WINDY GAP PROJECT STREAMFLOW FORECASTING

by
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INTRODUCTION

With the growth that has taken place along or near the Front Range of Colorado, the population of the Northern Colorado Water Conservancy District is nearly four times that when created in 1937. This population growth has obviously increased the municipal water supply needs within the District. In 1970, the municipalities of Boulder, Longmont, Loveland, Fort Collins, Greeley, and Estes Park created the Municipal Subdistrict of the Northern Colorado Water Conservancy District to develop a new project on the Colorado River for the importation of an additional and independent water supply through the already available facilities of the Colorado-Big Thompson Project. This new project is known as the Windy Gap Project.

The project consists of a diversion dam, pumping plant, and pipeline. The diversion dam is located on the Colorado River just downstream of its confluence with the Fraser River. This will make available water from the Fraser River drainage basin which is not presently controlled by the Colorado-Big Thompson Project system. During periods of high flows, water will be pumped via the pumping plant from a small reservoir behind the diversion dam through the pipeline to Lake Granby. From Lake Granby, the water will pass through the existing Colorado-Big Thompson Project system to East Slope facilities for delivery to the participants of the project.

The diversion dam and reservoir is small since a large mainstem reservoir was impossible to build from an engineering as well as a political and institutional standpoint. As a result, a large capacity pumping plant was required in order to capture the variable flows to average a yield of 54,000 acre-feet per year. In order to operate the pumping plant efficiently and maximize the water yield of the project in accordance with the water decrees and the pumping plant power and energy contracts, short-term streamflow forecasts are required.

This paper describes the Windy Gap streamflow forecasting system. It consists of a comprehensive hydrologic data collection network which transmits current information to the computer center at project headquarters in Loveland.

HYDROLOGIC DATA COLLECTION

The hydrologic data collection system is composed of fourteen Data Collection Platforms or DCP's located at remote sites in the Fraser River Watershed. Basic components of a remote site are a Sutron model 8004D DCP, battery and associated solar panel power supply, antenna and cabling, sensors and a shelter. Data acquisition is controlled, stored, and transmitted to a geostationary satellite by the DCP. The geostationary satellite is part of the Geostationary Operational Environmental Satellite/Data Collection System (GOES/DCS) and is managed by the National Environmental Satellite, Data, and Informational Service (NESDIS). From the geostationary satellite located at 135 degrees west longitude, the data is relayed to a downlink receiver and stored on a computer located at the Northern Colorado Water Conservancy District in Loveland, Colorado.

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A total of fifteen DCP's have been established with nine measuring river stage and six monitoring snow/weather conditions. A basic consideration in DCP location was to obtain good spacial distribution within the watershed. An emphasis was placed on good coverage at moderate to low elevation within the basin since a major portion of high elevation snow runoff is diverted through the Moffat Tunnel. Three of the river stage DCP's are located at established USGS stations and five on municipal and private property. Where a DCP was located on private property, an easement was obtained. Two of the high elevation snow/weather DCP's have been established on lower elevation property belonging to the United States Forest Service. Table 1 indicates the approximate elevation of each river stage and snow/weather reporting DCP. The location of each are shown in Figure 1.

Table 1
Data Collection Platform Type and Elevation

DCP	Station	Elevation (Meters)
1. Berthoud Pass	Snow/Weather	3450
2. Arrow	Snow/Weather	2950
3. Fraser	Snow/Weather	2790
4. Meadow Creek	Snow/Weather	2590
5. Cottonwood Pass	Snow/Weather	2720
6. Granby	Snow/Weather	2500
7. Upper Fraser River	River Stage	2900
8. Lower Fraser River	River Stage	2710
9. St. Louis Creek	River Stage	2540
10. Vasquez Creek	River Stage	2500
11. Ranch Creek	River Stage	2540
12. Crooked Creek	River Stage	2540
13. Ten Mile Creek	River Stage	2430
14. Strawberry Creek	River Stage	2630
15. Fraser River	River Stage	2400

Hardware associated with each stream gaging station includes a Sutron model 8004D DCP and 12-volt battery enclosed inside an environmental enclosure. The environmental enclosure is mounted inside the shelter near an incremental shaft encoder. The incremental shaft encoder is coupled to a Stevens recorder which in turn measures river stage. An antenna mast of galvanized pipe is attached to the side of the shelter and supports a yagi antenna and solar panel power supply. The transmission of river stage data will occur every four hours in a self timed mode. In the event that an exceptionally high river stage is reached, the DCP will switch to a random reporting mode and transmit data at a specified interval.

