A WATER BUDGET ANALYSIS OF THE LOWER JAMES RIVER FOR THE DROUGHT OF 1988

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Prepared by the North Dakota State Water Commission

Water Resource Investigation 14
North Dakota State Water Commission
David Sprynczynatyk, State Engineer

1990

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NORTH DAKOTA STATE WATER COMMISSION

Water Resource Investigation 14

Prepared by the NORTH DAKOTA STATE WATER COMMISSION

The work reported here was also submitted as a Masters Thesis to the North Dakota State University.

Bismarck, North Dakota

1990

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ABSTRACT

A hydrologic budget analysis was performed for the lower James River for the period June through September, 1988, to quantify the gains and losses during the 1988 drought period. Data were collected from various sources to determine the inflow, outflow, precipitation, evaporation, appropriations, and storage for each of five reaches analyzed. Streamflow records were used to determine inflows and outflows. Climatological data were used to estimate evaporation using Penman's combination method. Precipitation data from 28 measuring sites were used to estimate the volume of water received from direct precipitation onto the water surface. Annual water use data were used to estimate the volume of water pumped. Stage records were used to estimate the volume of water stored in the reaches.

The resulting analysis shows that the stream gained flow through three of the reaches. Results also indicate that the relationship between the private irrigators, the U.S. Bureau of Reclamation, and the U.S. Fish and Wildlife Service was mutually beneficial in the study area, because the adverse effects of the drought were shared. Results also showed that up to 2.6 acre-feet of water may be required from Jamestown Reservoir for each acre-foot used in the Oakes Test Area during extreme low flow years.

I. INTRODUCTION

Many states in the arid and semi-arid regions of the western United States employ the prior appropriation doctrine for water right management. The oldest water right then has the first right to water when the source of water is insufficient to meet all the demands. Management of heavily appropriated hydrologic systems under the prior appropriation doctrine is often difficult because of a lack of sufficient hydrologic data or the lack of an acceptable method for analyzing available data. One example of such a problem area is the lower James River in south central North Dakota.

The lower James River has been heavily appropriated for many years. Seven applications for water permits are presently pending, some of which have been pending for up to 12 years. Beginning in 1988, the U.S. Bureau of Reclamation (USBR), attempted to deliver water to the Oakes Test Area, a 5000 acre irrigation study area developed as a feature of the Garrison Diversion Project, from Jamestown Reservoir. This created an additional demand on an already heavily developed system. The resulting regulatory problems were compounded by severe drought conditions during 1988. It became difficult to differentiate between water released from Jamestown Reservoir and water which constituted the natural flow of the James River. Therefore, it was also difficult to protect the rights of the private irrigators and the rights of those involved with the Oakes Test Area.

One tool which can be helpful with such regulatory problems is the hydrologic budget analysis of the river reaches. While this method is simple in theory, great care must be taken in quantifying the parameters used as input. The methods commonly used to quantify input parameters for the hydrologic budget analysis is critically reviewed first. These methods are then used to determine the hydrologic budget for the lower James River for the period from June through September, 1988. The results are then discussed, and recommendations made to improve operation and data collection in the lower James River basin.

Some of the hydrologic data collected during the irrigation season of 1988 were not readily available to regulatory personnel during the water use season. However, it is important to evaluate the available data for a critical irrigation season such as 1988 to improve future management of the James River. It is likely that attempts will be made to supply the Oakes Test Area with water from Jamestown Reservoir again in future years. Results from this analysis should be helpful to all involved in managing the water resources of the lower James River.

II. PURPOSE AND SCOPE

The specific objectives of this study were:

1. To use the hydrologic budget technique to quantify the gains and losses along the lower James River during the irrigation season and drought of 1988.

2. To interpret the results of this hydrologic budget analysis relative to future operation of Jamestown Reservoir to supply water to the Oakes Test Area and relative to the interacting water rights established along the lower James River.

3. To evaluate the adequacy of available hydrologic data.

The tasks, completed to meet these objectives, included a search for and compilation of all related hydrologic data. Most of the data necessary for this study had previously been collected by others with different goals and objectives. These data were utilized to quantify the various parameters necessary for the hydrologic budget analysis. Evaporation, precipitation, withdrawals, inflows, and outflows were quantified for each reach of the river in the study area. A hydrologic budget analysis was performed for each reach utilizing the parameters thus identified. The analysis identified the accrual to the various stream reaches from ground-water seepage and from direct surface runoff. The tasks completed for this study are illustrated in Figure #1 in the form of a flow chart.

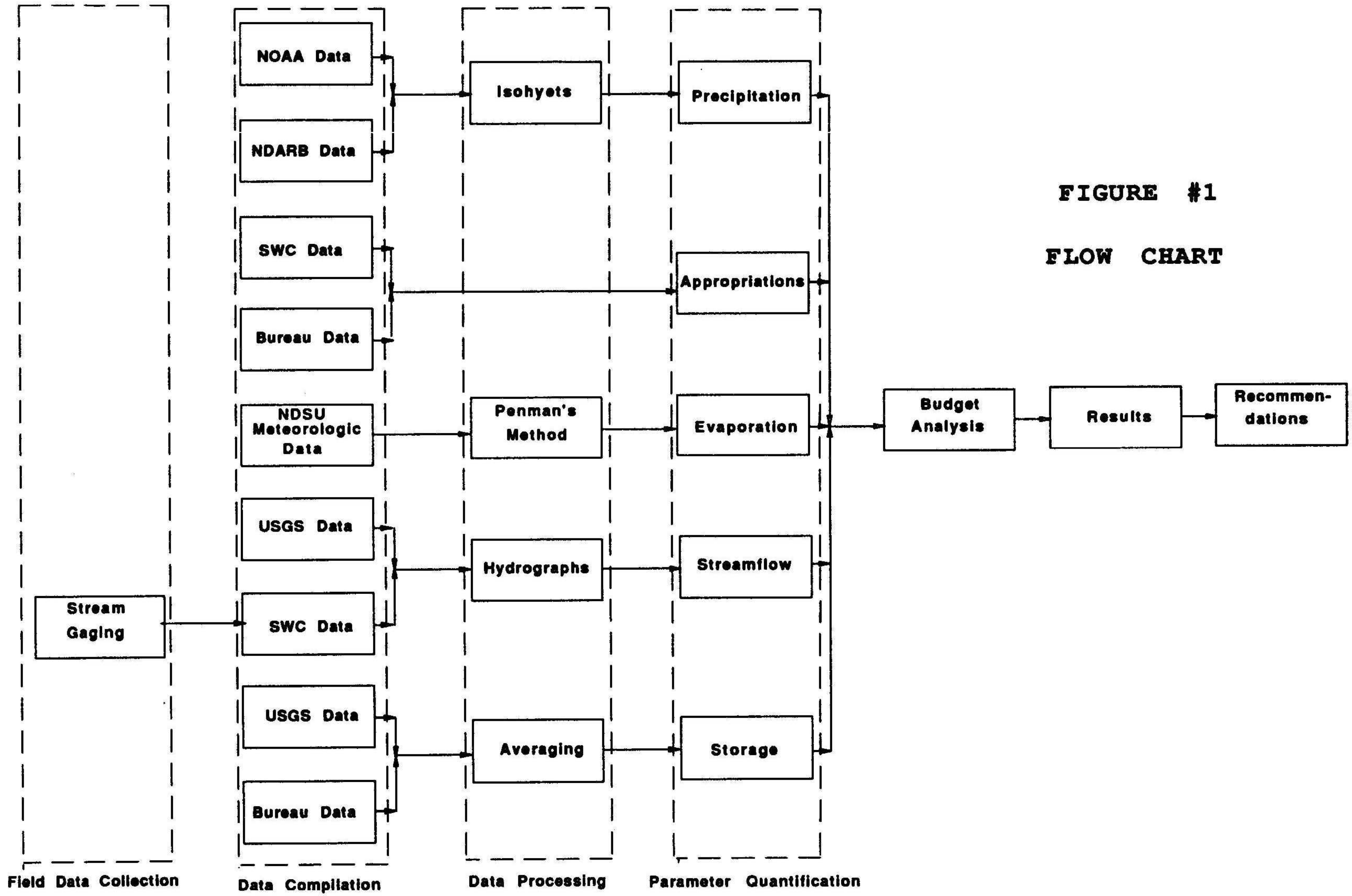


FIGURE #1

FLOW CHART

III. REVIEW OF METHODS OF MEASUREMENT, ESTIMATION AND ANALYSIS

Hydrologic Budget

A hydrologic budget analysis involves using a continuity type equation for the reach of stream or lake of interest as shown below (15).

$$I + P - O - E - W + A = \Delta S \qquad (1)$$

where:
- A = net volume gained or lost from natural processes such as direct surface runoff or seepage of ground water into the channel
- E = gross evaporative loss
- W = quantity pumped directly from the channel
- O = outflow from the reach
- ΔS = change in storage volume
- I = Inflow to the reach
- P = precipitation falling directly on the water surface

If all the other components are known or can be estimated, for instance, then the volume of accrual can be estimated using this method. However, one drawback of using this method is that the errors accumulated in estimating the input components will be directly reflected in the residual quantity, the estimate of which is the main objective (23,45). Problems can be encountered when using this method for time periods of less than one month (5,15). If the flow components are large relative to the parameter being estimated, then the results will be of questionable accuracy due to errors encountered in determining stream flow (23).

Despite drawbacks, the hydrologic budget is still an often used hydrologic tool (44,16). All these potential problems illustrate the fact that, although the budget is simple to conceive, care must be taken in determining the methodologies to be used for quantifying the various terms (45). When one component is left as the residual, care must also be taken in the interpretation of the budget results because this term will contain all the errors of the measured components (45).

Streamflow Data

Streamflow data essentially consist of stage readings converted to streamflow by using a stage-discharge relationship or rating curve. The methodology used in taking stage-discharge measurements is described by Rantz (35). These measurements are taken initially to define the relationship between stage and discharge at a site and subsequently to verify the relationship so defined. There are two methods of computing streamflow measurements, the mid-section and the mean-section methods. Research has shown that more accurate results and a significant time savings can be obtained by using the mid-section method (47).

Once the stage-discharge measurements have been taken, the data can be used to define the stage-discharge relationship or rating curve. The rating curve can be shown as:

$$Q = p(G - e)^N \qquad (2)$$

where: Q = discharge
G = gage height
e,N,P are constants to be determined by fitting the equation to actual data

When dealing with an irregular section control, the value of 'e' can be interpreted as the gage height of effective zero flow. This is not the height of any feature on the control, but rather it is a mathematical constant which is considered as a gage height to preserve the concept of a logarithmically linear stage-discharge relationship (35).

A discharge rating can take many forms, including plotted curves, tables, equations, or lists of descriptors (21). An equation can be the most convenient form, but caution is necessary while using curve fitting programs, especially when trying to extrapolate the relationship beyond the range of measurements actually taken.

The level of accuracy attributable to the discharge measurements is an important consideration. Carter and Anderson (9) studied this issue and concluded that if single discharge measurements were made at a number of gaging sites by the usual 0.2 to 0.8 method (using 30 sections and 45 second observations), the errors of two-thirds of the measurements would be less than 2.2 percent. They also concluded that the Price current meter measures the true velocity within one percent. Another study showed that, if a good stage discharge relationship is developed, then the error in estimating discharge is less than 5 to 10 percent (45).

There are many factors which can affect the accuracy of streamflow data which are therefore important to this study. One of these factors is the sensitivity of the control. The tendency of a small change in discharge to be reflected by a significant change in stage is a measure of a control's sensitivity (35). Therefore, it follows that if a control is to be sensitive it is necessary for the width of flow to be restricted at low stages. A change of one unit of recorded stage should represent a change of no more than 2 percent of the total discharge(35).

Another factor which can affect the accuracy of streamflow data is turbulence and the associated velocity pulsations. Revolving cup meters may over-register in turbulent waters (41). A Price meter will rotate when mechanically moved up or down, suggesting that vertical velocity components do register with these meters (9). The conventional Price AA meter will tend to overregister velocity under mountain stream conditions where the vertical components of velocity are greater due to the slope of the stream and the greater turbulence (20). However, under normal conditions where the vertical components of velocity are much smaller, no appreciable error should result from the use of Price meters (41,9).

Also to be considered is the fact that the velocity at any point in a stream is constantly fluctuating and so observing the velocity for 40 to 70 seconds as is done in standard practice may not be long enough to insure the accuracy of a velocity reading (35). However, these fluctuations are randomly distributed (9), and, due to this randomness and the fact that velocity is observed at 25 to 30 verticals during a discharge measurement, it is unlikely that these fluctuations would bias the entire measurement (35, 34).

Another factor which can affect the accuracy of a discharge measurement is the depth of water in the verticals. When a vertical axis cup-type current meter is used in water of shallow depth, it will tend to underregister due to the proximity of the cups to the water surface or to the streambed (34). The pygmy meter underregisters when set closer to the streambed than 0.3 foot (35). This would occur when employing the 0.6 depth method in water with depths less than 0.75 foot. Pierce (34) attempted to determine coefficients which could be used to compensate for this under-registration; however, Rantz (35) concluded that all efforts to define such coefficients had failed.

The velocity of the water in the measuring section can also affect the accuracy of a discharge measurement. Neither the type AA meter nor the pygmy meter should be used for measuring velocities less than 0.2 foot per second (35). Velocities as low as 0.1 foot per second can be measured, but the precision is generally better for velocities greater than 0.5 foot per second (34). Measuring sections should be selected so that velocities less than 0.4 foot per second will not be encountered (34).

One final factor which can have an adverse effect on the accuracy of streamflow data is the development of shifts in the stage-discharge relationship. In temperate climates, water-logged leaves will clog alluvial riffles each autumn, raising the effective elevation of these section controls (35). Beaver dams constructed each summer and fall are a very common cause of shifting ratings when natural controls are used. The stage-discharge relationship can be estimated during times of shifting controls by supplementing the available discharge measurements with a knowledge of shifting control behavior (35).

Evaporation

Another hydrologic component which needs to be quantified in a budget analysis is the evaporation. The literature abounds with various methods for estimating or measuring this component. These methods can be broken into six main categories:

1. Mass Transfer Techniques
2. Energy Budget Methods
3. Water Budget
4. Empirical Formulae
5. Direct Measurement
6. Combination (Penman) Method

A brief discussion of each category follows. Since the combination method is used in this study, only this method is discussed in detail. The mass-transfer technique originated from an aerodynamic law presented by John Dalton in 1802. Although Dalton (13) apparently never expressed it in mathematical form, he is credited as being the first to theorize that the quantity of liquid evaporated is directly proportional to the vapor pressure of the liquid at its temperature if all the other conditions are held constant. One drawback of this method is the difficulty in evaluating all the required terms such as the temperature of the water's surface (15).

The energy balance method is based on the principle of conservation of energy. The evaporation is calculated from consideration of the energy budget of the body of water. Use of the energy balance method has been seriously restricted due to the difficulty in measuring the various climatological variables involved in the computation (15). Linsley, et al. (23) noted that this method is not likely to be used on a broad-scale basis until instrumentation is improved. However, instrumentation is improving, and the method has been used in recent studies (44).

The water budget itself is often used to estimate evaporation. Linsley, et al. (23) notes that determinations of streamflow within 5 percent are considered excellent, and so if the inflow and outflow quantities are large relative to the quantity lost to evaporation, this method would yield results of questionable accuracy. This method should not be applied to time periods less than one month if estimates of evaporation within +/- 5 percent are desired (15). If the hydrologic budget is to be used to estimate a parameter other than evaporation, then some other method must be used to estimate evaporation.

The energy budget, mass-transfer, and water budget methods often require data which are not readily available. In these situations, use is often made of various empirical formulae. The majority of these formulae are based on the aerodynamic law first presented by Dalton (13) and take the approximate form:

$$E = k\ f(u)(e_s - e_d) \tag{3}$$

where:
- E = evaporation
- k = constant
- $f(u)$ = wind function in terms of wind velocity
- e_s = saturation vapor pressure at surface temperature
- e_d = actual vapor pressure

These formulae have many limitations (15). They require measurement of the surface temperature of the water, and, because this is often difficult to obtain, the mean air temperature is often substituted. This substitution can lead to large errors in the estimate of evaporation. Also, the wind velocity must be measured at the height specified in the formula (15).

Another method used to obtain evaporation data is direct measurement. This usually involves the measurement of the reduction in the depth of water in a carefully controlled container. The most popular container used is the Class A Weather Bureau Pan. The pan is usually situated near the body of water in question and in such a way as to make the weather conditions encountered by the pan as similar to those encountered by the body of water as possible.

The measured evaporation in the pan is used to estimate the evaporation from a lake through the use of a pan-to-lake coefficient. The use of a coefficient is necessary because of the different ways in which the two bodies of water acquire and dispose of energy (24). Evaporation from a pan is generally greater than from a vegetated surface or a pond due to the pan's excessive exposure and lower reflectance of solar radiation (17). There are many estimates of annual pan-to-lake coefficients in the literature. During time intervals of one month or less the coefficients may be very erratic (15). The monthly coefficients are much smaller than the annual average in the spring and larger than the annual average in the fall (1). A coefficient of 0.65 to 0.70 is appropriate for the period from February to May, a coefficient of 0.75 to 0.80 is appropriate for June, July, and August, and a coefficient of 0.85 to 0.95 is suitable for the remainder of the year (1). Some researchers in the past have felt that the land-based evaporation pan is not a suitable method for estimating the evaporation from a broad water surface. They felt that, if the data are available, calculating the evaporation would yield better results than attempting to directly measure it (19).

