USE OF STATE-OF-THE ART SYSTEMS

FOR OPTIMUM WATER MANAGEMENT

by

Edward E. Horciza[1]

INTRODUCTION

Water is, without a question, the lifeblood of California's economy and prosperity. Without an adequate water supply, the development and growth of the state's immense agriculture, industry, and commerce would not have been possible.

Since moist Pacific-frontal storms can produce intense precipitation and major floods, and effects from high pressure ridges off the coast of California can cause extended dry periods even during the "wet" season, the amount of annual runoff in California can be quite unpredictable.

This paper describes the state-of-the-art systems that Pacific Gas and Electric Company is using to optimize the management of such a variable water supply.

COPING WITH EXTREMES IN CALIFORNIA

Snowmelt runoff is of critical importance to California's water supply, as mountains cover about fifty percent of the state. The most significant snowpack is found above an elevation of about 1,500 m during the period from November through May. The snowpack's water content reaches its peak, of an average 80 cm in the Sierra Nevada Mountains, toward the end of March.

The snowpack in the Sierra Nevada Mountains can reach great depths during heavy snow years, and California holds several North American and United States' records for snowfall and snow depth (NOAA, 1973). For example, 990 cm of snow fell at PG&E's Tamarack weather station (Alpine County, elev. 2,440 m) in January 1911. That is a North American record for the greatest snowfall in one month. On March 11 of the same year, the snow on the ground at the Tamarack weather station reached 1,146 cm, which is a United States record for the greatest depth of snow on the ground at any one time. Another United States record for the greatest snowfall in a single storm occurred at the Mount Shasta Ski Bowl, when 480 cm fell from February 13-19, 1959.

Such enormous snowpacks produce, of course, very heavy snowmelt runoff. In watersheds which drain high mountain ranges, such as in the southern Sierra Nevada Mountains, heavy snowmelt runoff can continue until about mid-July during heavy snow years.

Rain on snow can produce floods of great magnitude. An example of such a flood is the flood of the North Fork Feather River in February 1986. A tropical storm, driven by a strong jet stream (which reached a velocity in excess of 340 km/hr near the Hawaiian Islands at an altitude of 10,000 m) caused a record rainfall of 46 cm in 24 hours, 104 cm in 6 days, and 130 cm in 15 days (Goodridge, 1986) on top of an existing snowpack (which ranged in depth from about 150 cm to 250 cm) along the Bucks Lake Ridge (DWR), running parallel to the North Fork Feather River. A peak flow of 2,550 cubic meters/second and a total runoff of 863 million cubic meters in one week (which is about one-third of the average annual runoff) resulted from such intense rain on top of snow at the North Fork Feather River at Pulga gaging station.

Presented at the Western Snow Conference, April 17-19, 1990, Sacramento, California.

[1]Senior Hydro Engineer, Pacific Gas and Electric Company, 245 Market Street, San Francisco, California 94106.

Other record floods in California, which were also caused by tropical rainstorms produced peak flows of 21,240 cu.m/sec. of the Eel River at Scotia in December 1964, 8,210 cu.m/sec. of the Sacramento River near Red Bluff in February 1940, and 2,100 cu.m/sec. of the Kings River above Pine Flat Reservoir in November 1950 (U.S.G.S.).

In contrast, due to the effects of high pressure ridges off the coast of California during winter months, dry seasons and back-to-back dry seasons occur periodically. Currently, only ten months during the past seven seasons (including 1989-90) have been wetter than average in California. Statistically, there is a predominance of dry seasons over wet seasons in California, as a significant percentage of the wet seasons are extraordinarily wet and only a relatively small number of dry years are extremely dry. Forty of the last 65 years were below average and only 25 were above average.

Due to such vagaries of the weather, the annual streamflow in California ranged during recent years from a low of 18.5 million cubic dekameters in 1977 to a high of 167 million cubic dekameters in 1983 (DWR).

In order to cope with such extreme water conditions and to manage its water resources, California has the most extensive water development system in the world, with approximately 1,300 dams and reservoirs, capable of storing 53 million cubic dekameters of water, numerous electrical generating and pumping plants, thousands of kilometers of canals and aqueducts, and tens of thousands of agricultural pumps pumping water from nearly 400 groundwater basins with an estimated 1,050 million cubic dekameters of stored groundwater (DWR). There are more than 300 water agencies in California serving millions of customers and an agriculture which has some $16.6 billion a year in revenues.

WATER RESOURCES MANAGEMENT AT PG&E

Pacific Gas and Electric Company (PG&E), which owns and operates fifteen hydroelectric watershed developments in Northern and Central California, also faces challenging problems in managing its water resources due to continuous changes in water conditions.