The six snow/weather stations are measuring/sensing snow water content, precipitation, air and snow temperature, and soil moisture. Wind direction/movement and solar radiation are also measured at the highest and lowest (elevation) DCP. Snow water content is measured in terms of pressure with a transducer coupled to a 3 meter hypalon snow pillow. Near the pillow is a rain gage and pole mounted steel enclosure. Within the steel enclosure is an environmental enclosure which houses the Sutron model 8004D DCP and 12-volt battery. A galvanized pipe is attached to the wood pole and supports a yagi antenna, solar panel power supply, air temperature, thermister, and wind sensor. Snow water content, snow temperature, soil moisture, solar radiation, and wind movement data will be updated every four hours. Precipitation and wind direction will be collected on a 1 hour basis and air temperature will be collected every 15 minutes.

All data will be transmitted every four hours to the GOES West satellite and relayed onto a 5 meter parabolic dish located at the Northern Colorado Water Conservancy District in Loveland, Colorado. Data is then stored on a hydrologic data collection computer.

WINDY GAP OPERATIONS

A state of the art computer based supervisory control and data acquistion (SCADA) system was developed to accomplish the goal of operating the Windy Gap Project. The SCADA system is an anticipatory closed looped control system requiring a minimum of human interaction. It operates in a real time environment to perform the tasks required to control and monitor the Windy Gap Project. The basic premise of the SCADA system is to