One method of calculating the evaporation from measured meteorological data which has seen extensive use is the combination method, as originally presented by Penman (23,32,33). This method combines an aerodynamically based relationship with an approximate energy balance. The Penman method has been described as one of the most complete theoretical approaches (11). A combination method was used by Grimmond et al. (16) in performing an urban water balance. The main benefits of this method are that it eliminates the need for a measurement of the water surface temperature and it allows estimates of evaporation to be made from standard meteorological data.

In deriving his combination method equations, Penman (32,33) first presented an approximate energy balance equation:

$$H = E + K + S + C \tag{4}$$

where:
- H = net radiation
- E = energy used in evaporation
- K = energy used in heating the air
- S = energy used in heating the test liquid
- C = energy used in heating the surroundings of the test material

For short periods of time such as a daily basis the values of S and C are very small relative to the other parameters and so it can be written:

$$H = E + K \quad (5)$$

E, the energy used in the transport of vapor, and K, the energy used in the transport of heat, are controlled by the same basic mechanism, but E is governed by $(e_s - e_d)$ and K is governed by $(T_s - T_a)$, and so he made the approximation:

$$K/E = \gamma(T_s - T_a)/(e_s - e_d) = B \quad (6)$$

where: B = Bowen's Ratio with diffusivities for air and vapor being equal
γ = psychrometric constant = 0.27 when using °F and mm Hg
T_s = temperature at the surface
T_a = air temperature
e_s = saturation vapor pressure at surface temperature
e_d = actual vapor pressure

Therefore,

$$H = E(1 + B) \text{ or } E = H/(1 + B) \quad (7)$$

Penman (32,33) also used a Dalton-type aerodynamic equation such as:

$$E = (e_s - e_d)\ f(u) \quad (8)$$

He then let E_a be the evaporation estimate obtained by substituting e_a, the saturated vapor pressure at mean air temperature, for e_s. In equation form:

$$E_a = (e_a - e_d)\ f(u) \quad (9)$$

Therefore, it can be written:

$$E_a/E = ((e_a - e_d)/(e_s - e_d)) = (1 - (e_s - e_a)/(e_s - e_d)) \quad (10)$$

Or if

$$(e_s - e_a)/(e_s - e_d) = \phi \quad (11)$$

Then,

$$E_a/E = 1 - \phi \quad (12)$$

As shown earlier:

$$E = H/(1 + B) = H/(1 + \gamma(T_s - T_a)/(e_s - e_d)) \quad (13)$$

Letting Δ be the slope of the temperature - vapor pressure curve at T_a, then,

$$T_s - T_a = (e_s - e_a)/\Delta \quad (14)$$

$$E = H/(1 + \gamma(e_s - e_a)/\Delta(e_s - e_d)) \quad (15)$$

$$H/E = 1 + \gamma\phi/\Delta \quad (16)$$

Therefore, Penman's equation for evaporation can be written (32,33):

$$E = (H\Delta + E_a\gamma)/(\Delta + \gamma) \quad (17)$$

where: E = evaporation
H = net radiation
E_a = evaporation estimate obtained by using the mean air temperature as an estimate of the surface temperature of the water
γ = psychrometric constant
Δ = slope of e:T curve at Ta

Bowen (3) developed a relationship describing the partitioning of the incoming heat into the portion used for evaporation and the portion used for the heating of the air.

This relationship is commonly known as Bowen's Ratio and can be written:

$$B = A/E = \gamma(K_n/K_w)((T_s - T_a)/(e_s - e_d)) \qquad (18)$$

where:
- B = Bowen's ratio
- A = Energy used in heating air
- E = Energy used in evaporation
- γ = psychrometric constant
- K_n = eddy diffusivity of heat
- K_w = eddy diffusivity of vapor
- T_s, T_a, e_s, and e_d are as defined earlier

In the preceding derivation, Penman (32,33) assumed that the eddy diffusivities for heat and vapor are essentially equal so that Bowen's Ratio could be estimated as

$$B = \gamma((T_s - T_a)/(e_s - e_d)) \qquad (19)$$

Penman (32,33) suggested that there was experimental evidence to confirm his assumption. Tanner and Pelton (39) found that Penman's estimation of the Bowen's Ratio does appear to account for advective heating and sensible heat loss from a wet surface.

Penman (32,33) based his derivation on the evaporation occurring from a theoretical open water surface. This theoretical derivation was then correlated to his observed values by employing an empirical wind function. Kohler (22) found that theoretical values of γ vary from 0.000317P to 0.000378P where P is the atmospheric pressure in inches of mercury, and he chose to use 0.00367P. Bowen (3) originally derived a value of 0.000317P. In experiments at Lake Hefner, γ for the Class A pan was found to be 0.000871P (22).

Therefore, this value must be used when using the Penman method to estimate Class A pan evaporation directly.

The theoretical open water surface on which Penman based his derivation has the radiation characteristics of the Class A pan, but permits no sensible heat loss through the walls of the pan. The annual coefficient for this theoretical pan is 0.7 (22). Therefore, annual lake evaporation can be estimated as:

$$E = 0.70((H\Delta + Ea\gamma)/(\Delta + \gamma)) \quad (20)$$

when using $\gamma = 0.000367P$

In his original derivation Penman utilized an empirical aerodynamic relationship for evaporation based on the saturation deficit and measured wind speed for an open water surface (32,33). Since then many people have modified the wind function originally employed by Penman, however, most of these modifications were suggested by researchers who were interested in applying Penman's combination method to the estimation of evapotranspiration from a cropped surface. Most of these modifications were the result of a need to allow for different roughness characteristics of the different surfaces (43,8,40,14,39).

Another peripheral equation utilized in Penman's method which has been often modified is that for H, the net radiation. Penman (32,33) used an equation for the net radiation which was originally presented by Brunt (4). This relationship has been modified by various researchers based on experimental data (46,14,31). In some instances these modifications are site specific and so regional coefficients should be used when available.

The equation for H, presented by Brunt (3), includes a factor of (1 - r) where r is the reflection coefficient or albedo of the surface in question. Most green crops will have a reflection coefficient of 0.25 while an average value for open water is 0.05 (10). This tends to augment evaporation estimates for open water compared with those for grass, but this is compensated somewhat by the greater aerodynamic roughness of grass. Penman (32,33) noted that r and B would be the only factors discriminating between the different surfaces. However, extensive research since then has shown that the surface roughness must also be considered (43,8,40,14,39).

Also discussed in the literature is the period of time which should be used as a basis for estimating the evaporation. Van Bavel (42) noted that a combination model is unsuited for the use of mean daily values, at least in principle. However, he noted that he obtained nearly the same results using mean daily values as using hourly values. He dismissed this as fortuitous. Tanner and Pelton (39) found the Penman method is suitable for making daily estimates. Doorenbos and Pruitt (14) warned that the use of 24-hour wind totals can result in over prediction of evaporation under conditions of strong day time and night time winds and under prediction of evaporation under conditions of strong day time winds and calm nights. They suggested that this problem could be eliminated by separating computations for day and night, but they did not recommend this practice, because it is complicated and the necessary data are often unavailable.

Ground-Water Interaction

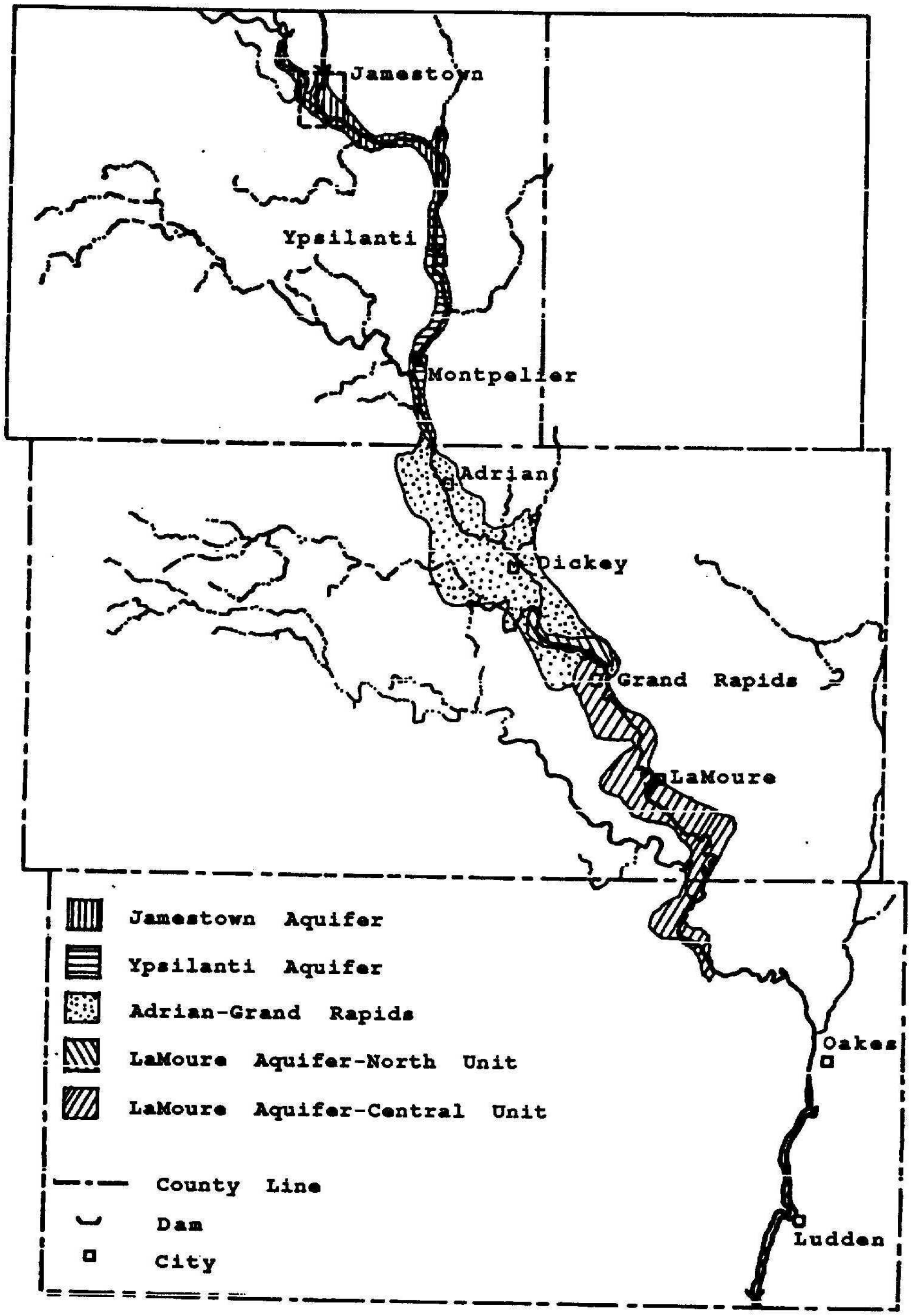
Wald and Christensen (43) published water resource data for the lower James River. Christensen and Miller (12) presented a study of the ground water and surface water systems of the lower James River. The interaction between the two systems was addressed by monitoring the water levels in observation wells and also the river stage, combined with a knowledge of the local geology. This discussion is presented as an example of one means of quantifying the ground water contribution to a stream for a budget analysis. The actual budget analysis which follows does not use these findings as input. The budget analysis which follows estimates the accrual as the residual in the budget. The results of the budget analysis which follow should verify these earlier findings.

Four aquifer units were found to directly interact with the James River. These are the Adrian-Grand Rapids Unit of the Spiritwood Aquifer System, and the Jamestown, Ypsilanti, and LaMoure Aquifers of the James River Aquifer System (12). The locations of these aquifers are shown in Figure #2.

Figure #2

Locations of Interactive Aquifers

(Adapted from Christensen and Miller (12))



The Adrian-Grand Rapids Unit of the Spiritwood Aquifer extends from the Stutsman-LaMoure county line to Grand Rapids, ranges in width from 1.5 miles to 6 miles, and covers an area of 60 square miles. The saturated thickness ranges up to 166 feet and averages 90 feet. From the Stutsman-LaMoure County line to the community of Dickey, water levels in the aquifer are 7 to 12 feet below the land surface in the James River floodplain, and, from Dickey to Grand Rapids, the piezometric levels vary from 5 feet below to 15 feet above land surface. The most significant discharge from this aquifer unit to the James River occurs between the Stutsman-LaMoure County line and Dickey (12).

The Jamestown Aquifer is located under the Seven Mile Coulee, Pipestem, and James River valleys, ranges in width from 0.25 miles to 1.5 miles, and covers an area of 9 square miles. The saturated thickness ranges up to 78 feet and averages 30 feet. The water level is generally about 2 feet below land surface in the floodplain of the James River. Lowered water levels in the aquifer caused by pumping can result in seepage from the river into the aquifer. This is likely the case for the four Jamestown municipal wells (12).

The Ypsilanti Aquifer is located from Section 25, Township 137 North, Range 63 West to Dickey, has a width of 0.5 mile or less, and covers an area of 8 square miles. The saturated thickness ranges up to 45 feet and averages 18 feet. The water level generally varies from 4 to 15 feet below the James River floodplain. Geologic, water level, and stage data indicate that the Ypsilanti Aquifer interacts with the James River (12).

The LaMoure Aquifer has an average saturated thickness of 40 feet and is composed of a north, central, and south unit. The north unit is located north of Grand Rapids, has a width varying from 0.25 mile to 1.0 mile, and covers an area of 4 square miles. The water table gradient in the north unit indicates discharge to the James River. The central unit has a width of 0.5 miles to 2.5 miles and covers an area of 30 square miles. The low-head dam west of LaMoure affects the water levels in the central unit and near this dam the river discharges into the aquifer. No significant interaction was found between the south unit of the LaMoure aquifer and the James River (12).

In an attempt to quantify the amount of water accrued by the James River from these interactive aquifers, Christensen and Miller (12) conducted "seepage runs" as a part of their study. These seepage runs consisted of taking several flow measurements at various sites along the James River. The measuring points were selected to coincide with the reaches of the river suspected of interaction with the ground water system. In each case the releases from the two reservoirs were held constant for a period of time prior to the taking of these discharge measurements so that steady state conditions could be approximated.

Initially, seepage runs were conducted in October of 1981 and 1982. The release from the reservoirs had been held constant for two weeks. It was concluded from the results that this was not a long enough period of time to obtain a steady-state flow downstream. Also, wind was noted to affect the discharge in some locations, thereby disrupting the steady-state assumption (12).

To alleviate these problems, two more seepage runs were conducted in February 1983 and 1984. The ice cover eliminated any wind effects. No releases were made from either of the reservoirs for five weeks prior to the 1983 work and for 10 weeks prior to the 1984 work. The work done in February 1983 found the flow in the James River to increase from 5 cfs to 11 cfs within the study area for a net increase of 6 cfs. The Adrian-Grand Rapids unit of the Spiritwood aquifer contributed approximately 4 cfs of this gain. In February, 1984 the flow increased from 6 cfs at Jamestown to 14 cfs at Grand Rapids for a net increase of 8 cfs. Again, the Adrian-Grand Rapids unit of the Spiritwood aquifer accounted for the majority of this gain (12).

Other Components

Winter (45) addressed the accuracy attributable to precipitation data used in hydrologic budget analyses. He found that error associated with areal averaging of precipitation resulting from one storm event can be as great as 60 percent. But he also found that the error may be as low as 5 percent when using seasonal estimates.

Bader (2) estimated that the annual water use data collected by the North Dakota State Water Commission (SWC) may be as accurate as 80 percent, however he also warned that this figure can vary when dealing with small study areas. The SWC has been testing a new flow meter which may produce more reliable data (2).

Wind can have an adverse effect on stage readings for lakes. Any determination of change in storage of a lake should be made using more than one water level measuring point to avoid errors resulting from wind (23). These problems were encountered in this analysis.

IV. HYDROLOGIC BUDGET ANALYSIS

Extreme drought conditions were encountered in the lower James River basin during the irrigation season of 1988. For instance, at Oakes only 4.26 inches of precipitation were received from April 1 through July 31, 1988. This is only 40 percent of the normal for this period. A total of 9.80 inches were received for the period April through September with 4 inches of this falling in September after the growing season was essentially complete. Temperatures meanwhile were far above normal and reached at least 107 °F during each of the three months, June, July, and August. According to data provided by the National Oceanic and Atmospheric Administration (NOAA), the average temperature in June was 10.3 °F greater than normal at Oakes. According to data provided by the U.S. Bureau of Reclamation (USBR), the accumulated growing degree days at Oakes for the period of May 1, 1988 to September 18, 1988 was 125 percent of normal.

High temperatures, combined with continual high winds, resulted in excessive evaporation as will be shown in the analysis to follow. Evaporative losses of this magnitude had not been anticipated and thus complicated the management of the system during 1988. Therefore, performing a hydrologic budget analysis for this period provides insight into the system's ability to convey water from Jamestown Reservoir to the Oakes Test Area under critical or worst case conditions.

