Research Technical Completion Report
Project A-074-IDA

PREDICTING DAILY IRRIGATION

PROJECT DIVERSIONS

by

Sung Kim

John R. Busch

Department of Agricultural Engineering
University of Idaho

Kyung Hak Yoo

Department of Agricultural Engineering
Auburn University

Idaho Water and Energy Resources Research Institute
University of Idaho
Moscow, Idaho

October 1983

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DESCRIPTION OF NOTATIONS

A = size of project in ha

A_i = size of subarea i in ha

$DMON_i$ = dummy variable for month i

$DYEAR_j$ = dummy variable for year j

Ea = irrigation application efficiency as a decimal

Ec = irrigation conveyance efficiency as a decimal

ET = actual evapotranspiration in mm/day

Etr = reference crop evapotranspiration in mm/day

ETsm = smoothed actual evapotranspiration in mm/day

Kc = weighted crop coefficient

MAET = moving average of ET in mm/day

MAPC = moving average of precipitation in mm/day

MAQdiv = moving average of diversion in ha-mm/ha/day

n = number of subareas

PC = precipitaion in mm/day

PCe = effective precipitation in mm/day

Qc = constant outflow in ha-mm/ha/day

Qexin = excess inflow from upstream irrigation projects in ha-mm/ha/day

Qexout = excess outflow from the irrigation project in ha-mm/ha/day

Qloss = irrigation delivery and application loss in ha-mm/ha/day

QNETdiv = irrigation net diversion in ha-mm/ha/day
= Qdiv + Qexin - Qexout

Qstr = change of water storage within the project in ha-mm/ha/day

$Qsub_i$ = water requirement of the subarea i in ha-mm/day

Quse = net crop water use in ha-mm/ha/day

Tap = irrigation application time in days

Tin = irrigation interval in days

Ttr = traveling time

Ttr_i = traveling time from diversion point to subarea i

U = irrigation application coefficient

W = weekly coefficient describing weekly variation in water use

ABSTRACT

The purpose of the research reported was to develop and apply methods for predicting daily irrigation diversions. Two types of models were developed to effectively predict diversions one day in advance and were applied to two large irrigation projects located in southeastern Idaho. The types of procedures developed and tested were (1) physical and (2) statistical procedures. In addition, variables related to predicting diversions were presented and their relationships described.

The physical model developed was designed to accurately represent the physical processes of water conveyance and use in an irrigation system. Required inputs included crop consumptive use and irrigation efficiencies in conjunction with time variables such as irrigation interval, irrigation application time and traveling time in the system. Results from the physical model indicated that more data would be necessary for accurate predictions in addition to updating procedures to account for seasonal variations within the system and management.

Statistical models were developed using multiple regression techniques. Required inputs included evapotranspiration, precipitation, weekly variation of water use, previous diversions and dummy variables used to account for monthly and seasonal variations of soil moisture management. Predictions from the statistical model followed actual diversions quite closely for three irrigation seasons.

It was concluded that the statistical models were superior to the physical modeling approach for predicting irrigation diversions.

CHAPTER 1

INTRODUCTION

The ability to predict water demands for irrigation projects can provide lead time for more effective river operations in a multiple-use river system. In the past decade irrigation scheduling for individual fields has proven beneficial and could be an effective aid in forecasting demand for a larger area. However, predicting daily irrigation demands for a project is a major problem, as it would be necessary to integrate individual field schedules and management practices of farmers in conjunction with the operation and management of the irrigation supply system. Such an effort would require frequent communications between farmers and system management, and would require trained technicians along with extensive record keeping. To reduce such intensive and costly efforts, the Bureau of Reclamation has developed a procedure whereby the irrigation demands of larger areas are determined by monitoring reference fields within project subareas (Buchheim and Brower, 1981).

Most irrigation projects have developed their own system scheduling procedures based upon individual experience. The procedures are usually quite unrefined especially when irrigation demands are changing rapidly. Also, when adequate water is available, larger flow rates than required are often diverted to assure adequate supplies to all users with a resulting increase in operational waste.

To more precisely predict irrigation demands for an irrigation project requires that the irrigation demands of fields be considered along with the physical configuration of the supply system to account for traveling time of water in the system. Constraining conditions such as water rights and system capacity must also be considered as well as unknown and hard-to-predict factors such as anticipated weather conditions and management response. A model for computing expected demand for irrigation water in a project area based upon different known and anticipated factors can be an effective tool to enhance water management at the project level and result in more effective river operations.

1.1 Study Objectives

The objectives of this study were to develop and apply a model to predict daily irrigation diversions. Specific objectives were:

1) To identify factors affecting irrigation diversions.
2) To develop procedures for predicting daily irrigation project diversions.
3) To apply and test the predictive procedures.

1.2 Previous Studies

Since the computerized irrigation scheduling concept was first presented by Jensen (1969), numerous irrigation scheduling procedures have been developed to assist irrigators and projects with water management (Franzoy and Tankersley, 1970; Kincaid and Heerman, 1974; Campbell et al., 1975; Lord et al., 1977). However, the majority of the procedures have been intended for use at the individual field and farm level rather than the project level.

In 1969 the United States Department of the Interior, Bureau of Reclamation (USBR) undertook a major effort to introduce and apply some of the computerized scheduling techniques that Jensen (1969) developed.

The U.S. Bureau of Reclamation (USBR) IMS (Irrigation Management Services) program has been intended to extend on-farm irrigation scheduling throughout a distribution system to coordinate water deliveries (Ploss et al., 1979). Since 1981 the WMC (Water Management and Conservation) program has been used by the USBR in providing an operation and maintenance function. Currently the program is being demonstrated or is interactive with 33 irrigation districts and operating units (USBR, 1982). The Bureau has defined distribution system scheduling as "the process of matching irrigation water deliveries to anticipated water requirements of the crops grown under the system of canals, laterals, turnouts, etc." (Ploss et al., 1979). Buchheim and Brower (1981) modified the techniques involved in IMS computerized irrigation scheduling to closely estimate future canal diversion requirements by predicting the daily demand of a total irrigation project. Daily irrigation diversion forecasts were based on climatic and reference crop data.

Claiborn (1975) investigated the irrigation water use on six irrigation projects in the Upper Snake River Region of southern Idaho. He analyzed river diversion data, conveyance system seepage loss data, crop distribution and return flow data using an inflow-outflow water balance analysis. He reported that irrigation efficiencies ranged from 10 to 42 percent and the reasonably attainable project efficiencies ranged 35 to 51 percent.

The Idaho Department of Water Resources (IDWR) reported on a program to promote irrigation conservation in Idaho (Hammond, 1978). This study concluded that water delivery organizations can improve water-use efficiencies through more intensive management practices and technology, and by adopting operating policies which encourage efficient use of water by member farmers.

As a part of the IDWR study for improved water-use efficiency, Kerpelman et al., (1976) concluded that "... The major perceived problems of the water organizations are anticipating demand and supplying enough water. Demand tends to be nonuniform and simultaneous. This indicates that delivery of water cannot be scheduled long in advance because farmers have not (and perhaps cannot assess) their irrigation needs far in advance. In addition, most farmers require water at the same time. Efficient delivery, which is a somewhat time-lagged process, is difficult under these circumstances..."

Allen and Brockway (1979) presented relationships between operation and maintenance costs, personnel requirements and water usage for irrigation water delivery organizations in southern Idaho. Yoo, Busch and Brockway (1982) have developed techniques to effectively inventory a large area, determine the costs and operating characteristics of irrigation system components. This information was used to obtain optimal system plans for districts in the Upper Snake River region of southeastern Idaho.

Kim (1981) analyzed daily water flow data from two large irrigation districts in the Upper Snake River region of southeastern Idaho. He found that seasonal irrigation water use was different for different years and in the different districts, but the water use patterns were similar for different years and districts.

Sutter et al. (1983) reviewed the distribution problems on the Upper Snake River of Idaho and developed a system for collecting, processing, and storing large amounts of data to provide an accurate accounting system for water deliveries. Use of the system allows available water supplies to be determined more precisely in conjunction with maintaining accurate water delivery records.

The importance of predicting irrigation diversions has been pointed out by the numerous studies. However, little effort has been devoted to predicting diversions.

To predict diversions, traveling time, application and conveyance efficiencies, and irrigation interval should be considered as important factors. Cultural practices, allowable soil moisture depletions, and moisture extraction patterns can also be significant factors in determining diversion requirements. In addition, institutional and social factors, such as water rights and holiday or weekend effects, need to be incorporated.

CHAPTER 2

SYSTEM SCHEDULING

According to the USBR (1982), system scheduling is optimizing the delivery of water throughout the project distribution system by identifying the constraints and limitations on the system and managing the water accordingly.

An irrigation system is a comprehensive system which contains complicated components. These components are hydrologic, hydraulic, economic, institutional and agronomic, and there is uncertainty associated with each. Uncertainty is due to uncontrollable factors including weather, water supply, system failure, crop status and management.

System scheduling contains two phases: on-farm irrigation scheduling and project irrigation scheduling. Since the two irrigation schedules are affected by each other, they cannot be considered independently.

To properly assess and predict irrigation schedules, it is necessary to consider various factors of irrigation system operation in conjunction with system components.

2.1 Irrigation Project Operation

A significant portion of irrigation water in the western United States is delivered to farms through supply systems operated by water-user organizations.

In Idaho, hundreds of locally based public and private organizations are charged with the distribution and delivery of irrigation water. The organizations, mutual canal companies and irrigation districts, are responsible for delivery of storage and natural river flow water to farm units. The mutual irrigation companies in Idaho are private and voluntary, whereas irrigation districts are public and involuntary and must follow definite procedures laid down by state and federal statutes (Allen and Brockway, 1979). Deliveries are made in accordance with water rights and project policy, and diversions are dependent on weather, requests for water delivery by farmers, arrangements made with reservoir authorities and the watermaster, and policy of the Board of Directors.

Three distinct methods of irrigation water delivery are commonly recognized in the U.S.; demand, rotation, and continuous flow. Combinations of two or more of these methods may be used in any system depending on the location of the farm with respect to the distribution system, the seasonal water requirements, or the available water supply.

In Idaho, a majority of irrigation organizations deliver water based on a continuous flow principle where delivery is provided at a constant rate. A few older systems in eastern Idaho operate under the principle of demand where the irrigator opens and closes farm turnouts according to his irrigation needs. In some systems where portions of a delivery organization's maintenance and water control duties are relegated to lateral associations, users along each lateral may share the water on a rotation basis (Allen and Brockway, 1979). For more details on irrigation project operation in Idaho the reader is referred to IDWR (1978) or Allen and Brockway (1979).

2.2 Components

System scheduling for irrigation projects must take into consideration soil-plant-water relationships at the site of water use, application system efficiencies and losses in the conveyance and distribution system. In addition, institutional components such as water rights, advance notice and management practices must also be considered. Though most factors are well explained in references (Jensen, 1975; Allen and Brockway, 1979), some time-related factors and cause-and - effect relationships have not been thoroughly defined.

2.2.1 Advance Notice and Traveling Time

An upstream control system is defined by Burt and Lord (1981) as "releasing water from an upstream source in anticipation of demand downstream". As nearly all irrigation systems use upstream control, irrigators are required to order water in advance as traveling time is required to convey water from the diversion point(s) to farm turnouts. Burt and Lord investigated the present operating procedures used by irrigation districts in California and found that the mean advance notice required was 32.9 hours. Allen and Brockway (1979) reported that normally a 24 to 28 hour advance notice was required by irrigation project personnel in southern Idaho. They also reported that two or more days traveling time were required to deliver water from the diversion to the distal end of the canal in several systems. It is possible that an irrigator, whose advance notice is less than the traveling time, may not receive his requested water at the desired time.

A specific traveling time is required for diverted water to reach each farm turnout within an irrigation project. However, due to management constraints in an irrigation project and difficulties in determining traveling time, it would not be practical to use different advance notices. Hence, most irrigation projects require a fixed advance notice that is the same for all users within the project.

Since irrigators do not assess (and perhaps cannot assess) their irrigation needs far in advance, the irrigation diversion for a project as determined by the advance notices may be a rough estimation at best. However, for effective river operations the irrigation diversion should be accurately determined in the advance of scheduling irrigation on fields. If diversions can be predicted with a degree of certainty, more effective river (and reservoir) operations can be achieved.

2.2.2 Losses

Losses and wastes in the conveyance and distribution of irrigation water to individual farms occur as seepage, evaporation, consumptive use, and operational losses and wastes. The losses and wastes vary with the type, design and management of an irrigation project. Seepage losses from canal and distribution systems are affected by the physical condition of the delivery system and may vary throughout the irrigation season. Seepage is also related to the diversion rate thus compounding the problem of estimating the amount of diversion required for seepage losses.

In addition to seepage losses, some operational waste is inevitable in distributing water throughout a project. This volume of water is generally comprised of spills from a canal system or a minimum flow rate required to maintain control of water throughout a project.

On-farm application in excess of crop requirements can result in surace runoff and/or deep percolation beyond the root zone. The surface runoff will return to the supply canal system or a drainage canal system or may be lost to deep percolation. Some of the surface runoff returned to the supply canal system may be used downstream within the same project or other projects.

Though losses may be classified separately, determining the individual values is very difficult. The total loss, however, must be considered in estimating total diversion requirements. On the basis of an entire river basin, losses from upstream use may be used downstream. However, at the project level, losses and wastes should be controlled.

2.2.3 Irrigator's Status

Irrigators often base individual water management practices on other factors in addition to crop water needs. Priorities of water rights, social events and farming practices such as harvesting can affect irrigation management.

Kim (1981) analyzed the daily irrigation outflows from a large irrigation project using autocorrelation techniques. He found a significant weekly cycle as shown in Figure 1. Such a cycle could be used to adjust the irrigation diversion to more closely match actual water use.

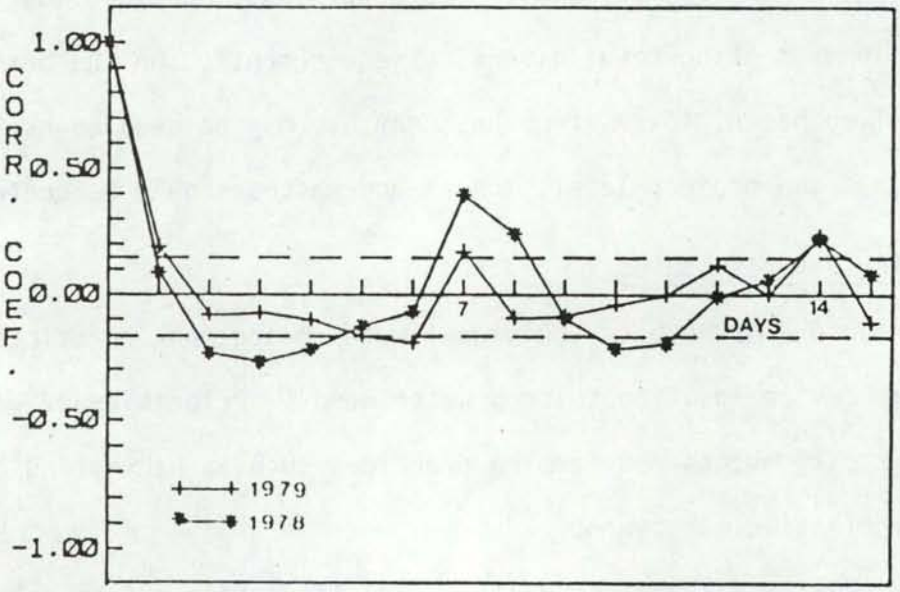

Figure 1. Autocorrelation coefficients of outflow from the Idaho Irrigation District.

CHAPTER 3

MODELS FOR PREDICTING IRRIGATION DIVERSION

As described in Chapter 2, irrigation diversions are affected by a myriad of factors, most of which are interrelated. It is important that both physical and institutional conditions be considered in a model used for predicting irrigation diversions.

Two types of predictive models were developed; a physical model and a statistical model. For the physical model, the effects of physical and institutional factors that influence irrigation scheduling were considered including efficiencies, traveing time, irrigation interval, evapotranspiration, weekly water-use patterns and effective precipitation. In the statistical model, a multiple linear regression model based on the physical model was developed. The coefficients were optimized using the least-squares method. Predicted values are considered the same as forecasted values in all applications.

3.1 Physical Model

The basic water balance in an irrigation project may be expressed as:

$$Qdiv + Qexin - Qloss - Quse - Qstr - Qexout = 0 \qquad [1]$$

where

Qdiv = irrigation diversion,

Qexin = excess inflow from upstream irrigation projects,

Qloss = delivery and application loss,

Quse = net crop water use,

Qstr = change of water storage within the project, and

Qexout = excess outflow from the irrigation project.

An irrigation system is a casual system in which an output cannot occur before the corresponding input (i.e., the effects cannot precede the cause). For hydrologic (and irrigation) systems, outputs are generally predicted from inputs. However, for predicting diversions, input must be predicted from assumed or/and estimated outputs.

