

**GLENN-COLUSA IRRIGATION DISTRICT WATER BALANCE MODEL:
A FOUNDATIONAL COMPONENT OF A DISTRICT RESOURCE
MANAGEMENT PLAN**

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ABSTRACT

Glenn-Colusa Irrigation District (GCID) is in the process of developing a Resources Plan (Plan) to establish improved policies and decision making processes to better and more actively manage its available water supplies. The first element of the Plan will address Water Supplies and Transfers; it will be developed through evaluation of the district's recent historical and future water demands relative to available surface water and groundwater supplies. The analyses will reveal the probabilities, magnitudes and durations of possible future water supply shortage and surplus conditions. When combined with supporting legal and institutional review, the analyses will provide a basis for managing available water surface and groundwater supplies, shaping conjunctive water management policy, and evaluating potential surface water transfers.

GCID is developing a water balance model, including related refinements to the District's water measurement, data management and reporting systems, to analyze historical and possible future water supplies and demands. The water balance will be calculated on a monthly time step for up to ten consecutive years, including winter months when rainfall is appreciable and irrigation demands are generally low. Individual water balances will be prepared for each of GCID's ten water operator areas, which can be combined to form the balance for the overall District. This paper provides a background description of GCID and discusses ongoing development of the water balance model and related improvements to GCID's flow measurement and data management procedures.

DESCRIPTION OF GLENN-COLUSA IRRIGATION DISTRICT

Overview

GCID's appropriative water rights on the Sacramento River began with an 1883 filing posted on a tree by Will S. Green, surveyor, newspaperman, public official, and pioneer irrigator. His first claim was for 500,000 miner's inches under 4 inches of pressure and led to the establishment of one of the earliest and largest water rights on the Sacramento River.

GCID was organized in 1920, after several private companies failed financially, and a group of landowners reorganized and refinanced the irrigation district, retaining claim to Green's historic water right. The disastrous rice crop failure of 1920-21 nearly destroyed the district at its inception, and the "great depression" took a further toll, making it

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necessary for the district to refinance in the 1930s. Additionally, the United States purchased lands within GCID during this period that would later become three federal refuges totaling approximately 20,000 acres.

Today, after surviving many challenges, GCID is the largest irrigation district in the Sacramento Valley. Located approximately eighty miles north of Sacramento, California, on the west side of the Sacramento River (**Figure 1**), the district encompasses approximately 175,000 acres, including 141,000 planted to agricultural crops, with rice being the dominant crop owing to the heavy clay soils and adequate water supply. Additionally, there are more than 20,000 acres within the three federal wildlife refuges and 5,000 acres of private lands managed to provide wildlife habitat. Winter surface water supplied by GCID to thousands of acres of rice land provides additional valuable habitat for migrating waterfowl during the winter months.