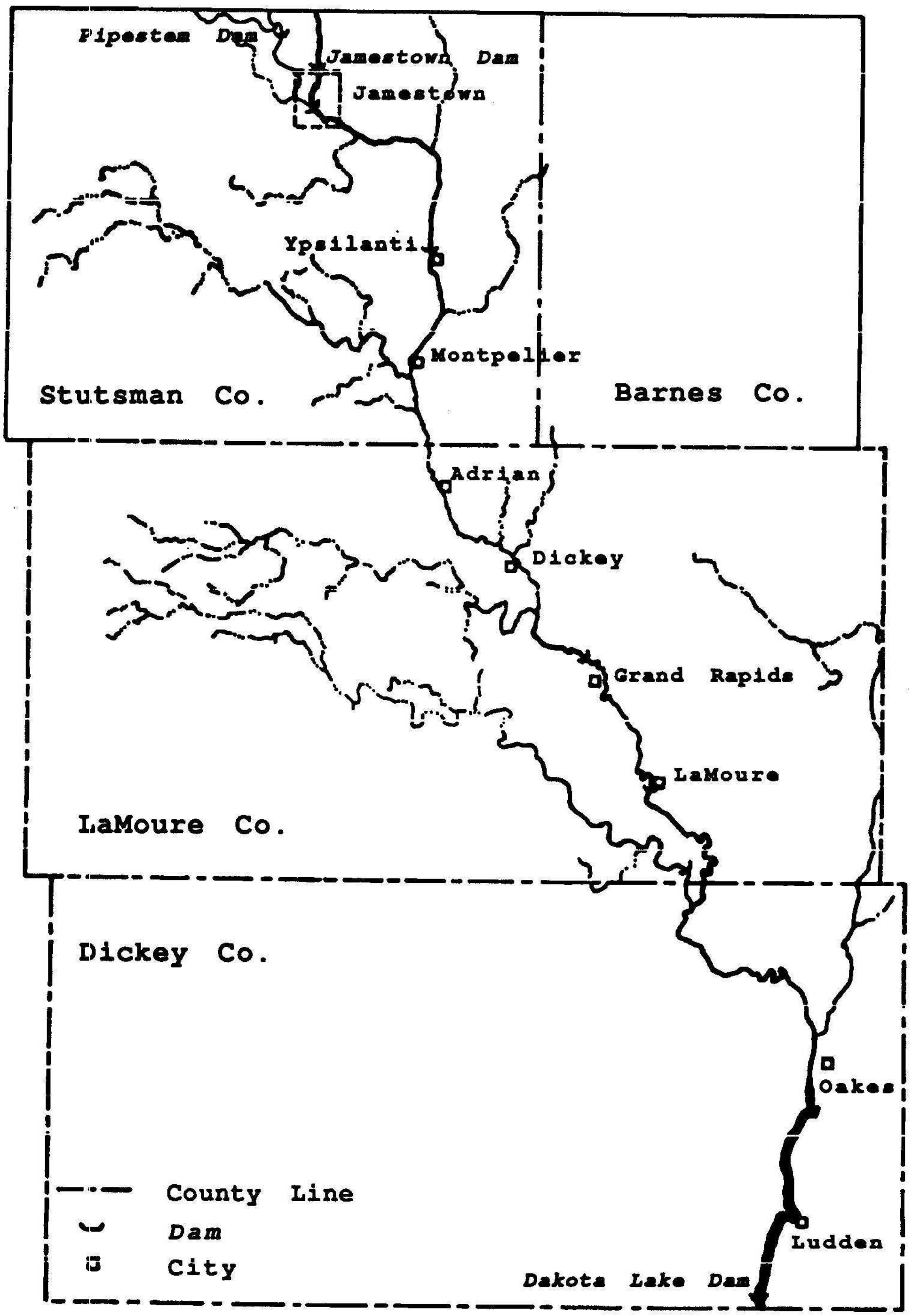
Project Area

The lower James River, as defined for this study, includes that portion of the James River in North Dakota downstream from Jamestown Reservoir, located just north of Jamestown, North Dakota. This includes approximately 135 river miles. The drainage area into Jamestown Reservoir is about 1760 square miles. The drainage area of the James River at the North Dakota-South Dakota border is about 5480 square miles. The study area is illustrated in Figure #3.

Most of the lower James River basin is covered with glacial drift interspersed with alluvial deposits. Therefore, most of the aquifers which interact with the lower James River are glacial drift aquifers (12).

Figure #3

Study Area



Christensen and Miller (12) described the geomorphology of this area. The James River flows onto the lake plain of glacial Lake Dakota in the southern part of the study area. The valley width varies from 0.5 mile in the upper end of the study area to 3 miles near LaMoure. The valley depth varies from about 150 feet on the upper end to only 40 feet where the river flows onto the Lake Dakota plain. The river slope changes from about 1.3 feet per mile between Jamestown and Grand Rapids to only 0.1 to 0.3 foot per mile below LaMoure where the river flows through pools of backwater created by Dakota Lake Dam. Through Dakota Lake the channel slope is reportedly as low as 0.05 foot per mile (6).

Jamestown Reservoir lies just outside the actual study area. Releases from this reservoir, however, played an important role in creating the streamflow conditions encountered on the lower James River in 1988. This reservoir was constructed in the early 1950's as an advance feature of the Garrison Diversion Project. The reservoir consists of a conservation pool of 28,910 acre-feet, a joint-use pool of 6,633 acre-feet, and an exclusive flood pool of 185,435 acre-feet. Flood pool releases are regulated by the U.S. Corps of Engineers and conservation releases are regulated by the USBR. This facility is important to this study because releases were made from this reservoir for the Oakes Test Area during the study period.

Pipestem Dam was constructed on Pipestem Creek approximately 3 miles northwest of Jamestown by the U.S.

Corps of Engineers for flood control purposes in the mid 1970's. Pipestem Creek is a major tributary of the James River and flows into the James River within the city of Jamestown. The drainage area of Pipestem Creek is about 1,040 square miles. The resulting reservoir consists of a small conservation pool of 9,870 acre-feet and a flood pool of 137,010 acre-feet. The conservation pool is for fish and wildlife and recreation. Because of low runoff volumes in 1988 no releases from the flood pool of this reservoir were made during the study period. Because water supply was not a part of this project's original authorization, no water was released from the conservation pool during the study period, June through September, 1988.

Dakota Lake Dam is located about 0.5 mile north of the North Dakota - South Dakota border within Dakota Lake National Wildlife Refuge. This is a low-head channel dam owned by the U.S. Fish and Wildlife Service (USF&WS). The capacity of this structure has been estimated as 3200 acre-feet and the surface area as 1600 acres. Many of the private irrigators, along with the USBR, have pump sites located within the backwater of this structure. This served to further complicate the management of the river system due to the difficulties associated with differentiating between the water stored in Dakota Lake, belonging to the USF&WS, and the inflows which are put to beneficial use by the other appropriators. A photograph of the spillway of Dakota Lake Dam is included in Appendix E.

The Oakes test area is located near Oakes in Dickey County and is a feature of the Garrison Diversion Unit. The Oakes test area consists of 5,000 acres of land originally designated for irrigation with Missouri River water prior to full-scale Garrison Diversion Project operation to allow study of return flow water quality. Due to delays encountered with delivery of Missouri River water, the USBR decided to irrigate a portion of this test area with water stored in Jamestown Reservoir on an interim basis. Delivery of water to 898 acres was attempted in 1988.

Data from four U.S. Geological Survey (USGS) gaging stations, which monitor river discharge in the study area, will be used in this study. Data from another station, which simply monitors the level of water in Dakota Lake, will also be used. The USGS gaging stations are listed in Table No.1 (18).

TABLE #1

USGS Gaging Stations

Station #	Station Name	Parameter Measured	Period of Record
06470000	James River at Jamestown	Discharge	45 years
06470500	James River at LaMoure	Discharge	38 years
06470800	Bear Creek Near Oakes	Discharge	12 years
06470830	James River at Oakes	Stage	6 years
06470875	James River at Ludden	Discharge	7 years

Water Rights

The state of North Dakota employs a prior appropriation water right system. Basically, this means that first in time is first in right. If there is insufficient water to satisfy all the existing water rights on a particular source, then the oldest water right will have first claim to the water which is available.

There are presently 20 active permits authorizing irrigation with water from the main stem of the James River below Jamestown Reservoir in North Dakota. These permits authorize the irrigation of 2860 acres with 3160 acre-feet of water at a total combined pumping rate of 57.8 cubic feet per second (cfs). These irrigation permits are listed in Table #2.

TABLE #2

Irrigation Water Permits

Permit #	Priority Date	Quantity Acre-Feet	Authorized Acres
153B	11/14/38	138.0	73.7
374	01/06/51	80.0	99.6
428	03/26/52	60.0	60.0
670	04/24/56	4.0	2.0
1337	10/29/65	80.0	135.0
1701	04/14/70	74.3	74.3
1702	07/13/73	58.4	58.4
1775	06/03/71	331.0	265.0
1948	06/18/73	334.0	252.7
2160	09/26/74	214.0	214.0
2160A	09/26/74	140.0	140.0
2191	01/03/75	432.8	288.0
2237	03/18/75	165.8	165.8
2240	03/19/75	135.0	135.0
2243	03/24/75	329.3	329.3
2366	02/02/76	135.0	135.0
2386	02/18/76	133.0	133.0
2453	05/17/76	127.0	127.0
2453A	05/17/76	16.0	16.0
2481	07/08/76	175.0	156.0

The USF&WS filed a claim for water for Dakota Lake Dam in 1934 claiming 3200 acre-feet for storage and 4800 acre-feet annually to maintain a full pool. While it is clear that the USF&WS has established a water right for this structure, the exact quantities associated with this right have not been determined. Section 61-04-01.2 of the North Dakota Century Code explains that, "Beneficial use shall be the basis, the measure, and the limit of the right to the use of water"(28). No perfected water permit has been issued for this project.

The USBR holds conditional water permit No. 434, which authorizes the storage of up to 230,000 acre-feet of water in Jamestown Reservoir for multiple purposes. One of these multiple purposes is water supply for irrigation. This water permit has a priority date of April 16, 1952. Because water permit No. 434 does not specifically describe the delivery of water to the Oakes Test Area, it was necessary for the USBR to file an application for temporary authorization to utilize water stored in Jamestown Reservoir for irrigation in the Oakes Test Area. This authorization was granted by the State Engineer via a letter dated May 16, 1988. The following condition was attached (30):

> "Water permits have been issued by the State Engineer which authorize the appropriation of water from James River downstream from Jamestown for irrigation purposes. Some of the water appropriated was released from Jamestown Reservoir under normal operations related to the evacuation of the flood control pool and the joint use pool.

To recognize the water rights of downstream irrigators holding water permits from the State Engineer the Bureau of Reclamation shall manage reservoir operations so as to provide water to these irrigators within the limits of past reservoir operation and available water."

The interaction of these various water rights during such extreme drought conditions resulted in many questions being raised. Do the private irrigators have a right to utilize a portion of the releases from Jamestown Reservoir? How are the evaporative losses assessed against the releases from Jamestown Reservoir and the natural flow? How is the water right associated with Dakota Lake administered because so many of the irrigators withdraw water from this pool?

This analysis will not necessarily answer all these questions, but it should provide insight which will be helpful in addressing these questions in the future.

Data Used

Streamflow

Streamflow data from the USGS gaging stations on the James River at Jamestown, LaMoure, and Ludden, and on Bear Creek near Oakes were used in the analysis. These data were supplemented with streamflow data collected by North Dakota State Water Commission (SWC) personnel at the temporary sites, JAM1 and JAM2. These data were collected in response to a request by the USBR for assistance in monitoring the releases from Jamestown Reservoir.

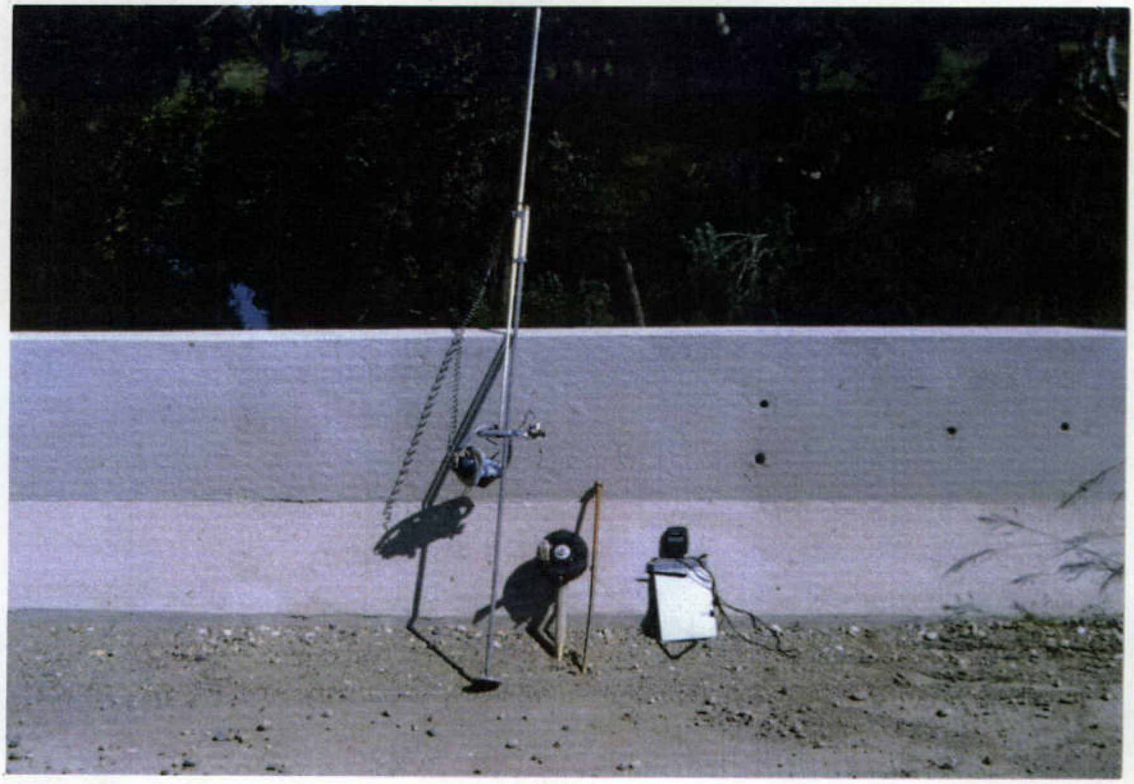
The first step in the selection of sites to be used for temporary gaging was to review what was already known about the nature of the James River. Christensen and Miller (12) found it impossible to take conventional current meter measurements downstream of Grand Rapids due to the presence of variable backwater and the extremely low gradients. Measurements attempted at a site in SW1/4 35-132-60 found the velocities to be too low and too easily affected by wind. Therefore, it was concluded that the USGS gaging station at LaMoure would be critical in monitoring the releases from Jamestown Reservoir since this would be the last point on the stream where reliable measurements could be taken. Once the flows passed this point they were simply "in the system".

The next step in the site selection process was a visual survey of the stream between Jamestown and LaMoure. The conditions of the stream at nearly every bridge were checked and sites were selected based on the spacing between the existing USGS gaging stations and the conditions of the stream at the site, following the criteria set forth by Rantz (35). The site in the NE1/4 23-137-63 near Montpelier was selected because of the stable control created by a rock riffle under the bridge and the existence of a measuring section having straight flow lines, a solid bottom, and nearly uniform depth. The site in the NE1/4 4-135-62 near Dickey was selected because of the rock riffle which served as stable control and also provided a good measuring section. Both sites were easily accessible and appeared as though they would provide satisfactory measuring sections for a wide range of flows.

Frequent discharge measurements were taken at these sites to define the relationship between stage and discharge and also to provide instantaneous flow values which were used in managing this system. A total of 15 measurements were taken at JAM1 and 16 were taken at JAM2 throughout the 1988 season. These measurements are summarized in Appendix A. These measurements were taken using a Price Pygmy current meter. The pygmy meter was used because the depths encountered were generally less than 1.5 feet. The depth was measured and the meter set at the appropriate depth using a top-setting wading rod. The width of the individual sections and of the stream was measured utilizing a Canfield tag-line consisting of a braided steel cable marked with brass beads at 2 foot increments. These measurements were taken following the procedures described by Rantz (35). The velocity was measured at 0.6 depth in each vertical,and this was assumed to be the mean velocity in the vertical. This method was used rather than the 0.2 and 0.8 depth method because the depths were all less than 2.5 feet. The equipment used in taking these measurements is shown in Figure #4.

Figure #4

Stream Gaging Equipment



Two different methods of measuring the stage were used at these sites. At JAM1 near Montpelier, a staff gage was installed just upstream of the control. The staff gage consisted of a 2 X 6 board to which porcelain-enameled iron gages were attached. The board is attached to a 10-foot rod which is driven into the stream bed. The enameled sections are graduated to every foot, .10 foot, and .02 foot with the elevation written on the section for each graduation. The stage of the water is easily read to the nearest 0.01 foot by interpolating between graduations. This method was used at JAM1 because the controlling rock riffle was directly under the upstream side of the bridge, eliminating any possibility of utilizing a wire-weight gage attached to the bridge.