Being able to predict daily irrigation diversions using the water balance equation [1], requires that the time-dependent variations of the components be taken into account. Considering various time factors, the daily irrigation diversion can be expressed as:

$$Qdiv(t1) = Qloss(t2) + Quse(t3) + Qstr(t4) + Qexout(t5) - Qexin(t6) \quad [2]$$

in which t1 is the time factor of Qdiv, and t2, t3, t4, t5, and t6 are time factors associated with Qloss, Quse, Qstr, Qexout, and Qexin, respectively. The time factors are necessary to account for travel times of water within an irrigation project. Therefore, the relationships between t1 and other time factors should be known before predicting Qdiv(t1).

The excess inflow from upstream irrigation projects, Qexin(t6), has been shown to have significant irregularities (Kim, 1981), and therefore may not be considered in management decisions regarding the diversion rate to an irrigation project. If the Qdiv(t1) is predicted properly, Qexout(t5) could be a constant flow or an unavoidable minimum flow. A change in water storage, Qstr(t4), may be a significant factor; however, it is difficult, it not impossible, to estimate.

If Qstr(t4) and Qexin(t6) are assumed to be negligible, and Qexout(t5) is a constant over an irrigation season, then equation [2] can be simplified as:

$$Qdiv(t1) = Qloss(t2) + Quse(t3) + Qc \qquad [3]$$

in which Qc is a constant outflow representing Qexout(t6).

Because Qloss(t2) and Quse(t3) may vary for each farm delivery and for time factors such as t2 and t3, Qdiv(t1) is more accurately predicted by dividing the irrigation district into several subareas. The subareas are determined by canal routes and distances from the diversion point. The irrigation diversion, Qdiv(t1), can then be expressed as:

$$Qdiv(t1) = \sum_{i=1}^{n} Qsub_i\,(t1 + Ttr_i) + Qc \qquad [4]$$

where

$Qsub_i\,(t1+Ttr_i)$ = water requirement of the subarea i at day $(t1 + Ttr_i)$,

Ttr_i = travel time from the diversion point to subarea i in days, and

n = number of subareas.

Subarea size is selected large enough so that the irrigation water requirement of the subarea, $Qsub_i\,(t1 + Ttr_i)$, is a weighted average for the crops in that area for day $(T1 + Ttr_i)$. To estimate the water requirement of a subarea, equation [5] was developed to include ET, effective rainfall, size of area, weekly effects, traveling time, irrigation interval, application efficiency, and conveyance efficiency.

$$Qsub_i\,(m2) = \frac{A_i W(m2)}{Ec_i(m2)\ Tin_i(m2)} \left[\sum_{m=m1}^{m2} \left(\frac{ET_i(m)}{Ea_i(m)} - PCe(m) \right) \right] \qquad [5]$$

where

$Qsub_i(m2)$ = water requirement of subarea i at day m2 in ha-mm/day,

$m2 = t1 + Ttr_i(m2)$,

t1 = time of diversion,

$Ttr_i(m2)$ = traveling time to subarea i at day m2 in days,

A_i = size of subarea i in ha,

$W(m2)$ = weekly coefficient describing weekly effects of water use at day m2,

$Ec_i(m2)$ = conveyance efficiency from diversion point to the subarea i at day m2,

$Tin_i(m2)$ = irrigation interval of subarea i at day m2 in days,

$m1 = t1 + Ttr_i(m2) - Tin_i(m2) + 1$

$ET_i(m)$ = actual evapotranspiration of subarea i at day m in mm/day,

$ET_i(m) = Kc_i(m) \cdot ETr(m)$,

$Kc_i(m)$ = weighted crop coefficient of subarea i at day m,

$ETr(m)$ = reference crop evapotransporation at day m in mm/day,

$Ea_i(m)$ = application efficiency of subarea i at day m, and

$PCe_i(m)$ = effective precipitation of subarea i at day m in mm/day.

The application time (Tap), which denotes the time required to irrigate a field, also affects the prediction of daily irrigation requirements. If the applicaiton time is 2 days and the application rate is fixed, the weighting coefficient of the first and second days would be 0.5 and 0.5, respectively. If half of the application rate is used during the second day of irrigation, the weighting coefficients of the first and second days are 0.67 and 0.33, respectively. To include the application time for subarea , Tap , equation [5] is written as:

$$Qsub_i(m2) = \sum_{\ell=\ell 1}^{m2} \left[\frac{A_i W(\ell) U(\ell 3)}{Ec_i(m2) Tin_i(m2)} \left[\sum_{m=m3}^{m2} (\frac{ET_i(m)}{Ea_i(m)} - Pce(m) \right] \right] \qquad [6]$$

where

$\ell 1 = m2 - Tap_i + 1$,

$\ell 3 = \ell - m2$,

$m3 = \ell 1 - Tin_i(m2) + 1$,

$U(\ell 3)$ is the application coefficient for day $\ell 3$ irrigation, and the other variables are the same as defined for equation [5].

By combining equations [4] and [6], Qdiv(t1) is computed as:

$$Qdiv(t1) = \sum_{\ell=1}^{n} \sum_{\ell=\ell 1}^{m2} \left[\frac{A_i W(\ell) U(\ell 3)}{A\ Ec_i(m2) Tin_i(m2)} \left[\sum_{m=m3}^{m2} \left(\frac{ET_i(m)}{Ea_i(m)} - PCe_i(m) \right) \right] \right] + Qc \qquad [7]$$

where

Qdiv(t1) = irrigation diversion in ha-mm/ha/day, and other variables are defined for previous equations.

3.2 Statistical Model

Because of the difficulties in estimating Qstr(t4), Qexout(t5), and Qexin(t6) in equation [2], these factors were ignored or assumed constant in the physical model. However, if historical data are available these effects can be simulated statistically.

The net diversion, QNETdiv(t1), represents actual water use within the project more closely than Qdiv(t1) and is defined as

$$QNETdiv(t1) = Qdiv(t1) + Qexin(t6) - Qexout(t5) \qquad [8]$$

Since actual water use is related to climatic, management and project factors, QNETdiv(t1) can be explained as a function of those factors.

$$QNETdiv(t1) = f\{ET(t), pc(t'), M(t''), project\ (t''')\}, \text{etc} \qquad [9]$$

where

$ET(t)$ = evapotranspiration of time t,

$pc(t')$ = precipitation of time t',

$M(t'')$ = management factors of time t'',

project (t''') = project factors of time t''', and

t1, t, t', t'', and t''' = time factors.

Project factors include seepage rate, rate of storage and project operating policy. The time factors in equation [9] indicate time periods which are related to irrigation interval, traveling time, advance notice and irrigation application times.

Since the function {·} will often be a complicated non-linear function of the variables considered, the relationship between input and output needs to be known. Relationships between net diversion and 7-day moving average evapotranspiration (MAET) computed by equation [10] for two irrigation projects in southeastern Idaho are shown in Figures 2 and 3.

$$MAET(t) = \frac{1}{7} \sum_{to=t-7}^{t-1} ET(to) \qquad [10]$$

where

$MAET(t)$ = moving average ET for the previous 7 days.

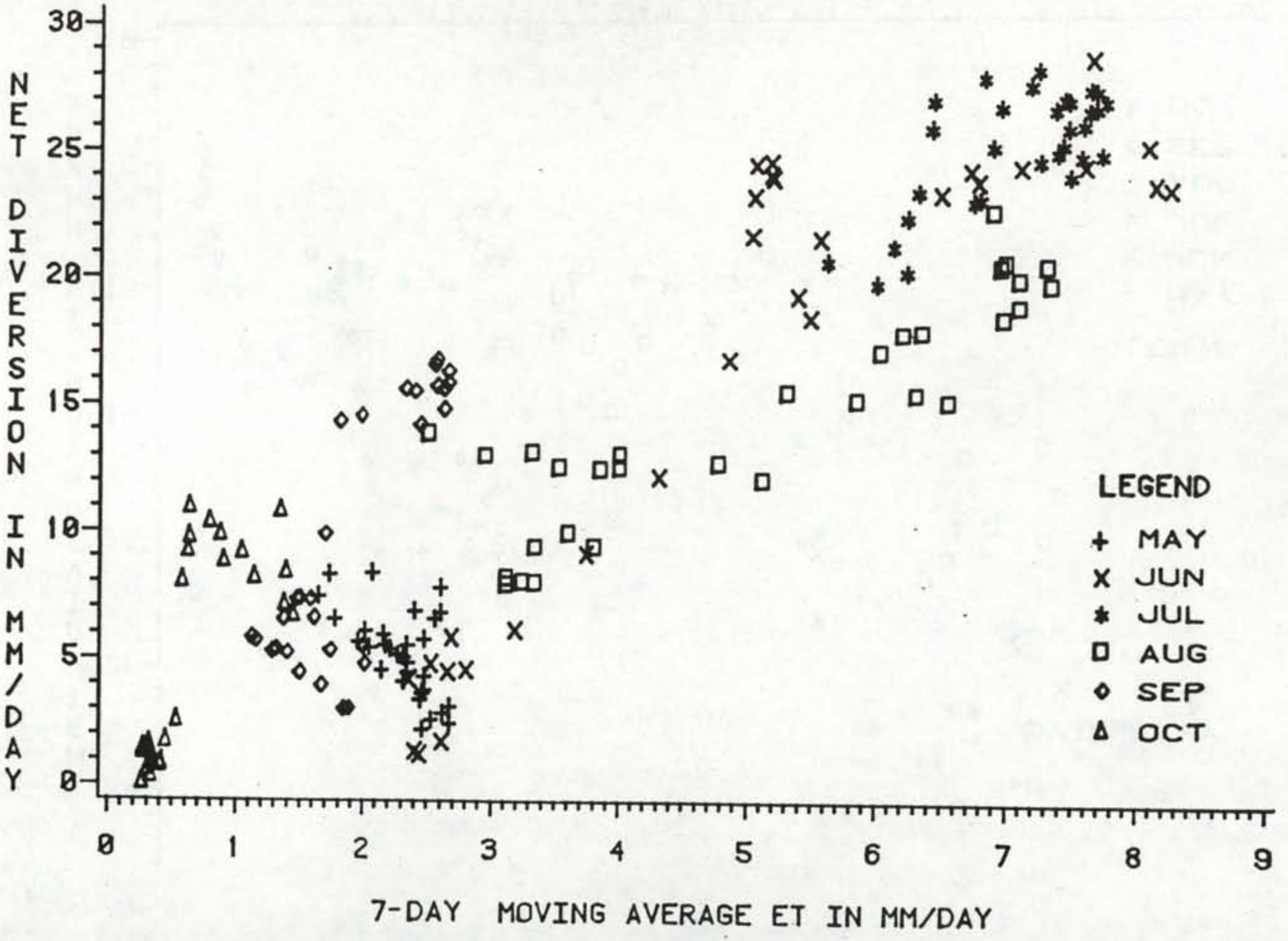

Figure 2. Daily net diversion vs. 7-day moving average ET for the Idaho Irrigation District for 1980.

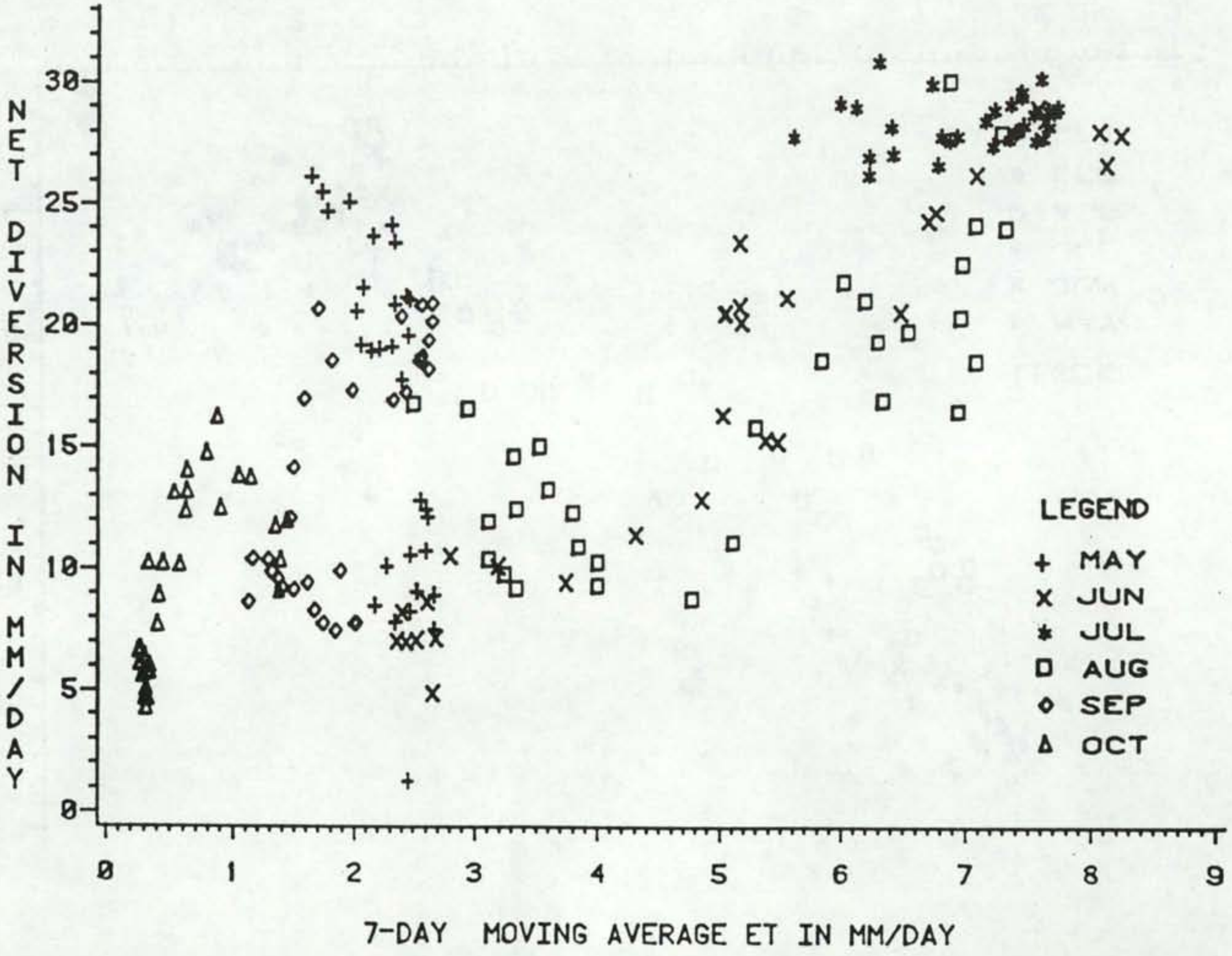

Figure 3. Daily net diversion vs. 7-day moving average ET for the Snake River Valley Irrigation District for 1980.

From the figures, it can be seen that a linear relationship exists between the net diversion and ET. Water use patterns also change throughout the irrigation season as shown by the clusters of monthly data in the plots. Therefore, predicting diverions over the irrigation season should take into account the change of water use patterns over the season. A monthly variable can be used to account for such variations within a season.

Figures showing the relationship between net diversion and MAET for 1978, 1979, and for all three years are contained in Appendix A.

Once a field is irrigated, moisture levels will decrease according to consumptive water use. Soil moisture levels in the early spring at the beginning of the irrigation season depend on the amount of winter precipitation in addition to the moisture present at the end of the previous season. When springtime moisture levels are less than field capacity, there is a need to fill the soil moisture reservoir in addition to supplying the consumptive use requirements of crops. After the early irrigations, irrigation requirement may be directly related to consumptive use until 1 or 2 weeks prior to harvest. Shortly before harvest periods (especially for grain and hay), soil moisture levels will normally decrease (Figure 4). Therefore, the irrigation diversion should account for the variation of soil moisture levels over the irrigation season.

Kim (1981) reported that a significant weekly cycle existed in irrigation water use. Therefore, for reasonable diversion forecasting, the weekly cycle must also be considered.