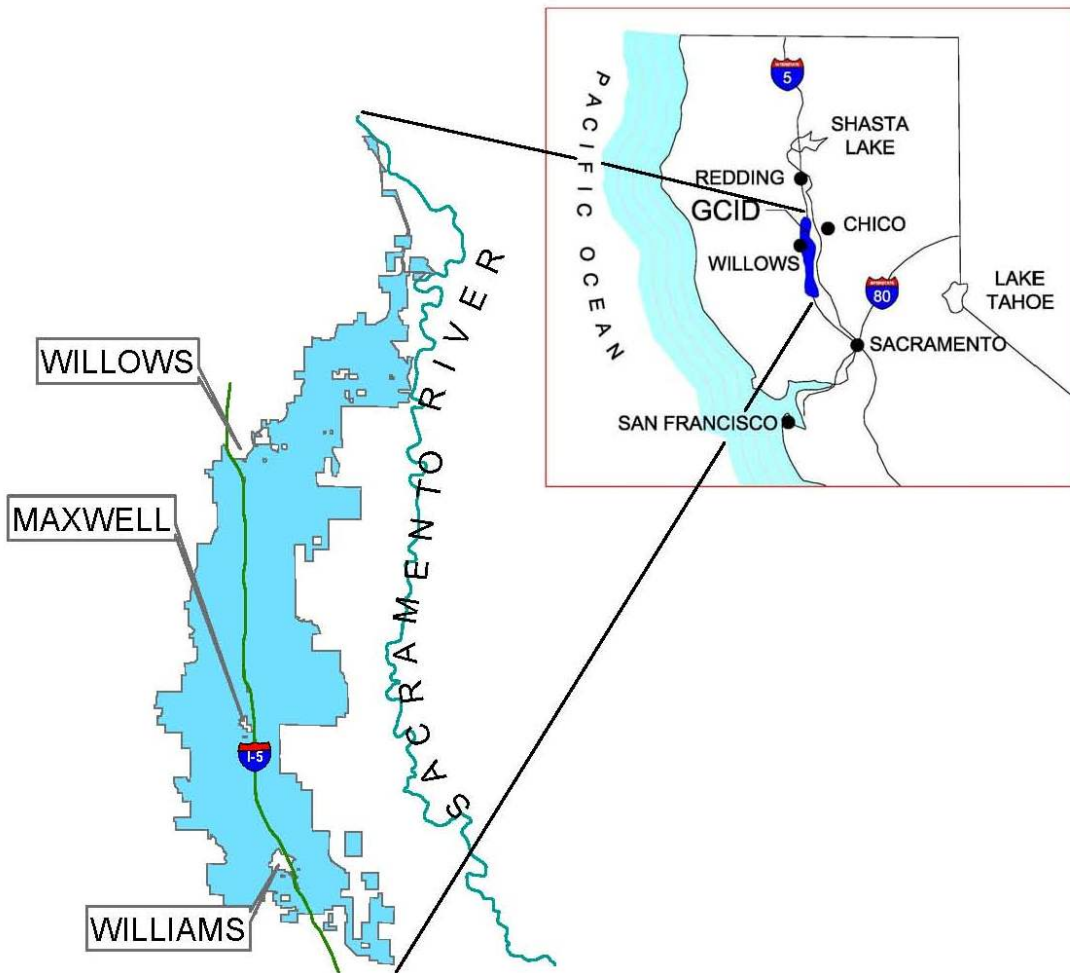


Figure 1. Map of GCID

GCID's main pump station and fish screen structure located near Hamilton City, with a maximum capacity of 3,000 cubic feet per second (cfs), is the largest diversion from the Sacramento River. The District's 65-mile long Main Canal conveys water into a complex system of nearly 1,000 miles of canals, laterals and drains constructed mostly in the early 1900s.

In 1990, the GCID's Sacramento River diversion was identified as a significant impediment to the downstream migration of juvenile salmon. Following the state and federal listing of the winter-run Chinook salmon as endangered under the Endangered Species Act, pumping restrictions were imposed on GCID by a court-ordered injunction, preventing GCID from diverting its full water entitlement. A long-term solution was developed to provide both safe fish passage past GCID's pump diversion and a reliable water supply to GCID by allowing them to divert their maximum capacity of 3,000 cfs. Key components of the solution included enlargement and improvement of the fish screen structure and the construction of a gradient control facility in the main stem of the Sacramento River to stabilize the river channel and ensure flow to the pump intake. These facilities were complete in 2002.

Surface Water Supplies

GCID holds both pre- and post-1914 appropriative water rights to divert water from the natural flow of the Sacramento River. GCID also has adjudicated pre-1914 water rights under the Angle Decree, issued in 1930 by the Federal District Court, Northern District of California, to divert water from the natural flow of Stony Creek, a Sacramento River tributary. In addition, as the successor in interest to Central Canal and Irrigation Company, GCID has, under a May 9, 1906 Act of Congress, the right to divert up to 900 cfs from the Sacramento River (Pub. L. No. 151, Ch. 2439).

From its first diversions until 1964, GCID relied upon its historic water rights and adequate water supply from the Sacramento River. The Sacramento River watershed encompasses 27,246 square miles and has an average runoff of about 22.4 million acre-feet. This is nearly one-third of the state's total natural runoff. In 1964, after nearly two decades of negotiations with the United States, GCID along with other Sacramento River water rights diverters entered into "Settlement Water Contracts" with the Bureau of Reclamation (Bureau). These Settlement Contracts were necessary at that time to allow the Bureau to construct, operate, and divert water for the newly constructed Central Valley Project (CVP). The contract provided GCID with 720,000 acre-feet of base supply during the months of April through October and 105,000 acre-feet of purchased CVP water during the months of July and August. The 825,000 acre-feet annual entitlement recognized under the settlement contract is inclusive of GCID's entitlement recognized under the Angle Decree, which, on average, yields about 15,000 to 18,000 ac-ft/yr. During a designated critical year when natural inflow to Shasta Reservoir is less than 3.2 million acre-feet, GCID's total supply is reduced by 25%, to a total of about 619,000 acre-feet.