At JAM2 near Dickey, a wire weight gage was attached to a hand-rail support on the downstream side of the bridge. A weight is lowered until it just touches the water surface. The stage is then read directly from a digital gage on the bridge. The cable suspending the weight is wound in a single layer around a drum so that one revolution of the drum corresponds to exactly one foot of cable.

For both sites local observers were contracted by the SWC to take daily stage readings. These readings were taken at approximately the same time each day. These readings were assumed to represent the mean daily stage. The 24-hour spacing of the readings was desired so that any errors accrued as a result of the above assumption might be offsetting.

The relationship between stage and discharge at these sites was defined through the use of least squares curve fitting capabilities available in SAS (36). An exponential curve of the following form was assumed:

$$Q = p(G - e)^{N}$$

where: Q = Discharge in cfs
G = Stage in feet
p, e, and N are constants defined by fitting the curve to the actual data

The values of p and N were first defined holding "e" equal to zero. The value of e was then adjusted by trial and error until an optimum coefficient of determination was achieved. Figure No. 5 shows the resulting curve for JAM1 and Figure No. 6 shows the rating curve for JAM2. The regression for JAM2 was based on the first 11 data points collected and the regression for JAM1 was based on the first 10 data points collected. These data points adequately defined the stage-discharge relationship in the range of interest. The coefficient of determination for the JAM2 regression was 0.9938 and for the JAM1 regression, it was equal to 0.9979.

Once the stage-discharge relationship was defined for these sites in equation form, the next step was to develop a continuous flow record from this relationship and the daily stage readings obtained from the contracted observers. These daily values are listed in Appendix B. This was accomplished by using a computer program to convert the daily stage readings to daily flow values. The hydrographs for the stations on the James River are shown in an upstream to downstream order in Figures #7 through #12. The hydrograph for the Bear Creek near Oakes gage is shown in Figure #13.

FIGURE #5

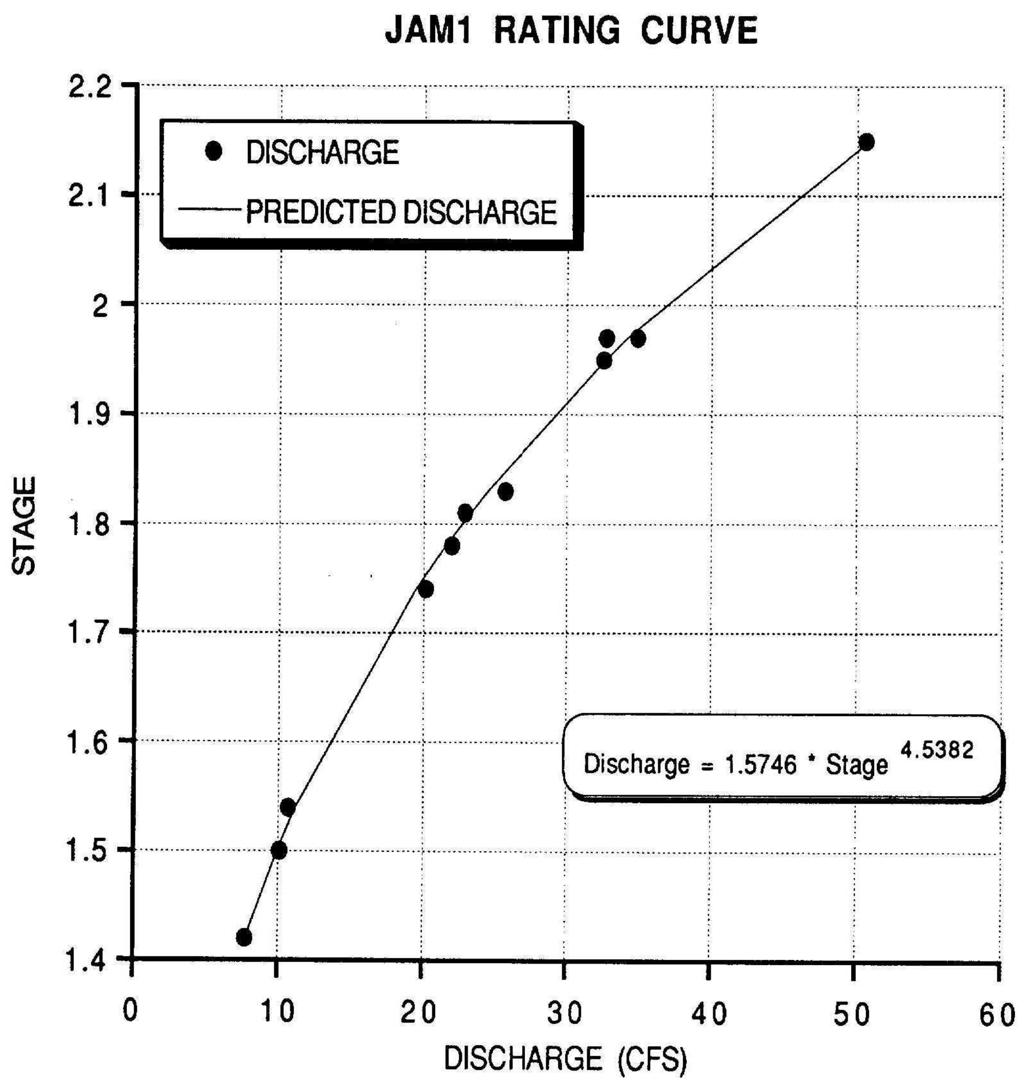

JAM1 RATING CURVE
DISCHARGE
PREDICTED DISCHARGE
Discharge = 1.5746 * Stage 4.5382
STAGE
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
0
10
20
30
40
50
60
DISCHARGE (CFS)

FIGURE #6

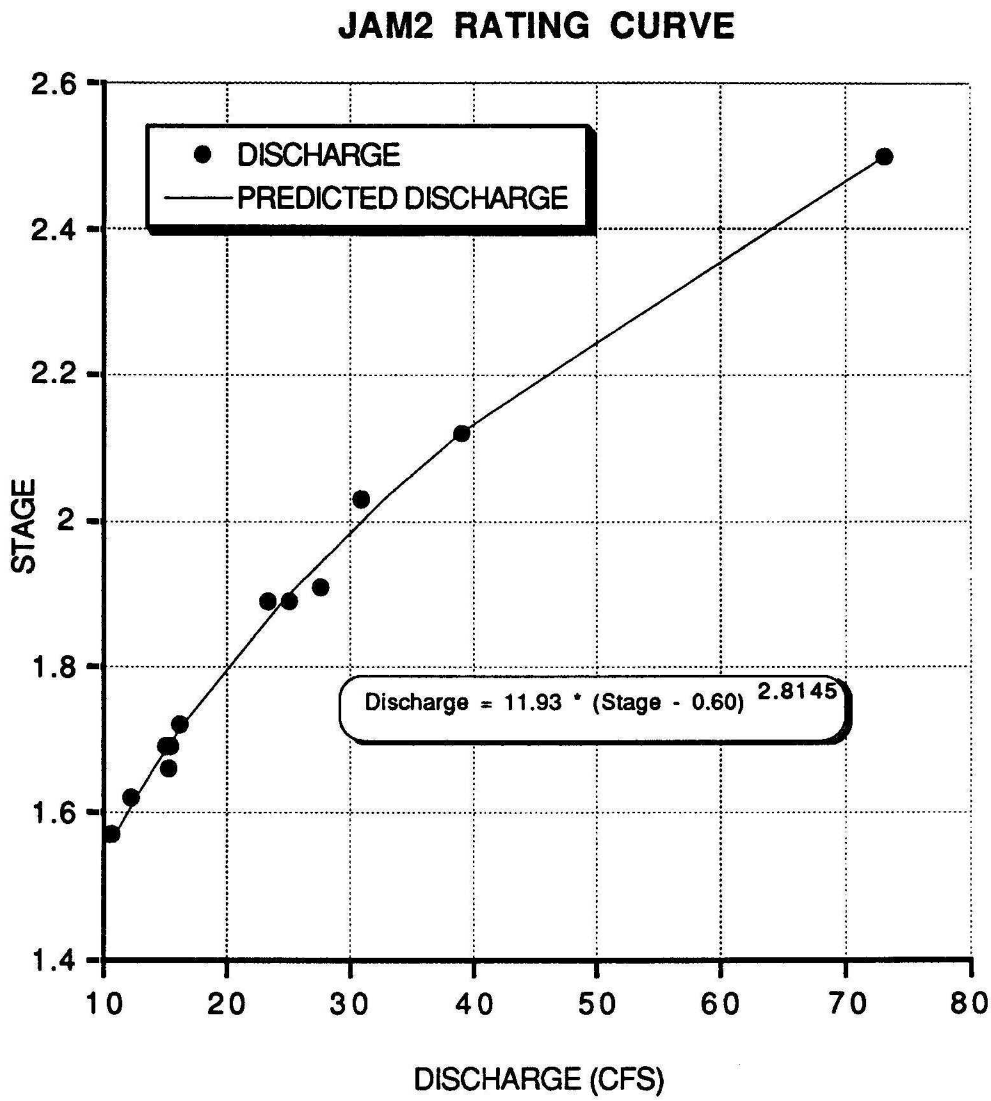

JAM2 RATING CURVE
DISCHARGE
PREDICTED DISCHARGE
Discharge = 11.93 * (Stage - 0.60) 2.8145
STAGE
2.6
2.4
2.2
2
1.8
1.6
1.4
10
20
30
40
50
60
70
80
DISCHARGE (CFS)

