculated for each data set. The average percent difference for annual volumes ranged from –0.2 percent for 15-minute and hourly readings to –1.9 percent for the twice a day readings and 12.7 percent for daily readings at 8 a.m. An increase from one to two readings a day decreased the average percent difference from 12.7 percent to –1.9 percent. This result is for sites that have some flow nearly continuously.

These sites with high flow variability would be expected to benefit from a detailed 15-minute record. However, the results indicated that yearly volumes calculated from an hourly record were appreciably less accurate than those calculated from a 15-minute record.

Knowing how data will be used is vital to deciding what time interval to use for data collection. This study indicates that if yearly volumes are the sole purpose of the data collection, 2-hour intervals may be enough. If the data are likely to be used for other system studies, as experience has shown is likely, hourly values are probably a good idea.

Data Management

ABSTRACT

Herein we will examine information proficiency. We will emphasize its importance to the success of your organization. We will explore its meaning through stories and definitions. We will seek to better understand its dynamics through economic models. A memorable story will be used to demonstrate its practical implications and some emerging principles. Finally, we will offer some guidelines so that you can formulate your own.

ABSTRACT

This paper will discuss the analysis of historic annual crop production and monthly water distribution reports for over 500 districts supplied water from the United States Department of the Interior, Bureau of Reclamation (Reclamation) water projects. A multi-year trend analysis of the published data for the period 1980 to 1993 will also be presented. Reclamation has traditionally collected annual crop census data on all Reclamation projects. Crop census data has been used for a variety of activities related to administering and evaluating the Federal Reclamation program. Crop census data includes the type of irrigation service, crops produced, number of acres of each crop, crop yields, gross crop values, and water delivery statistics (acre-feet delivered to farms). The data is reported in "Summary Statistics, Water, Land, and Related Data" which is published annually and provided to Reclamation offices; Senators, Representatives, and Governors of the 17 Western States; major colleges, depository libraries, administrative agencies, contracting organizations, public and private interest groups, and other Federal agencies.

ABSTRACT

Julesburg Irrigation District is located in extreme northeast Colorado in the South Platte basin. The District manages delivery of surface water to over 300 parcels of land totaling 19,000 acres. Water delivered in the District's three-canal network is either storage release from the off-channel Julesburg Reservoir or direct diversion from the South Platte. The District's ability to analyze the efficiency of its water delivery system is limited by several factors, including the nonexistence of a computerized water delivery records database. Computers have not previously been used in any capacity in the District's operations. This paper examines District water delivery operations and documents the design and development of spreadsheet-based software tools for recording and processing water delivery records. Tool development considerations include: complement District's existing records format; a simplified data entry system which requires minimal computer usage background; report generating capacity for individual District producers; and expandability as additional needs and desired functions are identified.

ABSTRACT

This paper will discuss the analysis and results of the ongoing effort to produce the Colorado River System Consumptive Uses and Losses Report. USBR is required to publish the annual consumptive uses and losses of water from the Colorado River System after each successive five-year period in consultation with the seven western states within the basin. Records of diversions and return flows are not available to allow for direct computation of agricultural consumptive uses in the tributary areas of the basin. Recently, satellite imagery and aerial photography was used to develop irrigated acreage and associated crop data within a GIS database. This data was field checked and compared to other data sources available. Based on this data and meteorological information, estimates of agricultural consumptive use were developed using the modified Blaney-Criddle and Erie methods to estimate crop evapotranspiration.

ABSTRACT

We will discover the history of the Storm software. We shall then examine its use within San Luis Water District and Panoche Water District. Then we shall explore the development and thinking behind the Storm product. Finally, we will review Storm's use by districts with varying patterns of operations and its vision for the future.

Water Balances at the District, Project or River Basin Level

ABSTRACT

A model and system process has been developed to determine water demand and supply within irrigation districts in southern Alberta. The Irrigation District Model (IDM) is a suite of tools that will assist irrigation districts in making daily water management decisions and in planning future development. The IDM consists of three modules; the Irrigation Requirements Module (IRM), the Network Management Module (NMM) and the Water Order Desk Module (WODM). The IRM uses weather data and parcel data (soils, crops and irrigation equipment) to calculate daily demands. The calculated demands from IRM are then combined into the NMM to assist the irrigation district in optimizing the scheduling and routing of water within their canals and reservoirs. The IRM can also be used to determine the effect of demand when farming practices are altered or lands are added to the irrigation district. The NMM provides the

time-series water routing solutions, taking into account canal and reservoir rule curves, conveyance losses and weather effects. When used together, IRM and NMM provide districts with a method of determining potential water supply shortages and methods (policies) to mitigate their effects. The WODM provides the irrigation districts with a tool for scheduling their present day water releases. The WODM utilizes NMM to determine the release schedules based of farm orders and current policies.