Additionally, the District holds a water right under a State Water Resources Control Board (SWRCB) permit to divert “winter water” from the Sacramento River between November 1 and March 31 at a rate of up to 1,200 cubic feet per second (cfs). This water supply is used for rice straw decomposition, maintenance of waterfowl habitat, and minor fall, winter, and early spring irrigation. The permit provides 150,000 acre-feet for rice straw decomposition and 32,900 acre-feet for crop consumption.

Groundwater Supplies

Approximately 200 privately owned groundwater wells are located within GCID’s boundaries. Most of these wells draw from the Tehama Formation at depths ranging between 200 and 500 below ground surface. Additionally, as part of program to explore deeper aquifer systems, GCID has completed construction of three deep wells and plans for a fourth. These wells were designed and constructed to draw from formations generally below depths of 700 feet to minimize the likelihood of interference with shallower, private wells.

In recent years, GCID has supplemented its available surface water supplies with groundwater from local privately owned wells. It has accomplished this with a voluntary conjunctive water management program. This program involves more than 100 private landowners who are reimbursed by GCID for each acre-foot contributed to GCID’s supply. This program has produced up to 67,000 acre-feet of supply in a single year as a means of offsetting critical year surface water curtailments. However, impacts resulting from competing local needs for groundwater as well as air emission regulations have resulted in more restricted use of groundwater.

Water Conservation

In addition to relying more on groundwater to offset surface water shortages, GCID has an aggressive drainwater recapture program involving gravity and pumped diversions from drains into district laterals for supply to farms. It is estimated that GCID currently recycles approximately 155,000 acre-feet annually. Drainwater not recaptured by GCID is available to and is an important supply source for some downstream water suppliers, including Provident, Princeton-Codora-Glenn Irrigation District, Maxwell Irrigation District, and the Colusa Basin Drain Mutual Water Company.

Additional water conservation measures appropriate to the conditions within GCID include conveyance system automation, district-level water measurement, and farmland return flow measurement. Precision farming techniques, laser land leveling, micro-irrigation, and other on-farm irrigation technology improvements have been used effectively within GCID in the last decade to improve water use efficiency and reduce diversions in times of shortage.

Water conservation measures are typically the most expensive options and can be in conflict with the regional water management characteristics of the area. The hydrologic characteristics of the region that GCID lies within can be described as a “flow-through”

system, in that the vast majority of the water not consumptively used returns to drains and is rediverted by others, recharges the regional aquifer to the benefit of groundwater pumpers within and outside of GCID, or returns to other waterways and is reused downstream. Therefore, the actions of an upstream district such as GCID can have a considerable effect on downstream areas.

A RESOURCE PLAN AS A FRAMEWORK FOR IMPROVED DISTRICT MANAGEMENT

GCID's core purpose is to provide reliable, affordable water supplies to its landowners. Fulfilling this purpose requires that GCID manage its water, financial, human, and other resources in a strategic, integrated manner. Management processes that were well designed at the time and have served the District reliably for many years are being reviewed and, where necessary, revised in response to new challenges and changing conditions. The district resource plan will document these processes to serve as a basis for policy formulation and management decision making. Some of the more important challenges to district water supplies and the principal elements of the GCID resources plan are described in the following sections.

Challenges to GCID Water Supplies

As previously noted, according to its settlement contract with the federal government, GCID's Sacramento River supplies can be cut by 25% when Shasta Reservoir inflow is less than 3.2 MAF. This represents a supply reduction of more than 200,000 acre-feet in years when shortages occur, or about 1.4 acre-feet per irrigated acre. Historically, these shortages have occurred about 10% of the time; however, the effects of climate change on precipitation and runoff patterns could result in more frequent shortages.