FIGURE #7

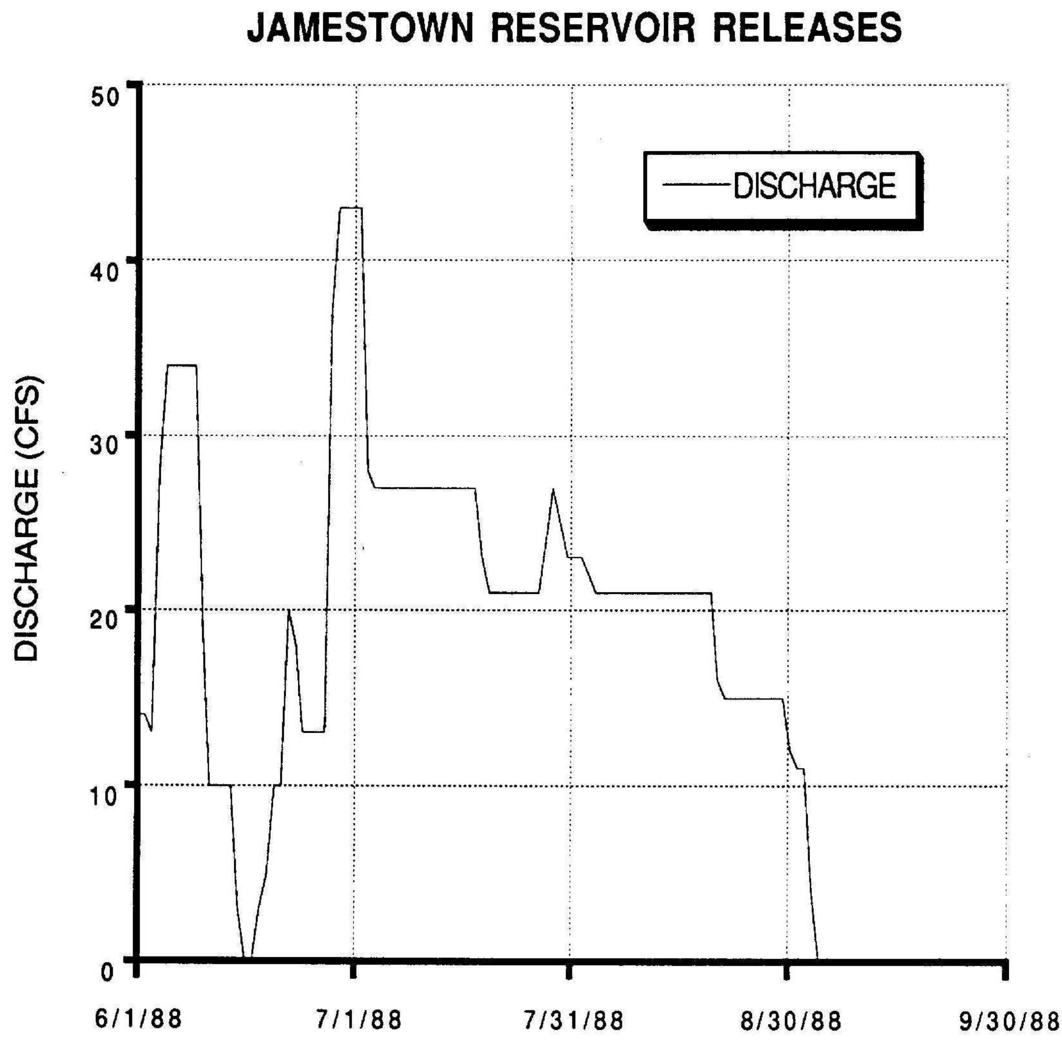

JAMESTOWN RESERVOIR RELEASES
DISCHARGE
DISCHARGE (CFS)
50
40
30
20
10
0
6/1/88
7/1/88
7/31/88
8/30/88
9/30/88

FIGURE #8

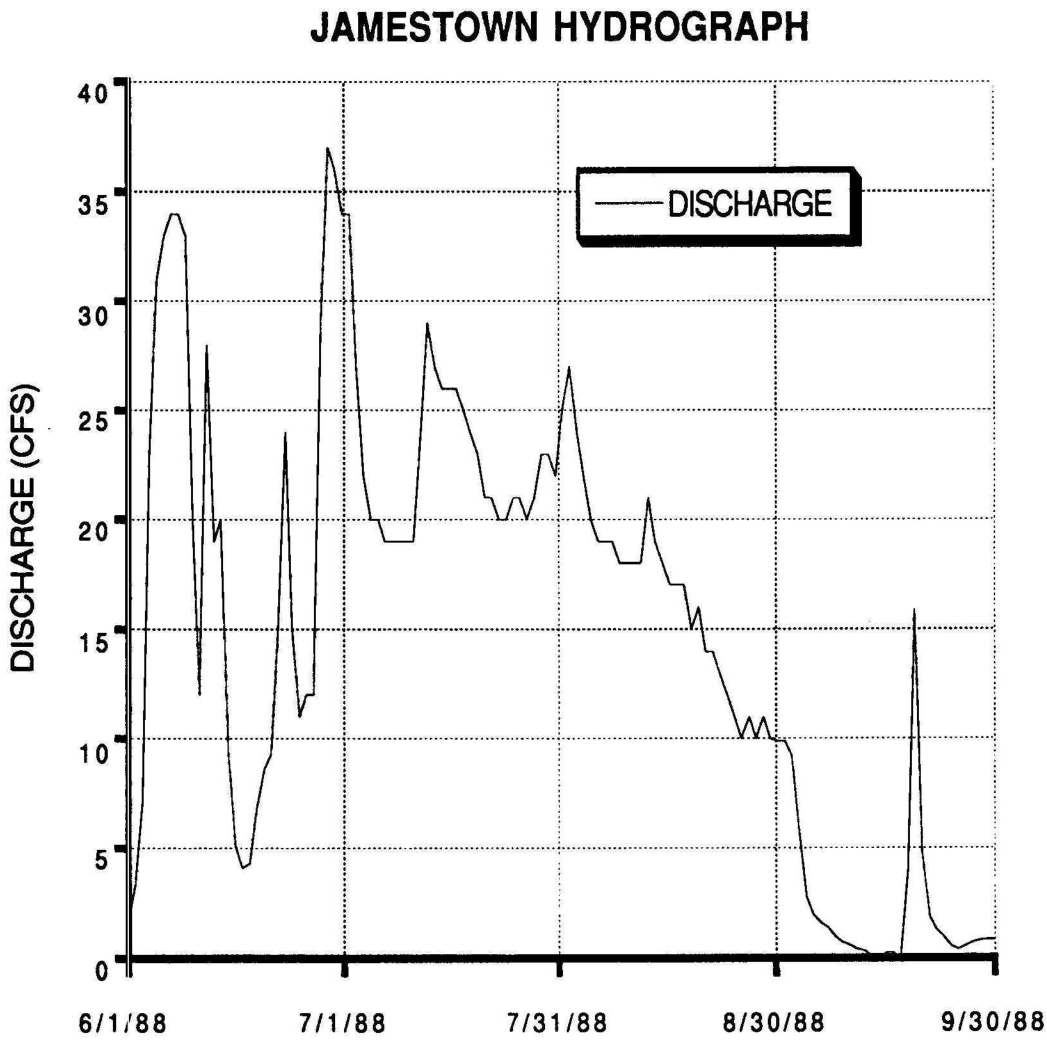

JAMESTOWN HYDROGRAPH
DISCHARGE
DISCHARGE (CFS)
40
35
30
25
20
15
10
5
0
6/1/88
7/1/88
7/31/88
8/30/88
9/30/88

FIGURE #9

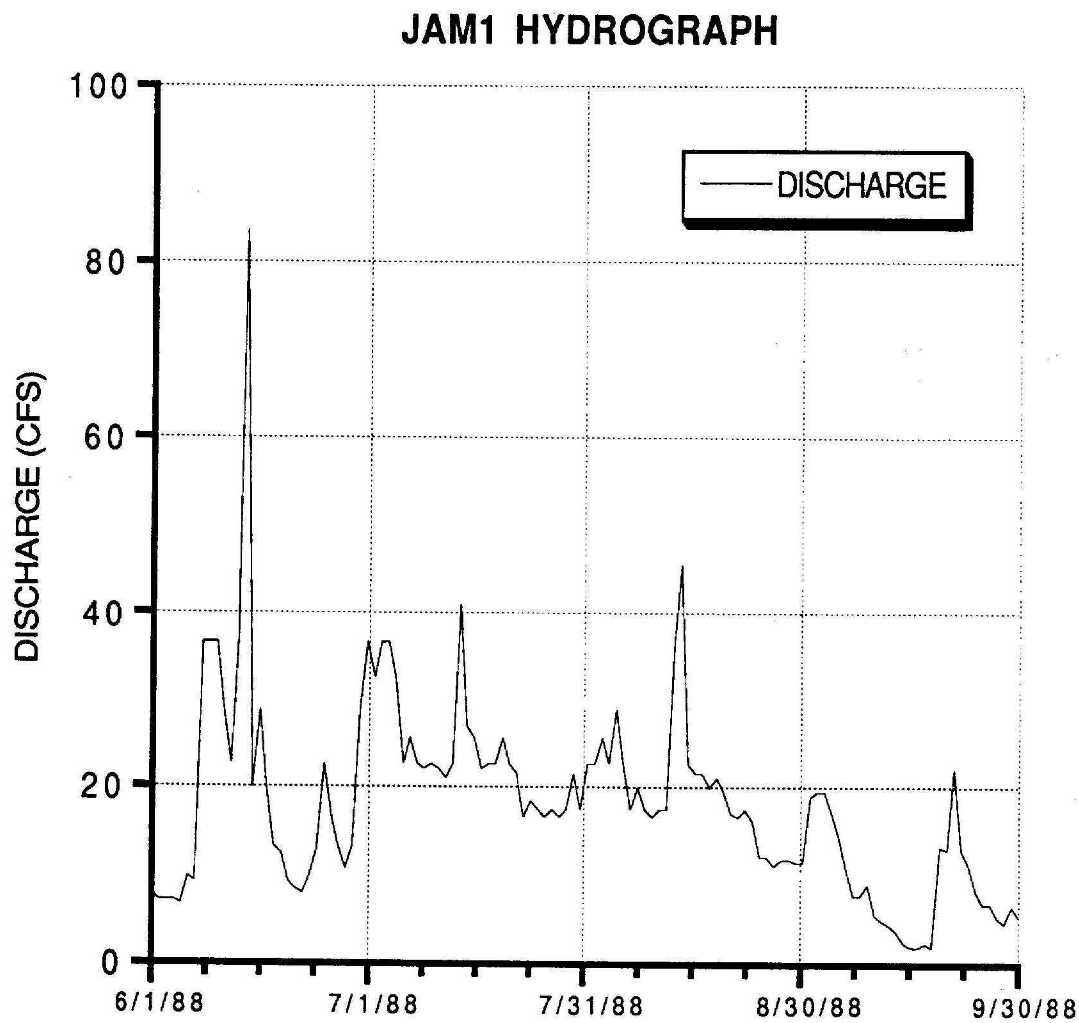

JAM1 HYDROGRAPH
DISCHARGE
DISCHARGE (CFS)
100
80
60
40
20
0
6/1/88
7/1/88
7/31/88
8/30/88
9/30/88

FIGURE #10

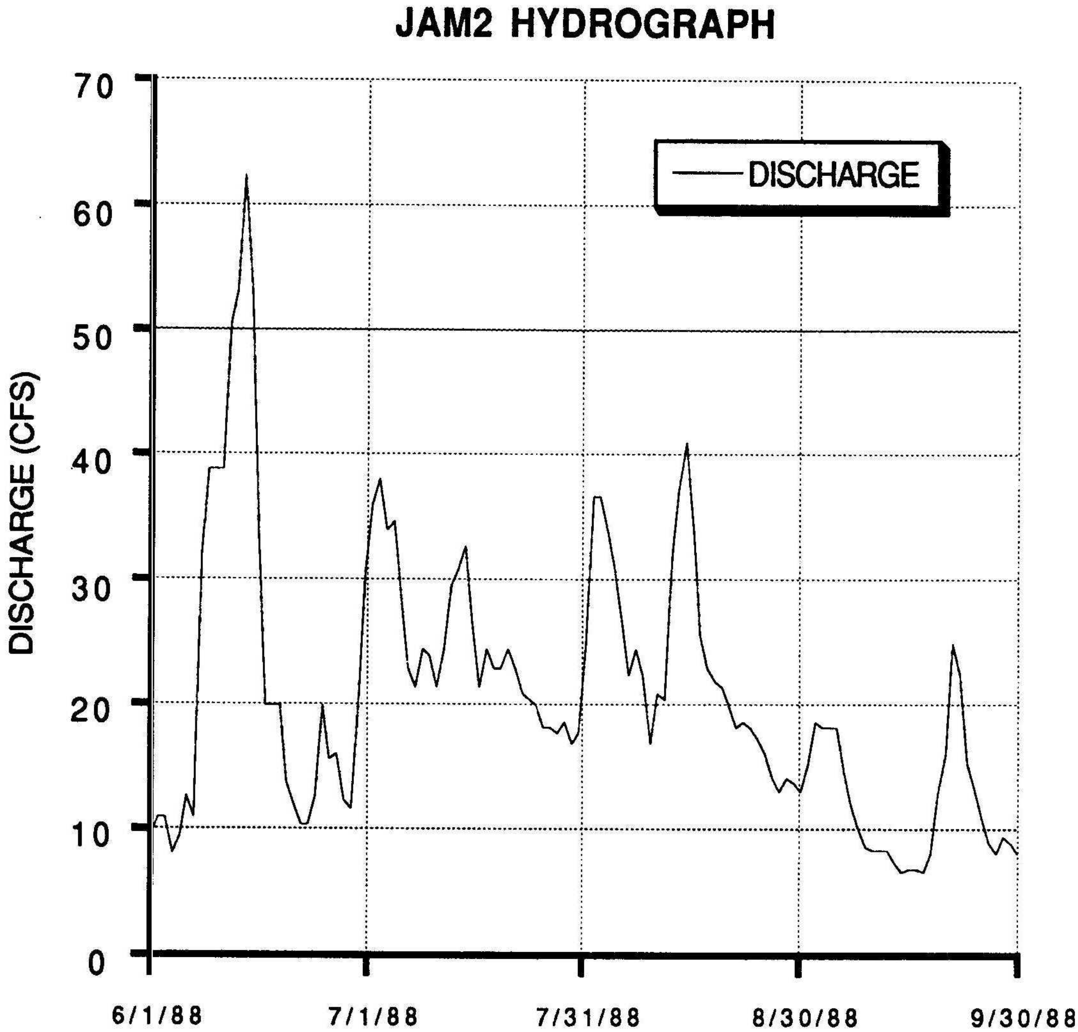

JAM2 HYDROGRAPH
DISCHARGE
DISCHARGE (CFS)
70
60
50
40
30
20
10
0
6/1/88
7/1/88
7/31/88
8/30/88
9/30/88

FIGURE #11

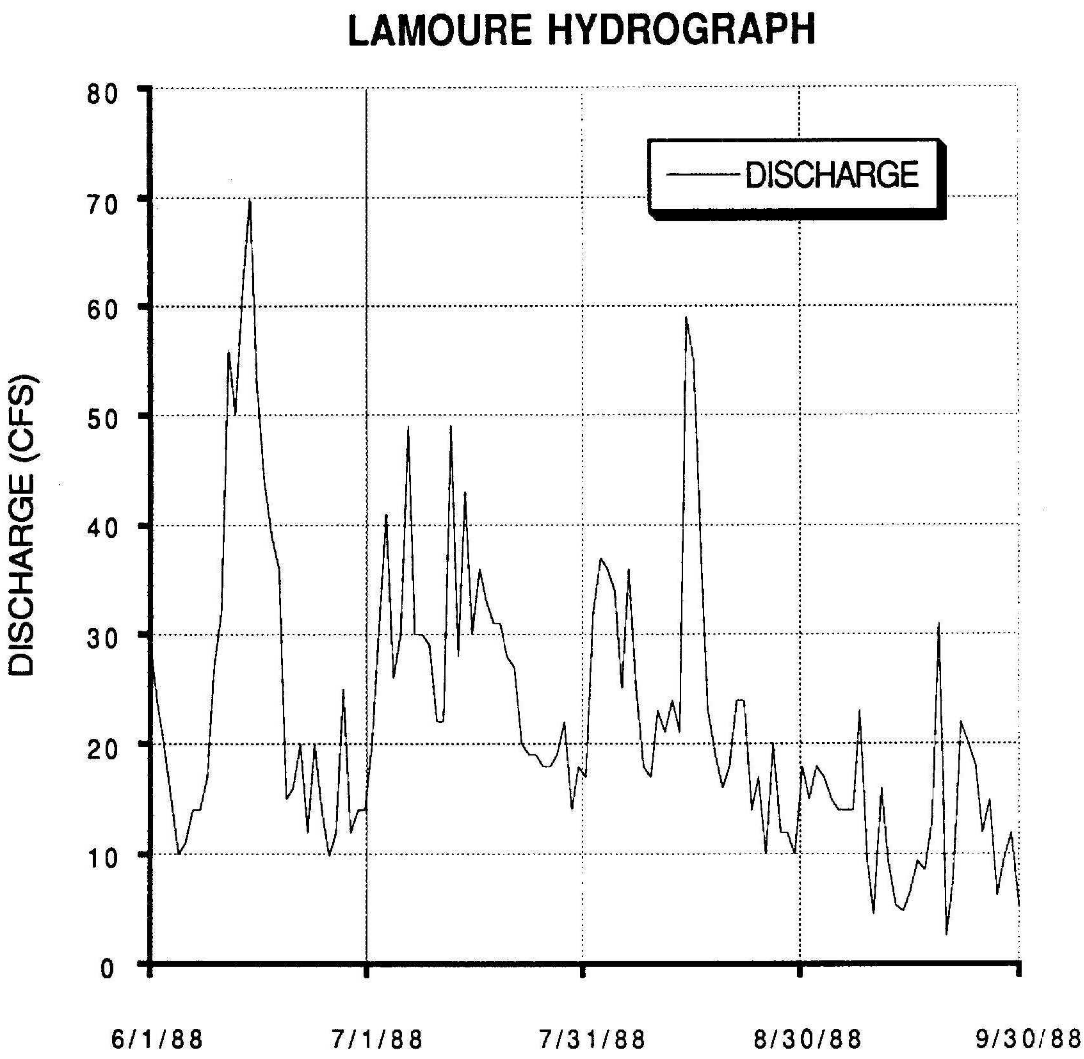
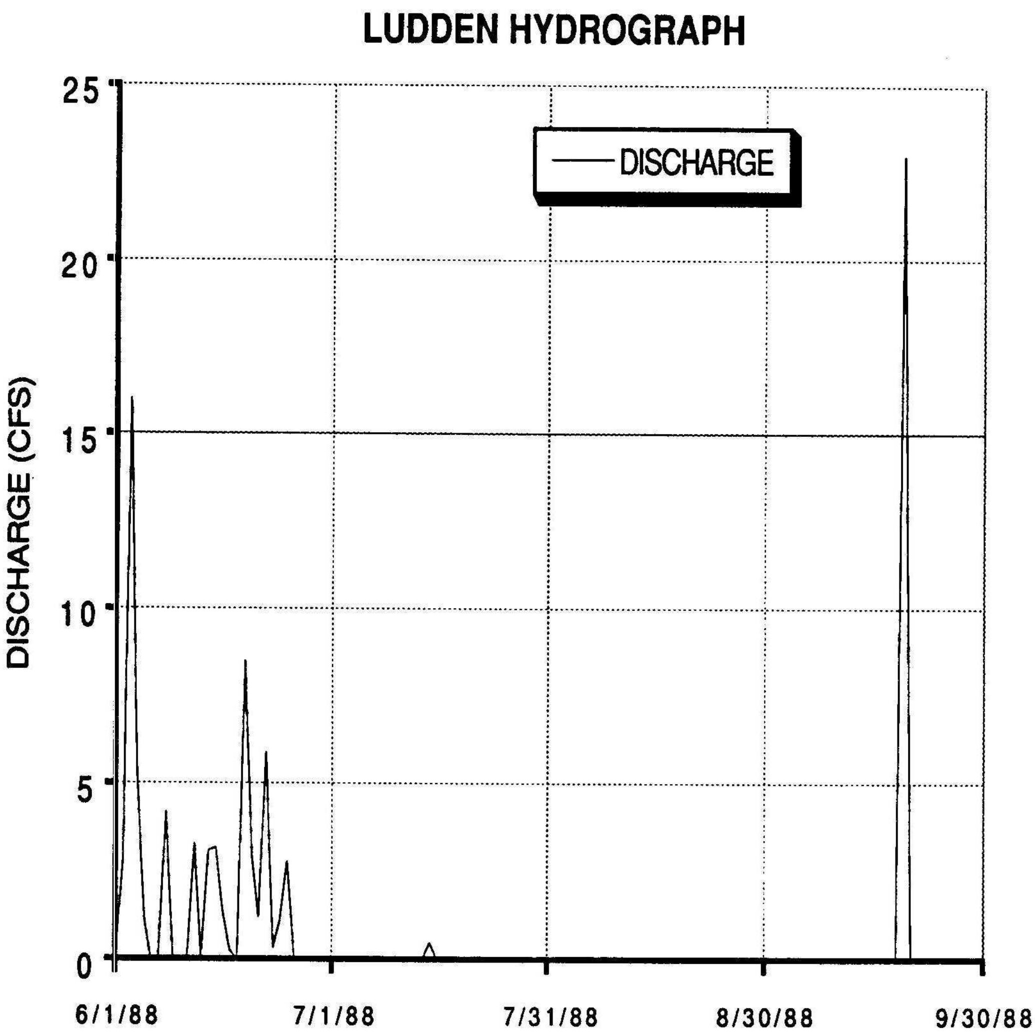
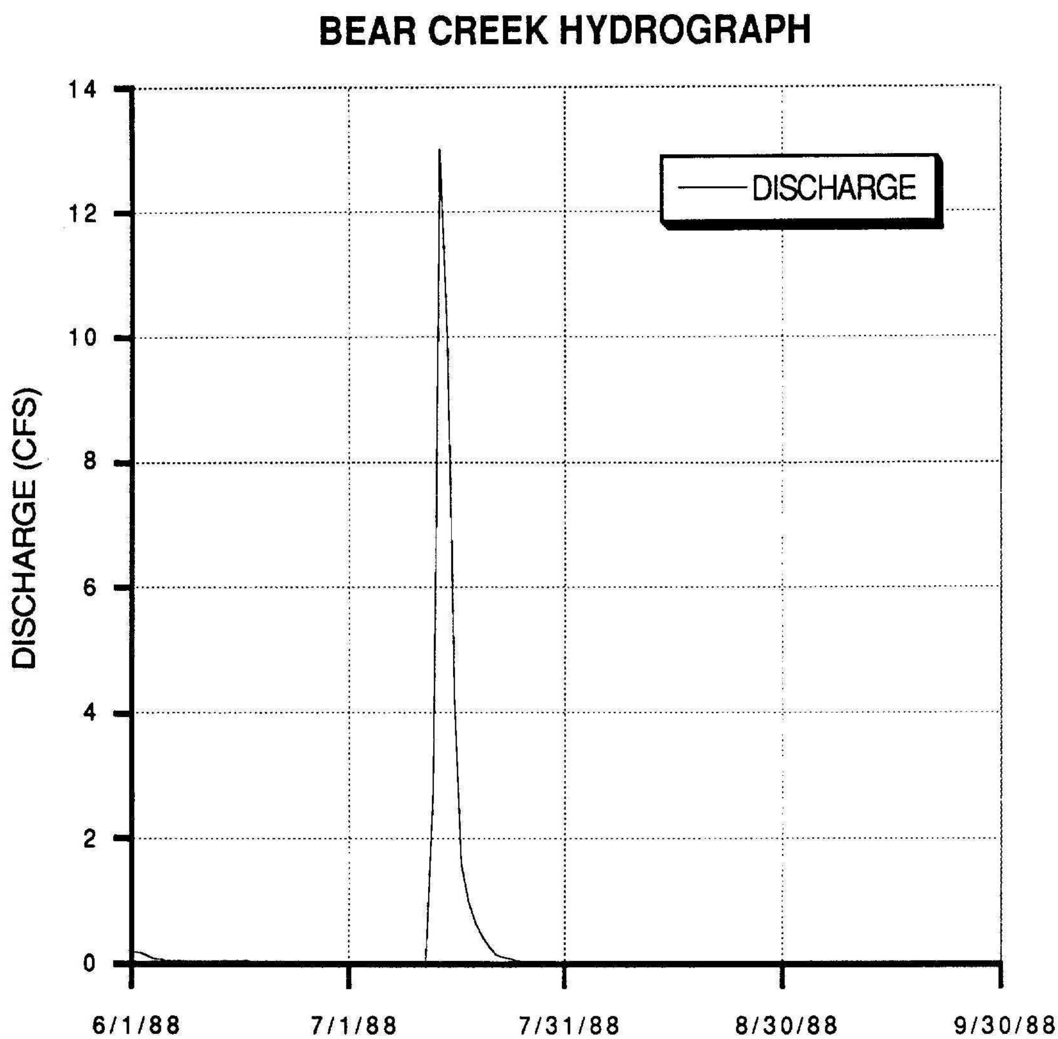

LAMOURE HYDROGRAPH
DISCHARGE
DISCHARGE (CFS)
80
70
60
50
40
30
20
10
0
6/1/88
7/1/88
7/31/88
8/30/88
9/30/88

FIGURE #12



LUDDEN HYDROGRAPH
DISCHARGE
DISCHARGE (CFS)
25
20
15
10
5
0
6/1/88
7/1/88
7/31/88
8/30/88
9/30/88

FIGURE #13


BEAR CREEK HYDROGRAPH
DISCHARGE
DISCHARGE (CFS)
14
12
10
8
6
4
2
0
6/1/88
7/1/88
7/31/88
8/30/88
9/30/88

Appropriations

The SWC requires all irrigation permit holders to file annual use reports. The permit holder is asked to report the number of acres irrigated and the number of acre-feet of water pumped. They are also asked to report the pumping rate of their system and the number of hours pumped. If the system is metered, they are also asked to report the beginning of season and end of season meter readings. Each report is reviewed by a hydrologist before the data are entered into the computerized data base. The reported volumes used and acres irrigated for each permit in the various reaches for the period June - September, 1988 are presented in Table No. 3.