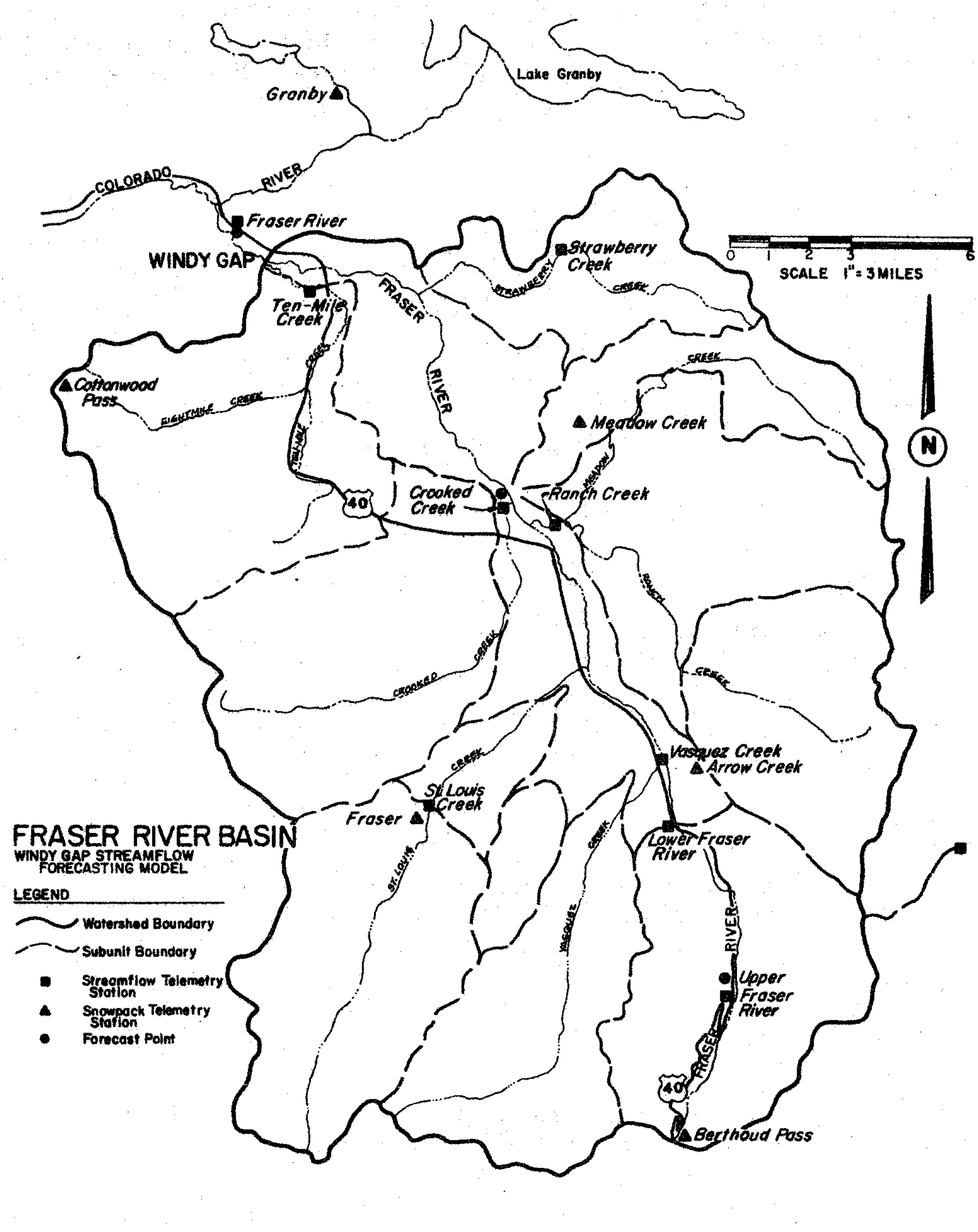

Figure 1. - Subwatersheds and Data Collection Stations in the Fraser River Basin.

maximize the amount of water diverted while minimizing power cost and meeting the constraints as a result of legal and institutional requirements. The two primary functions of the SCADA system are:

1. Automatically operate the bypass flow system based on downstream demands, upstream flows, and reservoir levels.

2. Automatically start, stop, and sequence the pumps based on the reservoir level and upstream and downstream flow requirements.

The SCADA system computers are connected to the hydrologic data collection computer via high speed CPU link in order to obtain real time runoff forecasts. These data are then integrated into the SCADA system and set point target values are established for pumping and flow control algorithms automatically. This procedure allows the SCADA system to anticipate streamflows using a hydrologic simulation model and establish optimum pumping and power schedules.

HYDROLOGIC SIMULATION MODEL

Currently, annual forecasts of runoff from the Fraser River Basin are made using statistical correlations between peak seasonal snow accumulation during previous years and resultant streamflow. These forecasts are made each spring assuming that "average" weather conditions will prevail during the subsequent snowmelt runoff season. Extension of these early-season forecasts to a short-term basis using such methods is difficult since precipitation and meteorological conditions during the ensuing melt season can vary widely from year-to-year. However, short-term forecasts are possible using timely information from the GOES satellite data collection network and a dynamic hydrologic simulation model.

Subalpine Water Balance Model

The "Subalpine Water Balance Model" (WATBAL) developed by Leaf and Brink (1973) is being used to forecast residual streamflows in the Fraser River Basin. This model simulates winter snow accumulation, the shortwave and longwave radiation balance, snowpack condition, evapotranspiration, snowmelt, and subsequent runoff on as many as 25 response units. Each response unit is defined by relatively uniform slope, aspect, and forest cover. Results from all response units are compiled into a "composite overview" of an entire watershed. The Fraser River Basin was resolved into 8 subwatersheds (Figure 1) averaging 14 response units per subwatershed. Figure 2 is a generalized flow chart of WATBAL.

