CENTRAL ARIZONA PROJECT CONCEPT OF OPERATION

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ABSTRACT

The Central Arizona Project (CAP), presently under construction, will convey Arizona's remaining entitlement of Colorado River water to three central Arizona counties. As a result of the recently completed CAP Real-Time Operations Study, a concept of operation has been developed. The concept of operations defines three types of operation beginning with an initial manned operation in 1985, a transition operation, and a permanent operation using a computer assisted remote control system. Under the permanent operation, computer models will be run in advance to define weekly and daily pumping plant and check gate schedules.

INTRODUCTION

Scheduled to deliver Colorado River water to the Phoenix area in 1985 and Tucson in 1987, The Central Arizona Project (CAP) is one of the largest water conveyance systems in the United States and it offers a unique opportunity for application of modern operation concepts. Recognizing this opportunity and the need to select the proper operation concept and associated type of control system the USBR has completed the CAP Real-Time Operation Study.

The CAP concept of operation developed by the Operation Study is similar to operation concepts used for control of large power distribution systems and the California Aqueduct. The concept centers around the use of computer models off-line in advance to generate pumping plant and check gate schedules which meet water and power operating objectives and constraints. The operating schedules will be implemented daily by a computer assisted remote control system.

CAP OVERVIEW

The CAP was authorized by Congress in 1968 after years of controversy, court battles, and legislative maneuvers. The project's 300 plus miles of aqueducts, will convey Arizona's remaining entitlement of Colorado River water to Central Arizona. The Colorado River water will be used in Central Arizona to defer the overdraft of the groundwater supply. Recipients of CAP water include Municipal and Industrial users in major metropolitan areas, Indian and Non-Indian agricultural users, mining and power production interests, and wildlife and recreation entities.

Initial construction on the project began in 1971 at the Navajo Power Station in Page, Arizona. The Federal participation in the Navajo Plant assures CAP of adequate power for operation. The sale of available excess energy from the Navajo Station will also provide the CAP with additional revenues. Over half of the Granite Reef Aqueduct from the Colorado River to Phoenix is completed or under construction. Contracts for relift pumping plants, Salt-Gila Aqueduct, and associated project features will be initiated in the near future.

PHYSICAL DESCRIPTION

Havasu Pumping Plant, located on the rugged shoreline of Lake Havasu will lift CAP water 820 feet to the mouth of the Buckskin Mountain Tunnel. Six 500 ft^3/s pump units in the Havasu Plant will utilize over half of the project's power source when operating at capacity.

After passing through the 6.8 mile concrete lined Buckskin Mountain Tunnel the water will enter the head of the open channel Granite Reef Aqueduct (GRA). The initial 18 mile Reach of the GRA will have an operational storage capacity of approximately 4400 af. The GRA extends 190 miles to the Phoenix area with three intermediate pumping plants, seven inverted wash siphons, and two intermediate horseshoe section tunnels. The relift pumping plants all have a capacity of 3000 ft^3/s with lifts of

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101, 103, and 180 feet. Dual radial gate check structures are located at approximately 6.5 mile intervals in the open channel sections to control water levels and flow. No wasteways are included in the open channel section of the GRA.

The Salt-Gila Aqueduct (SGA) begins at the terminus of the GRA with the 76-foot pump lift at the Salt-Gila Pumping Plant. The SGA extends 58 miles from the Phoenix area toward Tucson. Expected to be similar in design to the GRA with an initial capacity of 2,700 ft^3/s, the SGA will step down in capacity as delivery points are established along its length.

Picacho Mountain Pumping Plant signifies the terminus of the SGA and the initial point of the Tucson Aqueduct. Still in the preliminary planning stages, the Tucson Aqueduct will convey CAP water the remaining 60 miles to the Tucson area.

The Operation Study which developed the operating concepts outlined herein considered only the real-time operation of the Granite Reef and Salt-Gila Aqueducts without seasonal regulatory storage features.

CONCEPTS OF OPERATIONS

Considering the timing and quantity of water delivered, and the limitations involved in completing and accepting the CAP control system, the proposed concept of operation for CAP facilities can be broken into three basic types of operation.

The initial manned operation, commencing almost immediately following completion of the project's physical facilities, should correspond to a period of low initial water deliveries. Control of the pumping plants and aqueduct check gates will be accomplished by personnel at the pumping plants and along the aqueduct.