The USBR supplied data on a weekly basis for the amount of water withdrawn at their pumping plant. For the period of June 1 through September 8, 1988, they reported pumping 1526.9 acre-feet and that a total of 120.7 acre-feet were returned to the James River from their drains (7).

TABLE #3

Reported Useage During the Study Period

Reach	Permit #	Reported Useage (Acre-Feet)
Jamestown Dam to Jamestown Gage	670	4.0
Jamestown Gage to Montpelier	None	None
Montpelier to Dickey	2453	107.4
Dickey to LaMoure	1702	50.4
	1775	212.9
LaMoure to Ludden	428	70.4
	1701	40.0
	1337	100.0
	2240	95.6
	374	66.2
	2160A	125.0
	2160	321.0
	1948	294.2
	2191	325.0
	2243	289.5
	2366	130.0
TOTAL		2227.6

Precipitation

Precipitation data were obtained from the North Dakota Atmospheric Resource Board. These data are collected by volunteer observers across the state. Daily precipitation data from 22 of these sites were used in the analysis which follows (29). Precipitation data published by the National Oceanic and Atmospheric Administration (NOAA) were also used in this analyses (27). In all, data from 28 sites were used. These data are listed in Appendix C. The locations of these stations are shown in Figure #15.

The locations of these sites were plotted along with the corresponding values of precipitation. Where there were adequate data points, isohyets were constructed and used to estimate the average precipitation over the particular river reaches. In the upper end of the study area there were not enough data available to construct reliable isohyets and so average values were applied somewhat subjectively to the various reaches. The resulting values of precipitation used for each reach are shown in Table #4.

TABLE #4

Precipitation Estimates

Reach	Precipitation
Jamestown Dam to Jamestown Gage	7"
Jamestown Gage to Montpelier	10"
Montpelier to Dickey	11"
Dickey to LaMoure	8.5"
LaMoure to Ludden	9.5"

Evaporation

There were three sources of data available for use in estimating the evaporation from the water surface of the James River in this study area. One of these sources was the North Dakota State University (NDSU) Soil Science Department. The department operated a Class A Weather Bureau pan near Oakes, North Dakota. Readings were taken on Mondays, Wednesdays, and Fridays beginning on June 6, 1988 and ending on August 30, 1988. These data were collected specifically for use in one of the Soil Science Department's computer simulation models. These data were incomplete for use in this analysis, but they were useful as a check on the method of estimation ultimately used.

There were also Class A pan data available as published by the NOAA, which publishes pan evaporation data for five sites in North Dakota (26). Unfortunately, the nearest station for which data were available was at Carrington, approximately 45 miles north of the north end of the project area.

The third source available was the climatological data collected by NDSU and the SWC near Oakes. These data were used in conjunction with Penman's combination method to estimate evaporation. This method was chosen because the required data are available and because it has been a commonly used method through the years. Penman's equation is (32,33):

$$E = (H\Delta + E_a\gamma)/(\Delta + \gamma)$$

where: E = evaporation
Δ = slope of e:T curve at Ta,
γ = psychrometric constant
H = net radiation
E_a = evaporation estimate obtained by using the mean air temperature as estimate of water surface temperature in an aerodynamic relationship

The values used for Δ were calculated from the mean daily temperature (23). As recommended by Kohler (22), a value of 0.000367P, where P is atmospheric pressure in inches of mercury, or 0.00066P, where P is in mb, was used for the psychrometric constant. Thus a coefficient must be used to adjust these estimates of evaporation from a theoretical free water surface to the real water surface. As recommended by the ASCE's Hydrology Handbook (1), a coefficient of 0.80 was used for the period of interest, June through September. Therefore,

$$E = 0.80(H\Delta + E_a\gamma)/(\Delta + \gamma) \qquad (21)$$

where: $\gamma = 0.00066P$
P = atmospheric pressure in mb

The equation used to obtain E_a is the same as originally used by Penman (32,33) ie

$$Ea = (0.2625 + 0.1409u)(e_a - e_d) \qquad (22)$$

where: u = wind speed in meters per second
e_a = saturated pressure in mb
e_d = actual pressure in mb

The equation used to obtain H is that presented by Doorenbos and Pruitt (14), ie

$$H = 0.95R_s - 2.00(10)^{-9}(T_a + 273.16)^4 (0.34 - 0.044(e_d)^{1/2})$$
$$(-0.35 + 1.5\, R_s/R_a) \qquad (23)$$

Where: R_s = observed solar radiation
R_a = extraterrestrial solar radiation

The resulting estimates of evaporation are shown in Table No. 5, along with the pan data at Oakes and at Carrington. The pan data have been adjusted using a pan-to-lake coefficient of 0.80.

TABLE #5

Evaporation Estimates

Month	Oakes Pan	Carrington Pan	Penman's
June	---	9.3"	8.4"
July	9.2"	9.4"	8.5"
August	6.7"	7.6"	6.8"
September	---	4.7"	4.0"
Totals	---	31.0"	27.7"

Instream Storage

The budget analysis requires an estimate of the change in storage for each reach. On June 1, 1988, the first day of the study period, the flow in the James River was very low, nearing minimum base flow conditions. However some live flow was noted throughout the reaches. On September 30, 1988, the last day of the study period, the flow conditions in the James River were nearly identical. All the small channel dams and pools were full with some small amount of live flow both on the first and last days of the study period. It is reasonable to assume that the volume of water stored within these reaches was the same at the beginning and end of this period. Therefore, the change in storage for the reaches above LaMoure was assumed to be zero.

This does not apply to the reach from LaMoure to Ludden. Stage data from the USGS station at Oakes were used along with some miscellaneous stage readings taken from bridges by USBR personnel. All available readings for June 1, 1988 were averaged and applied to a stage-capacity relationship for Dakota Lake to obtain a total volume stored on June 1. This relationship is included in Appendix D. The same was done for September 30, 1988 and the difference between the two values was used as the change in storage. This results in a change in storage of a negative 785.8 acre-feet. Because wind has such an affect on the level of water in Dakota Lake, it is difficult to estimate the volume stored at any one time with much certainty. A plot of the stage measured at the USGS gage at Ludden is shown in Figure No. 14. The jagged nature of this plot illustrates the effect wind has on this parameter. However, averaging was done to partially eliminate this effect. A map showing the locations of the precipitation stations, streamflow stations, and the meteorological station is shown in Figure #15.

FIGURE #14

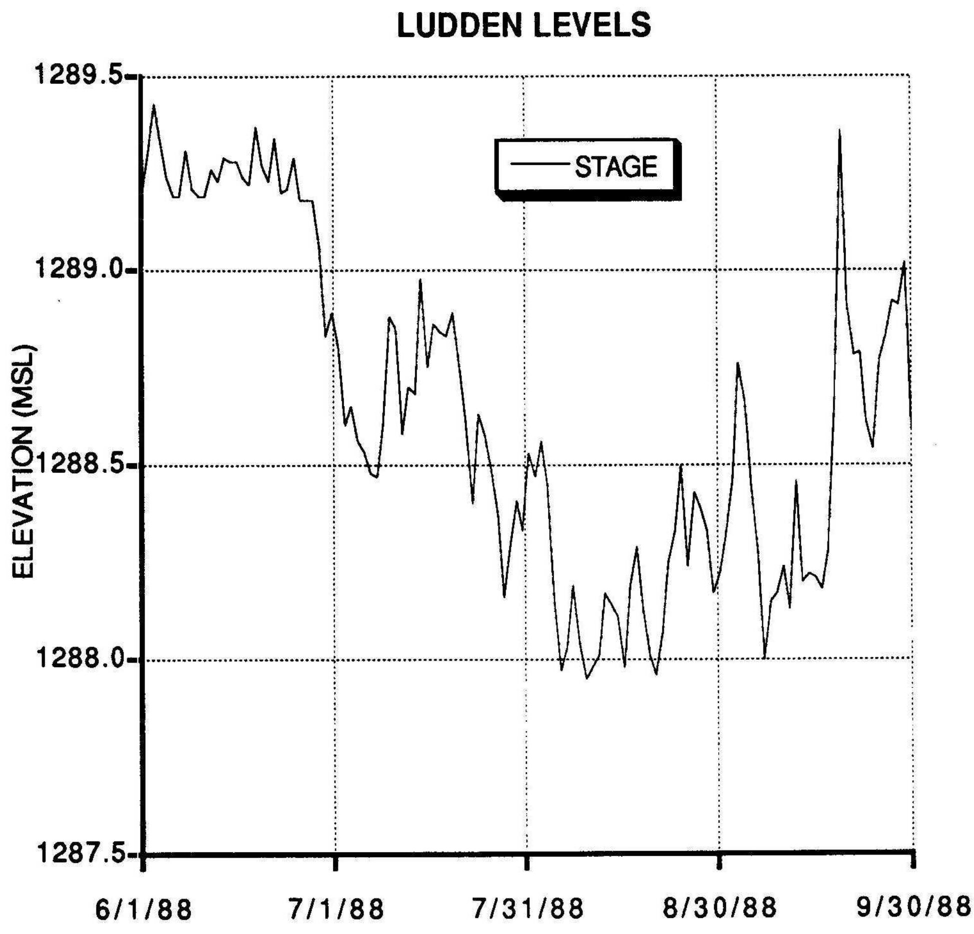
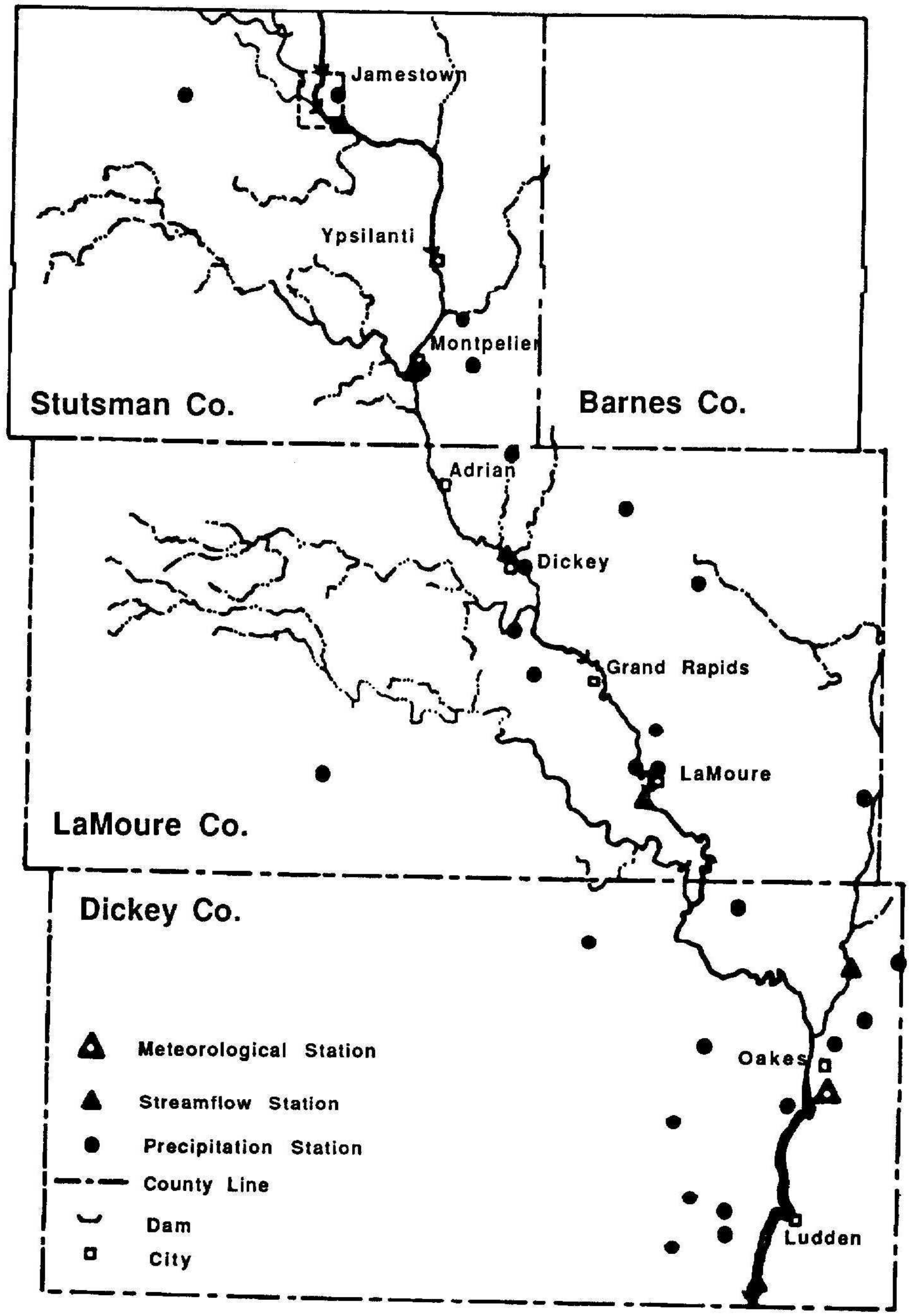

LUDDEN LEVELS
STAGE
ELEVATION (MSL)
1289.5
1289.0
1288.5
1288.0
1287.5
6/1/88
7/1/88
7/31/88
8/30/88
9/30/88

Figure #15

Locations of Data Stations



Analysis

The objective of this study was to account for the releases from Jamestown Reservoir and to quantify the gains and losses encountered by the James River during the critical period of June through September, 1988. A hydrologic budget analysis of this system was performed to meet this objective. As described earlier (equation #1), the hydrologic budget equation is generally written as:

$$I + P - O - E - W + A = \Delta S \qquad (24)$$

where:
- A = net volume gained or lost from natural process such as direct surface runoff or seepage of ground water into the channel
- E = gross evaporative loss
- W = quantity pumped directly from the channel
- O = outflow from the reach
- ΔS = change in storage volume
- I = inflow to the reach
- P = precipitation falling directly on the water surface

The terms can be rearranged so that the quantity to be estimated as a residual is on the left side of the equation as shown below:

$$A = (E + W + O + \Delta S) - (I + P) \qquad (25)$$

If all the other terms are known or can be estimated, then the hydrologic budget equation can be used to estimate the net gain to the stream from natural processes. For this analysis, the James River was divided into the following five sub-reaches:

1. Jamestown Dam to Jamestown Gage
2. Jamestown Gage to Montpelier
3. Montpelier to Dickey
4. Dickey to LaMoure
5. LaMoure to Ludden

All of the terms on the right side of the equation were then quantified and used to estimate the accrual to the river from ground-water seepage and from direct surface runoff for the period of June through September, 1988.

The budget equations for each reach are discussed below separately.

Jamestown Dam to Jamestown Gage

This reach of the James River consists of approximately 6 miles of channel between Jamestown Dam and the USGS gaging station, James River at Jamestown(No.06470000) and has a surface area of 43.2 acres. Throughout this reach, the James River is flowing through the city of Jamestown. There are no major users in this reach; however, a survey during the summer of 1988 revealed the existence of more than 100 small private lawn watering pumps. There is one water permit in this reach, No. 670, which authorizes the irrigation of 2 acres with 4 acre-feet of water. Within this reach, the James River may discharge to the Jamestown aquifer (12).

