ALGORITHMS FOR AUTOMATIC CONTROL OF DIVERSION DAMS

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ABSTRACT

The nature of the upstream river inflow to a reservoir of a typical diversion dam determines how the releases downstream are made. River inflow can be (1) intermittent or (2) continuous with a wide variation in magnitude. The application of local automatic control for the releases from a diversion dam that has intermittent river inflow is limited. For this case, it is better to install a remote monitoring system and make the releases by manual operation. The diversion dam that has a continuous river inflow can utilize onsite control algorithms for the local automatic regulation of the releases downstream. This paper discusses the typical diversion dam and the two basic operational concepts. The criterion for selecting a remote monitoring-manual operated system versus a local automatic controlled system is included. The general concept of the remote monitoring system and the design of a practical local automatic controller are then discussed and a summary is provided.

INTRODUCTION

There are many small diversion dams constructed on natural river channels that are designed to divert water into canal systems for conveyance to irrigation and municipal projects downstream. The operation of the diversion dam requires continuous attention if releases and the routing of flood flows are to be efficient. In most cases, 24-hour attendance by operating personnel would be uneconomical. At remote sites, it would be impractical. Scheduled visits to the diversion dam by operators are usually infrequent. Therefore, the diversion of river inflow into the canal system may not be successful when large variations in the magnitude of the river inflow occur unannounced. Relatively simple control systems can be designed that will assist in the operation of the diversion dam. A remote monitoring system would provide information to operating personnel that would make a manual operation more efficient. When applicable, onsite control algorithms would provide local automatic regulation of the downstream water releases requiring minimum supervisory intervention.

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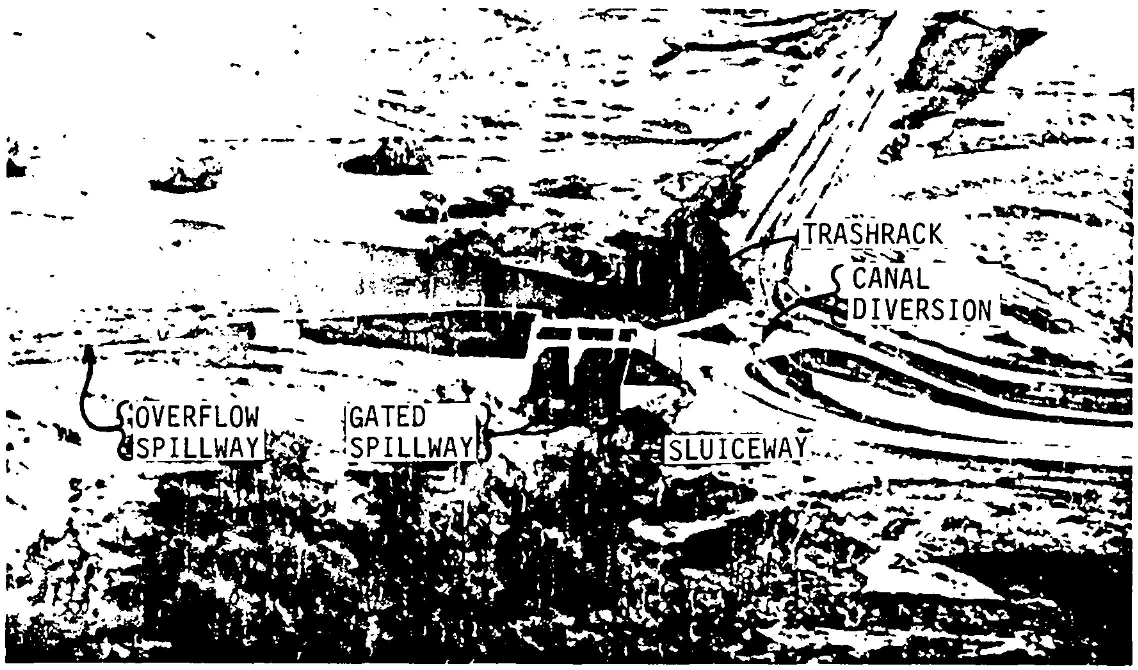

Figure 1. - A typical diversion dam represented by the Bretch Diversion Dam and Canal, Mountain Park Project, Oklahoma.

OPERATION OF A TYPICAL DIVERISON DAM

A typical diversion dam has three main features. They are the canal outlet, the sluiceway, and the spillway structures, figure 1. The canal outlet diverts river inflow to a canal system up to a designed capacity. The sluiceway is designed to sluice the sediment bedload and to route the smaller flood inflows to the river channel downstream. The higher flood flows are routed through the spillway structure. The spillway can be controlled by gates or it can be uncontrolled using the overflow type structure. In some cases the spillway feature can consist of both the controlled and uncontrolled types.