During this period, a shakedown of the aqueduct mechanical and electrical systems will take place, as well as "off-line" and "on-line" debugging of the control system. The duration of the initial operation will be approximately 12 months. At the conclusion of this phase, "final" acceptance tests will be performed by the control system contractor.

The transition operation will be characterized by increasing water deliveries, and a continuation of the final "on-line" checkout and debug of the remote control system by project personnel. During the transition period the pumping plants and aqueduct check gates will be controlled remotely by the remote control system with manuel back-up in the field. After a transition period of 6 to 12 months, the remote control system should become fully functional. At that time, most of the major distribution systems could be completed, and permanent operations can be initiated.

On an annual basis, an operating plan will be developed using the Colorado River water allocation for CAP, water and power contracts, and master water delivery schedules for the service area. The annual plan will outline water diversion requirements at the Colorado River on a monthly basis and will identify monthly allocations of water service contracts and operating policy.

Coordination of CAP water user schedules and water availability in conjunction with Colorado River operations will produce an annual operating plan which will be coordinated through Western Area Power Administration (WAPA) to schedule yearly CAP power requirements and market excess Navajo energy.

Within the framework of the annual operating plan, coordination with water users and Colorado River operations will occur on a monthly basis to generate an operating plan which will distribute each users monthly allocation into weekly delivery schedules. This updated information will be used by WAPA for refined power scheduling and marketing.

On a weekly basis, the water users will be required to notify the CAP Operations Center of their weekly water orders by the preceding Wednesday for the following week. The water scheduling staff will compile and approve the water orders. The staff will also process scheduling programs on the computer system in the Operations Center to determine a set weekly operation at the Havasu Pumping Plant, and nominal schedules at the relift plants. It is expected that the Havasu Pumping Plant will normally operate as scheduled during the weekly period. This essentially firm Havasu operation will insure that CAP's portion of Navajo power can be utilized effectively, consistent with water delivery and power marketing requirements. When emergency or unforeseen conditions arise which require CAP to utilize energy in excess of the scheduled amount, power will be obtained through other sources within the integrated Federal power system, or purchases from commercial suppliers.

Under most operating conditions, the water users will be allowed the flexibility to contact the project water scheduling staff and update the water delivery schedules on a daily basis. The daily changes in delivery schedules must be telephoned in to the Operations Center by 9 a.m. on the preceding day to be approved and incorporated in the following days operating schedules.

The updated daily water delivery orders will be input as data into the scheduling computer models. The models will be run on the computer at the Operations Center, and will define an operating schedule at the pumping plants and check gates for the following day. The control operators will review, and approve the schedules prior to implementation by the control system.

During actual operations for the following day, conditions which deviate significantly from the projected operations (unusual or emergency conditions), will be detected by the control system, and will generally require a response by the control system operators. Small deviations may trigger the processing of special computer programs which evaluate conditions, and suggest an appropriate response to the operators. More unusual problems may require operator response based on experience. This experience will be developed by the control system operators throughout their terms as trainees during the initial and transition operations.

When unusual or emergency conditions have been cleared, the computer scheduling programs will be rerun using the current aqueduct conditions. The revised schedules will be reviewed, approved, and implemented.

Unusual and emergency conditions will require close coordination with WAPA, and, depending on the severity of the situation, coordination with the water users and Colorado River operations. During partial or complete power failures of the system, load shedding operations as the result of an outage at Navajo Power Plant, or various other emergency conditions, close coordination will be required with WAPA power schedulers. Curtailment in deliveries will require coordination with water user entities.

OPERATIONS CENTER FUNCTIONS

The Operations Center will house the control system, control system operators, water scheduling staff, and administrative, operations and technical staff. The center will be the main control point for the entire CAP system. The capability to transfer control to a local site will be available, but during normal conditions, the Operations Center will direct all aqueduct operations.

The control system computer will be an integral part of the Operations Center. The computer is expected to be dual in nature for reliability. The dual aspect of the system should extend to all parts of the computer.

The computer system will direct the collection of telemetered aqueduct system status and alarm data, process the information to check for software generated alarms, display appropriate information to the control system operators, and implement control commands. The computer will utilize the current telemetered information to maintain an updated hydraulic representation of the aqueduct in memory at all times.