The inflow to this reach was the 3922.6 acre-feet released from Jamestown Reservoir. The outflow from this reach was the 3649.0 acre-feet which passed the Jamestown Gage. The evaporative loss was the 27.7 inches, as estimated tilizing the Penman equations and the climatological data rom Oakes. This evaporative loss of 27.7 inches over 43.2 acres equates to a loss of 99.7 acre-feet. The precipitation for this reach was estimated as 7 inches over 43.2 acres or 25.2 acre-feet. The change in storage for this reach between June 1 and September 30, 1988 has been estimated as zero.

Use of 4.0 acre-feet was reported under permit No. 670. However, the volume of water used by the 100+ private lawn watering systems also needed to be estimated. If it was assumed that each system watered an acre and that 18 inches of water were applied, this resulted in a withdrawal of 150 acre-feet. Therefore, the volume of water pumped directly from this reach of river was estimated as 154 acre-feet. Therefore, equation #25 can be evaluated:

$$A = (E + W + O + \Delta S) - (I + P)$$

$$A = (99.7 + 154.0 + 3649.0 + 0.0) - (3922.6 + 25.2)$$

$$A = -45.1 \text{ acre-feet}$$

Jamestown Gage to Montpelier

This reach of the James River includes the 24.8 miles of channel between the Jamestown Gage and the SWC temporary gaging site near Montpelier, JAM1, in the NE 1/4 23-137-63. The surface area of the river in this reach is 127.7 acres.

There are two active permits which authorize the withdrawal of water from this reach; however, neither used water in 1988. The Jamestown sewage lagoon outlet is located within this reach. Also, within this reach, the Ypsilanti aquifer interacts with the James River (12).

The inflow to this reach was the 3649.0 acre-feet measured at the Jamestown Gage, plus the 221.0 acre-feet released from the Jamestown lagoons or a total of 3870.0 acre-feet. The outflow was the 4392.2 acre-feet as measured at Montpelier. The evaporative loss was 27.7 inches over 127.7 acres or 294.8 acre-feet. The precipitation was estimated as 10 inches over 127.7 acres or 106.4 acre-feet. The change in storage for this reach was also assumed to be zero. There was no water pumped directly from this reach. Therefore, equation #25 can be evaluated:

$$A = (E + W + O + \Delta S) - (I + P)$$

$$A = (294.8 + 0.0 + 4392.2 + 0.0) - (3870.0 + 106.4)$$

$$A = 710.6 \text{ acre-feet}$$

Montpelier to Dickey

This reach of the James River consists of 19.1 river miles with a surface area of 92.3 acres. This reach extends from the SWC temporary gaging site at Montpelier, JAM1, in the NE 1/4 23-137-63 to the SWC temporary gaging site at Dickey, JAM2, in the NE 1/4 4-135-62. There was one permit in this reach under which water was appropriated in 1988. Within this reach, the Adrian-Grand Rapids unit of the Spiritwood aquifer discharges to the James River (12).

The inflow for this reach was the 4392.2 acre-feet as measured at Montpelier, and the outflow for this reach was the 5041.7 acre-feet as measured at Dickey. The evaporative loss from this reach was 27.7 inches over 92.3 acres or 213.1 acre-feet. The precipitation was estimated as 11 inches over 92.3 acres or 84.6 acre-feet. The amount of water appropriated from this reach was 107.4 acre-feet. The change in storage was assumed to be negligible. Therefore, equation #25 can be evaluated:

$$A = (E + W + O + \Delta S) - (I + P)$$

$$A = (213.1 + 107.4 + 5041.7 + 0.0) - (4392.2 + 84.6)$$

$$A = 885.4 \text{ acre-feet}$$

Dickey to LaMoure

This reach consists of 31.4 river miles and a surface area of 259.0 acres. This reach extends from the SWC temporary gaging site at Dickey, JAM2, in the NE1/4 4-135-62 to the USGS gaging station, James River at LaMoure (No.06470500), in the NE1/4 11-133-61. The control for the LaMoure gaging station is a rock-rubble channel dam which backs water to Grand Rapids. There are two permits in this reach under which water was appropriated in 1988. Within this reach, the Adrian-Grand Rapids unit of the Spiritwood aquifer discharges to the James River and the James River may discharge to the LaMoure aquifer (12).

The inflow to this reach was the 5041.7 acre-feet measured at Dickey and the outflow was the 5503.0 acre-feet measured at LaMoure. The evaporative loss was 27.7 inches over 259 acres or 597.9 acre-feet. The precipitation was estimated as 8.5 inches over 259 acres or 183.5 acre-feet. The volume withdrawn was 263.3 acre-feet. The change in storage was assumed to be negligible. Equation #25 can be evaluated:

$$A = (E + W + O + \Delta S) - (I + P)$$

$$A = (597.9 + 263.3 + 5503.0 + 0.0) - (5041.7 + 183.5)$$

$$A = 1139.0 \text{ acre-feet}$$

LaMoure to Ludden

This reach consists of 48.8 miles of channel with a corresponding surface area of 1450.0 acres. This reach extends from the USGS gage at LaMoure in the NE1/4 11-133-61 to the USGS gaging station, James River at Dakota Lake Dam near Ludden (No. 06470875) in the NE 1/4 34-129-60. This reach is characterized by gradients as low as 0.1 to 0.3 feet per mile and by the presence of variable backwater created by Dakota Lake Dam which serves as the control for the Ludden gage. There are 11 permits under which water was appropriated from this reach in 1988. The point of diversion for the Oakes Test Area is also located within this reach.

In the northern end of this reach, the James River may interact with the LaMoure Aquifer (12).

The inflow to this reach is the total of the 5503.0 acre-feet measured at LaMoure, the 71.9 acre-feet measured at the Bear Creek near Oakes gage (No. 06470800), and the 120.7 acre-feet contributed by the USBR drains or a total of 5695.6 acre-feet. The outflow was the 172.9 acre-feet measured at Ludden. The evaporative loss was 27.7 inches over 1450.0 acres or 3347.1 acre-feet. The precipitation was estimated as 9.5 inches over 1450.0 acres or 1147.9 acre-feet. The volume withdrawn by the private irrigators was 1857.2 acre-feet and the volume pumped for the Oakes Test Area was 1526.9 acre-feet. The change in storage was estimated as a negative 785.8 acre-feet.

Therefore, equation #25 can be evaluated:

$$A = (E + W + O + \Delta S) - (I + P)$$

$$A = (3347.1 + 3384.1 + 172.9 - 785.8) - (5695.6 + 1147.9)$$

$$A = -725.2 \text{ acre-feet}$$

Jamestown Dam to Ludden

It should also be a useful exercise to examine the entire reach from Jamestown Dam to Ludden. This includes 135 channel miles and a total surface area of 1972.2 acres. The inflow was the 3922.6 acre-feet released from Jamestown Reservoir, the 221.0 acre-feet released from the Jamestown lagoons, the 71.9 acre-feet contributed by Bear Creek, and the 120.7 acre-feet contributed by the USBR's drains or a total of 4336.2 acre-feet. The outflow was the 172.9 acre-feet as measured at Ludden. The evaporative loss was 27.7 inches over 1972.2 acres or 4552.5 acre-feet. The quantity gained from direct precipitation was 1547.6 acre-feet. The total volume pumped by the private irrigators was 2231.9 acre-feet plus the estimated 150 acre-feet for lawn watering in Jamestown or 2381.9 acre-feet. The Oakes Test Area withdrew 1526.9 acre-feet. The change in storage was a negative 785.8 acre-feet. Therefore, equation #25 can be evaluated:

$$A = (E + W + O + \Delta S) - (I + P)$$

$$A = (4552.5 + 3908.8 + 172.9 - 785.8) - (4336.2 + 1547.6)$$

$$A = 1964.6 \text{ acre-feet}$$

Results of this analysis are summarized in Table #6.

TABLE #6

Results of Analysis (ac-ft)

Reach	**I**	**O**	**P**	**E**	**W**	**ΔS**	**A**
1	3922.6	3649.0	25.2	99.7	154.0	0.0	-45.1
2	3870.0	4392.2	106.4	294.8	0.0	0.0	710.6
3	4392.2	5041.7	84.6	213.1	107.4	0.0	885.4
4	5041.7	5503.0	183.5	597.9	263.3	0.0	1139.0
5	5695.6	172.9	1147.9	3347.1	3384.1	-785.8	-725.2
Entire Reach							
	4336.2	172.9	1547.6	4552.5	3908.8	-785.8	1964.6

V. RESULTS AND DISCUSSION

The accrual for the reach between Jamestown Reservoir and the Jamestown Gage was shown to be a negative 45.1 acre-feet, meaning that 45.1 acre-feet were lost from the system and are unaccounted for. Such a loss in this reach could be the result of two things; this volume of water could have been pumped by the 100+ private lawn watering systems or it could have been lost through seepage into the Jamestown Aquifer. In the analysis it was estimated that the 100+ private lawn watering systems watered an acre each and that 18 inches of water or 150 acre-feet were pumped. If, for instance, 23.5 inches rather than 18 inches were pumped this would explain the apparent loss of another 45.1 acre-feet. The city of Jamestown has municipal wells completed in the Jamestown aquifer ranging from 100 to 1800 feet from the river, and pumping from these wells may induce seepage from the river (12). It is possible that these 45.1 acre-feet were lost due to seepage from the river into the Jamestown aquifer. Another possible explanation is that this apparent loss of water may simply be the result of error. The 45.1 acre-feet represents little more than one percent of the total reported releases from Jamestown Reservoir.

The accrual between the Jamestown Gage and the temporary gage at Montpelier was a positive 710.6 acre-feet. Some large precipitation events did occur in the vicinity of Montpelier and a large share of this accrual may be due to direct surface runoff within this reach. This reach of the river may interact with the Ypsilanti aquifer (12).

The accrual for the reach between Montpelier and Dickey was calculated as 885.4 acre-feet. The downstream end of this reach, between the cities of Adrian and Dickey, interacts with the Adrian-Grand Rapids unit of the Spiritwood aquifer (12). This aquifer has been identified as a contributor to the base flow of the James River (12).

The accrual for the reach between Dickey and LaMoure was calculated as 1139.0 acre-feet. Between the cities of Dickey and Grand Rapids, this reach of the river interacts with the Adrian - Grand Rapids Unit of the Spiritwood aquifer (12). Near the downstream end of this reach, the river also interacts with the Central Unit of the LaMoure aquifer (12).

The accrual between the LaMoure Gage and Ludden was shown to be a negative 725.2 acre-feet. The river in the north end of this reach may interact with the LaMoure aquifer (12), but it is unlikely that this interaction would be the cause of a loss of such a significant volume of water. This apparent loss of water may be the result of error. As Linsley (23) warned, if the other components are large relative to the parameter being estimated, the results may be of questionable accuracy. Winter (45) also warned that the residual term will contain the errors of the measured parameters. This particular reach of the river seems to fit that scenario. The evaporation component is relatively large due to the 1450 surface acres, and so any error in its estimation would be more significant than in the upstream reaches. The volume of water withdrawn by the private irrigators is large in this reach and there could be error in their reports of annual use. Error may have also resulted from the estimates of the volume stored in Dakota Lake due to an uncertain stage-capacity relationship and wind effects on the stage readings.

The accrual for this entire study area was shown to be 1964.6 acre-feet. This equates to a steady contribution of 8.3 cfs for the entire 120-day period of interest. Therefore, the quantity of accrual estimated by this budget analysis verifies the earlier findings by Christensen and Miller (12). However, the estimates resulting from this budget analysis may include direct surface runoff from the infrequent thunderstorms experienced during this period, whereas Christensen and Miller's estimates were based on field work done under winter conditions when there was no direct surface runoff.

The total reported use by the private irrigators was 2231.9 acre-feet on 2298 acres. This is significantly less than the 3160 acre-feet and 2859 acres authorized. This is even less than the 2550.8 acre-feet authorized for the acreage irrigated during 1988. The total accrual, from ground-water seepage and direct surface runoff, was 1964.6 acre-feet, and the volume gained from precipitation falling directly on the water surface was 1547.6 acre-feet. Together with the 221.0 acre-feet released from the Jamestown lagoons and the 71.9 acre-feet contributed by Bear Creek, the total volume of water making up the natural flow of the James River during this period was 3805.1 acre-feet. The 2231.9 acre-feet used by the private irrigators represents 59 percent of this volume.

The total volume of water released from Jamestown Reservoir during this period was 3922.6 acre-feet. The total volume pumped by the USBR for the Oakes Test Area was 1526.9 acre-feet. Therefore, the USBR used only 39 percent of the water it put into the system, or, put another way, for every acre-foot pumped at Oakes the USBR released 2.6 acre-feet at Jamestown.

The 1573.2 acre-feet of unused natural flow, the 2395.7 acre-feet of water put into the system and unused by the USBR, and the 785.5 acre-feet lost from the storage in Dakota Lake combined to meet the evaporative loss. This raises the issue of whether or not the USBR's rights were being infringed upon, because water which it was releasing for use at the Oakes Test Area under authorization from the State Engineer was being used to make up evaporative losses to the benefit of the private irrigators. The private irrigators did benefit from the USBR's releases, because the 3805.1 acre-feet of natural flow would not have been adequate to meet the 4552.5 acre-feet of evaporative losses. The USF&WS also benefitted from the USBR's releases, because the level of Dakota Lake was only 7.6 inches below the top of the weir on September 30. This decline of 7.6 inches is significantly less than the 18.2 inches of net evaporative loss (evaporation minus precipitation) measured for this area during the study period.

Conversely, the USBR benefitted from the natural flow and the fact that not all of the natural flow was appropriated by the private irrigators. A total of 1573.2 acre-feet of this natural flow was used to make up a portion of the evaporative losses downstream. The USBR also benefitted from the existence of Dakota Lake Dam, because the reservoir served to re-regulate the releases from Jamestown Reservoir, detaining excess inflows and allowing the USBR to operate its project with only 172.9 acre-feet being lost downstream.

It is important to note that in this analysis, the volume of water accrued from direct ungaged surface runoff is not differentiated from the volume of water accrued from ground-water seepage. While precipitation was infrequent during the study period, the little that did occur resulted from thunderstorms, some of which were of an intensity sufficient to produce surface runoff, especially in the urbanized Jamestown area. It would be very difficult to determine the volume of direct surface runoff resulting from these storms. Hydrograph separation would be an ineffective method because wind seriously affects the discharge at some of the gaging sites. The other alternative would be to model each of the contributing watersheds, and such an effort is beyond the scope of this study.

Another limitation is the fact that the climatological data used to estimate the evaporation were collected over a dry land surface and may have differed from what would have been collected over or near Dakota Lake. The fact that Dakota Lake is a small lake probably helped to minimize any resulting error because the turbulent transport of the water vapor was likely sufficient to minimize any local accumulation of water vapor over the lake's surface. It is possible that in the upper reaches the wind velocities near the water surface were significantly less than those measured near Oakes due to the protection of the river valley. However the valley is shallow in the reach containing Dakota Lake, and this is the reach for which the evaporative component is large.

The estimates of the volume of water stored in Dakota Lake may have also been the cause of error in this analysis. This lake has not been surveyed in recent years and the stage-capacity relationship used in this analysis was an estimate based on the original plans from the 1930's. It is possible that some significant siltation has occurred since then. Also, the level of water in this lake is easily affected by wind to such a degree as to make it very difficult to estimate what the level of water would be if it were unaffected by wind. Additional stage data at other bridges over the lake would be helpful in the future. A photograph showing a typical view of Dakota Lake is included in Appendix E.

Another potential source of error in this analysis is the estimate of the amount of water pumped by the private irrigators. Many of these irrigation systems do not include totalizing flow meters. In some instances, the estimates of the amount of water pumped for these systems, which are not metered, may be in error. The accuracy of the state-wide annual use data base is thought to be within 80 percent, however, this can vary greatly when analyzing a small area such as the lower James River (2). The accuracy of this data and the availability of instantaneous water-use data could be improved by requiring that all the systems include working totalizing flow meters.

VI. RECOMMENDATIONS AND CONCLUSION

Future Operations

One of the objectives of this analysis was to interpret the results relative to the future operation of Jamestown Reservoir to supply water to the Oakes Test Area. This study has shown that the evaporation component can vary greatly. The mean evaporation from shallow lakes and reservoirs for the period June through September for this area is 21.5 inches (37). The calculated evaporation for this period was 27.7 inches, an increase of 29 percent. During low flow years, a portion of this demand may be assessed against the water released from Jamestown Reservoir for use in the Oakes Test Area.

The natural flow was adequate to meet the needs of the private users, but it would have been inadequate to meet both the entire evaporative demand and the demand for irrigation water from the private irrigators. However, newly adopted rules dealing with water appropriation specify that a storage right only authorizes a seasonal fill from which evaporative losses must be assessed. Therefore, it would not have been necessary for the level of Dakota Lake to have been maintained at as high a level as occurred during this period. Therefore, in future years, more of these evaporative losses should be assessed against the water stored in Dakota Lake.

This analysis has shown that the private permit holders did benefit from releases of water made from Jamestown Reservoir during this study period. Because normal operation of Jamestown Reservoir has involved the evacuation of the joint-use pool prior to fall freeze-up, the State Engineer has issued permits which allow beneficial use to be made of this water. Thus, when the USBR desired to use water from the joint-use pool for the Oakes Test Area, a potential conflict was created. Partially because of these conflicting claims to the water released from the joint-use pool and partially because of the nature of the lower James River system, it should be recognized that as much as 2.6 acre-feet of water may be required from Jamestown Reservoir for each acre-foot used by the Oakes Test Area during extreme low flow years such as 1988.