PG&E's hydro system includes 57 main storage reservoirs with a total capacity of about 2.7 million cubic dekameters, 89 diversion and regulating reservoirs and 44 auxiliary dams, for a total of 190 dams. The system also includes 690 kilometers of conduits, which include canals, flumes, tunnels, and pipes and 71 hydroelectric powerhouses. The company also maintains an extensive hydrometeorological network, which consists of 50 snow courses, 50 weather stations and over 600 water level gages.

The PG&E company of today is a result of about 520 mergers of water, gas, and electric companies and its oldest predecessor companies date back to the early years of the California gold rush.

To this day, PG&E uses many hydraulic facilities, which were inherited from predecessor companies and were built many years ago. These structures were sized to the needs of those companies at that time and are often inadequate to utilize fully the available runoff, especially during major rainstorms and peak snowmelt runoff. During dry seasons, the limited storage capacity of these small reservoirs makes it difficult to meet all water and power demands, especially during late summer and early fall.

This, combined with very stringent environmental, recreational, and safety requirements by regulatory agencies and contractual commitments make it a difficult task for PG&E to operate optimally its water systems.

Field operating personnel, system dispatchers, and technical and engineering support personnel have made it possible over the years for the company to operate hydro facilities efficiently despite constantly changing conditions and demands.

Near-optimum water management and full compliance with license and contract requirements would not have been possible, however, without the use of an extensive array of monitoring and controlling equipment, telecommunications, computers, and computer software.

WATER MANAGEMENT TOOLS AT PG&E

PG&E is still using many old, proven methods and equipment to measure, calibrate, monitor, record, regulate, control, and utilize water resources. A systematic and continuous effort, however, is made to research and develop new methods, to search the market for better devices, and to test and possible adopt them for use.

Starting with the top of the watersheds, we still perform manual snow surveys. The use of helicopters, however, has speeded up the surveys and has made them less hazardous than in the days when snow survey parties used skis to travel to the snow courses.

Use of telemetered snow sensor data during the last several years has given us an ability to assess changes in the snowpack, resulting from storms and snowmelt. A telephone link via computer modems gives us an ability to access daily snow sensor and precipitation information from California Data Exchange Center's data base. In addition, we daily automatically access data from 29 company-operated weather stations, 260 flow monitoring stations, 116 reservoirs and 90 powerhouses from our Power Control Department's database. The availability of such current data is of a significant value in making better short-term water management decisions.

PG&E maintains over 600 streamflow gaging stations in natural channels and canals to monitor releases and spills at dams, flows in streams and canals, and deliveries to water customers.

Historically, strip-chart recorders were used to record water surface elevations at these gaging stations. Laborious hand-reductions of the chart traces and manual computations were then used to determine the daily average flows.

When Analog to Digital Recorders became available during the 1960s, we replaced; most of the strip-chart recorders with the new paper-punched tape recorders. The punched-tape data was reduced by optical readers and then transferred to magnetic tapes. These paper-punched tape recorders were certainly labor-saving devices; however, they and the readers were subject to occasional mechanical malfunctions and were limited to 15-minute, half-hour, or hourly punches.

During the last several years, the company has replaced all paper-punched tape recorders with strip chart recorders equipped with optical encoders which are interfaced with electronic data logger units. In some cases, the data is sent over telephone lines or radio to switching centers or is telemetered to Supervisory Control and Data Acquisition (SCADA) system's remote terminal units (RTUs). This new equipment better enables us to monitor real-time flow data so as to ensure compliance with license and contractual requirements and to provide surveillance required by dam and canal safety projects. The equipment also provides a truly continuous record and information needed to optimize water operations.

Should an encoder or data logger malfunction occur, an electronic digitizer, interfaced with a personal computer (PC) is later used to reduce the strip chart trace. The rating of gage height to discharge relationships at gaging stations is still manually performed using mechanical current meters. However, PG&E has constructed weirs at gaging station controls at all locations where this was feasible.

In 1968 we designed two types of self-cleaning weirs (triangular and trapezoidal), utilizing the Venturi principle, to minimize effects from sediment deposition, trash, and snow. Ten such weirs were constructed at locations subject to severe sediment and snow problems, most of them located at high elevations in the Sierra Nevada Mountains. After many years of severe conditions, all of these weirs have performed above all expectations and have made it possible to obtain accurate flow records at locations where previously the quality of records was very poor.

An accurate measurement of flow in closed conduits has always been very difficult, if not impossible, due to random flow characteristics in the conduits. PG&E has through the years tested and used many types of mechanical and differential producing flow meters, but without an accurate calibration the accuracy of these meters has ranged from fair to poor.

Several pipe-flow measuring methods were developed prior to World War II, such as the salt-velocity method and several pressure-time methods, but these methods required elaborate equipment, dewatering of the conduit, highly trained testing personnel, several days of testing, and were quite expensive. As a result, only pipe flow tests with a high benefit-to-cost ratio, such as acceptance tests on large hydroelectric plants, were ever performed.