Traditionally, GCID has responded to water supply shortages by increasing production of groundwater and by intensifying drainwater recapture operations, where possible. Increased frequency of shortage means that GCID will rely on these supply augmentation measures more frequently, with unknown effects on groundwater conditions and downstream water suppliers and irrigators.

GCID's Sacramento River "winter" water right has become a critical supply source because it facilitates rice straw decomposition, a relatively new, environmentally friendly farming practice that offers an alternative to rice straw burning, and helps to sustain critical winter waterfowl habitat. However, Sacramento River diversions under GCID's winter water right are subject to Term 91, a provision applicable to all appropriative rights with a priority date after August 16, 1978. Essentially, Term 91 requires that GCID suspend diversions under its winter right whenever the State Water Project and/or federal Central Valley Project are making releases of stored project water to satisfy water quality regulations in the Sacramento-San Joaquin Bay-Delta.

To the extent that Term 91 reduces GCID's ability to divert winter irrigation water, particularly in the months of February and March, landowners have little choice but to

rely on groundwater to meet their needs. Winter irrigation demands in GCID, while still small relative to summer demands, are increasing, due to expansion of vegetable and tree crops.

Resource Plan Elements and Objectives

GCID's Resource Plan will address water supplies, water transfers, operations and maintenance, and finances. A summary of the key issues being addressed in each plan area is presented below.

Water Supplies. The Plan will analyze various water supplies available to meet existing and future water demands within GCID. The permits, licenses and contracts under which GCID is allowed to divert surface water will be inventoried. For each water supply source, the following attributes will be evaluated: conditions under which water may be diverted (purpose, period, place of use; diversion limits, etc.); hydrology and water supply availability; and historical diversion and use by GCID. For each supply source, an assessment will be made regarding its vulnerability to possible future legislative or regulatory action, climate change, and other factors that are reasonably foreseeable and definable. Based on the preceding assessment, monthly (or possibly bi-monthly) time series of water supply availability will be developed for each surface water source. Different time series may be developed reflecting different assumptions about future water supply reliability. Groundwater conditions, availability, development, and use within GCID will be characterized. This will involve describing the hydrogeology of the region based on available production and gas well logs, hydrogeologic data, and other information. The locations and capacities of existing production wells will be compiled and mapped (within the limits if available data). The existing Stony Creek Fan Integrated Groundwater and Surface Water Model (SCFIGSM) or a regional model of the Sacramento Valley (presently under development) will be reviewed and updated, if necessary, based on the preceding task. The model(s) will be used to evaluate alternative groundwater development and use scenarios as a means of establishing practical, sustainable operational limits.

Water Transfers. The Plan will characterize historical and future water transfers for purposes of quantitative analysis. GCID has historically engaged in water transfers, including annual transfers within the basin and occasional transfers out of the basin. These historical transfers will be documented in terms of monthly transferred water volumes for purposes of analysis. In addition to maintaining historical in-basin transfers, GCID intends to meet its obligations to the Sacramento Valley Water Management Agreement (Phase 8) and to develop a decision framework for evaluating potential future in basin and out of basin transfers beyond Phase 8. Under this task, hypothetical future water transfers will be characterized for purposes of analysis. This will take the form of rules defining the frequency of potential transfers, and related schedules of monthly transferred water volumes.

Operations and Maintenance. The Plan will focus on continued reliability by GCID to meet customer water needs at an affordable cost. The Plan will include a complete

evaluation of all District facilities and privately owned facilities used by the District to provide a basis and priorities for annual maintenance activities and capital improvement plans. Annual maintenance activities and system improvements will be prioritized by evaluating cost-benefit ratios. The plan will also evaluate the need for increased staffing necessary for efficient year-round operations and requirements for completing system maintenance during narrow system shut periods.

Finances. The Plan will include a master program to provide a basis for long-term financial planning, including reserve funds and carryover, risk analysis of uncertain budget items (e.g., water transfer revenues and power costs) to facilitate scenario analysis for long-term planning, analyze potential impacts of major uncertain budget elements over 5-year period by evaluating best-case, worst-case, and most-probable scenarios, and examine existing rate structures, and analyze a basis for land-based and water charges.