Model Calibration

In developing the Windy Gap forecasting system, WATBAL was calibrated to 4 subwatersheds in the Fraser River Basin as follows:

1. Vasquez Creek
2. Ranch Creek
3. Ten Mile Creek
4. Strawberry Creek

All are key tributaries that characterize the hydrologic regime of the basin. Table 2 summarizes pertinent geographic characteristics of each.

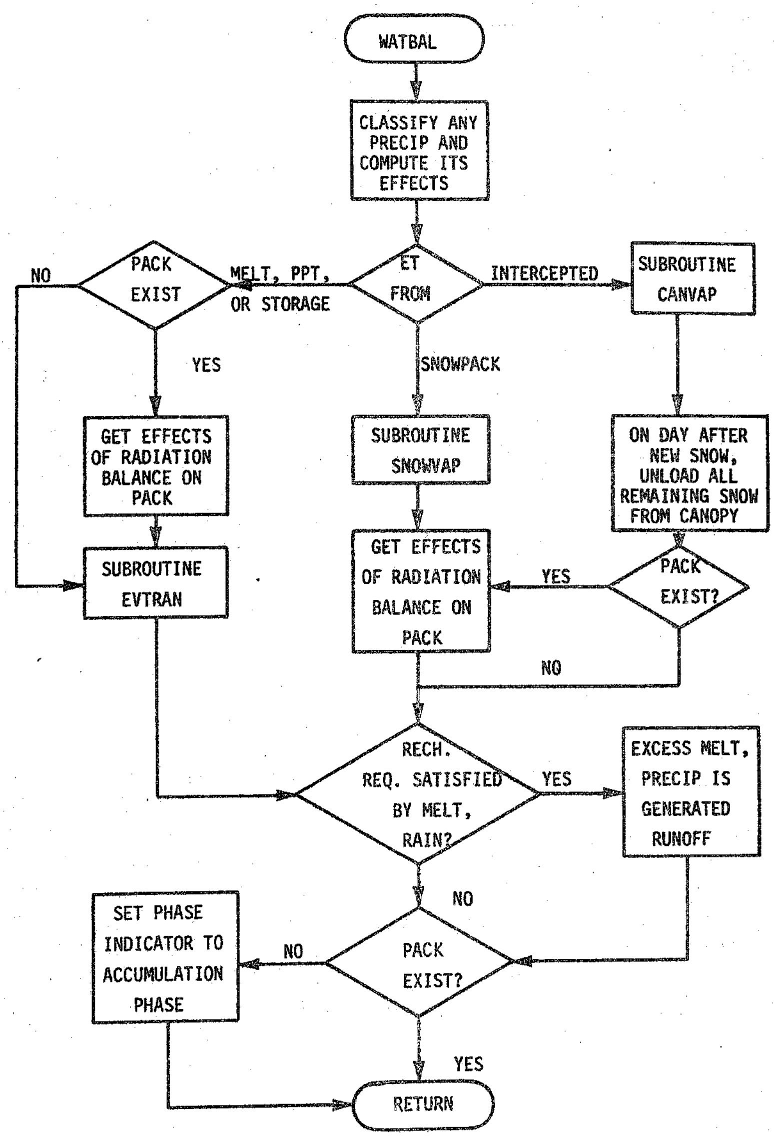

Figure 2. - Flow Chart of Subalpine Water Balance Model (WATBAL).

TABLE 2

GEOGRAPHIC CHARACTERISTICS OF FRASER RIVER
BASIN CALIBRATION SUBWATERSHEDS.

Watersheds	Drainage Area (km2)	Mean Elev. (m.m.s.l.)	Aspect	No. 1/ Response Units
Vasquez Creek	70.00	3,314	NW	12
Ranch Creek	132.00	2,912	SW	20
Ten Mile Creek	96.3	2,586	N	14
Strawberry Creek	44.1	2,798	W	14

1/ Includes all forested and open areas

Having fixed model parameters for each of the 8 subwatersheds comprising the Fraser River Basin, several additional years of record will be used in future validation studies of the streamflow forecasting system.