PUMPING PLANTS OPERATION

After an appropriate period to phase out pumping plant operators which will be on temporary assignment during the initial and transition periods, the pumping plants are expected to be operated remotely during normal, and most unusual and emergency operating conditions. However, maintenance personnel will be assigned to the plant, and available for short-term emergency operations if required. The control system will telemeter status and alarm conditions "continuously" from the plants to the Operations Center, with control commands telemetered back to the plants at the appropriate time. During long term unusual and emergency conditions, the pumping plants may be manned by roving operator teams and operated locally in coordination with the Operations Center. During normal operations, the roving teams will visit the pumping plants periodically to monitor the remote operations.

Havasu Pumping Plant will be operated to optimize the extent of offpeak pumping within the limits of available operational storage in Reach 1 and water delivery requirements. The plant's operation will be on a firm weekly cycle with changes in pumping operations made only when unforeseen circumstances require deviations.

The relift plants will be operated under a variety of water-power operating concepts. Various computer models will be used at different times to specify in advance the desired relift plant operations. Three types of operations are currently defined. Optimal operation (maximize offpeak pumping) of the relift plants may be possible during certain flow ranges using water/power optimization models. A non-optimal, onpeak, offpeak operation may be specified using the constant volume concept model. The pumping plants could also be operated on a baseload concept, cycling pumps to match downstream delivery requirements using simplified operating models. This concept will be used during initial operations. In addition, the baseload concept would be required at high aqueduct flows, when water deliveries are scheduled on a pro-ration basis. Regardless of the concept utilized, the operation of the relift plants will be defined nominally on a weekly basis, and updated daily to reflect changes in delivery orders.

CHECKGATES OPERATIONS

The check structures will be operated remotely to control pool water levels and flows. The computer scheduling models will develop a daily schedule of checkgate movements consistent with the water-power concept incorporated in the models. The computer models will prescribe gate operations which will assure that specified flows or levels are maintained.

As with the pumping schedules, once a daily schedule of gate movements are defined by the models, the control system operators will review the schedule for errors, make changes where necessary, and implement the schedules in the control system. The following day, the control system will automatically move the gates according to the schedules, unless directed otherwise.

During emergency situations, control of the gates can be made remotely, or locally at the check structures. The control system operators will make gate changes as suggested by emergency operating programs or by personal experience. After an emergency condition has been cleared, the scheduling models will be updated and rerun, defining a new pumping plant and gate schedule which will be implemented through the control system.

TURNOUTS OPERATION

The gated turnouts will be operated remotely by the control system. Flow changes will be made by the control system at the times scheduled by the water users, consistent with operating policy. Should a change be required in the planned turnout schedule, the control system operators will make the change remotely. At the non-gated turnouts, flowmeter readings will be telemetered to the Operations Center and displayed for operator surveillance.

PERSONNEL REQUIRED

The control system operator staff will be large enough to have two men on duty at all times. The operator staff will also have other duties that can be performed when the system is functioning normally.

At least one member of the water scheduling staff will be on duty 7 days a week, one shift per day. This staff will compile monthly, weekly, and daily water orders and coordinate with the water users, WAPA, and with Colorado River operations.

The control system and Water Operations Division will be supported by an engineering technical staff familiar with the control system hardware and software, the aqueduct electrical and mechanical systems, and the operating principals and concepts. This staff will consist of a number of electronic engineers, civil engineers, and support technicians. The engineering technical staff will assist the operating staff with major problems, perform on-going studies, and evaluate overall system effectiveness. This staff will also make software improvements to the control system as necessary.

The two roving operator teams are expected to consist of two men each. The normal procedure for the teams will be to visit individual pumping plants on a regular basis evaluating and monitoring the remote operation.

The operating personnel required under permanent operations will be somewhat less than under the initial or transition operations. The staff reduction will be accomplished by returning temporary personnel to their respective projects, transfers to the Tucson Aqueduct, shifting jobs to become control operators, and by attrition in the control system operator staff. The permanent control system operator staff is expected to consist of twelve system operators who will man the control system at the Operations Center at all times, four system operators who will form roving operating teams and four system operators who will work with the water scheduling staff in developing daily operating schedules.

COMPUTER MODELS

The current concept of computer models fall into three general categories of operation specification programs, operation design programs, and simulation programs.

The operation specification programs are computer models which define target depths or target flows throughout the aqueduct as a function of time over a 24-hour period. These programs can define an array of operation specifications. The two models currently used define an optimum water-power operating concept and a constant volume operating concept. Other specification programs may be written to define operations under other operating concepts.