The IDM algorithms are based on real-time demand and operations, and are significantly different to hydrological modeling practices which route water to a single point. On-farm demand is calculated using on-farm cropping data collected at the field level. A data warehouse has been developed to integrate all present and historical cropping, climate, irrigation system, and conveyance information. The warehouse was designed with a GIS layer such that all components could be spatially represented and sequenced with respect to the irrigation district's conveyance network. This paper presents an overview of each of the IDM tools and a status of their development and testing. It then provides details of the design and operation of the Network Management Module.

ABSTRACT

Fresno Irrigation District (FID) is located in the Central California San Joaquin valley and services approximately 245,000 acres of farmland and urban development. FID acquired the system in the 1920's, which included over 600 miles of canals and distribution works constructed between 1870 and 1900. The canal system was constructed with a rotation schedule to deliver a fixed flow rate and volume of water to each acre paying for water service. Surface irrigation delivery and schedule has changed little since FID was formed mainly due to limited canal capacity and limited storage facilities for surface supplies. As a result, FID begins irrigation deliveries in early spring when the application of surface water exceeds crop evapotranspiriation (ET). Excess water percolating through the root zone from over applied surface water is the largest contributor to groundwater recharge and maintaining a flexible groundwater supply within FID.

Conventional wisdowm states that increasing on-farm irriigation efficiencies would improve district efficiencies by reducing deep percolation, discounted as lost in the irrigation efficiency equation. This statement is true for other districts and agencies where groundwater is not

ABSTRACT

Due to declining per capita production of food grains and increasing numbers of people living in poverty and hunger, there is a growing need worldwide to identify and develop new lands with adequate agricultural potential. With today's inexpensive computers and software, identifying promising agricultural lands need not be difficult or costly. Fairly simple analyses of readily available digital elevation models and basic climate data – supplemented with topographic maps and limited soils information – provide everything needed for an initial land and climate survey. In addition to identifying possible agricultural lands, such data can also help indicate appropriate crops, estimate surface water supplies, and predict irrigation water requirements. This study of the Patuca river basin in Honduras used such data to determine that, for the inter-mountain valleys, natural rainfall and typical unregulated surface water flow during the dry season is much less than the water requirements needed for economic agricultural development. Consequently, considerable water storage and irrigation development would be required. To provide water during the dry season as well as a source of power which could assist in financing irrigation developments, five potential reservoir sites were identified. It is hoped that this study will provide a methodology – and serve as a model for training programs – that will facilitate making river basin, regional, or country-wide studies of the potential for development of land and water resources. Finally, due to the limited credit available to the governments of many developing countries, the promotion of private sector financing and the creation of private sector corporations to manage development is recommended.

ABSTRACT

Readily available data on annual water applied as irrigation and rainfall and water use of irrigated crops were collected from about 1500 properties

in the Riverland region of South Australia and the Sunraysia region of Victoria and New South Wales of the Western Murray-Darling Basin of Australia. Two terms were defined – Annual Water Balance Efficiency (AWBE) and Annual Water Balance (AWB). AWBE is calculated as a ratio of total water use by crops to total water applied by irrigation or rainfall, expressed as a percent. AWB is calculated as a difference between total water applied (irrigation plus rainfall) and crop water use expressed as a depth in mm.

The water balance data is used to display how effectively irrigators are managing irrigation by crop type or irrigation system. Data is also displayed on water balance efficiency by irrigation region and season. There is a fair linear regression between AWB and summed daily water balance. AWB, as an estimate of drainage, overestimates the amount of excess or deficit calculated on a daily basis and summed over a year. However, the relationship does indicate that AWB can predict net water lost (drainage) below the root zone on an annual basis. However, care needs to be taken to ensure that the data collected is accurate.