A typical diversion dam can have two basic operating characteristics based on the nature of the upstream river inflows. The upstream river inflows can be intermittent or relatively constant. Intermittent inflows to the diversion dam reservoir will occur when the principal source of water is from rainfall storm runoff within the upstream drainage basin. Relatively constant inflows will occur when the principal source of water is released from a larger storage reservoir upstream. The operation of the diversion dam is considerably different when the inflows are intermittent compared to a relatively constant inflow.

Special operating procedures are necessary to regulate the diversion dam releases when the characteristics of the inflow are intermittent. During the dry periods the sluiceway and in some cases the spillway gates are opened to a maximum position, and the canal gates are closed. The natural drainage of the river channel continues downstream and any requirements for riparian water rights, fish and wildlife habitat downstream can be satisfied without operator attendance. The initial water wave traveling down the dry river channel, resulting from a rainfall storm runoff occurrence, will be heavily laden with sediment and debris and occasionally an uprooted tree. With the sluiceway and spillway gate wide open the initial wave front of the storm runoff can also be routed downstream without operator's attendance. The initial sediment load and debris is therefore not captured in the reservoir area. After the initial wave front passes through the diversion dam structure, the sluiceway gates are lowered to a minimum opening and the spillway gates are closed by an operator. The water level in the reservoir is allowed to rise up to the maximum designed depth of the canal system before the canal outlet gates are opened. Raising the reservoir water level up to the maximum design depth of the canal system before opening the canal outlet gates, prevents floating debris from plugging the canal outlet trashrack at the lower elevations.

Therefore, an operator's attendance is required to operate the diversion dam only when the intermittent flood inflows occur. The rain storm is unpredictable and could vary significantly in intensity and duration from one storm occurrence to the next. Combine these characteristics of rain storm runoff with the many special operating procedures required at the diversion dam, the operator will have to make many critical decisions at the appropriate time if canal diversions and routing flood flows downstream during a rainfall storm occurrence are to be successful. The application of local automatic control, generally, is not practical when most of the operation is dependent on operator's judgment. The diversion dam water releases should be made manually by the operator. However, a simple remote monitoring system can be implemented. Key information could be provided to the operator at the appropriate times that would be beneficial to the manual control of the diversion dam releases.

A diversion dam that has a relatively constant inflow has several operational advantages, compared to one that has intermittent inflow. The constant inflow is predictable to a certain extent. The diversion rate to the canal system can be scheduled in advance. The reservoir water level can be checked up and maintained at an elevation equal to the maximum designed depth of the canal system. Minor variations, or mismatches, between the inflow and scheduled canal diversions can be routed through either the canal outlet or the sluiceway.

Therefore, frequent operator attendance, on an hourly basis, is required to operate a diversion dam that has a relatively constant inflow. Repetitive adjustments of the canal outlet sluiceway gates are required to route minor variations in the inflow. The application of local automatic controllers are practical, when repetitive gate operations are involved on a long term basis. Relatively simple algorithms can be designed that will automatically regulate the canal outlet and/or sluiceway water releases. As a result, the operator's required attendance on an hourly basis can be reduced significantly.