The net diversion is shown as a function of ET, precipitation, management and project factors in equation [9]. Assuming a linear

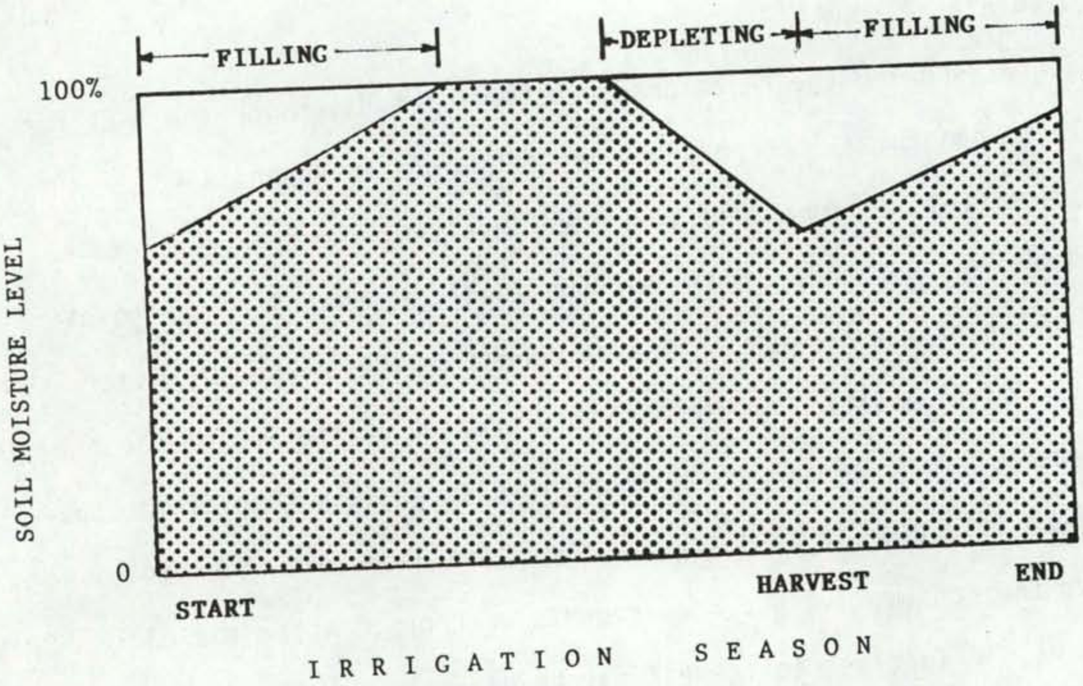

Figure 4. Soil moisture levels over an irrigation season.

relationship between QNETdiv and moving average ET (MAET), moving average precipitation (MAPC) and management factors such as soil moisture condition and weekly cycle, the net diversion can be predicted by equation [11]. Dummy variables are used to account for weekly, monthly and yearly effects.

$$\begin{aligned} \mathrm{QNETdiv}(t) &= \alpha + \beta_i * \mathrm{DMON}_i(t) + \gamma_j * \mathrm{DYEAR}_j(t) \\ &+ \eta_1 * \mathrm{DWEEK}(t) * \mathrm{MAQdiv}(t-1) \\ &+ \eta_2 * \mathrm{MAET}(t-1) + \eta_3 * \mathrm{MAPC}(t-1) \\ &+ \eta_4 * \mathrm{Qdiv}(t-1) + \mathrm{Error}(t) \end{aligned} \qquad [11]$$

where

$\mathrm{DMON}_i(t)$ = Dummy variable for month i, day t

DMON_i = 1 if t is in month i
0 if t is in another month

$\mathrm{DYEAR}_j(t)$ = Dummy variable for year j

DYEAR = 1 if t is in year
0 if t is in another year

DWEEK(t) = Dummy variable for weekly cycle

= 0 if t is Saturday or Sunday
1 if t is Monday through Friday

MAQdiv(t-1) = 7-day moving average of diversion for day t-1

$$= \frac{1}{7} \sum_{to=t-7}^{t-1} \mathrm{Qdiv}(to)$$

MAET(t-1) = 7-day moving average of ET for day t-1

$$= \frac{1}{7} \sum_{to=t-7}^{t-1} \mathrm{ET}(to)$$

MAPC(t-1) = 7-day moving average of precipitation for day t-1

$$= \frac{1}{7} \sum_{to=t-7}^{t-1} PC(to)$$

Qdiv(t-1) = Diversion for day t-1

Error (t) = Error for day t

α, β_i, γ_j, η_1, η_2, η_3, η_4 = regression coefficients

Change in storage, Qstr, can be accounted for partially in the coefficient of the previous diversion, η_4, in equation [11] because the net diversion is influenced by previous diversions. Other management factors and climatic factors which represent consumptive water use of the crops are explained at least partially by the dummy variables.

CHAPTER 4

APPLICATION OF THE MODEL

4.1 Description of the Study Area

The study area is located along the east side of the Snake River near the city of Idaho Falls in southeastern Idaho (Figure 5). The area was first brought under irrigation in the late 1880's. Roughly 18,600 ha are irrigated with water diverted from the Snake River, of which 11,700 ha are in the Idaho Irrigation District and 6,900 ha in the Snake River Valley Irrigation District. Both districts divert water from the Snake River, and both receive some waste or excess water from upstream irrigation districts.

The topography of the area is uniform with an average slope of 0.002 m/m at an elevation of 1370 to 1460 m. Major soil types of the study area are silt loam, loam and sandy loam textures. Crops grown in the study area are potatoes, grain, alfalfa, and pasture. Border, furrow and sprinkler irrigation systems are used to apply water to these crops. The distributon of crops and irrigation systems, and dates of corps grown are shown in Tables 1 and 2.

The area is semi-arid with 280 to 330 mm of annual precipitation of which 130 mm occurs during the May through August growing season. A more thorough description is given by Yoo et al. (1982).

4.2 Application of Procedures and Results

4.2.1 Physical Model

For application of the model, the Idaho Irrigation District was divided into 9 subareas and the Snake River Valley Irrigation District

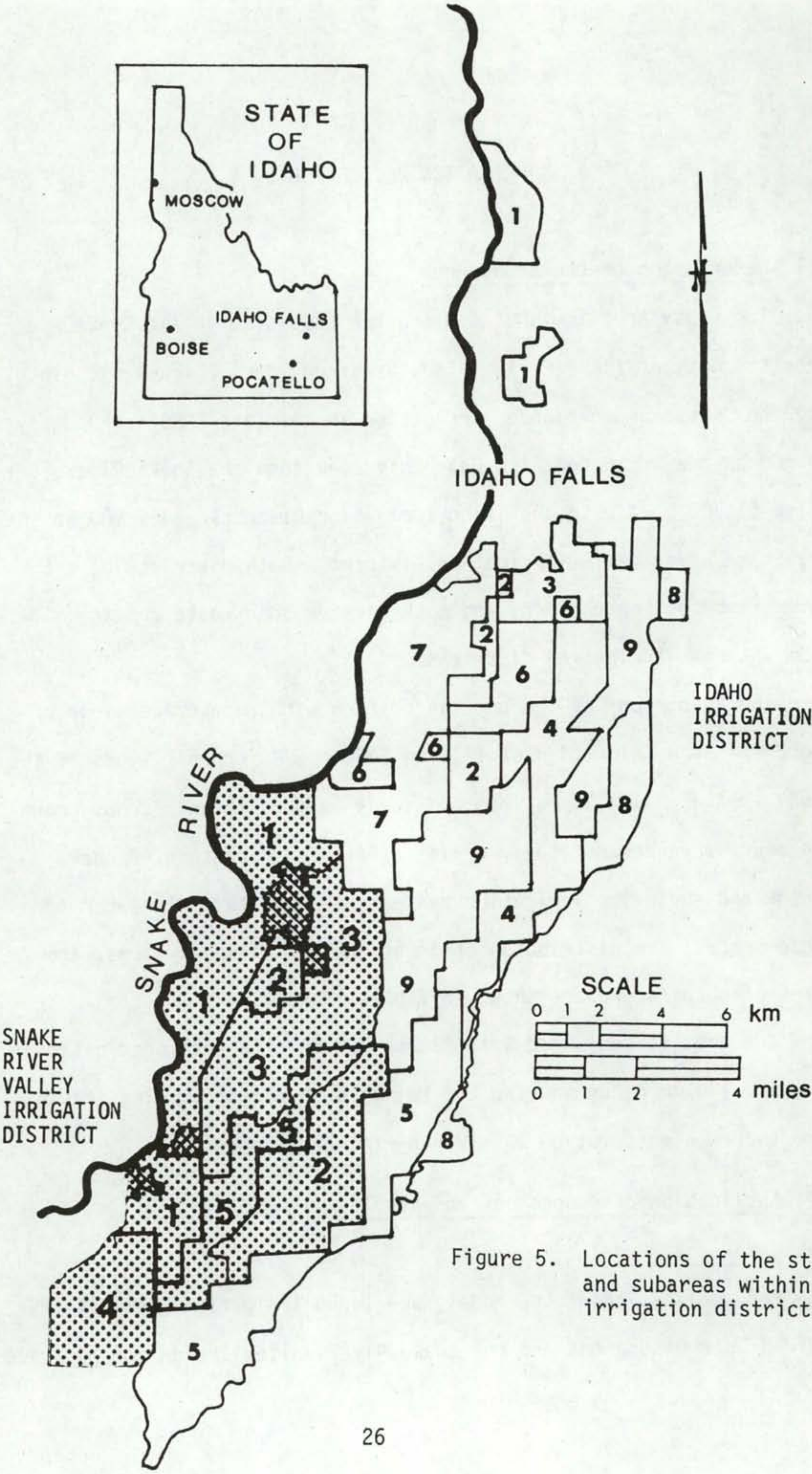

Figure 5. Locations of the study area and subareas within the irrigation districts.

Table 1. Crop distribution and irrigation systems in the study area in 1978†

		Idaho Irrigation District		Snake River Valley Irrigation District	
		ha	% of irrigated area	ha	% of irrigated area
CROPS	Potatoes	3,163	27	1,851	27
	Grain	4,627	40	2,764	40
	Hay	2,178	19	1,627	23
	Pasture	1.597	14	710	10
TOTAL		11,565	100.0	6,952	100.00
IRRIGATION TYPES	Border	6,119	53	3,424	49
	Furrow	1,220	11	408	6
	HM[1/]	2,985	26	2,360	31
	SR[2/]	1,053	8	833	12
	CP[3/]	189	2	108	2
TOTAL		11,565	100	7,133	100
IRRIGATED area		11,565	82*	6,951	78*
NON-IRRIGATED area		2,487	8*	1,941	22*
TOTAL		14,052	100	8,892	100

† Data from Yoo et al. (1982)

[1/] HM - Hand move sprinkler

[2/] SR - Side-roll sprinkler

[3/] CP - Center-pivot sprinkler

* % of total area for irrigated and non-irrigated areas

into 5 subareas. The subarea boundaries were determined according to the canal routes and distances from the diversion points (Figures 5, 6 and 7). Subarea size ranged from 505 ha to 2360 ha, and the average field size was 16 ha. The subarea size was large enough to assume that the irrigation water requirements were a weighted average for all crops in the subarea on any given day.

Table 2. Planting, effective cover and harvest dates for crops grown[1/]

Crop	Plant	Effective Cover	Harvest
Winter wheat	MAR 25[2/]	JUL 1	AUG 10
Spring wheat	APR 5	JUL 8	AUG 17
Alfalfa	MAR 25[2/]	APR 25	JUN 25, AUG 14
Potatoes	MAY 15	JUL 18	SEP 20
Pasture	APR 25	JUL 25	OCT 30

1/ Data from Allen and Brockway (1979)
2/ Date growth commences

Table 3 contains data showing subarea size, traveling time, delivery efficiency, and application efficiency for each subarea. Traveling time and delivery efficiency were estimated for each canal section from the diversion point to the downstream end of the district using data from Netz (1980). Application efficiencies were estimated for the irrigation application systems using data presented by Yoo et al. (1982).

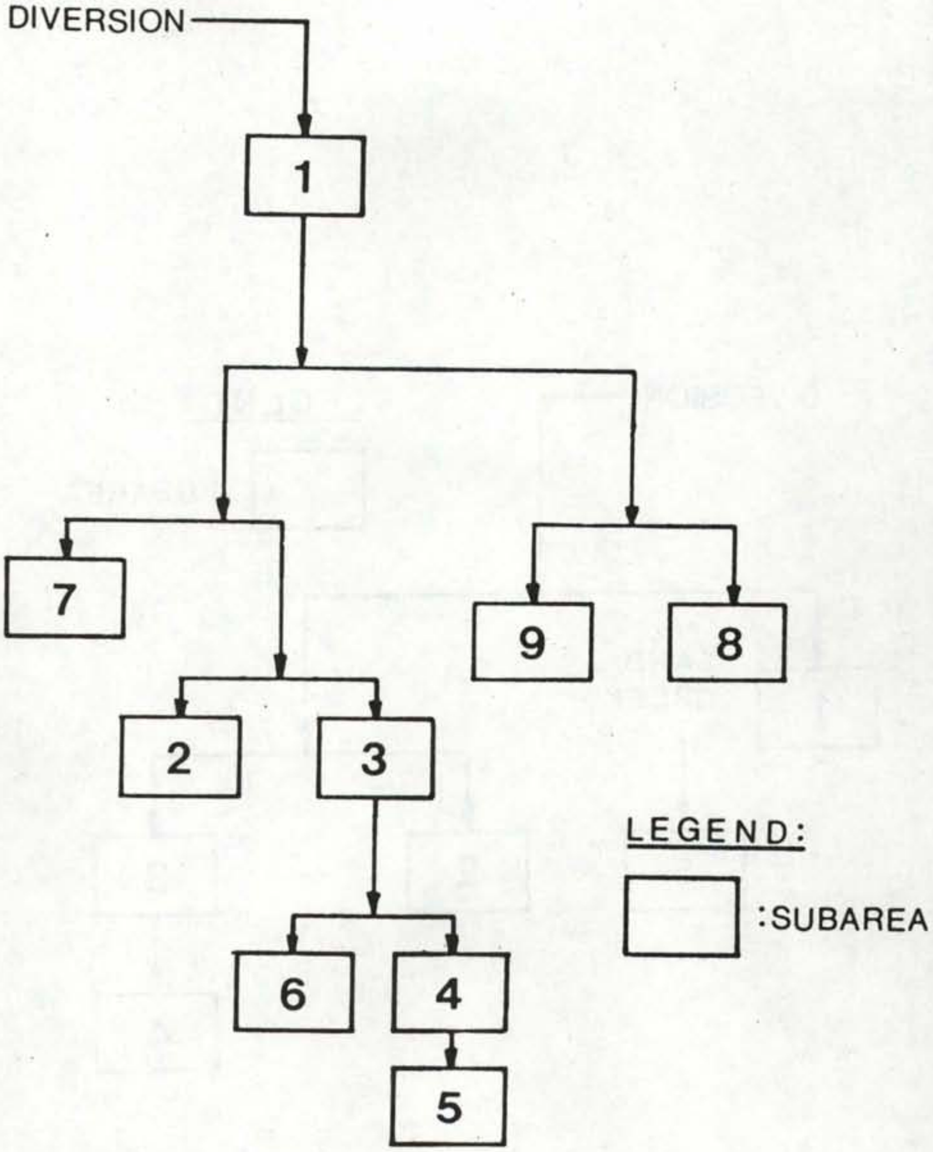

Figure 6. Schematic diagram of the canal routes of the distribution system with subareas in the Idaho Irrigation District.

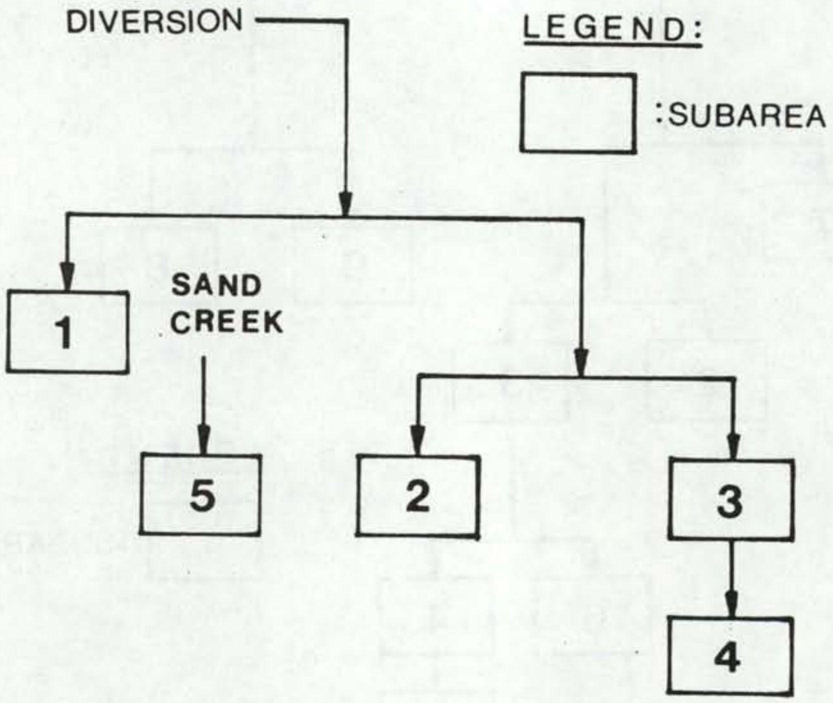

Figure 7. Schematic diagram of the canal routes of the distribution system with subareas in the Snake River Valley Irrigation District.

Table 3. Area, distance, traveling time, delivery efficiency, and application efficiency of each subarea

Subarea No.	Area Served (ha)	Distance* (km)	Traveling* time (hours)	Conveyance efficiency (%)	Application efficiency (%)
ID1	505	16.70	3.8	92	42
ID2	561	30.67	14.3	87	45
ID3	493	22.83	6.0	90	43
ID4	1,441	37.51	14.9	87	48
ID5	2,143	55.82	29.7	82	59
ID6	913	32.04	14.4	85	52
ID7	2,118	35.01	15.1	76	61
ID8	1,031	51.36	39.0	75	44
ID9	2,360	38.60	22.3	67	48
SN1	2,053	20.12	14.9	87	56
SN2	1,273	21.57	13.1	88	52
SN3	1,992	23.98	17.4	89	58
SN4	746	29.45	22.3	90	49
SN5	866	8.03		90	50

*From district diversion to the downstream end of subarea

Reference crop ET was estimated by the modified Penman combination method, and predicted ET was assumed as the average ET from the last irrigation day to one day before the predicted operating day. Effective precipitation was assumed to be 85 percent of the actual precipitation from the last irrigation day to one day before the predicted operating day. No prediction for precipitation was made.