ABSTRACT

In tropical, monsoon climates of South-East Asia, irrigation facilities supplement rain in the wet season and allow for crops to be cultivated during the dry season. In these areas, water needs are typically estimated by considering the evapotranspiration of irrigated crops, plus water requirements for seepage, percolation and drainage, particularly in rice irrigated areas. But, these considerations are insufficient in design, management, and characterization of performance in many areas. Recycling, or reuse of return flows, plays an important role in most rice-irrigated areas in the humid tropics. Additionally, depletion of water by non-crop vegetation can represent a significant component of the water balance.

In the Dry Zone of Sri Lanka, an average annual rainfall of 1000 mm falls mostly (70%) in a 3 month period. During the dry season, reference evapotranspiration less rainfall is about 700 mm, indicating that much additional supply is meant to support crops. In this climatic context, irrigation has dramatically changed the local environment by allowing eco-systems quite similar to that of the wet zone to flourish. In these systems, recharge of shallow groundwater by percolation from irrigated fields, canals, and tanks, has provided a continuous supply of water for natural vegetation and homestead gardens. Much of the water used by this non-

crop vegetation is beneficial. Growth of fruit and coconut trees can be quite profitable, while other trees enhance the environment. A first estimate of the water balance made in 1996 in part of the command area of the Kirindi Oya irrigation scheme, Sri Lanka, shows that evapotranspiration by non-crop vegetation to be similar to that of the rice, the main crop in the area.

In 1998 IWMI performed a comprehensive water balance in the area, based on surface flow measurements, rainfall data, and estimation of crop water requirements. This water balance showed that evaporation consumed 78% of the total amount of water available (net inflow minus committed). The amount of evaporation is split into process depletion – crop for 28%-, direct evaporation from tanks (7%), inter-seasonal fallow (10%) and from non-crop vegetation for 55%. A further analysis using remote sensing techniques has fully confirmed that perennial vegetation covers most of the non-paddy areas, and consumes a large amount of water through withdrawal from the groundwater.

The main conclusion from this study is that non-crop vegetation is a significant consideration in tropical humid environments in planning, management and performance assessment. Designers, managers, and researchers need to specifically incorporate the evaluation of evaporation by non-crop vegetation in their approach of water requirements. Further investigation is needed to estimate water consumption per sub-class of non-crop vegetation and to assess their respective beneficial use.

ABSTRACT

The main components of the water balance, applied to an irrigation scheme, are the canal water supply, rainfall and crop evapotranspiration. Canal water supply and rainfall are inputs to the system while the most significant output of the system is evapotranspiration. The relationship between the in and outgoing terms of the water balance were used in this study to define the overall project efficiency and characterize the delivery performance. The contribution of rainfall to the water balance was expressed in different ways. This resulted in various indicators for the performance of the water delivery.

The approach was applied to the Doroodzan Irrigation System in Iran and the performance indicators were determined for the total project during five consecutive growing seasons and for four irrigation districts of the scheme during two years. The results reveal that the water balance

performance indicators over a time period not only reflect the role of the system management with respect to the efficient use of rainfall, but also demonstrate adequacy, reliability and equity in delivery. The values of the indicators provide information on the quality of the management with respect to variations in cropping pattern and rainfall. Based on the assessment, some other water management practices also qualified for this scheme and a number of recommendations are made to improve water delivery.

The terms of the monthly water balance were used in this analysis. Evapotranspiration was estimated using real time climatic data from the region in which the irrigation scheme was located and processing the data with the latest version of CROPWAT (1966). Data about the cropping pattern were derived from land surveys. The effective rainfall was estimated using both the forecasted and actual precipitation, and applying the method of the USDA.

ABSTRACT

The specific relationship between on-farm and district-wide irrigation efficiency is not well understood. On-farm irrigation evaluations may yield different numerical values than district-wide or region-wide evaluations, leading to confusion for the general public, and at times, perhaps even water policy decision makers.

Conservation efforts directed at raising on-farm efficiencies do not necessarily lead to real water savings at the district level, since district-wide efficiency may already be high. The root cause of this effect, of course, is that water not consumed on one farm may be reused on another. But even for those who understand this concept in general terms, the relationship between performance over an area and the geographic extent of that area remains ambiguous. The quantitative relationships between irrigation performance parameters, the extent of water reuse practiced, and the geographic scale of the assessments have only recently been developed.