WATER BALANCE MODEL

Objectives

Since 1964, GCID has prepared an annual Report on Water Measurement (annual report) that serves as a record of water operations for each irrigation season. It consists primarily of a series of tables that summarize water diversions, deliveries, drain flows and drainwater recapture on a monthly and annual basis. The report also documents the water rates and policies in effect each year. The report contains a large amount of information and enables tracking of trends in certain operating parameters.

The objective of the water balance model is to enhance the value of the data presented in the annual report by augmenting and combining it in the form of a water balance that accounts for all water entering, leaving and stored within the District over specified periods for time. Beyond tracking trends in certain individual operating parameters, the water balance will allow GCID managers to assess historical operational performance under different water supply and demand conditions. The main outcome from the water balance will be an improved understanding of GCID system characteristics and operational performance, which, in turn, will provide an improved basis for identifying, assessing and planning potential water management and facility improvements. It is also expected that the water balance will reveal opportunities to improve GCID's water measurement and data management processes.

A particular purpose in developing the water balance is to characterize exchanges of water between GCID canals, laterals, drains and irrigated lands and the underlying groundwater system through the processes of recharge (by canal seepage and deep percolation of applied water) and discharge (groundwater pumping). It is generally accepted that the diversion and application of surface water in GCID results in appreciable net recharge to underlying groundwater aquifers. The water balance will help to improve recharge estimates, which, in turn will improve GCID's ability to manage underlying groundwater, including improved calibration of groundwater models.

Phased Model Development

The water balance model is being developed in phases in consideration of GCID’s needs and resources, and the adequacy historical operations data. The historical data currently available will allow initial model development and approximate calibration. As historical data is improved, the model will be refined, leading to increased confidence in model results and interpretation. Eventually, once system characteristics are sufficiently defined, it is envisioned that the model will be modified to function in a planning mode. In that mode, hypothetical cropping and water demand scenarios will be user definable and the model will calculate associated water demands. Water demands will then be compared to available water supplies under different user definable hydrologic scenarios.

The model will be a “data driven”, meaning that various water supply and demand scenarios will be specified through user selection of the data inputs. Water demand patterns for various crop-soil-system-management-weather combinations will be developed, and the user will be able to define model runs by specifying the combinations he wants to evaluate. Initially, the combinations will be developed to represent past, historical operations. Later, different combinations will be developed to represent future, hypothetical scenarios. The demand patterns will be generated by a Water Demand Generator and stored in a Water Information System. Similarly, various water supply patterns will be developed and will be selectable by the user, for example, to represent wet, normal, or dry conditions, or different mixes of surface water and groundwater use. The model will then track flows through the system according to the specified water supplies and demands and designated system characteristics selected in the model. A depiction of the relationship between data sources, the Demand Generator, and the water balance model are illustrated in Figure 2.