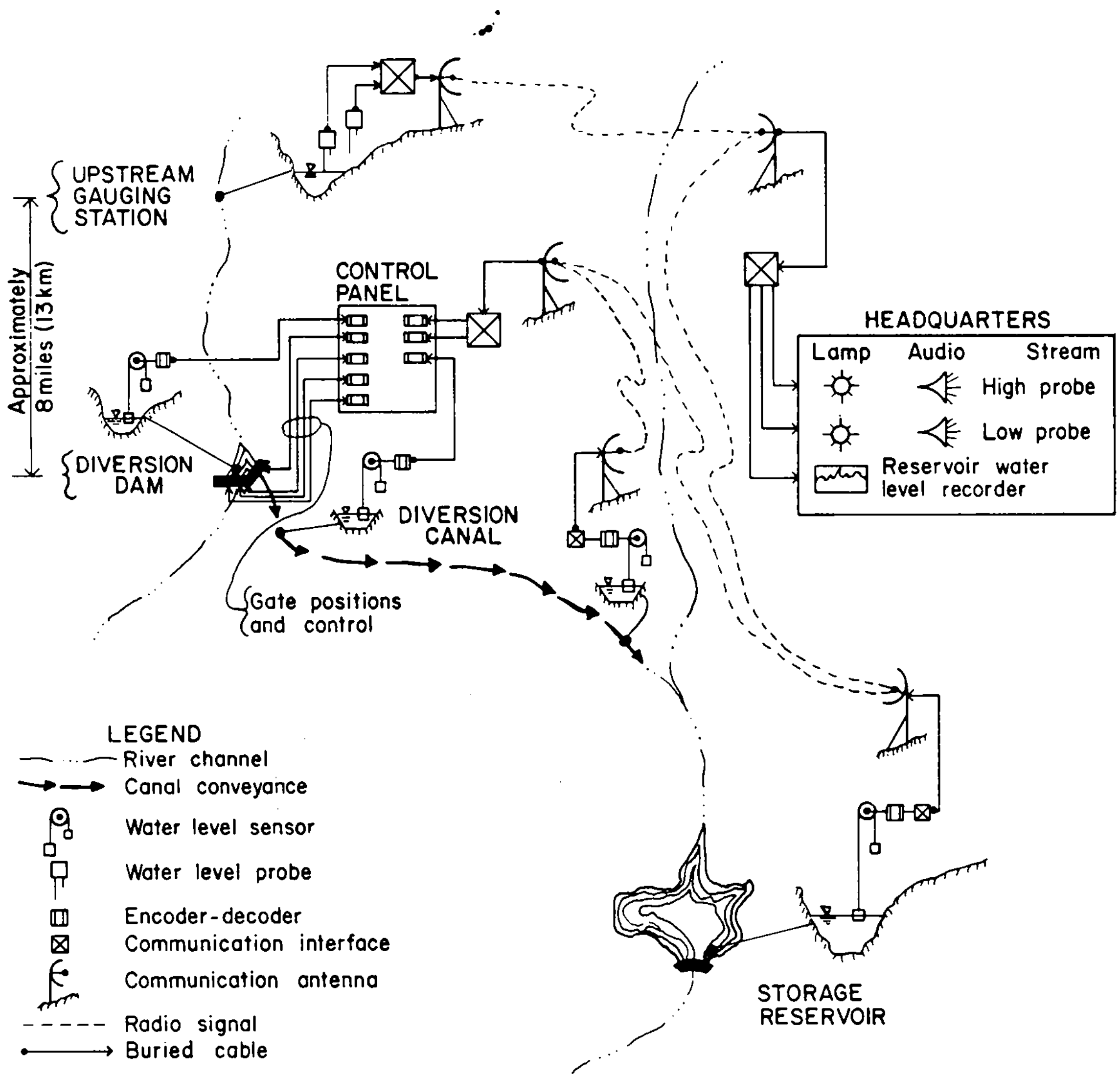

Figure 2. - Schematic of a remote monitoring system for manual control of the downstream releases at the diversion dam.

REMOTE MONITORING - MANUAL CONTROL

The general layout of a typical diversion dam that diverts intermittent flood inflows into a drainage basin of a larger storage reservoir downstream is illustrated in figure 2. The key information that should be provided by a remote monitoring system to the operator that manually controls the releases at the diversion dam would be:

1. Advanced indication of the rainfall storm runoff and its magnitude at the operator's headquarters.

2. Water level indication of the downstream storage reservoir at both the operator's headquarters and the diversion dam control panel.