The weekly coefficient, W, was assumed the same as obtained by Kim (1981). Weighting coefficients of 1.1, .8, and .7 were assigned to weekdays, Saturday, and Sunday, respectively.

During the peak water use period, the irrigation interval is shorter than at the beginning and end of the irrigation season. To simplify computations, a constant irrigation interval of 5 days was used for the given projects. Irrigation application times also change depending on the irrigation system and crop water requirement. However, a constant value of 2 days, was used as the application time. Since a majority of fields were irrigated in less than two days, 0.53 and 0.47 were assumed as the weighting coefficients for the first and second days of irrigation, respectively.

For the physical model, the net diversion was estimated by equation [12] assuming the outflow, Qc, equal to zero.

$$QNETdiv(t1) = Qdiv(t1) + Qexin(t1) - Qexout(t1 + 2) \qquad [12]$$

where

$QNETdiv(t1)$ = Net Diversion at day t1 in ha-mm/ha/day

$Qdiv(t1)$ = actual diversion at day t1 in ha-mm/ha/day, and

$Qexout(t1+2)$ = total excess outflow from project at day (t1 + 2) in ha-mm/ha/day.

To compute the trend of ET, daily ET values were smoothed using equation [13].

$$ETsm(t1) = \frac{1}{5} \sum_{to=t1-2}^{t1+2} ET(to) \qquad [13]$$

where

ETsm(t1) = smoothed ET in mm/day at day t1, and

ET(to) = actual ET at day to in mm/day.

The net diversion was estimated one day in advance using equation [12] in which Qdiv(t1) was obtained using equation [7] without the Qc term. Outflow from a district was accounted for in the Qexout term, and other data inputs were those described previously in this chapter. Predicted and actual net diversions, ET, precipitation for the two irrigation projects during the 1979 crop year are plotted in Figures 8 and 9. Plots for 1978 and 1980 are in Appendix B.

The trend and magnitude of actual net diversions were roughly matched by the predicted net diversions throughout the irrigation season as shown in Figures 8 and 9. The greatest discrepancy between predicted and actual values occurred early and late in the irrigation season. This difference might be attributed to soil moisture management controlled by irrigation management and/or errors in estimation of the effective precipitation. Irrigation efficiencies could also have changed throughout the season that were not accounted for by the constant irrigation efficiencies used. In addition to the efficiencies, time factors such as irrigation interval, traveling time were also changing throughout the season.

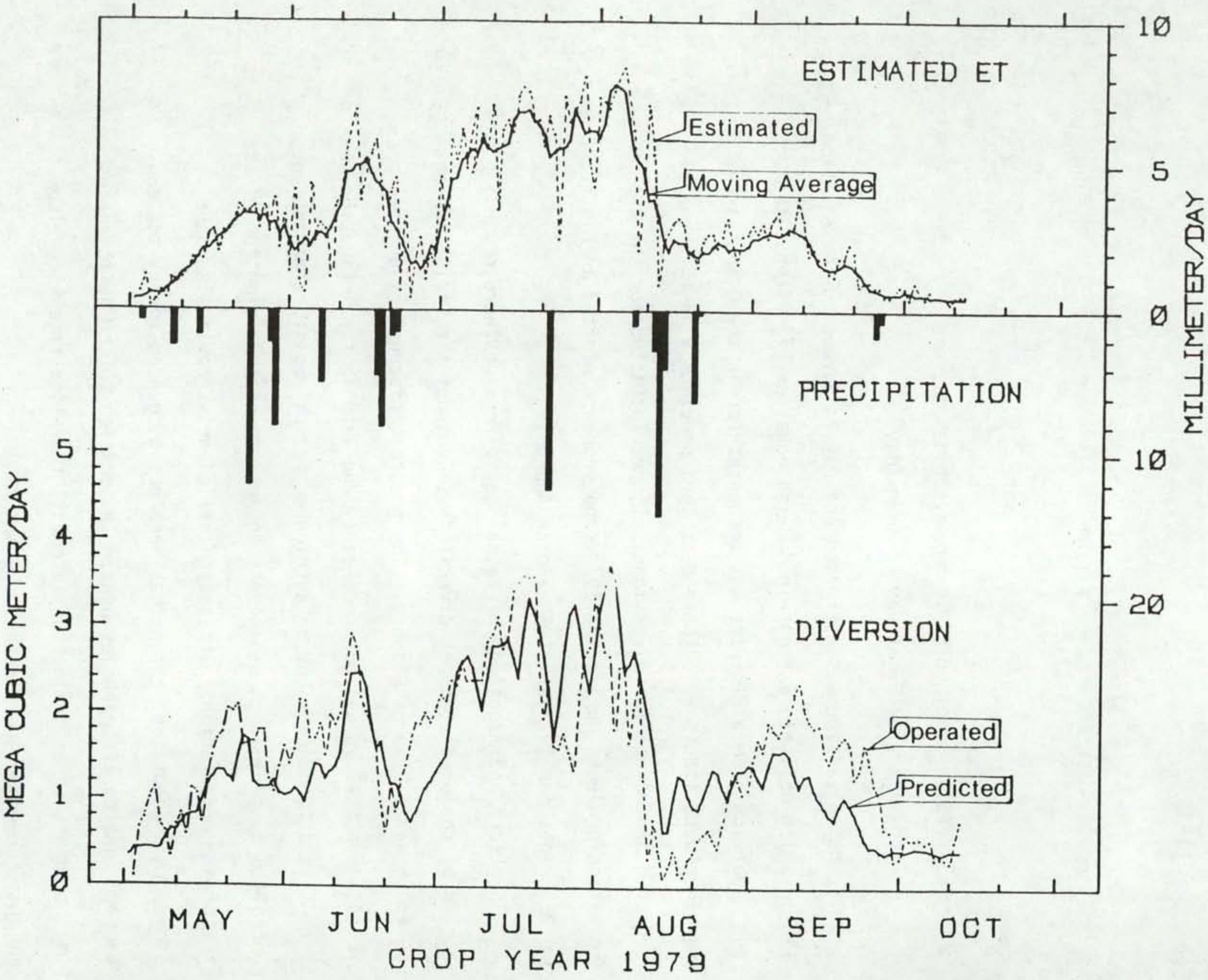

Figure 8. Estimated ET, 5-day moving average ET, precipitation, predicted net diversion and operated net diversion for the Idaho Irrigation District during the 1979 crop year.

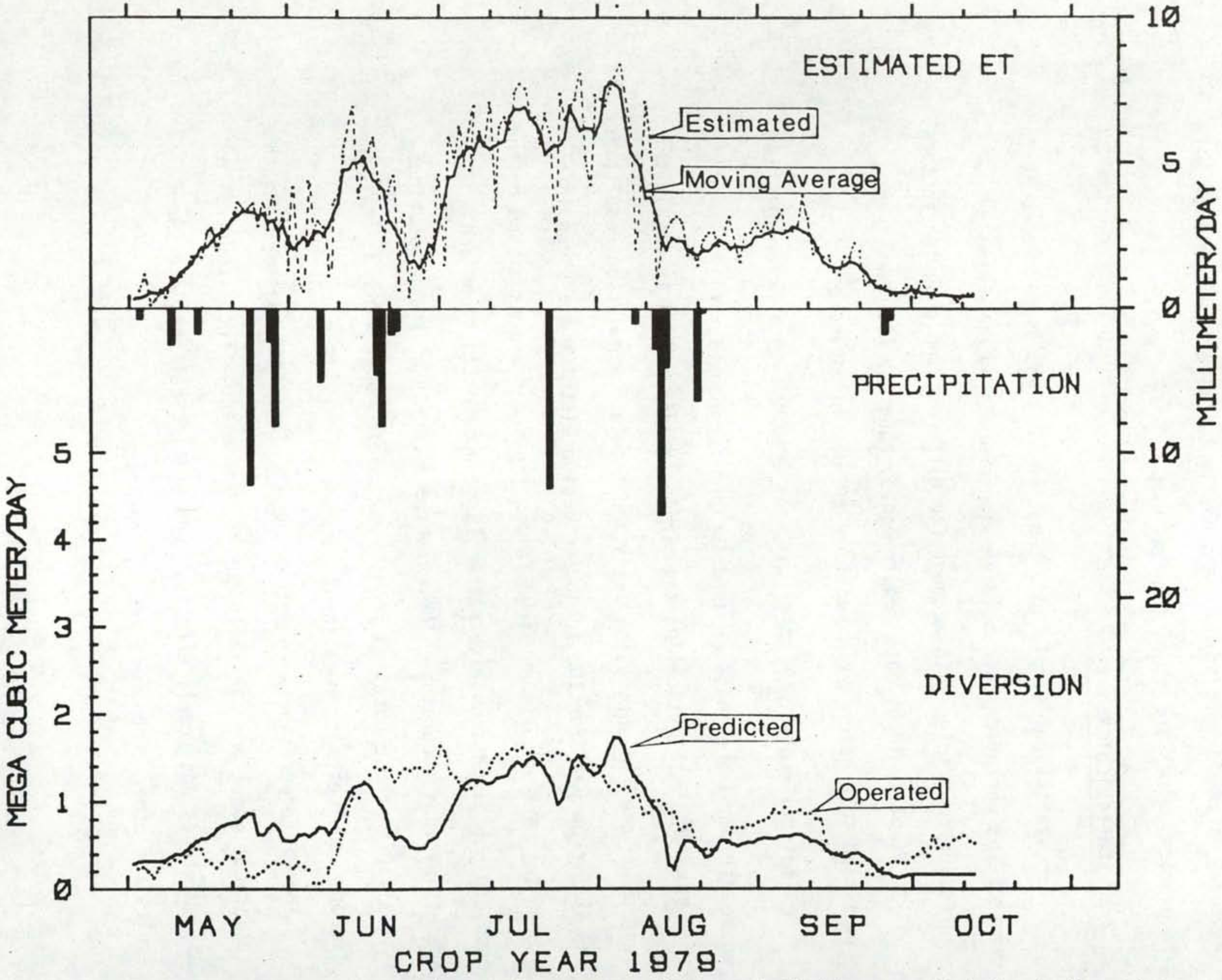

Figure 9. Estimated ET, 5-day moving average ET, precipitation, predicted net diversion and operated net diversion for the Snake River Valley Irrigation District during the 1979 crop year.

The results could be improved by using weekly or monthly updated values of the various parameters instead of using seasonal values. However, it would be difficult and costly to collect and analyze data to provide values for short time periods.

4.2.2 Statistical Model

For statistical simulation, equation [11] was used to account for most of the variations of the diversion process by obtaining proper regression coefficients to account for different and changing factors.

To simplify input data requirements, equation [11] was first simplified to predict net diversions one day in advance.

$$\text{QNETdiv}(t) = \alpha + \eta_1 * \text{MAET}(t-1) + \eta_2 * \text{MAPC}(t-1) + \text{Error}(t) \quad [14]$$

where all terms are the same as described for equation [11].

The TROLL statistical package (MIT, 1982) was used to obtain the regression coefficients using daily input data. Simulation results for the 1979 crop year for the Idaho Irrigation District are shown in Figure 10. The results obtained follow the trend and magnitude of the recorded net diversions with rather large underestimations and overestimations occurring. The relative accuracy of the predictions is similar to those obtained from the physical model which is more complex and requires much more input data.

The differences between actual and simulated diversions using this statistical model are partially due to management effects (control of soil moisture) and yearly effects. The statistical parameters and results for other crop years are in Appendix C.

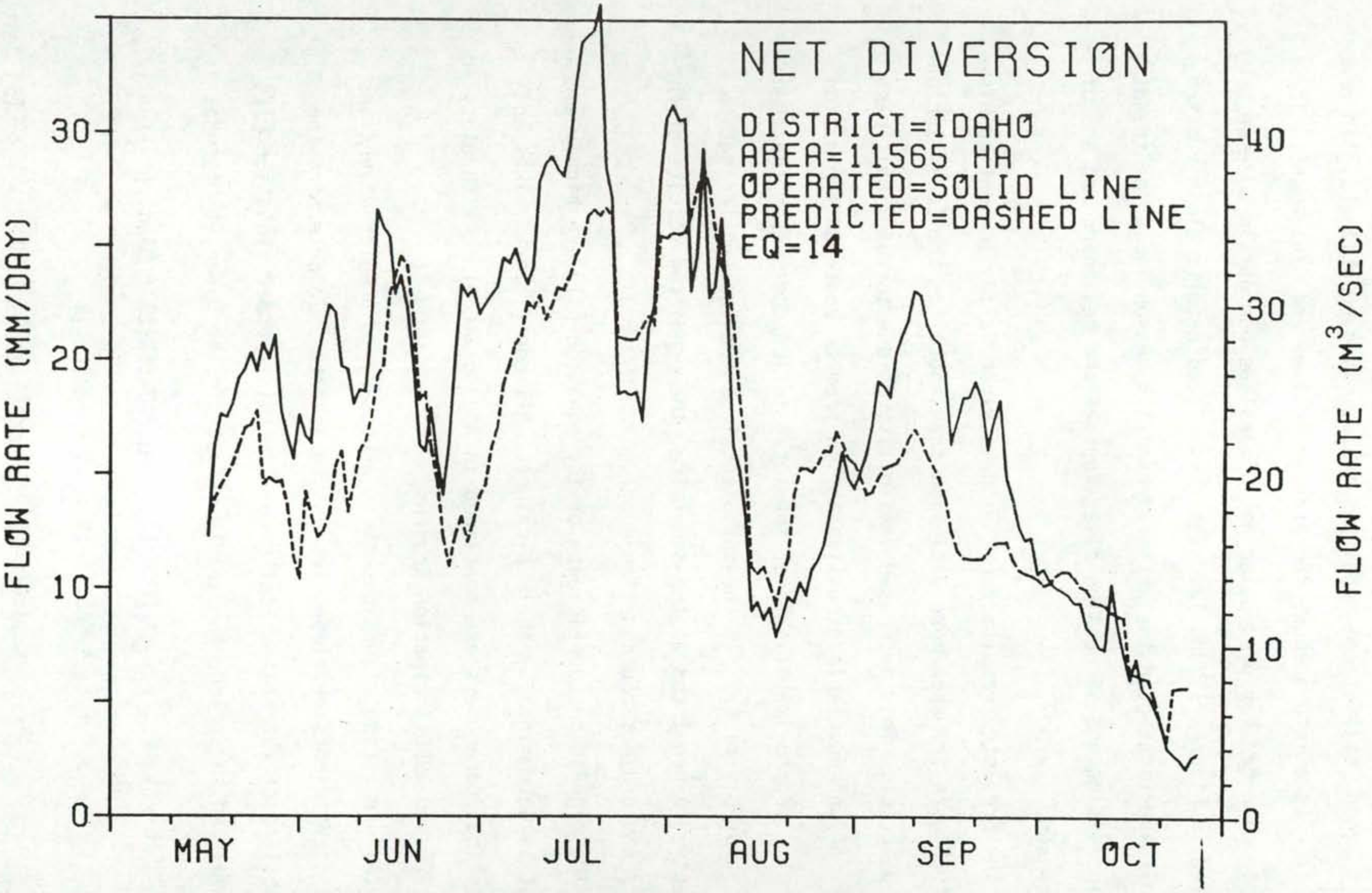

Figure 10. Prediction for Idaho Irrigation District using equation [14]; 1979

A second statistical model was tested using equation [11] in order to better take into account the effects of time and management. The results obtained for predicting net diversions one day in advance are plotted in Figures 11 and 12. These simulated results closely match actual diversions over the entire irrigation season including trends for increasing and decreasing diversions at the beginning and end of the season.

The predicted results for the Snake River Valley Irrigation District (Figure 12) show more variation than those for the Idaho Irrigation District. This increased variability is due to the significant amount of unpredictable excessive inflow from an upstream irrigation project. (Approximately 25% of the total inflow comes from the Idaho Irrigation District.) If the net diversions for the two irrigation projects are predicted at the same time, the predicted results of the downstream project could be improved.

The regression coefficients of the equation [11] are highly significant as determined by their t-values. All coefficient values and statistical parameters are contained in Appendix C along with plots for the 1978 and 1980 irrigation seasons.