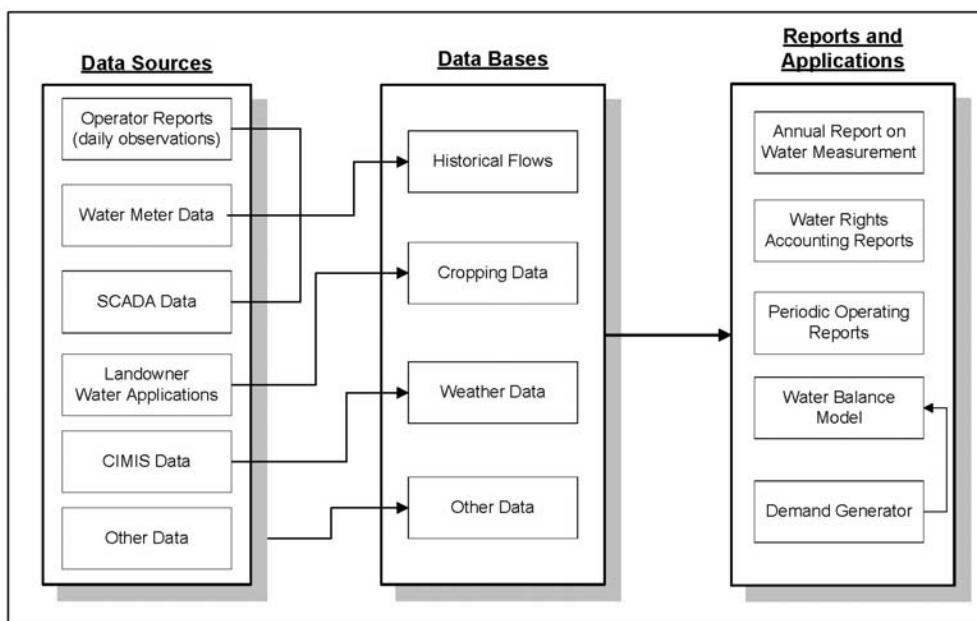


Figure 2. Plan Data Sources, Data Bases, and Reports and Applications

Water Balance Structure

The structure of the water balance (Figure 3) was developed based on consideration of the layout of the GCID irrigation and drainage systems, the structure of GCID’s water operation organization, and the availability of historical water operations data. The model domain was defined to include the entire area within GCID, including the three federal wild refuges. The cities of Willows and Williams and several other towns are contained completely within GCID but are not represented in the initial model. Municipal water use within cities and towns, and rural residential water use, is derived entirely from groundwater and is small relative to agricultural water use. Representation of municipal water use may be added to future versions of the model.

GCID is represented by five “accounting centers” shown as boxes within the dashed line in Figure 3. These are the Main Canal, Laterals, Farmland, Drains and Refuges accounting centers, which, collectively account for all water flowing into, through and out of GCID. The accounting centers are connected by flow paths. According to conservation of mass, for each of these five accounting centers and time step, the sum of inflows and outflows, plus any changes in water storage, must equal zero. Historical discharge measurements are available for the flow paths marked with the circular cross symbol. All other flow paths must be independently estimated or determined by water balance closure.