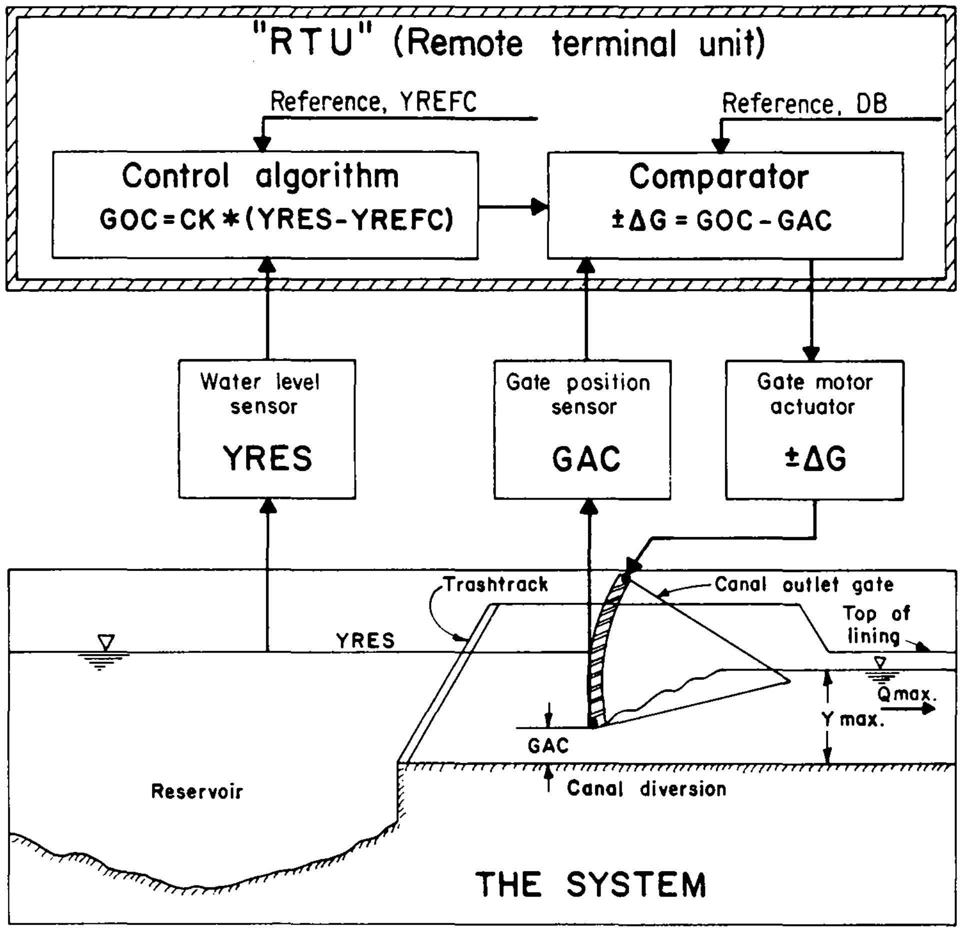

Figure 3. - Schematic of a local automatic control system for automatic regulation of the canal outlet gate at the diversion dam.

3. Set the referenced YREFC elevation for zero canal outlet discharge at least 1.0 ft (0.3m) below the YRES (max.) selected in step 2 above.

4. Determine the maximum gate opening, GOC (max.), for the maximum canal prism discharge when the reservoir water surface elevation is at the selected YRES (max.) determined in step 2 above.

5. The proportionality factor, CK, is determined as follows:

$$CK = \frac{GOC\ (max)}{(YRES\ (max) - YREFC)} \qquad (2)$$

The control algorithm, equation (1), can easily be adapted to a micro processor-based RTU (remote terminal unit) located onsite at the diversion dam. The required control parameters would be included as data input and could be adjustable if necessary. The real-time RTU would then calculate the required gate opening, GOC, based on the current reservoir water surface elevation, YRES, as illustrated

3. Water level indications from both the upper and lower ends of the diversion canal system at the diversion dam control panel.

4. Gate position indication of all the diversion dam gates at the control panel including the water level from a location immediately upstream.

Advanced indication of the rainfall storm runoff at the operator's headquarters will alert the operator when flood inflow to the diversion dam is going to occur. The advanced indication would be from a water level probe at a gauging station upstream on the main tributary to the diversion dam. The water level probe would be set to a typical low storm runoff. When the water level at the gauging station reached the low level probe, a transmitter would be activated sending a radio signal to the operator's headquarters. The received radio signal would initiate an audible signal and a visual lamp indication. The transmitted signal could also initiate an audio beep signal on the operator's mobile radio system. Therefore, attendance at headquarters would not be necessary when the storm runoff water level probe is activated.

A second water level probe at a higher elevation should also be installed at the same upstream gauging station. The second higher water level probe would represent a typical high rainfall storm runoff occurrence. The second probe, would activate a different audio sound and a second lamp indication. The operator could then anticipate a higher flood flow. If he has kept a log of the time when the low and high probes were activated, he would have a good indication of the storms intensity. A very short interval may indicate that a flash flood will occur at the diversion dam.

The water level indication of the downstream reservoir at both the headquarters and the diversion dam will give the operator an immediate knowledge of the available storage. He can then determine how much of the flood inflow at the diversion dam he can divert to the canal system. The water level indication of the upper and lower ends of the diversion canal help the operator determine when the canal has reached its maximum flow capacity. The water level indication from the lower end of the diversion canal is particularly useful when local rainfall storm runoff can enter the canal system. Local storm runoff could cause the canal to exceed its flow capacity at the lower end. The lower end water level readout at the diversion dam will provide an immediate indication to an operator that he may have to reduce the diversion rate to the canal system and increase the flow to the downstream river channel.