In forecasting diversions it is necessary to predict diversions using coefficients developed from historic data. To determine the suitability of the statistical model for this purpose, equation [11] was modified to exclude the yearly effects in the $\mathrm{Dyear}_j(t)$ term as

$$\begin{aligned} \mathrm{QNETdiv}(t) = \alpha + \beta_i * \mathrm{DMON}_i(t) &+ \eta_1 * \mathrm{DWEEK}(t) * \mathrm{MAQdiv}(t-1) \\ &+ \eta_2 * \mathrm{MAET}(t-1) + \eta_3 * \mathrm{MAPC}(t-1) \\ &+ \eta_4 * \mathrm{Qdiv}(t-1) + \mathrm{Error}(t) \qquad [15] \end{aligned}$$

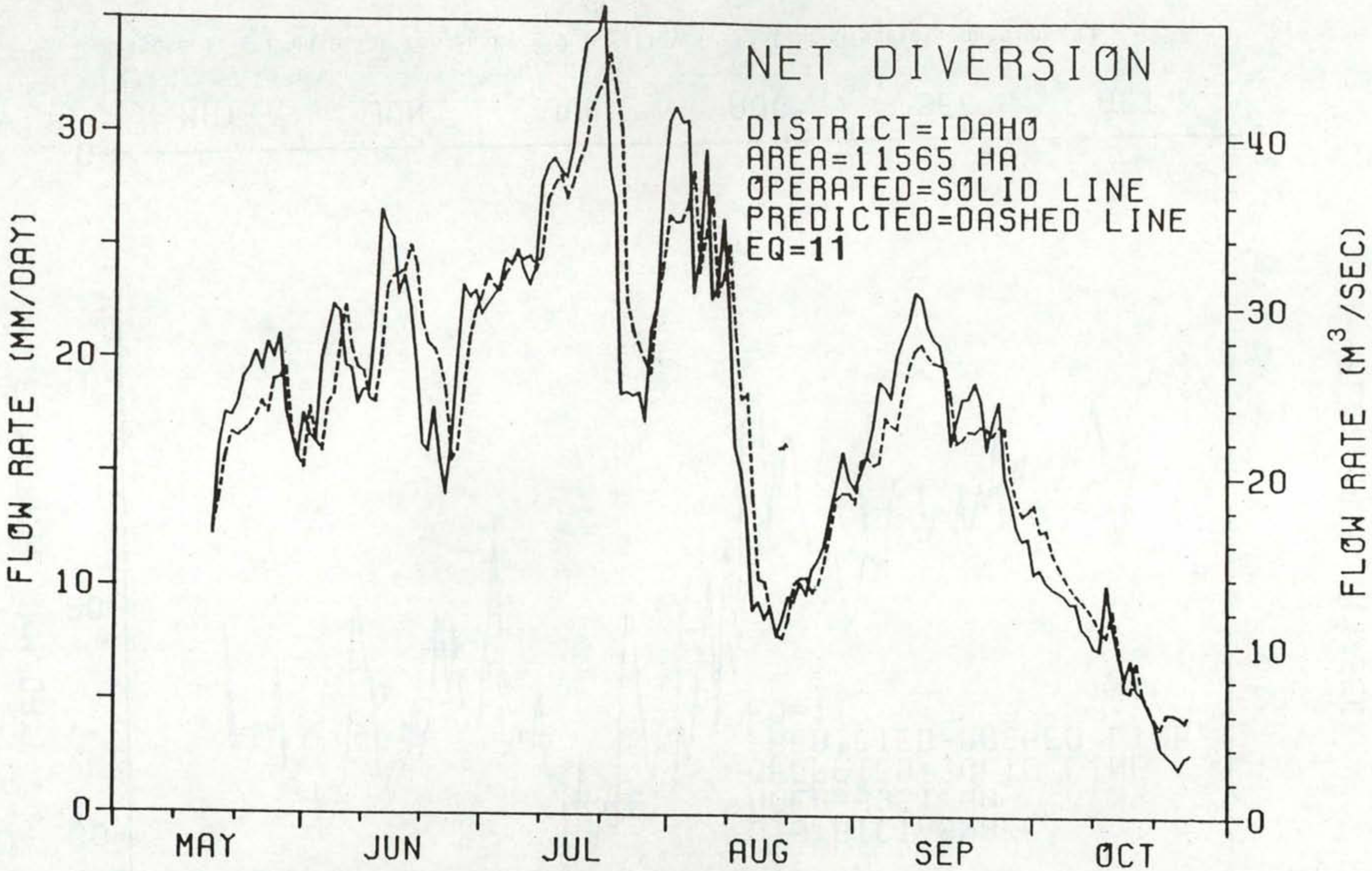

Figure 11. Prediction for Idaho Irrigation District using equation [11]; 1979

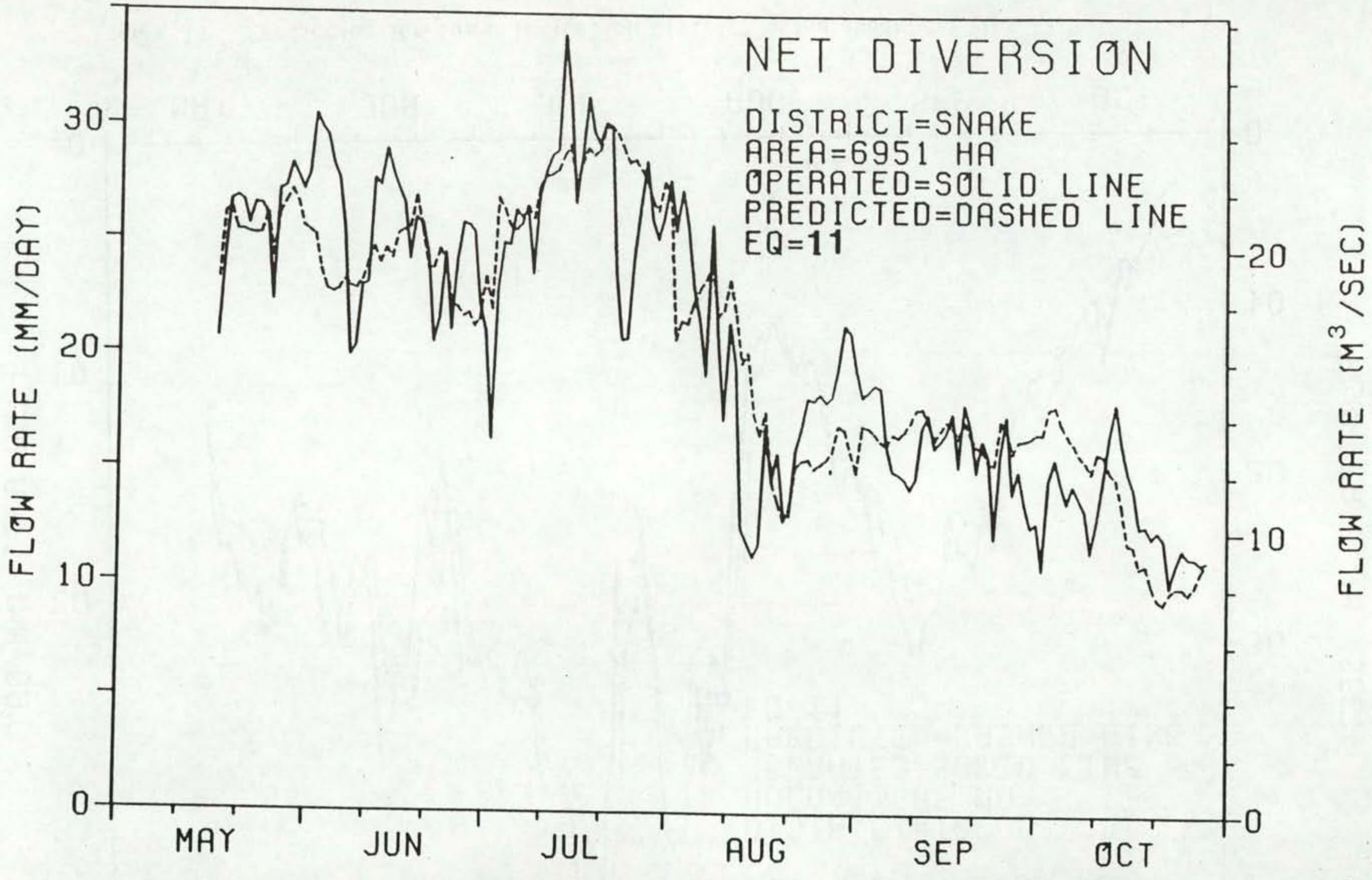

Figure 12. Prediction for Snake River Valley Irrigation District equation [11]; 1979

Data from 1978 and 1979 were used to compute all coefficients for equation [15]. These coefficients in the equation were then used in predicting net diversions for 1980 using input data from that year. Results for the Idaho Irrigation District are shown in Figure 13. Predicted values match actual values quite closely with minor underestimation and overestimation occurring over the irrigation season. The overestimation occurring during the early irrigation season is due to above average precipitation received in 1980.

These results show that the parameters for predicting net diversions can be developed with a minimum of historic data. To improve the accuracy of the model for prediction it would be desirable to include a yearly factor that would represent soil moisture conditions at the beginning of the irrigation season. A procedure for updating the coefficients of monthly dummy variables would also be beneficial. Simulation results and plots for 1978 and 1979 using equation [15] are contained in Appendix C.

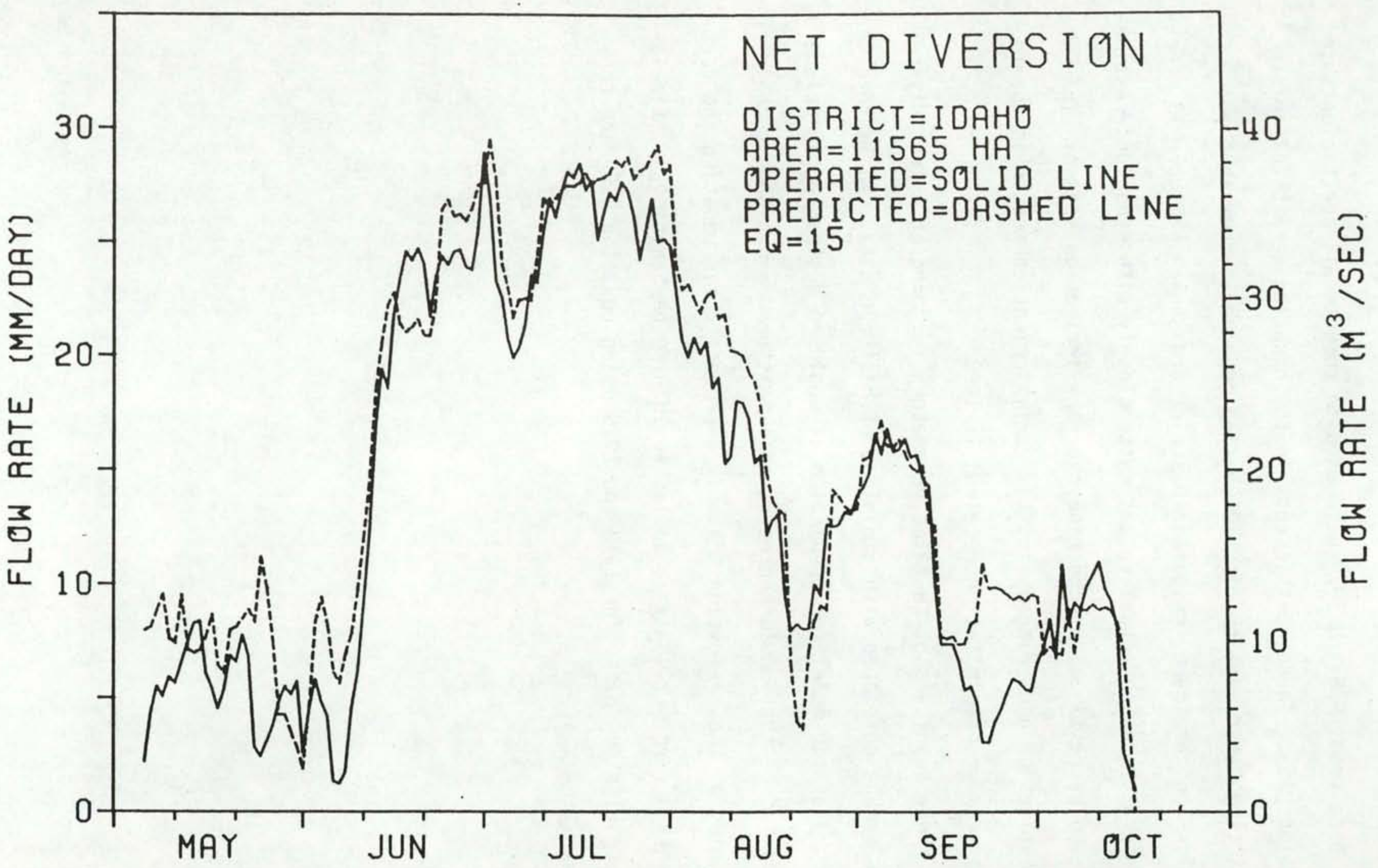

Figure 13. Prediction for Idaho Irrigation District using equation [15]; 1980

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Factors affecting irrigation diversions were identified and procedures for predicting daily irrigation project diversions were developed and applied in meeting the objectives of this study. Physical and statistical models were developed and tested for two irrigation projects in southeastern Idaho. It can be concluded from the application of the models developed in this study that daily irrigation diversions can be forecasted one day in advance.

A physical model was developed using evapotranspiration, precipitation, irrigation efficiencies, and time factors as required input variables. The results of applying the physical model to the two irrigation projects indicated that more variables were needed to accurately predict daily irrigation diversions. Overestimation and underestimation occurred in the irrigation season, especially in the early and late portions. Reasons for the discrepancies were that irrigation efficiencies were changing throughout the irrigation season and that time factors such as traveling time and irrigation interval were also changing over the irrigation season. In addition, variables to account for changes of the soil moisture storage, both daily and seasonal, were not considered. To improve the physical model, additional parameters and the relationships of certain parameters with respect to time need to be included. The task of updating coefficients and accounting for changes of the soil moisture storage would be difficult and costly.

To overcome the shortcomings of the physical model, statistical simulation models were developed and tested. Accounting for the change of soil moisture storage over the irrigation season was accomplished by using dummy variables for each month, and daily soil moisture storage change was accounted for by incorporating previous diversions. The predicted diversions matched actual diversions quite closely throughout the irrigation season as regression correlation coefficients were above 0.90. It was also possible to predict diversions for the 1980 season using data from the 1978 and 1979 seasons for developing regression coefficients.

Whereas a physical model would require extensive data that are difficult to obtain, the statistical model requires easily obtained parameters such as precipitation, diversion and outflow records, and climatic data to estimate evapotranspiration for several years. In addition, regresssion coefficients can be easily updated using a statistical package on a digital computer. Once the coefficients are obtained, computation is very simple and the other statistical information, such as the confidence interval of the forecasted value, can be obtained.

For the irrigation project modeled, the unknown excessive inflow from the upstream projects resulted in forecasting errors. The results could be improved by the effective combination of the several projects in the modeling and forecasting process.

The results show that statistical simulation and prediction of irrigation diversions has more advantages than physical simulation. Since data for daily diversions are available for most irrigation projects and climatic information can be obtained at or near projects, statistical simulation is possible for most of irrigation projects using existing data.

5.2 Recommendations

Precipitation affected the irrigaiton diversion very significantly. A constant portion of the precipitation was used as the effective precipitation for the physical model and a linear coefficient was estimated statistically for the statistical model. However, the relationship between measured and effective precipitation is dependent upon the actual precipitation and field condition. Therefore, forecasting diversions could be improved by further developing procedures for estimating effective precipitation.

In this study, diversions were forecasted one day in advance of the actual diversion operation. However, a longer advance time may be required to effectively manage an irrigation or river system. The developed statistical model could be used for the above purpose with minor modifications. Confidence limits along with the advance time could be estimated statistically and the information used to optimize management decisions.

REFERENCES

Allen, R.G. and C.E. Brockway. 1979. Relationship of costs and water use efficiency for irrigation projects in Idaho. Idaho Water Resources Research Institute, University of Idaho, Moscow, Idaho. 288 p.

Buchheim, J.F. and L.A. Brower. 1981. Forecasting water diversions to meet irrigation requirements. ASAE Paper No. 81-2094. ASAE, St. Joseph, MI 49085.

Burt, C.M. and J.M. Lord, Jr. 1981. Demand theory and application in irrigation district operation. Proceedings of the Irrigation Scheduling Conference. ASAE, St. Joseph, MI 49085. p. 150-158.

Campbell, M.D., J.F. Buchheim, and L.A. Brower. 1975. Wide area irrigation scheduling for effective use of water. Proceedings of the Second World Congress on Water Resources, Volume I, New Delhi, India. p. 215-224.

Claiborn, B.A. 1975. Predicting attainable irrigation efficiencies in the Upper Snake River Region. M.S. Thesis, Idaho Water Resources Research Institute, University of Idaho, Moscow, Idaho.

Franzoy, C.E. and E.L. Tankersley. 1970. Predicting irrigations from climate data and soil parameters. TRANSACTIONS of the ASAE 13(6): 814-816.

Hammond, J. 1978. A program to promote irrigation conservation in Idaho. State of Idaho Department of Water Resources, Improved Water Use Efficiency Project: #535 Final Report, Boise, Idaho. 43 p.

Idaho Department of Water Resources. 1978. A program to promote irrigation conservation in Idaho. Boise, Idaho. 43 p.

Jensen, M.E. 1969. Scheduling irrigations with computers. Journal of Soil and Water Conservation 24(5): 193-195.

Jensen, M.E. 1975. Scientific irrigation scheduling for salinity control of irrigation return flows. U.S. Environmental Protection Agency, Office of Research and Development, Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma.

Kerpelman, L.C., B.L. Gettleman, and B.E. Rovin. 1976. Incentives for improved water use efficiency. Idaho Department of Water Resources, Statehouse, Boise, Idaho. 162 p.

Kim, S. 1981. Analyzing and predicting irrigation diversions in southeastern Idaho. M.S. Thesis, Department of Agricultural Engineering, University of Idaho, Moscow, Idaho. 122 p.