FORECASTING SYSTEM DESIGN

The way in which WATBAL is used to update streamflow forecasts has been discussed by Leaf (1980). A primary model response is area snowpack water equivalent; this variable is plotted as a function of time in Figure 3. Typically, the seasonal snowpack builds to a "peak" in late spring. To the left of this peak is the winter snow accumulation season (full snowcover) and to the right is the snowmelt runoff (snowcover depletion) season.

Updating of the model to reflect existing conditions can be achieved through adjustment of simulated water equivalent based on GOES Satellite transmissions of real-time snow pillow data. During the runoff season, additional control can also be achieved using direct estimates of a real snowcover. The control functions shown in Figure 3 are relationships which adjust point measurements to area estimates of snowpack on each response unit.

Operational Forecasts

Basic data inputs to WATBAL are daily air temperature and precipitation. Streamflow forecasts will be made using a method similar to one developed by the Corps of Engineers (U.S. Army, 1972). The procedure combines: (a) five-day forecasts of temperature and precipitation (expressed as departures from normal) with (b) the long-term normals, and (c) synthetic sequences of temperature and precipitation derived from frequency analyses (also expressed as departures from normal). The forecast combines (a), (b), and (c) to arrive at an input sequence of assumed future conditions. The forecast system provides for inputting an extended period of record which is updated each day using real-time GOES Satellite-transmitted data. The synthetic data sequences can be either minimum, moderate, or extreme, depending on anticipated weather conditions and objectives of the forecast.

STREAMFLOW ROUTING

Figure 4 is a Line diagram showing a concept plan of the Windy Gap Streamflow Forecasting System. Simulated inflows from the subwatersheds are combined at 4 nodes and subsequently routed down the Fraser River to Windy Gap. A significant impact on streamflow forecasts results from Denver Water Board diversions out of the Basin via the Moffat water tunnel. These diversions are subtracted from simulated river flows at node 3. Subtractions will be based on telemetered discharge data from East Portal which gages combined diversions from the Fraser and Williams Fork systems. Telemetered data from river gages at nodes 1, 2, and 4 provide additional controls on the system.