The operation design programs make up the heart of the "off-line" concept of operation. The design programs will use the specified operating criteria (flow as a function of time or depth as a function of time in each pool) to design operating schedules for the pumping plants and check structures. These "designed" operating schedules will reflect operating constraints of limited hydraulic transient generation and operating objectives of limited water level fluctuations in the pools.

The simulation program represents the actual aqueduct. The simulation program uses approximate mathematical techniques to model gradually varied unsteady state flow in open channels. This technique has been thoroughly tested over a number of years.

WPOM

The Water-Power Optimization Model (WPOM) falls under the category of operation specification program. The WPOM is currently under development for use under actual operations.

Using operation research techniques, WPOM optimizes the use of aqueduct prism operational storage to minimize onpeak energy use. The optimization process is constrained by the operating constraints (primarily downstream rates)(Yeh, 1979).

CVM

The Constant Volume Model (CVM) is also categorized as an operation specification program. Using turnout demands, initial conditions, and target storage values for each pool, the CVM develops pump schedules and target pool levels for onpeak and offpeak time periods.

Although the constant volume approach does not produce an optimal onpeak, offpeak operation, the approach does provide for a great deal of operational flexibility. With the aqueduct prisms at a relatively constant target storage throughout the day, flow changes can be made throughout the system almost instantaneously. In contrast to the traditional operation which requires long lag times for introducing flow changes and no onpeak, offpeak pumping, the constant volume concept allows for pumping and check gate flow changes to be made simultaneously with acceptable pool level fluctuations. The concept is not workable for medium to large flow changes due to the variation in pool levels during the flow changes.

Under the constant volume concept, low flows tend to have higher checked water levels and high flows tend to have lower checked water levels. This variation is due to the difference in wedge storage between high and low flows.

GSM

Under the category of operation design programs, one Gate Stroking Model (GSM) was formulated for use in connection with the WPOM (Yeh, 1979) and one GSM was developed for the CVM (Falvey, 1979). The GSM developed for WPOM uses specifications of flow as a function of time at each check structure and a finite difference-staggered net method to arrive at gate schedules which minimize hydraulic transient activity. The GSM related to CVM used depth as a function of time as a specification and a characteristic grid method to generate gate schedules which minimize hydraulic transient activity (Bobley, 1978) (Wylie, 1969).

Do to the nature of the gate stroking concept, an open channel flow problem cannot be completely specified. One degree of freedom is necessary for the solution procedure to progress. The degree of freedom allowed within the GSM is depth in each pumping plant afterbay pool. This pool is allowed to "float" according to the input specifications for the other pools and initial conditions.

ASM

The Aqueduct Simulation Model (ASM) falls into the category of simulation programs. The model uses the method of specified time intervals (a particular type of method of characteristics solution) to solve the partial differential equations defining gradually varied unsteady flow (Shand, 1971). The model has boundary routines which model checkgates, pumping plants, turnouts, and changes in section. The model can also perform calculations in trapezoidal sections, round sections, and horseshoe sections.

USE OF COMPUTER MODELS

Under actual operations, a version of ASM will be running at all times in the computer operating system using telemetered water levels, gate opening, and pump flows from the aqueduct. The ASM calculated water surface and flow profiles will be used by the control system to generate certain software alarms.

At 10 a.m. each day, the ASM will run on the control system using projected turnout schedules, actual 10 a.m. hydraulic conditions, and the gate and pump schedules for that day. This run will yield the projected conditions in the system as of midnight that day. From these projected conditions and the turnout schedules for the next day, an operation specification program (WPOM or CVM, etc.) will generate the desired operation specifications for the next day. The operation design program (GSM) will then use the projected initial conditions and operation specifications to design the gate and pump schedules for the next day.

Initially, the model generated pump and gate schedules will be evaluated by the ASM using the projected initial conditions. Should these evaluations indicate an undesirable operation has been designed, the operation specification and operation design programs will be rerun with proper biasing at the problem areas. It is expected that operating experience with the specification and design programs will eliminate the need for a daily ASM evaluation of the operating schedules.

Once the next days schedules have been evaluated by the computer models, the schedules will be made available to the control system operators. The daily gate and pump schedules for the next day are expected to be available to the control system operators by no later than 4 p.m. each day. The control system operators will visually inspect the schedules on the control system display screens and authorize the system to implement the schedules at the proper time the next day.

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