Kincaid, D.C. and D.F. Heermann. 1974. Scheduling irrigations using a programmable calculator, ARS-NC-12. Agricultural Research Service, USDA. p. 1-10.

Lord, J.M., G.D. Jardine, and G.A. Robb. 1977. Operation of a water management ET model for scheduling irrigations. ASAE Paper No. 77-2053, ASAE, St. Joseph, MI 49085.

Massachusetts Institute of Technology. 1982. TROLL 1982 Version. MIT Center for Computational Research in Economics and Management Science And MIT Information Services, Cambridge.

Netz, K. 1980. Evaluation of canal seepage in the Snake River Fan, Bonneville and Bingham Counties, Idaho. Unpublished Master's Thesis, Agricultural Engineering Department, University of Idaho, Moscow, Idaho. 79 p.

Ploss, L.F., J.F. Buchheim, and L.A. Brower. 1979. Irrigation project distribution system scheduling. Presented at the Irrigation and Drainage Specialty Conference, ASCE, Albuquerque, New Mexico.

Sutter, R.J., R.D. Carlson, and D. Lute. 1983. Data automation for water supply management. Proceedings, ASCE Journal of Water Resources Planning and Management, 109(3): 237-252.

United States Department of the Interior, Bureau of Reclamation. 1982. Water management and conservation program, Annual Report 1981. Engineering and Research Center, Denver, Colorado.

Yoo, K.H., J.R. Busch, and C.E. Brockway. 1982. Optimal planning of irrigation distribution and application systems for a large irrigated area. Idaho Water and Energy Resources Research Institute, University of Idaho, Moscow, Idaho. 235 p.

APPENDIX A

PLOTS OF NET DIVERSIONS VS. 7 DAY MOVING AVERAGE ET

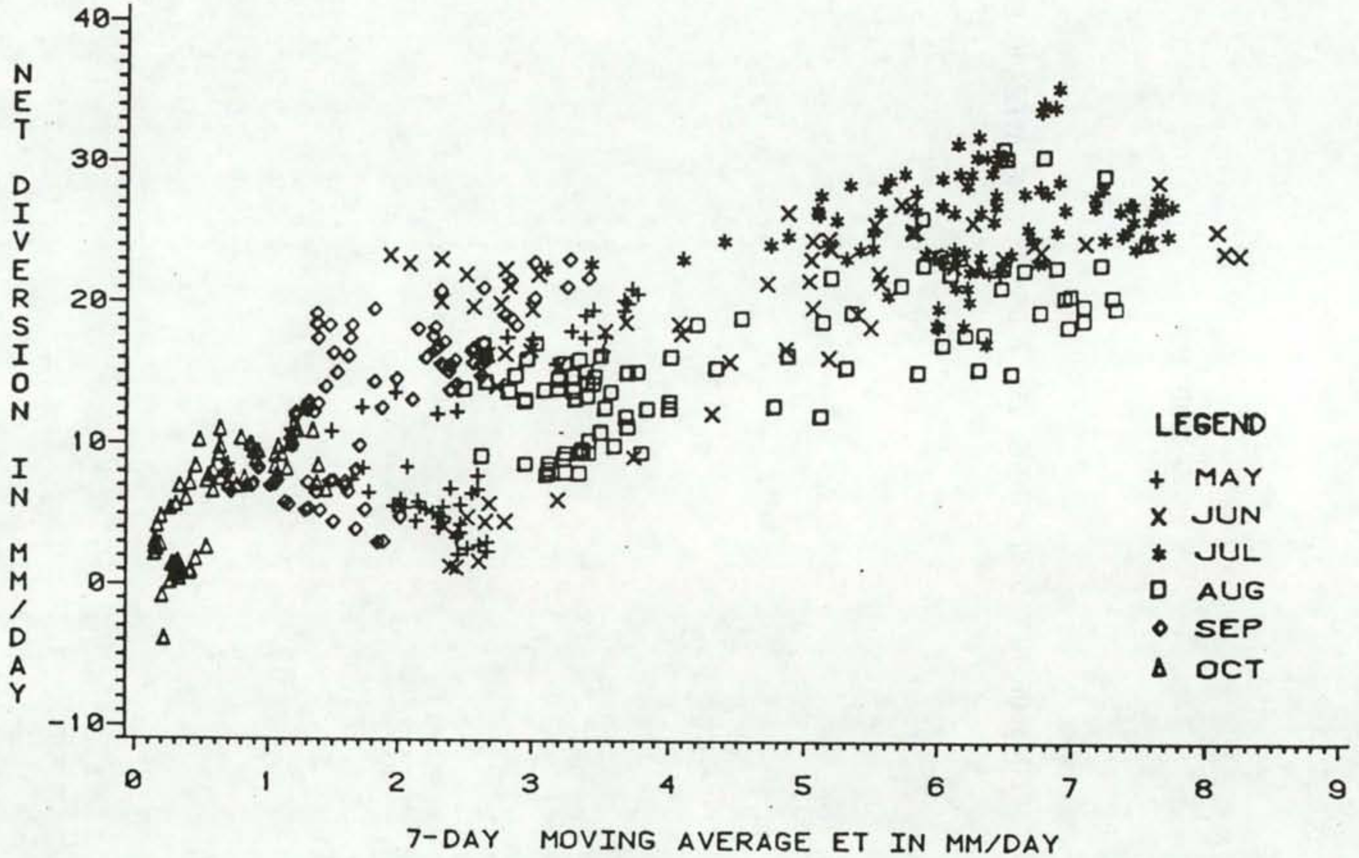

Figure A-1. Idaho Irrigation District; 1978, 1979, and 1980 crop years.

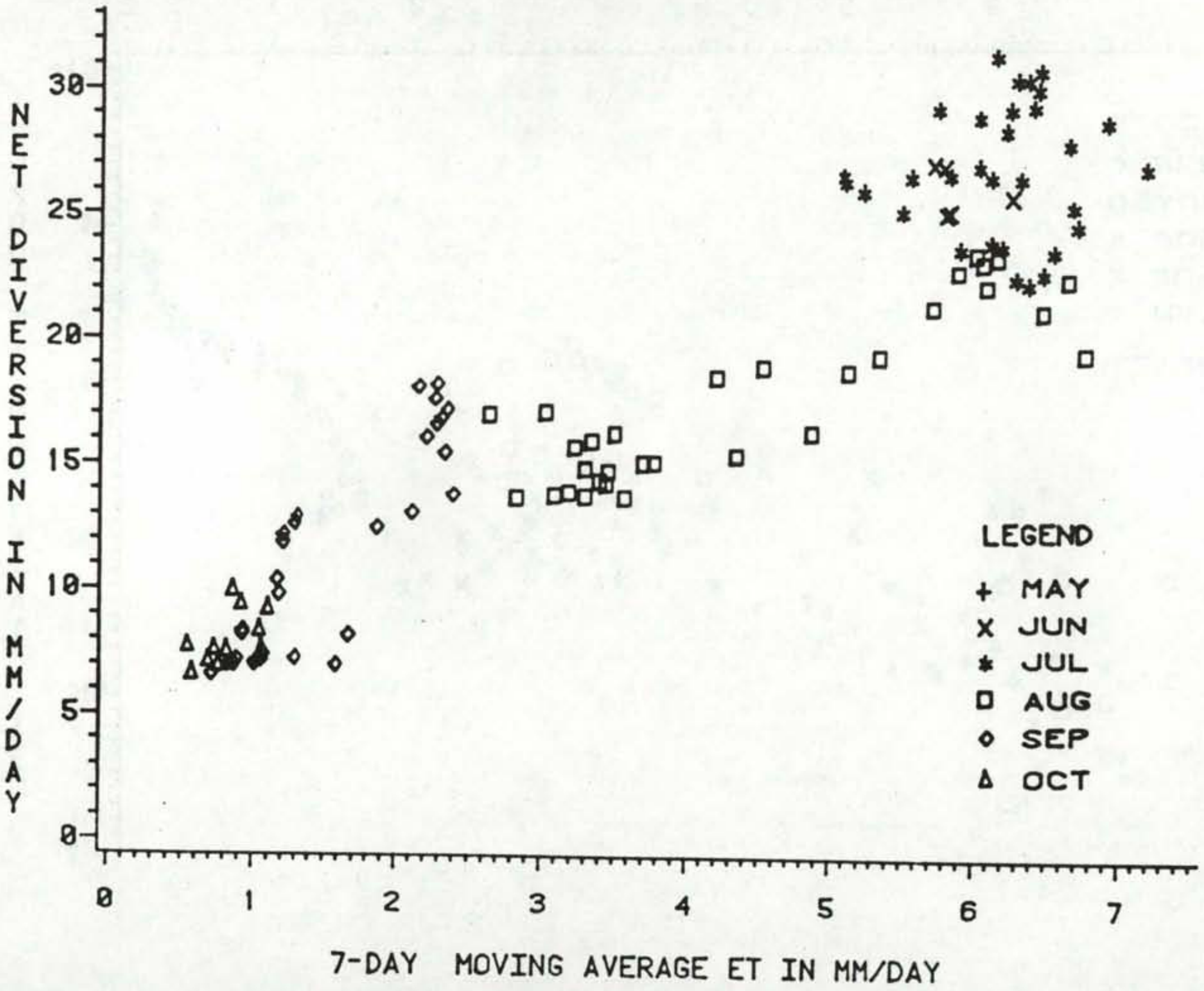

Figure A-2. Idaho Irrigation District; 1978 crop year.

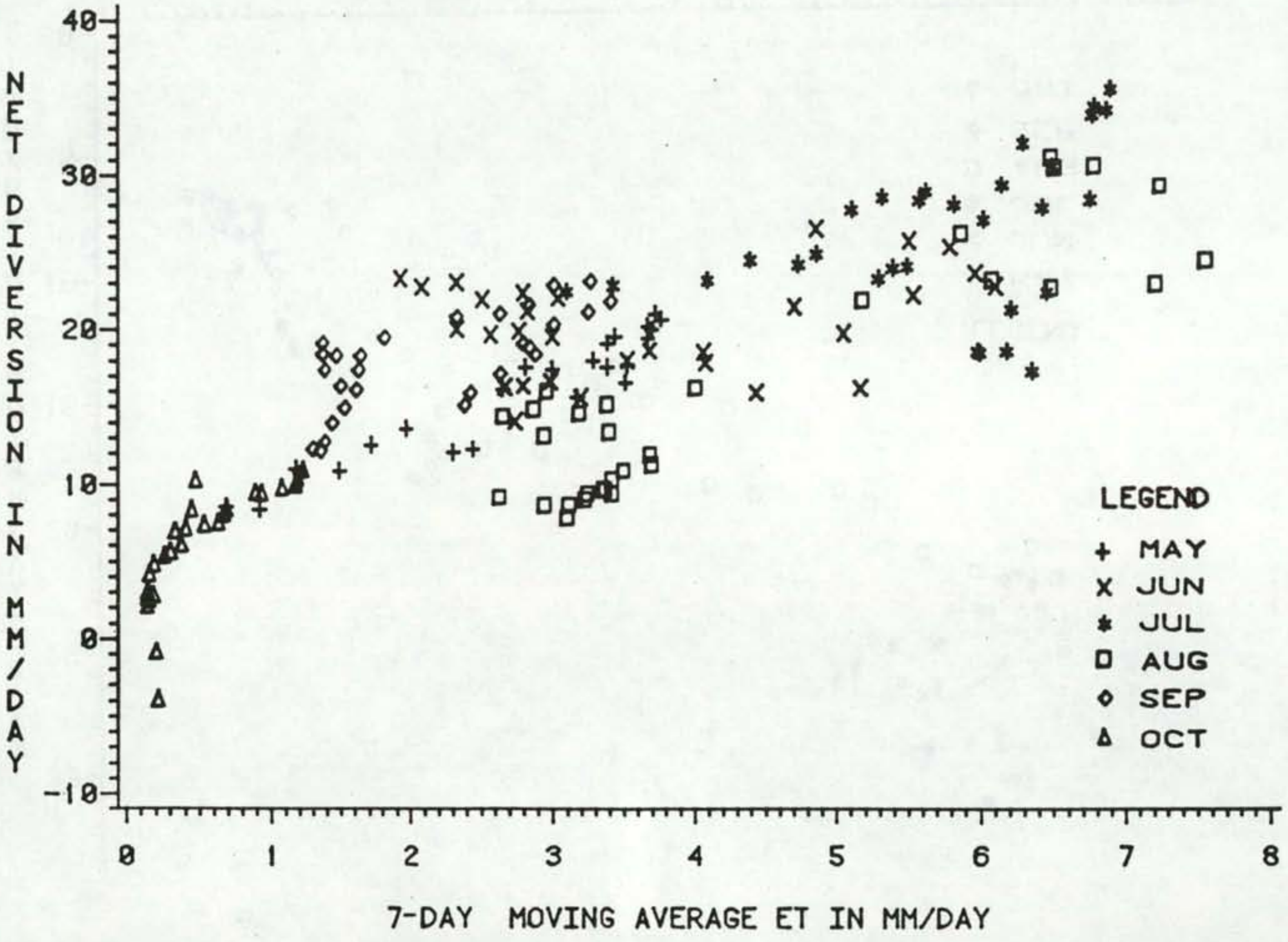

Figure A-3. Idaho Irrigation District; 1979 crop year.

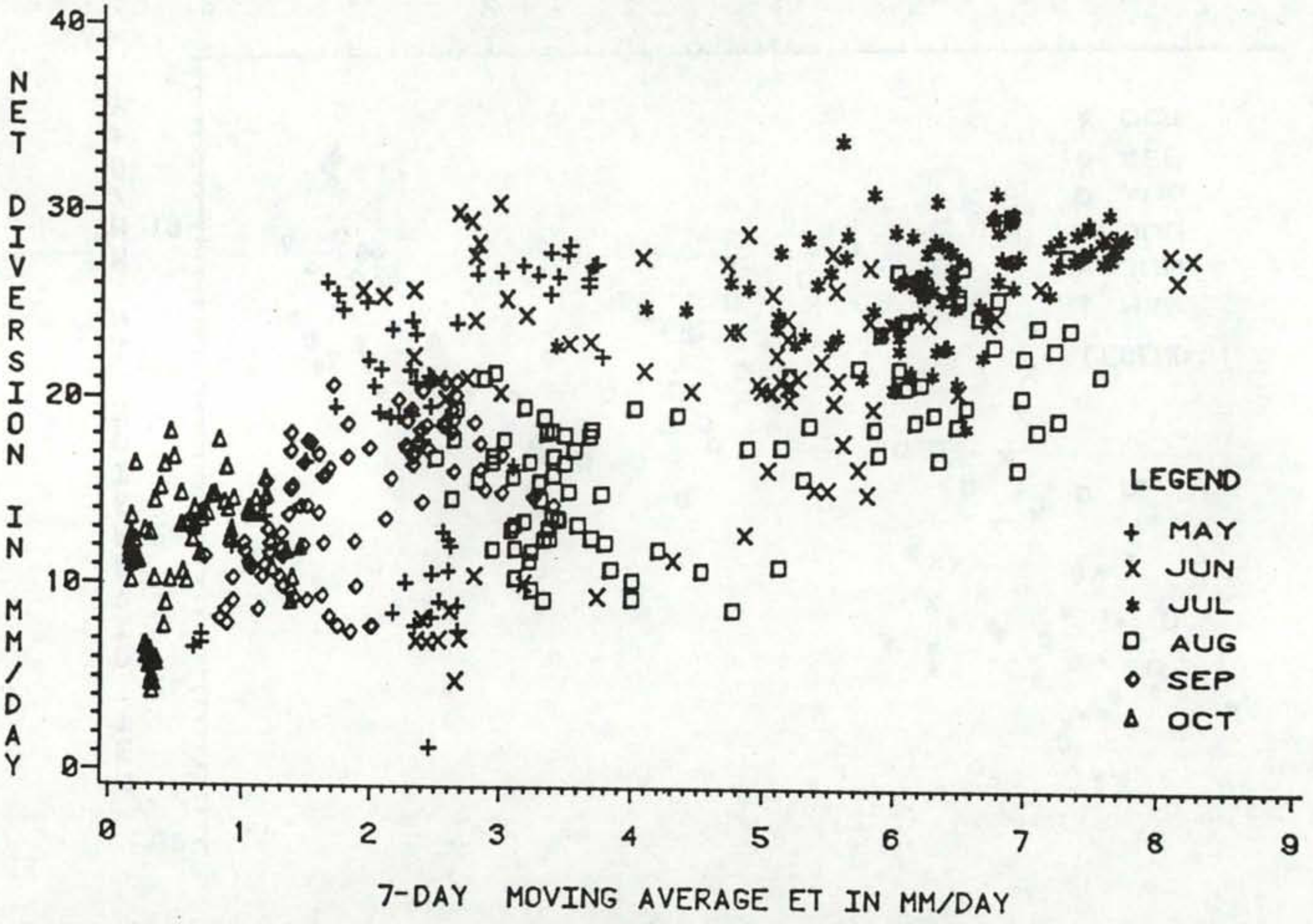

Figure A-4. Snake River Valley Irrigaiton District, 1978, 1979, and 1980 crop years.