A readout of all the gate positions and the diversion dam reservoir water level at the gate control panel will assist the operator when changes in flood routing downstream and canal diversion are necessary. The control panel readouts would be particularly beneficial at night when precise visual observations of gate and water level staff gauges are difficult during stormy conditions.

CONTROL ALGORITHMS - LOCAL AUTOMATIC CONTROL

Local automatic control has practical application when repetitive gate operations are required for long periods of time. Continuous diversion of river inflow into the canal system is an example. The simplest concept that will provide satisfactory automatic regulation of the canal outlet gates at the diversion dam is proportional control. The control algorithm for the proportional control concept is:

$$GOC = CK*(YRES - YREFC) \tag{1}$$

where: GOC = the canal outlet gate opening. If the outlet has more than one gate, all gates are opened equally.

CK = the constant proportionality factor

YRES = the diversion dam reservoir water surface elevation

YREFC = the referenced diversion dam reservoir water surface elevation when canal diversion is zero

The canal outlet gate opening, GOC, is proportional, CK, to the water surface elevation offset, (YRES-YREFC). As the river inflow increases, the offset increases and the canal outlet gate opening will increase. Likewise, when the river inflow decreases, the offset decreases, and the canal outlet gate opening will decrease. When the offset is equal to or less than zero, the canal outlet gate will be closed. When the reservoir water surface elevation reaches a preselected value, i.e., a maximum offset, the canal outlet gate will be at its maximum opening and diverting the maximum designed discharge.

The control algorithm, equation (1), requires the careful selection of the control parameters (refer to figure 3): (1) the maximum GOC for the maximum canal prism discharge, QC; (2) the maximum YRES selected for the maximum GOC and QC; (3) referenced YREFC selected for zero GOC and QC; (4) CK is equal to the maximum GOC divided by the maximum selected offset (YRES (max.)-YREFC).

The selection of the above control parameters YRES and YREFC are based on the operating characteristics of the diversion dam. The operator's experience should be used when selecting the maximum offset, (YRES-YREFC). The following steps and criteria can be used as a guideline:

1. Determine the canal prism maximum design depth, Y max., for the maximum prism discharge, QC max., based on specifications, calculations, field observation, or operator's experience.

2. Set the maximum reservoir water surface elevation, YRES (max.) at least 0.2 ft (0.06m) above the maximum canal depth determined in step 1 above.

in figure 3. The required gate opening, GOC, is then compared to the actual measured gate opening, GAC. If the difference is greater than the dead band, DB, typically equal to 0.1 ft (0.03 m) the gate actuator will move the gate until the difference, ΔG, is equal to zero. The direction of gate travel depends on the polarity of ΔG.

The same basic control algorithm, equation (1), can also be applied to the sluiceway gate, if the sluiceway is used to automatically regulate the higher inflow when the canal diversion has reached its maximum discharge. The control algorithm for the sluiceway would be:

$$GOSL = SLK\ (YRES - YREFSL) \qquad (3)$$

The control parameters for the sluiceway gate control algorithm, equation (3), are selected following the same steps (described above) used for the canal outlet gate. However, the maximum YRES for equation (3) is set at a reservoir water surface elevation that requires operations of the spillway gate or at the crest of the overflow type spillway. The reference elevation YREFSL is set at the maximum YRES used for the canal outlet gate.

As the diversion dam water surface elevation rises above the maximum YRES selected for the canal outlet gate, the the canal diversion will begin to exceed the flow capacity of the canal prism. An additional control algorithm can be added to the canal outlet local automatic control system that would reduce the gate opening as the water level rises above YRES (max.). The same basic approach is used to establish the control parameters for equation (1). However, logic must be included in the RTU to activate the new control parameters and reverse the direction of gate movement. An alternative would be to operate the canal outlet gates manually when the reservoir water surface elevation exceeds the maximum YRES selected for the canal outlet gates.

SUMMARY

A simple remote monitoring system that provides certain key water levels and gate positions at appropriate times will assist the operator's judgment making process. When repetitive gate operations for long periods are involved, a local automatic control system has practical application.

A simple control algorithm, based on the proportional control concept, can automatically regulate the canal outlet and sluiceway gates. The operator's experience is used to select the proper control parameters. River inflows can be automatically controlled up to the capacity of the canal outlet and sluiceway with the minimum of supervisory intervention.

It is recommended that the controlled or gated type spillway structure be operated manually when the river inflow exceeds the capacity of the canal outlet and sluiceway. Continuous attendance of an operator at the diversion dam, when the spillway structure is operating, would be a good operation policy for safety purposes.