This paper presents analytical solutions relating irrigation efficiency (IE) and Irrigation Consumptive Use Coefficient (ICUC) as determined for one field, and IE and ICUC for multiple fields, as affected by tailwater or drainage water reuse between fields.

ABSTRACT

This paper illustrates the water accounting procedure developed by IWMI in two basins: Bhakra in India and Huruluwewa in Sri Lanka with differing climatic conditions, water availability, cropping pattern, and water management policies. The purpose of water accounting is to evaluate the present status of water use and productivity, and to provide an indication of where gains can be made.

Results show that Bhakra is essentially a closed basin (no uncommitted outflows), while Huruluwewa is open (uncommitted outflow exists). At Bhakra, opportunities for savings are limited to reducing non-beneficial evaporative depletion. At Huruluwewa, there are significant opportunities to tap uncommitted outflow. At Huruluwewa, productivity per unit command can be increased through an increase in productivity of water supplies (by saving more water) while at Bhakra, a key issue is sustaining productivity, as exploitation of water resources is at its limit.

ABSTRACT

A unique study to examine the impacts of irrigation project modernization was funded by the Research Committee of the World Bank and managed by the International Program for Technology Research in Irrigation and Drainage (IPTRID). The project examined 16 irrigation projects in 10 developing countries, 15 of which have been partially modernized in some aspects of hardware and/or management. Besides developing specific recommendations for donor agencies interested in irrigation project modernization, this project also accomplished the following:

1. A Rapid Appraisal Process (RAP) was developed to quickly (within a week) evaluate an irrigation project to assess what type of modernization is needed.
2. External performance indicators were quantified and modified. These characterize the inputs and outputs of irrigation projects, including amounts of water, yield, and economics.
3. Internal process indicators were developed and quantified for each irrigation project.

This paper focuses on the RAP as well as various external performance indicators that are related to water balances – a small fraction of the total report. The complete report has been reproduced by FAO of the United Nations in Rome.

ABSTRACT

The Klamath Project lies within two adjoining river basins, the Klamath River Basin, which originates in south-central Oregon and courses through northern California on its way to the Pacific Ocean and the Lost River, which straddles the California – Oregon state boundary. These basins were hydrologically separate in their natural state and have been linked as a result of project facilities and operations. Water is supplied to Project lands from reservoirs constructed on both rivers. The Project enjoyed a full water supply from its first operation in the early 1900s until issues involving endangered species and Indian tribal trust responsibilities arose in 1992. Potential changes to Project operations to address these concerns could reduce the water available to the Project. Questions have arisen regarding the historical efficiency of the Project's operation and whether efficiency improvements could offset some of the potential

reduction in water supply. Water balances were prepared to assist in addressing these questions. The Project was divided into sub-regions and a monthly water balance prepared for each for the period 1961 through 1997. The paper describes the considerations applied to the delineation of sub-regions, the approach used to estimate evapotranspiration, the results of the water balances in terms of historical project efficiency and limits of the analysis due to uncertainties in accuracy of historical data.

ABSTRACT

The Grassland Drainage Area in the west side of the San Joaquin Valley is a 97,000 acre irrigated area. The area is underlain with perched water high in selenium, salt, and boron. The area has implemented the Grassland Bypass Project to manage these drainage flows. An agreement with the Bureau of Reclamation and Waste Discharge Requirements issued by the Regional Water Quality Control Board put strict limits on the amount of selenium that can be discharged to the San Joaquin River. The management of the drainage flows and selenium loads requires a complex series of measuring methods including traditional and new techniques. The water balance, along with the chemical load is used to manage drainage from the area. The methods and how they are used in management of the subsurface drainage flows will be presented.

ABSTRACT

Cal Poly Irrigation Training and Research Center (ITRC) has conducted several water balances for regions or districts within the San Joaquin Valley. In each case, the greatest unknown component for the water balance is subsurface flows (ITRC, 1994).

Water balance calculations can be confusing, especially in districts where there is groundwater pumping. Some of the common problems of creating correct water balances include:

1) Not defining the boundary of evaluation.
2) Double counting water.
3) Counting all pumped water as a water supply.