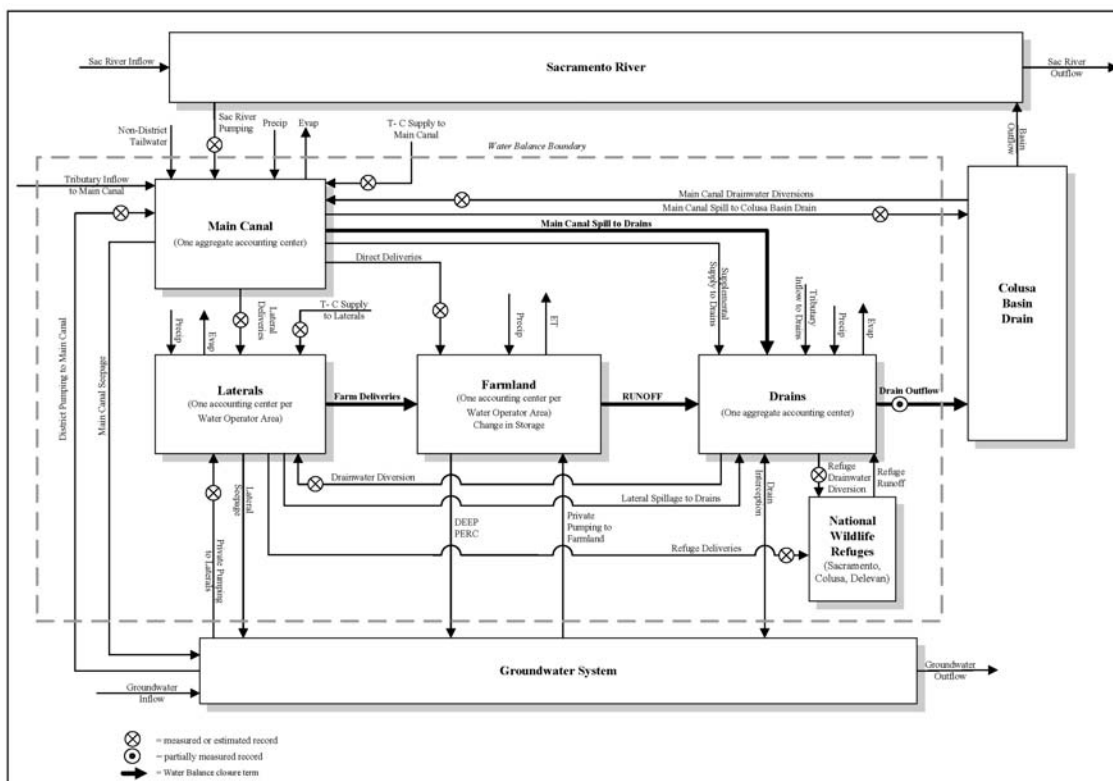


Figure 3. Water Balance

The boxes outside the dashed line in Figure 3 represent GCID's water sources and drainage destinations. The flow paths that cross the dashed line represent the various inflows to and discharges from GCID. As previously discussed, GCID's principal water sources are the Sacramento River and groundwater. Ultimately all water flowing into GCID and not consumed by evapotranspiration (ET) is discharged to either the Sacramento River via the Colusa Basin Drain or to underlying groundwater aquifers.

Main Canal Accounting Center. Reliable records of Main Canal discharge are limited to historical Sacramento River pumped diversions measured near the head of the main canal; no records are available for intermediate locations along the canal. Therefore, the Main Canal will be represented as a single accounting center in the initial model. GCID is in the process of rating several of its Main Canal checks as part of its SCADA expansion program. When sufficient historical records are available at intermediate locations, consideration will be given to segmenting the Main Canal into multiple accounting centers. Among other things, this may allow more spatially discrete estimates of main canal seepage. Dominant Main Canal inflows are pumped diversions from the Sacramento River and deliveries from the Tehama-Colusa Canal (which also are diverted from the Sacramento River at Red Bluff Diversion Dam). Principal Main Canal outflows are deliveries to laterals and direct deliveries to farms adjoining the canal.

Laterals and Farmland Accounting Centers. GCID laterals and associated farmland are grouped into ten Water Operator Areas (WOA's), with each lateral belonging entirely to one WOA. Thus, although illustrated as a single accounting center in Figure 3, the water balance will have ten paired Lateral and Farmland accounting centers, each pair representing a WOA. Primary inflows to laterals are measured deliveries from the Main Canal and, for certain laterals, measured deliveries from the Tehama-Colusa Canal. The primary outflow is deliveries to farms. For the Farmland accounting centers, the principal inflows are farm deliveries from laterals and precipitation; major outflows include crop ET, runoff (tailwater) and deep percolation.

Drains Accounting Center. There are several ephemeral creeks that originate in the Coast Range foot hills west of GCID and generally course southwestward through GCID toward the Colusa Basin Drain and eventually to the Sacramento River. During winter and early spring these creeks carry rainfall runoff, with highly variable flows depending on rainfall duration and intensity and storm patterns. Flows typically decrease to insignificant levels by early spring. During the irrigation season, typically beginning in early April, the creeks serve primarily as drains for the collection and conveyance of irrigation return flows, including operational spills from the Main Canal and laterals and tailwater from irrigated farmland. Individual drains (creeks) typically collect return flow from multiple WOA's and a single WOA may discharge tailwater to multiple drains. Also, drains serve as a water source, and in some cases, the sole water source, for certain laterals. Due to this complex arrangement, drains are represented in the initial model as a single water accounting center. Roughly 80% of the drain flow leaving GCID during the irrigation season is measured. Records are maintained of winter creek/drain flow to the extent possible given the need to safely pass storm flows.

Model Flow Path Calculation Procedures and Initial Calibration

Water balance calculations will be performed on a monthly time step with results rolled up to monthly or longer periods for calibration, interpretation, and analysis. Calculation of the historical water balance begins with the Main Canal accounting center, followed by the ten Lateral accounting centers, the ten Farmland accounting centers, and the Drains accounting center in sequence. For each accounting, the associated flow paths are determined from historical measurements or independent estimates or by water balance closure. The flow path selected for closure is typically the one for which there is no historical record and independent estimates are least reliable.