The following additional observations during the study may be beneficial for future operations of Jamestown Reservoir.

One of the problems encountered in this initial year of Oakes Test Area operation was the relatively large travel times involved at these lower flows. The initial releases from Jamestown Reservoir peaked on June 5 and, based on a simple interpretation of the hydrographs, this peak apparently reached LaMoure on June 15. However, there were significant thunderstorms between Jamestown and LaMoure during this period which likely reduced the apparent travel time for this wave. Below LaMoure the stream is even more sluggish due to the extremely low gradients and the presence of backwater. Thus, when adjustments were made in the release rate at Jamestown Dam it would be at least 10 days before their effects on the flow at LaMoure could be assessed and attempting to assess their effects on the level of water in Dakota Lake was virtually impossible. Because of the effect the wind has on the flow at LaMoure, it is very difficult to learn any more about the travel time between Jamestown Reservoir and LaMoure than the fact that, at low flows, travel time will likely be on the order of 10 days. This may be beneficial to note relative to future operations.

One alternative means of improving the operational capabilities of this system would be to draw Dakota Lake down in the summer by pumping from the system without any releases from Jamestown Reservoir. This would improve the lake's ability to function as a re-regulation reservoir. When inflows were greater than the demand, the excess inflows would be retained in the reservoir. The lake could then be refilled with releases from Jamestown Reservoir in the fall. These releases could be made at a much greater rate, minimizing system losses by decreasing the volume of water which would be lost to evapotranspiration.

Future Data Collection

One recommendation resulting from this analysis should be to require all the private irrigators to install flow meters on their systems. In order to effectively manage this system, it is necessary to be able to account for all the inflows to and outflows from the system at any given time with the greatest level of accuracy practically possible. This would greatly increase the accuracy and timeliness of the data available for a major component in this accounting process.

Another recommendation is that the control for the USGS gaging station at LaMoure be rebuilt. The rock-rubble dam, presently serving as the control, is in a state of ill repair and not only serves as an unstable control, but may also pose a threat from a safety perspective. A new control would solve the problems encountered with a shifting stage-discharge relationship and could also be constructed with a low-flow notch so that wind would not have so great an effect on discharge. The control's sensitivity would thus also be improved, and a better measuring section for low flows could be constructed. A photograph of this structure is included in Appendix E along with a photograph showing a volumetric measurement being taken rather than a current meter measurement because of shallow depths of flow.

It is also recommended that additional stage data for Dakota Lake be collected. These data should be collected daily throughout the irrigation season from both the Ludden and Kendall bridges and perhaps also from bridges upstream of Oakes. These data may be helpful in learning more about wind effects on the level of water in this lake.

The pan evaporation data collected by NDSU should be expanded so that daily values are obtained throughout the irrigation season. This would provide an additional means for estimating the evaporation in this area and would only require a slight expansion of an existing data collection program. Much could be gained from a little additional expenditure.

Another factor which needs to be addressed is the timeliness of the data which are being collected. Accurate information on as timely a basis as possible is essential for managing water supply systems. Sutter et al.(38) described how data automation has improved the management of the Snake River in Idaho. The metering requirement for the private irrigators will help, but a means of obtaining readings from these meters also needs to be devised. One possibility would be to supply them with post cards on which they would note weekly meter readings. Also the streamflow data for the USGS gaging stations need to be even more readily available than it already is. Instantaneous stage readings are easily obtained by accessing on-site data loggers, however more frequent discharge measurements need to be taken to obtain continuous verification of the stage-discharge relationship. The evaporation and meteorological data need to be accessible throughout the irrigation season. This may be accomplished by simply making this need known to the people in charge of this data collection.

Recommendations can also be made relative to future studies. A budget analysis for subsequent years would be helpful in learning more about this system and its performance during years with different weather conditions.

A hydrologic model could be developed for the entire lower basin. This would be a helpful tool for managers, because runoff volumes resulting from precipitation events could be predicted thus providing a means of quantifying the natural flow during the operating season. Such a model would also be helpful in quantifying the accrual from direct surface runoff and that from ground-water seepage independently.

Further work could be done towards quantifying the contribution from the ground-water system to the James River by studying the aquifer characteristics and the water levels for the aquifers and the stream. This might also provide a means of estimating the accruals from ground-water seepage and direct surface runoff independently.

Conclusion

The objectives of this study were met. Hydrologic budget techniques were used to quantify the gains and losses along the lower James River during the irrigation season and drought of 1988. The results of this budget analysis were interpreted relative to future operation of Jamestown Reservoir to supply water to the Oakes Test Area and relative to the interacting water rights established along the lower James River. The adequacy of the available hydrologic data was addressed.

In conclusion, 1988 was an extreme year and much was learned about the James River by examining its performance during such a season. The season was severe not only due to a lack of precipitation, but also because of an excess of evaporation.

Meyer (25), after studying hydrologic conditions throughout the 1930's, noted that, "The serious effects of the great drought of the last decade resulted more from excessive evaporation than from deficient precipitation". This was also the case for the lower James River during the irrigation season of 1988.

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VIII. APPENDIX

A. Streamflow Measurement Data for JAM1 and JAM2

JAM1

Date (mm-dd-yy)	**Stage** (feet)	**Discharge** (cfs)	**Shift*** (feet)
05-31-88	1.42	7.74	0.0
06-07-88	1.95	32.54	0.0
06-09-88	1.97	34.87	0.0
06-13-88	2.15	50.59	0.0
06-16-88	1.81	22.86	0.0
06-23-88	1.50	10.11	0.0
06-27-88	1.54	10.74	0.0
06-30-88	1.97	32.73	0.0
07-06-88	1.83	25.68	0.0
07-12-88	1.78	21.96	0.0
08-17-88	1.74	20.17	0.0
09-08-88	1.48	7.14	-0.08
09-27-88	1.45	5.96	-0.12
10-11-88	1.67	9.12	-0.20

*The rating curve was developed based on regression of first eleven data points, therefore shift is zero for these initial points. Increasing shifts later in the year appeared to be the result of fallen leaves and debris clogging the control.

A. Streamflow Measurement Data for JAM1 and JAM2 (continued)

JAM2

Date (mm-dd-yy)	**Stage** (feet)	**Discharge** (cfs)	**Shift*** (feet)
05-24-88	1.69	15.05	0.0
05-31-88	1.62	12.21	0.0
06-07-88	1.66	15.26	0.0
06-09-88	2.12	39.02	0.0
06-13-88	2.50	73.18	0.0
06-16-88	2.03	30.91	0.0
06-23-88	1.57	10.68	0.0
06-27-88	1.72	16.15	0.0
06-30-88	1.69	15.41	0.0
07-06-88	1.91	27.59	0.0
07-12-88	1.89	23.32	0.0
08-17-88	1.89	25.02	0.0
09-08-88	1.61	9.86	-0.07
09-27-88	1.66	7.65	-0.19
10-11-88	2.03	5.31	-0.60

*Rating Curve was developed with regression of first twelve data points. Shift developed later in the year due to debris clogging the control. At this site the debris included a dead cow.

B. **Daily Stage Data for JAM1 and JAM2**

JAM1

June Date	June Stage (feet)	July Date	July Stage (feet)	August Date	August Stage (feet)	September Date	September Stage (feet)
06-01	1.43	07-01	2.00	08-01	1.80	09-01	1.78
06-02	1.40	07-02	1.95	08-02	1.80	09-02	1.80
06-03	1.40	07-03	2.00	08-03	1.85	09-03	1.80
06-04	1.40	07-04	2.00	08-04	1.80	09-04	1.75
06-05	1.38	07-05	1.95	08-05	1.90	09-05	1.70
06-06	1.50	07-06	1.80	08-06	1.80	09-06	1.60
06-07	1.48	07-07	1.85	08-07	1.70	09-07	1.50
06-08	2.00	07-08	1.80	08-08	1.75	09-08	1.50
06-09	2.00	07-09	1.79	08-09	1.70	09-09	1.55
06-10	2.00	07-10	1.80	08-10	1.68	09-10	1.40
06-11	1.90	07-11	1.79	08-11	1.70	09-11	1.38
06-12	1.80	07-12	1.79	08-12	1.70	09-12	1.35
06-13	2.00	07-13	1.80	08-13	2.00	09-13	1.30
06-14	2.40	07-14	2.05	08-14	2.10	09-14	1.20
06-15	1.75	07-15	1.87	08-15	1.80	09-15	1.15
06-16	1.90	07-16	1.85	08-16	1.78	09-16	1.15
06-17	1.75	07-17	1.79	08-17	1.78	09-17	1.20
06-18	1.60	07-18	1.80	08-18	1.75	09-18	1.15
06-19	1.58	07-19	1.80	08-19	1.78	09-19	1.70
06-20	1.48	07-20	1.85	08-20	1.75	09-20	1.70
06-21	1.45	07-21	1.80	08-21	1.70	09-21	1.90
06-22	1.43	07-22	1.78	08-22	1.70	09-22	1.70
06-23	1.50	07-23	1.68	08-23	1.72	09-23	1.65
06-24	1.59	07-24	1.72	08-24	1.70	09-24	1.55
06-25	1.80	07-25	1.70	08-25	1.60	09-25	1.50
06-26	1.68	07-26	1.68	08-26	1.60	09-26	1.50
06-27	1.60	07-27	1.70	08-27	1.58	09-27	1.43
06-28	1.53	07-28	1.68	08-28	1.60	09-28	1.40
06-29	1.60	07-29	1.70	08-29	1.60	09-29	1.50
06-30	1.90	07-30	1.78	08-30	1.60	09-30	1.45
		07-31	1.70	08-31	1.60		

B. **Daily Stage Data for JAM1 and JAM2 (continued)**

JAM2

June Date	Stage (feet)	July Date	Stage (feet)	August Date	Stage (feet)	September Date	Stage (feet)
06-01	1.52	07-01	2.00	08-01	1.90	09-01	1.73
06-02	1.57	07-02	2.08	08-02	2.09	09-02	1.82
06-03	2.17	07-03	2.11	08-03	2.09	09-03	1.81
06-04	1.47	07-04	2.05	08-04	2.05	09-04	1.81
06-05	1.52	07-05	2.05	08-05	2.00	09-05	1.82
06-06	1.62	07-06	1.96	08-06	1.93	09-06	1.73
06-07	1.57	07-07	1.86	08-07	1.85	09-07	1.67
06-08	2.02	07-08	1.83	08-08	1.89	09-08	1.61
06-09	2.12	07-09	1.89	08-09	1.85	09-09	1.57
06-10	2.12	07-10	1.88	08-10	1.73	09-10	1.56
06-11	2.12	07-11	1.83	08-11	1.82	09-11	1.57
06-12	2.27	07-12	1.89	08-12	1.81	09-12	1.58
06-13	2.30	07-13	1.98	08-13	2.02	09-13	1.54
06-14	2.40	07-14	2.00	08-14	2.10	09-14	1.52
06-15	2.30	07-15	2.03	08-15	2.15	09-15	1.53
06-16	2.05	07-16	1.93	08-16	2.05	09-16	1.54
06-17	1.80	07-17	1.83	08-17	1.91	09-17	1.54
06-18	1.80	07-18	1.89	08-18	1.86	09-18	1.60
06-19	1.80	07-19	1.86	08-19	1.84	09-19	1.77
06-20	1.65	07-20	1.86	08-20	1.83	09-20	1.86
06-21	1.60	07-21	1.89	08-21	1.80	09-21	2.05
06-22	1.55	07-22	1.86	08-22	1.76	09-22	2.01
06-23	1.55	07-23	1.82	08-23	1.77	09-23	1.85
06-24	1.62	07-24	1.81	08-24	1.77	09-24	1.81
06-25	1.80	07-25	1.80	08-25	1.75	09-25	1.75
06-26	1.70	07-26	1.76	08-26	1.73	09-26	1.68
06-27	1.71	07-27	1.76	08-27	1.68	09-27	1.66
06-28	1.61	07-28	1.75	08-28	1.65	09-28	1.74
06-29	1.59	07-29	1.77	08-29	1.69	09-29	1.75
06-30	1.79	07-30	1.73	08-30	1.68	09-30	1.75
		07-31	1.75	08-31	1.67		

C. Precipitation Data

North Dakota Atmospheric Resource Board Data
June - September, 1988

Location	Precipitation (inches)
SE 1/4 27-140-65	5.62
NW 1/4 28-138-62	11.63
SE 1/4 09-137-62	12.53
NE 1/4 03-136-62	10.79
SE 1/4 15-136-61	9.01
SW 1/4 03-135-62	11.28
NW 1/4 08-135-60	8.72
SW 1/4 22-135-62	7.76
NE 1/4 02-134-62	7.38
SW 1/4 24-134-61	10.08
SW 1/4 35-134-61	9.53
NE 1/4 11-133-59	11.82
NW 1/4 19-132-61	7.99
SE 1/4 09-132-60	9.87
NW 1/4 24-132-59	10.79
SE 1/4 10-131-59	10.19
NW 1/4 01-130-60	8.14
SE 1/4 12-130-61	9.02
SW 1/4 31-130-60	6.52
NW 1/4 04-129-60	7.05
SE 1/4 09-129-60	7.21
SE 1/4 13-129-61	7.55

National Oceanic and Atmospheric Administration Data
June - September, 1988

Location	Precipitation (inches)
Edgeley	6.92
Fullerton	7.20
Jamestown	7.30
LaMoure	8.78
Montpelier	13.41
Oakes	7.69

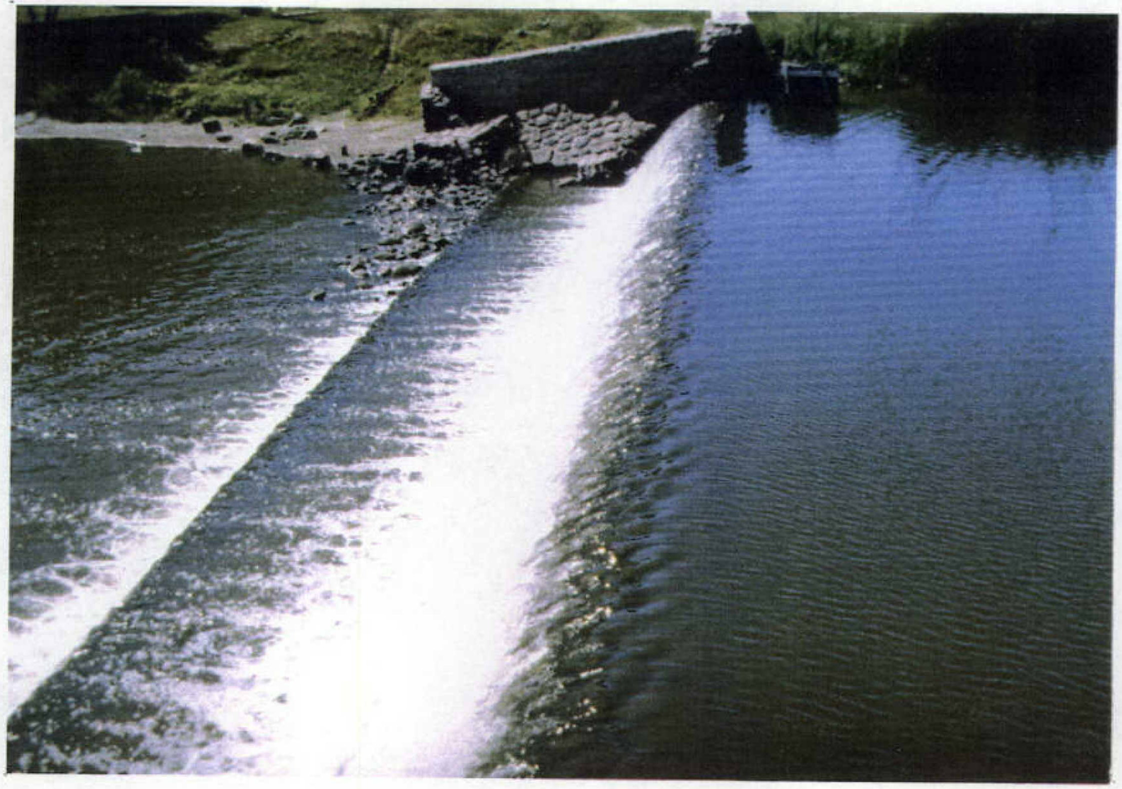
D. **Dakota Lake Stage Capacity Data**

Elevation (ft)	Capacity (ac-ft)
1284.0	
1284.2	25.0
1284.4	40.0
1284.6	70.0
1284.8	125.0
1285.0	175.0
1285.2	250.0
1285.4	325.0
1285.6	425.0
1285.8	550.0
1286.0	650.0
1286.5	1000.0
1287.0	1375.0
1287.5	1800.0
1288.0	2250.0
1288.5	2725.0
1289.0	3250.0
1289.1	3360.0

E. Photos: Dakota Lake Dam

Typical View of Dakota Lake

LaMoure Dam



Volumetric Measurement