During the early 1970s, PG&E started developing a low-cost dye dilution method, using newly available tracer dyes, to measure flow in pressurized pipes. This research and development continued for several years.

In November 1983 the company participated in an Electric Power Research Institute sponsored comparative tests of five methods approved by the American Society of Mechanical Engineers and International Electrotechnical Commission, at the Cootenay Canal Generating Station in British Columbia, Canada. The tests were designed to compare the accuracy and repeatability of all the methods against a standard and the average of all the results. PG&E's dye dilution method results plotted, for all practical purposes, in the center of the band of results of all the methods. The spread of this band was about two to three percent. PG&E has used the dye dilution method in over 100 efficiency tests of hydraulic turbines, pipe-flow, and open channel flow measurements over the past 15 years.

The dye dilution method is a low-cost method which does not require a dewatering of the conduit, but utmost care must be taken in performing it, especially in assuring good mixing of the dye, accurate measurement of the injection pump output, and correct calibration of the fluorometer, in order to achieve a high accuracy (about 1-1/2%) of the measurement.

In recent years, PG&E started to test various portable acoustic flowmeters to find an even more accurate method of measuring pipe flows. These tests were performed on pipes of various sizes (from 0.3 m to 6 m diam.) and at locations downstream and upstream from flow distorting pipe sections such as bends and converging and diverging sections, against accurate standards.

As a result of these tests, several types of acoustic flowmeters with both clamp-on and intrusive transducers were selected, purchased, and installed by the company.

So far, we have purchased four portable ultrasonic flowmeters for performing efficiency tests on hydroelectric generating units. The testing equipment also includes lap top computers with printers and modems and specialized devices for monitoring servo stroke and generator output. These devices were designed and built to our specifications.

We have also permanently installed a two-path sonic flowmeter at our Potter Valley Powerhouse, three eight-path sonic flowmeters at the Helms Pumping and Generating Plant, and two ultrasonic flowmeters at the Butt Valley Powerhouse. At Butt Valley, the flowmeters also serve as components of a penstock protection system and an on-line efficiency monitoring system.

This year, we will install eight flow meters at the four penstocks of our Pit No. 5 Powerhouse. These meters will also be a part of efficiency and penstock protection systems.

PG&E's Helms Pumped Storage Project located on the North Fork Kings River in the Sierra Nevada Range is of vital importance to company in providing 1,212 MW of fast response, on-peak capacity and in minimizing the spillage of water during peak runoff.

Water is being cycled between two reservoirs with a combined usable storage of about 236,000 cubic dekameters, when economic off-peak energy is available for pumping. Helms Plant is powered by three 480,000 hp reversible pump turbines and the maximum static head is 532 meters. This head combined with the size of the units place these among the forerunners of the world in reversible units. At full head, 255 m3/s of generating flow and 204 m3/s pumping flow can be achieved through the three units. As the upstream reservoir is somewhat oversized as to storage and the downstream reservoir has prior to the construction of the Helms Plant spilled frequently, the project plays also a water conservation role by transferring water into the upper reservoir during times of heavy natural inflow into the lower reservoir.

In order to optimize resource utilization, PG&E has installed state-of-the-art SCADA systems at most of our hydroelectric projects and other generating, transmission, and distribution facilities.

Electrical and water data is electronically transferred from sensors to RTUs at powerhouses, then to master units at major switching centers and from there to the System Dispatch computer in San Francisco. This data is then used by the Energy Management System (EMS) and Hydro-Thermal-Optimization (HTO) computer models to optimize the utilization of all available electrical resources and to help the system dispatchers to better schedule our water resources.

In order to acquire a long-term hydro forecasting and scheduling tool, PG&E developed the Hydroelectric Systems Scheduling (HYSS) computer model during 1982 and 1983. The HYSS model provides optimum monthly scheduling of water resources for 23 watersheds over a two-year horizon. The model considers all hydraulic facilities and all significant constraints in each hydro development. The HYSS model won the International Institute of Management Sciences' prestigious Franz Edelman Award in 1986.

Currently, the Company is in the process of developing a mid-term hydro thermal optimization model to provide optimum weekly and monthly scheduling of water resources and available electrical resources for a period of up to five years.

With a rapidly growing demand for water resources and non-polluting, renewable energy, it is essential that we optimize the use of our water resources in California and the entire western United States. State-of-the-art monitoring and control systems are important tools to achieve such optimum utilization of the available water supply, especially during extreme seasons.

REFERENCES

State of California, Department of Water Resources, Sacramento.

Goodridge, J. (1986) On going to extremes in California rainfall. pp. 35, November 1986.

NOAA Technical Memorandum, NWS WR 28, June 1973.