Initial model calibration will focus on matching modeled aggregate to historical Drain Outflow volumes and timing during the irrigation season. This is being approached in the following manner. First, historical records of inflows to GCID have been checked and quality controlled to create the most accurate possible record of total district inflow. Then, independent estimates of crop ET have been calculated using crop coefficients developed specifically for GCID based on 2002 actual ET maps produced using the SEBAL energy balance algorithm. The difference between precipitation, GCID inflow and crop ET (plus any change in storage) represents the total GCID outflow, which is discharged either to drains or to underlying groundwater. Modeled drain flow volumes will be matched as closely as possible to measured volumes by adjusting flows paths between GCID and the underlying groundwater system; namely, Main Canal and lateral seepage and deep percolation of applied water. This will be performed first for the full irrigation season to minimize the effects of storage changes and then on a monthly basis to match drain flow timing as closely as possible.

Model Platform

The water balance model is being coded in GoldSim risk analysis and simulation software. GoldSim is a flexible, dynamic system simulation platform for analyzing, visualizing and simulating the behavior of complex natural, financial, and engineered systems. System simulation software like GoldSim can provide a viable alternative to spreadsheet programs because model inputs, model logic, and results processing can be handled in a modular fashion, where information is made available plainly within the model components rather than hidden in spreadsheet cells. GoldSim is user-friendly and allows the modeler to quickly build model logic and build simple user interfaces for the end-user. It was chosen for this application mainly because of its visual orientation and to allow model operation by users with a wide range in computer expertise.

SUPPORTING IMPROVEMENTS TO FLOW MEASUREMENT AND DATA MANAGEMENT PROCESSES

Like many irrigation districts in the western United States, GCID is in the process of improving its flow measurement and related data management processes. Existing processes have evolved in a manner that adequately supported water operation and administration, but do not necessarily support more recent efforts to refine water

management policy and practice in response to existing and anticipated challenges to water supply reliability.

Until 2009, GCID maintained a spreadsheet-based data management system that had been designed to produce operational reports and summary tables contained in the annual Report on Water Measurement. The spreadsheet system employed macro programs to enable semi-automated data entry, but the data was stored in a highly compartmentalized manner, making data access, analysis and reporting difficult. The system performed adequately for nearly 20 years for routine operations but was cumbersome for investigative analyses and ad hoc reporting, and it was not structured to receive and manage data from GCID's expanding SCADA network.

In early 2009, GCID migrated its spreadsheet data system to a Microsoft Access relational data base. This involved extracting data stored in hundreds of spreadsheets and assembling the data in one large Access data base. All of the historical data was salvaged. The new data base retained as much of the terminology as possible from the old system, including measurement site reference numbers and names. Like the old one, the new system includes data input screens designed to facilitate hand entry of operator reports submitted orally by radio and in writing.

One major objective of the conversion to a data base environment was to accommodate the growing volume of operational data from SCADA sites. Over time, it is expected GCID's reliance on SCADA will increase and on operator reports will decrease. This trend is typical of many irrigation districts that are implementing SCADA systems for remote monitoring and control of water distribution systems. It is anticipated that the capacity limits of Access will be exceeded and the data base system will have to be migrated to a higher capacity platform, such as SQL server or Oracle. This migration will be relatively straightforward now that data is stored in data base tables. Eventually, GCID intends to house or access all of the data needed for water balance analysis in an integrated Water Information System (WIS). A major consideration in the design of the WIS is to enable routine updates of the water balance model by district staff, without assistance from outside consultants.

GCID employs a variety of flow measurement methods, ranging from continuous recording ultrasonic acoustic velocity meters to once-per-day weir depth measurements. Here, too, measurement has evolved to support routine water operations and administration, with primary emphasis on Sacramento River diversions and secondary emphasis on major internal operations (flow division) sites and drain outflows.

GCID recently completed a comprehensive evaluation and ranking of existing and prospective flow measurement sites, considering site importance, the annual volume of water passing the site, and measurement cost. Highest priority was placed on large, currently unmeasured operational and boundary measurement sites. Identified flow measurement improvements will be implemented over a period of several years.

SUMMARY

The development of a Resources Plan is a necessary step in improving policies and decision making processes to better and more actively manage water supplies. When combined with supporting legal and institutional review, the Plan will provide a basis for managing available water surface and groundwater supplies, shaping conjunctive water management policy, and evaluating potential surface water transfers.

At the core of the plan, a water balance model will serve as the best tool to improve the District's water measurement, data management and reporting systems, and to analyze historical and possible future water supplies and demands.