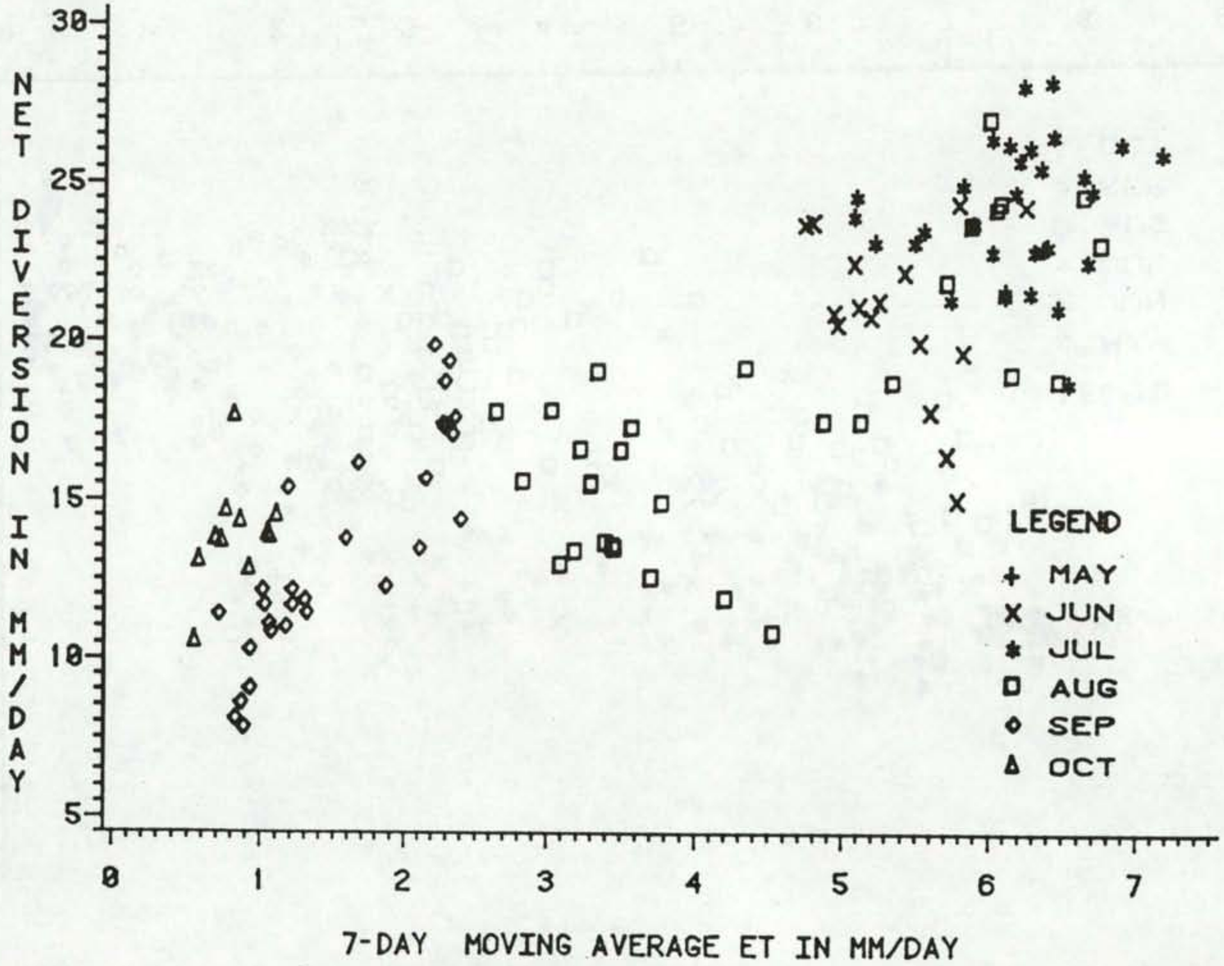

Figure A-5. Snake River Valley Irrigation District; 1978 crop year.

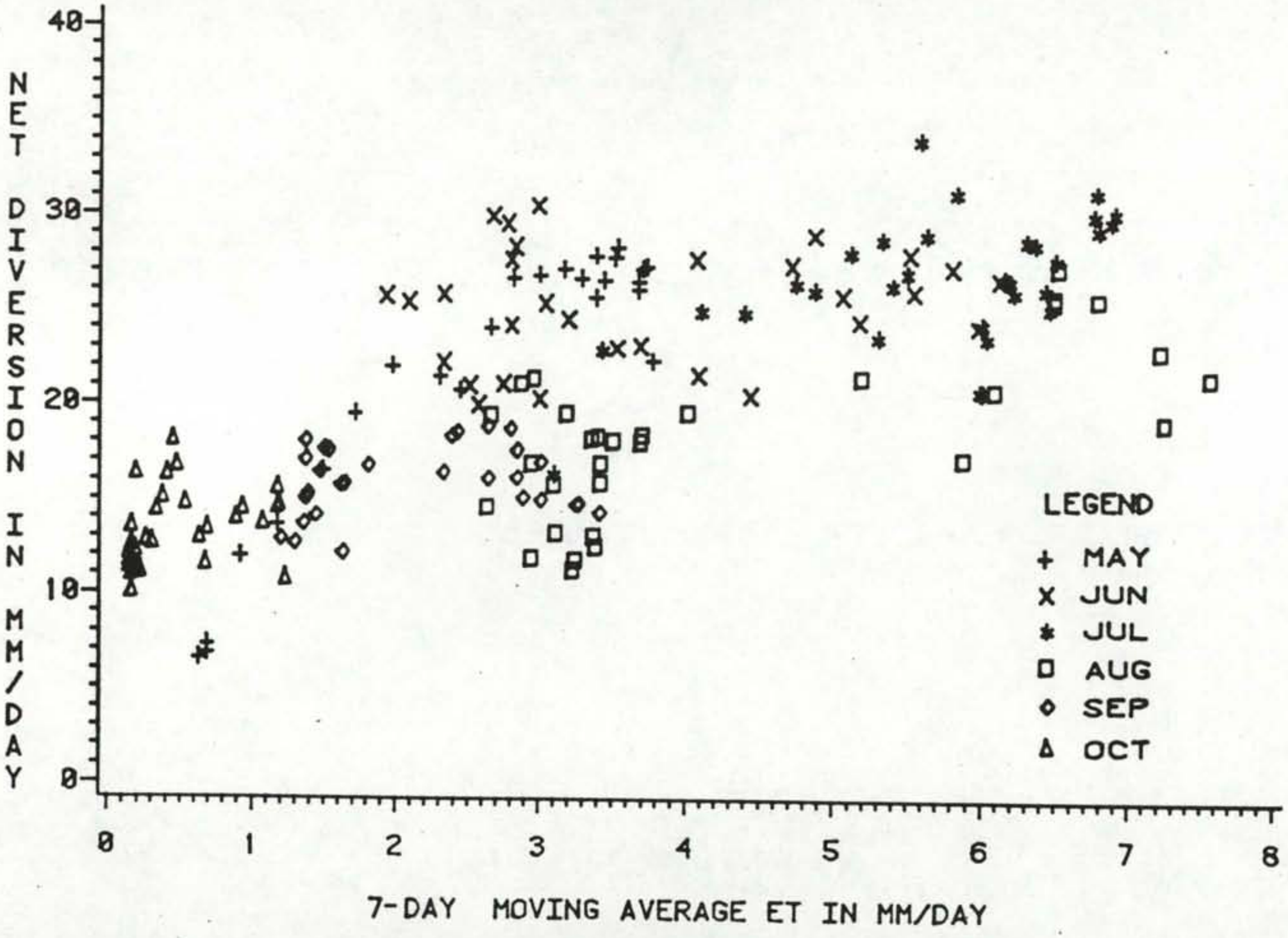

Figure A-6. Snake River Valley Irrigation District; 1979 crop year .

APPENDIX B

ESTIMATED ET, 5-DAY MOVING AVERAGE ET, PRECIPITATION, ACTUAL NET DIVERSION AND PREDICTED NET DIVERSION BY THE PHYSICAL MODEL

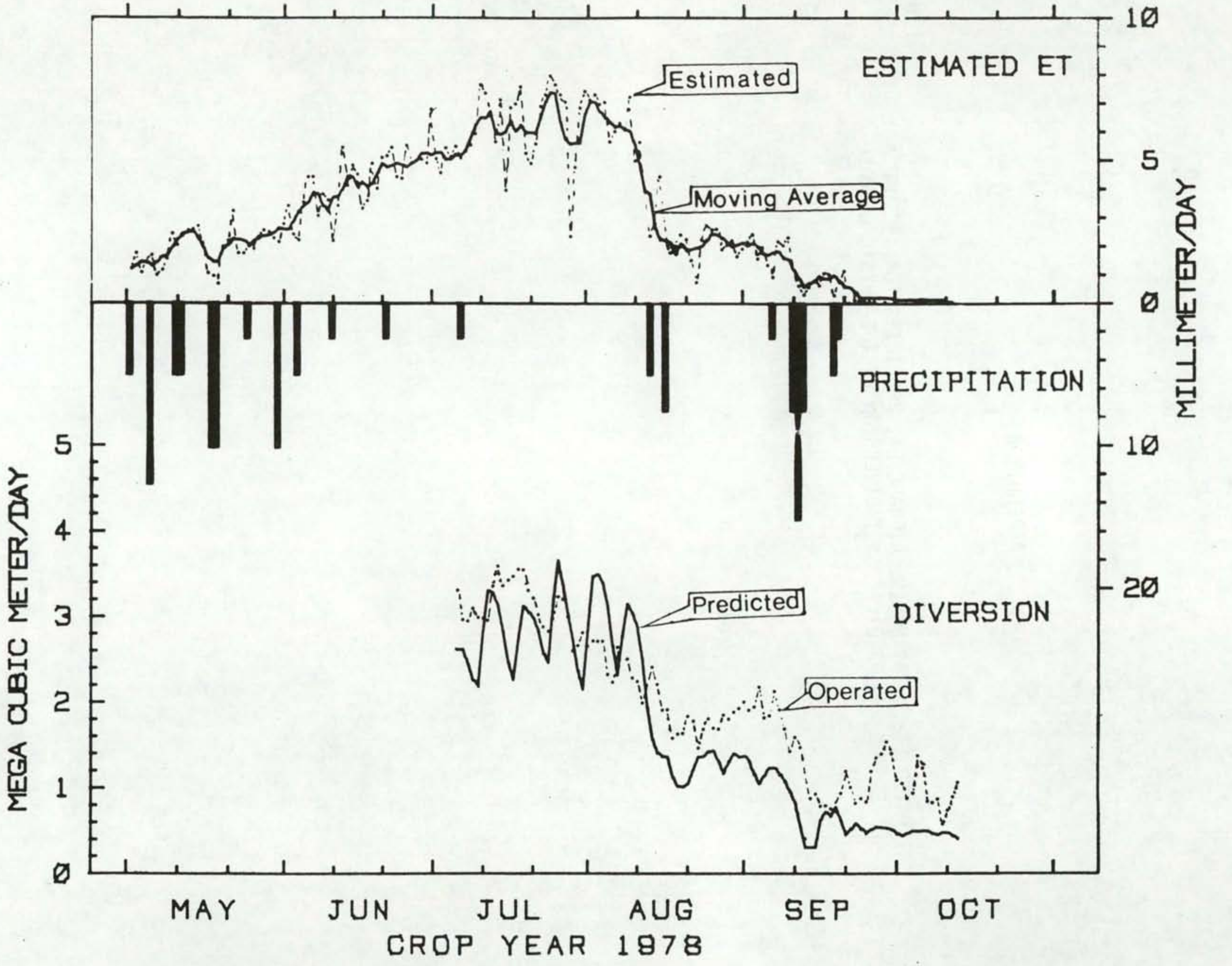

Figure B-1. ET, precipitation and diversions for Idaho Irrigation District; 1978 .

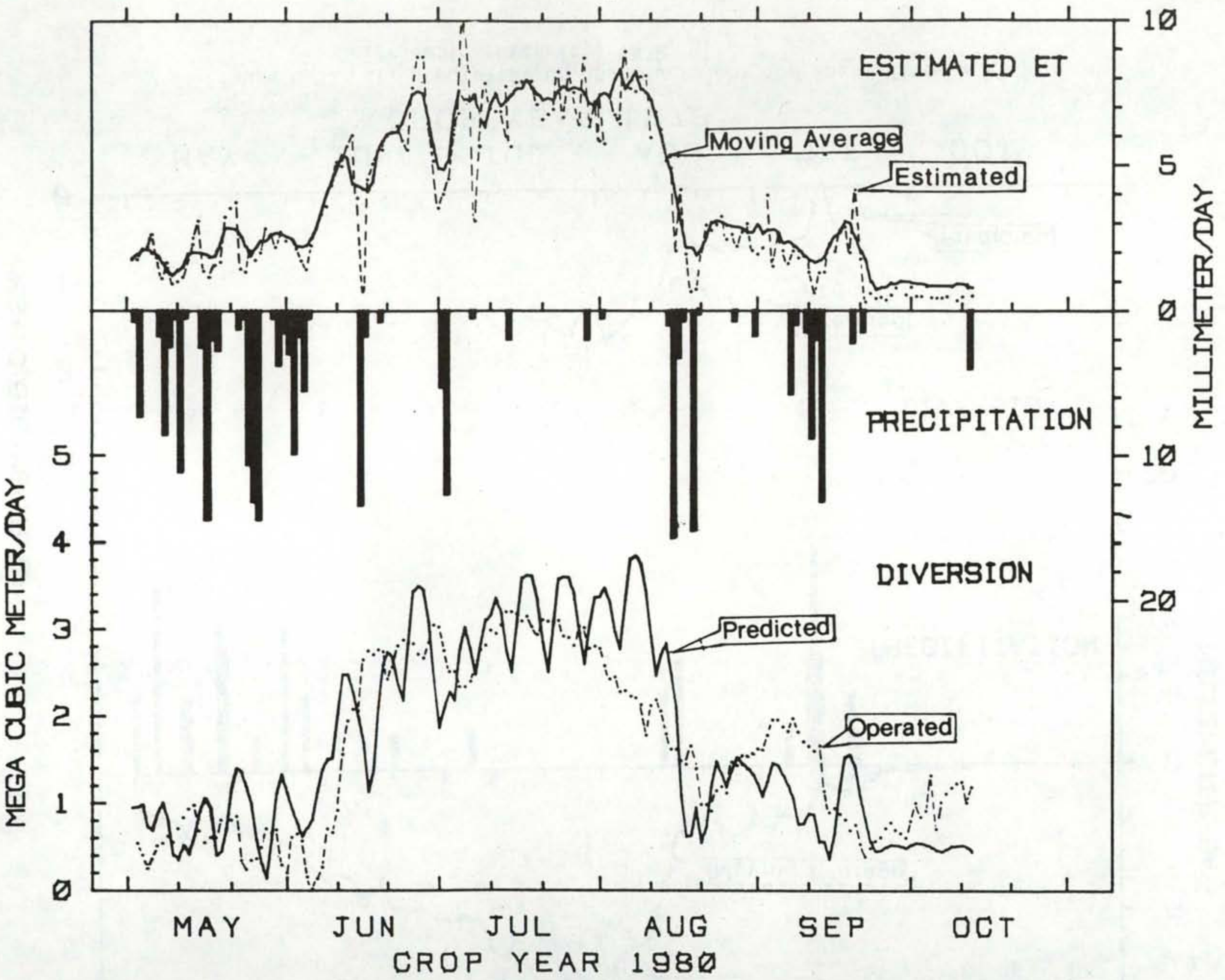

Figure B-2. ET, precipitation and diversions for Idaho Irrigation District; 1980.