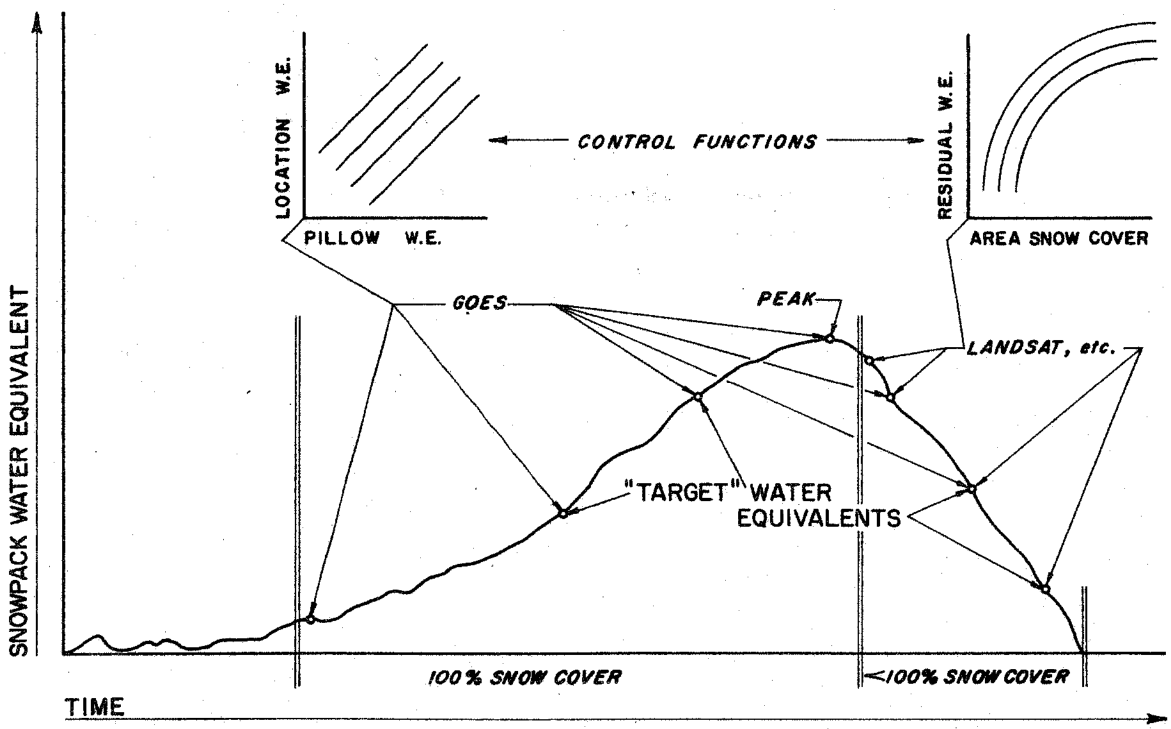

Figure 3. - Use of Real-time Data in
Updating Simulated Snowpack Water Equivalent.

WINDY GAP CONCEPTUAL MODEL

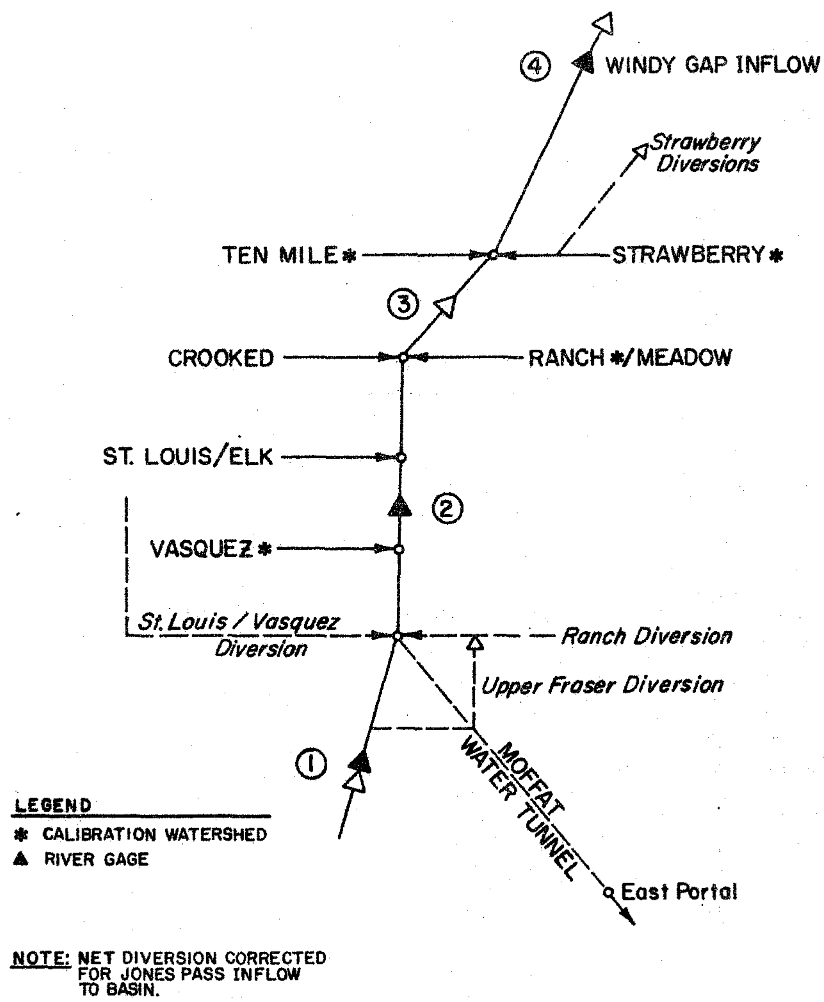

Figure 4. - Streamflow Forecasting

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