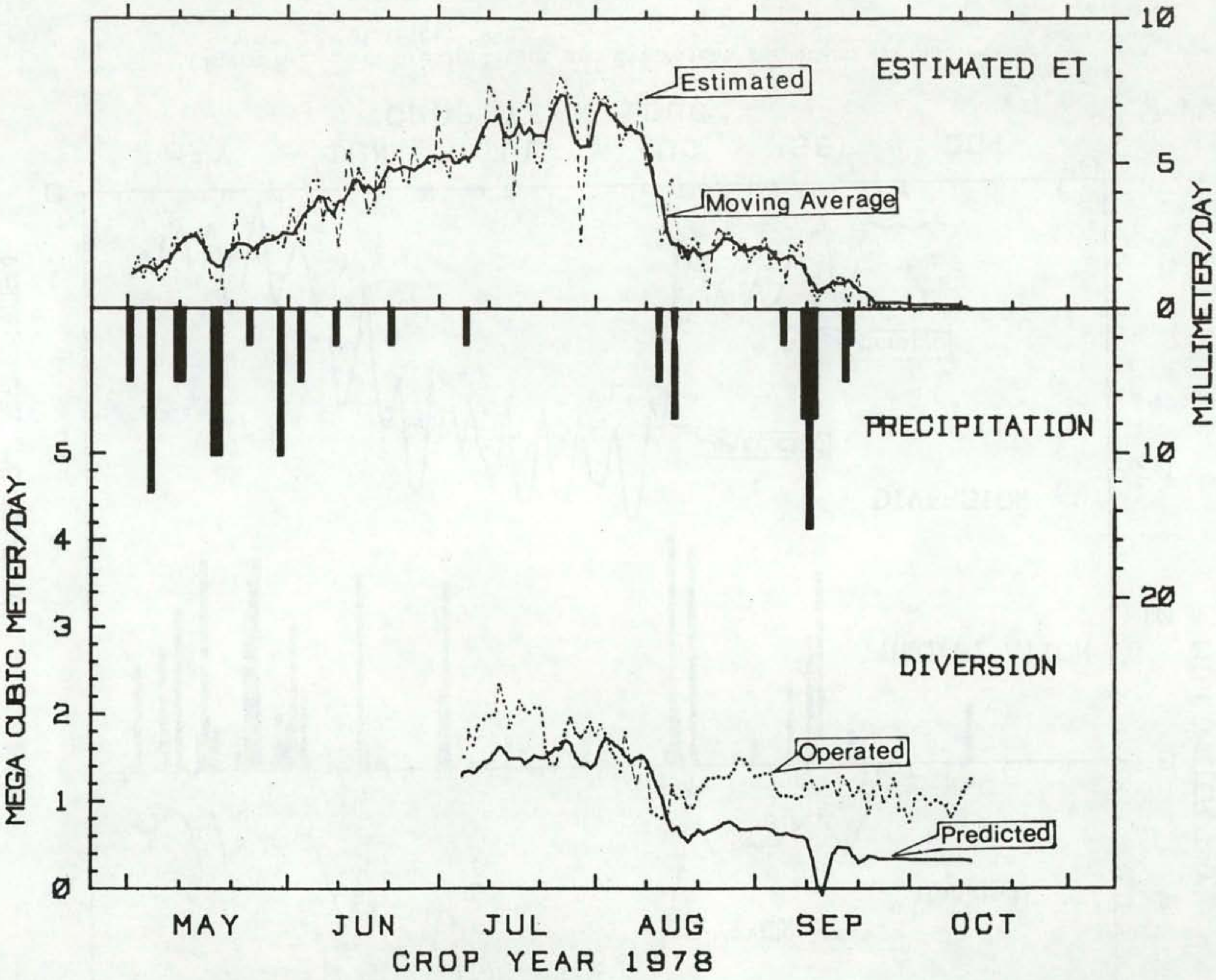

Figure B-3. ET, precipitation and diversions for Snake River Valley Irrigation District; 1978.

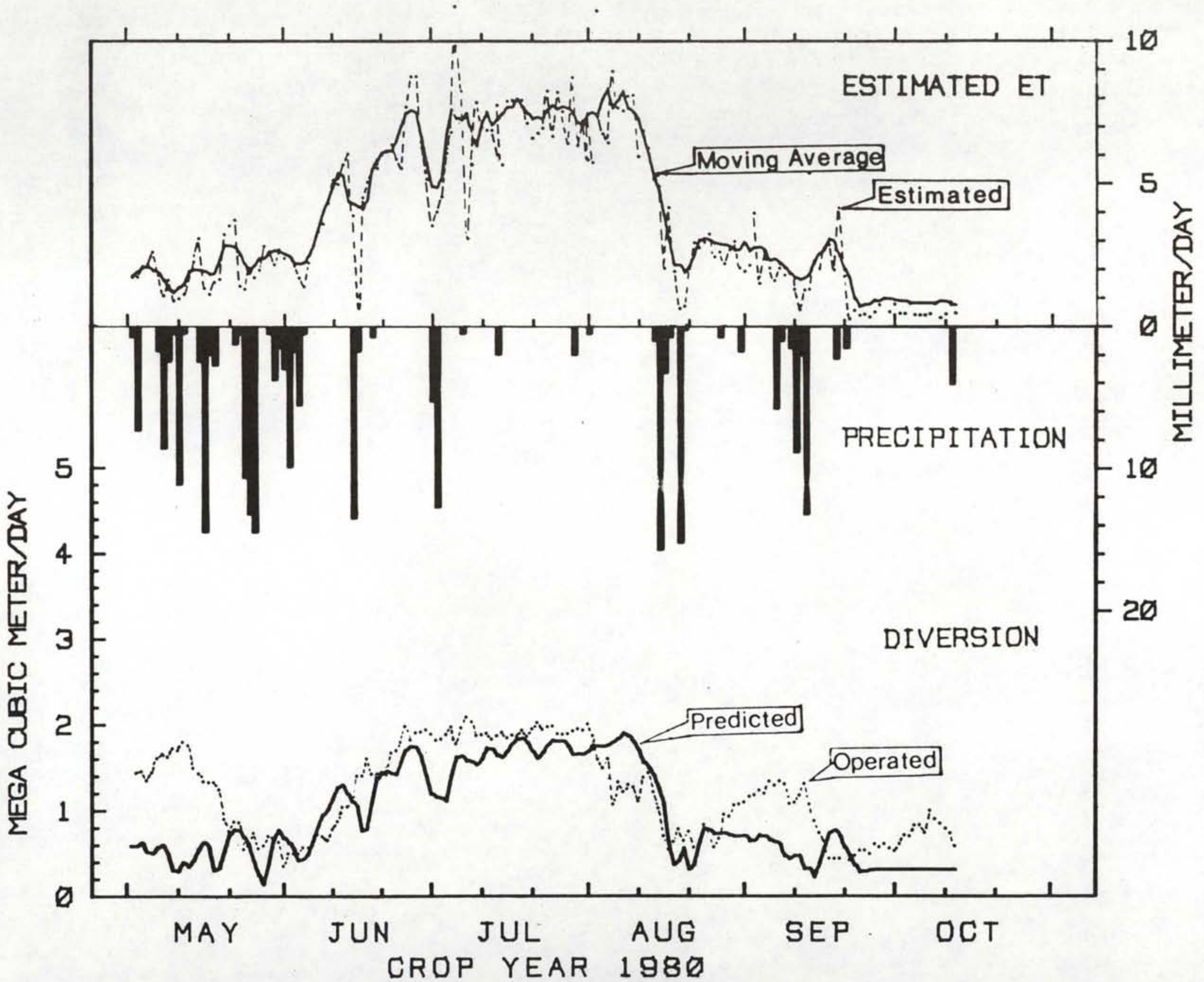

Figure B-4. ET, precipitation and diversions for Snake River Valley Irrigation District; 1980 crop year.

APPENDIX C

STATISTICS AND PLOTS OF THE STATISTICAL MODEL

Table C-1. Statistics for Idaho Irrigation District using equation [14].

$$QNETdiv(t) = \alpha + \eta_1 *MAET(t-1) + \eta_2*MAPC(t-1) + Error(t) \qquad [14]$$

Years	1978, 1979, 1980
No. of Observations	440
R^2	0.749
Standard Error	4.216

Coefficient	Value	Standard Error	T-statistic
α	7.55	0.448	16.86
η_1	2.782	0.0931	29.88
η_2	-1.847	0.1525	-12.11

Table C-2. Statistics for Snake River Valley Irrigation District using equation [14].

Years	1978, 1979, 1980
No. of Observations	452
R^2	0.529
Standard Error	4.718

Coefficient	Value	Standard Error	T-statistic
α	12.01	0.4974	24.14
η_1	2.038	0.1028	19.82
η_2	-0.8585	0.1701	-5.046

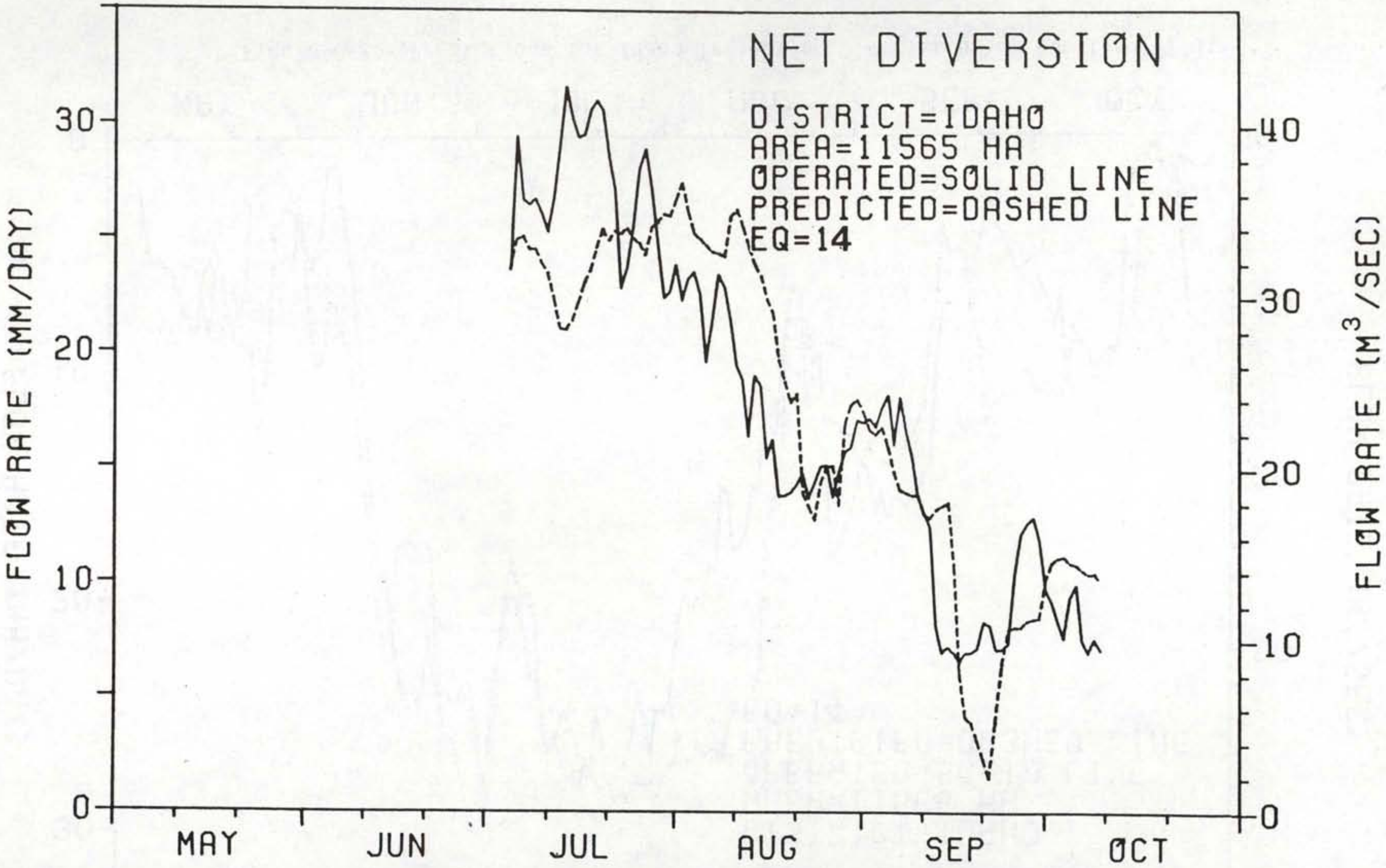

Figure C-1. Predictions for Idaho Irrigation District using equation [14]; 1978.

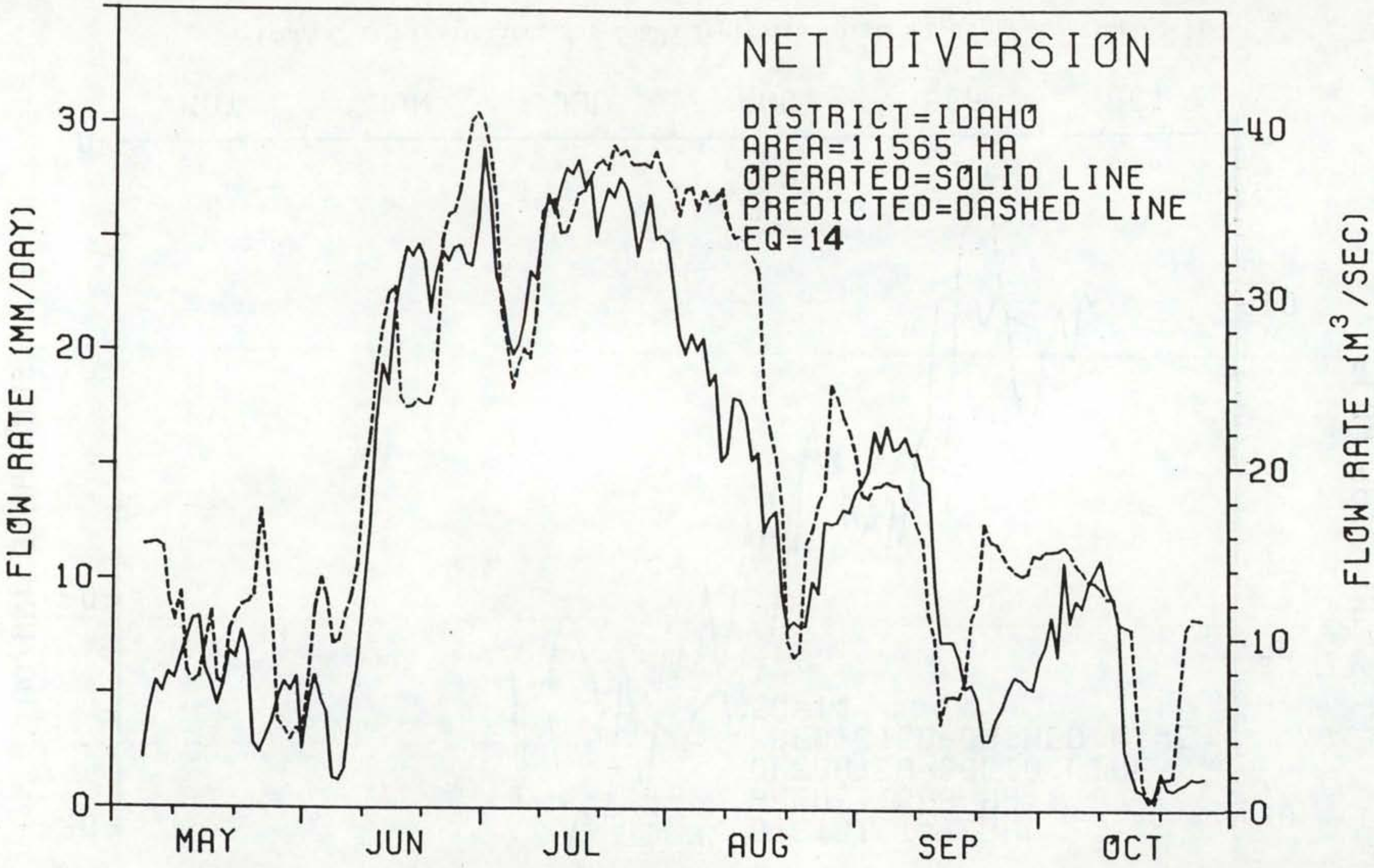

Figure C-2. Predictions for Idaho Irrigation District using equation [14]; 1980.

Table C-3. Statistics for Idaho Irrigation District using equation [11].

$$\begin{aligned} \mathrm{QNETdiv}(t) = {} & \alpha + \beta_i *\mathrm{DMON}_i(t) + \gamma_j *\mathrm{DYEAR}_j(t) \\ & + \eta_1 *\mathrm{DWEEK}(t)*\mathrm{MA\ Qdiv}(t-1) \\ & + \eta_2 *\mathrm{MAET}(t-1) + \eta_3 *\mathrm{MAPL}(t-1) \\ & + \eta_4 *\mathrm{Qdiv}(t-1) + \mathrm{Error}(t) \qquad [11] \end{aligned}$$

Years 1978, 1979, 1980

No. of Observations	440
R^2	0.924
Standard Error	2.347

Coefficient	Value	Standard Error	T-statistic
α	0.1829	0.7476	0.2446
β_{June}	0.5388	0.4827	1.1163
β_{July}	1.1370	0.5700	1.9949
β_{August}	-2.085	0.4878	-4.2733
$\beta_{\mathrm{September}}$	-0.04761	0.4902	-0.09713
β_{October}	-1.343	0.5674	-2.3672
γ_{1979}	-0.3773	0.3233	-1.167
γ_{1980}	-1.2492	0.3443	-3.628
η_1	0.03137	0.01098	2.856
η_2	0.6150	0.1543	3.985
η_3	-0.9695	0.1068	-9.078
η_4	0.7358	0.03863	19.05

Table C-4. Statistics for Snake River Valley Irrigation District using equation [11].

Years	1978, 1979, 1980
No. of Observations	452
R^2	0.746
Standard Error	3.485

Coefficient	Value	Standard Error	T-statistic
α	5.587	1.391	4.016
β_{June}	-2.657	0.6402	-4.151
β_{July}	-1.603	0.7575	-2.116
β_{August}	-7.316	0.6587	-11.107
$\beta_{September}$	-4.704	0.6596	-7.132
$\beta_{October}$	-4.675	0.7851	-5.955
γ_{1979}	1.251	0.4477	2.794
γ_{1980}	-0.4462	0.4325	-1.032
η_1	0.01666	0.01229	1.356
η_2	0.8626	0.1712	5.037
η_3	-1.045	0.1434	-7.286
η_4	0.5279	0.05358	9.853

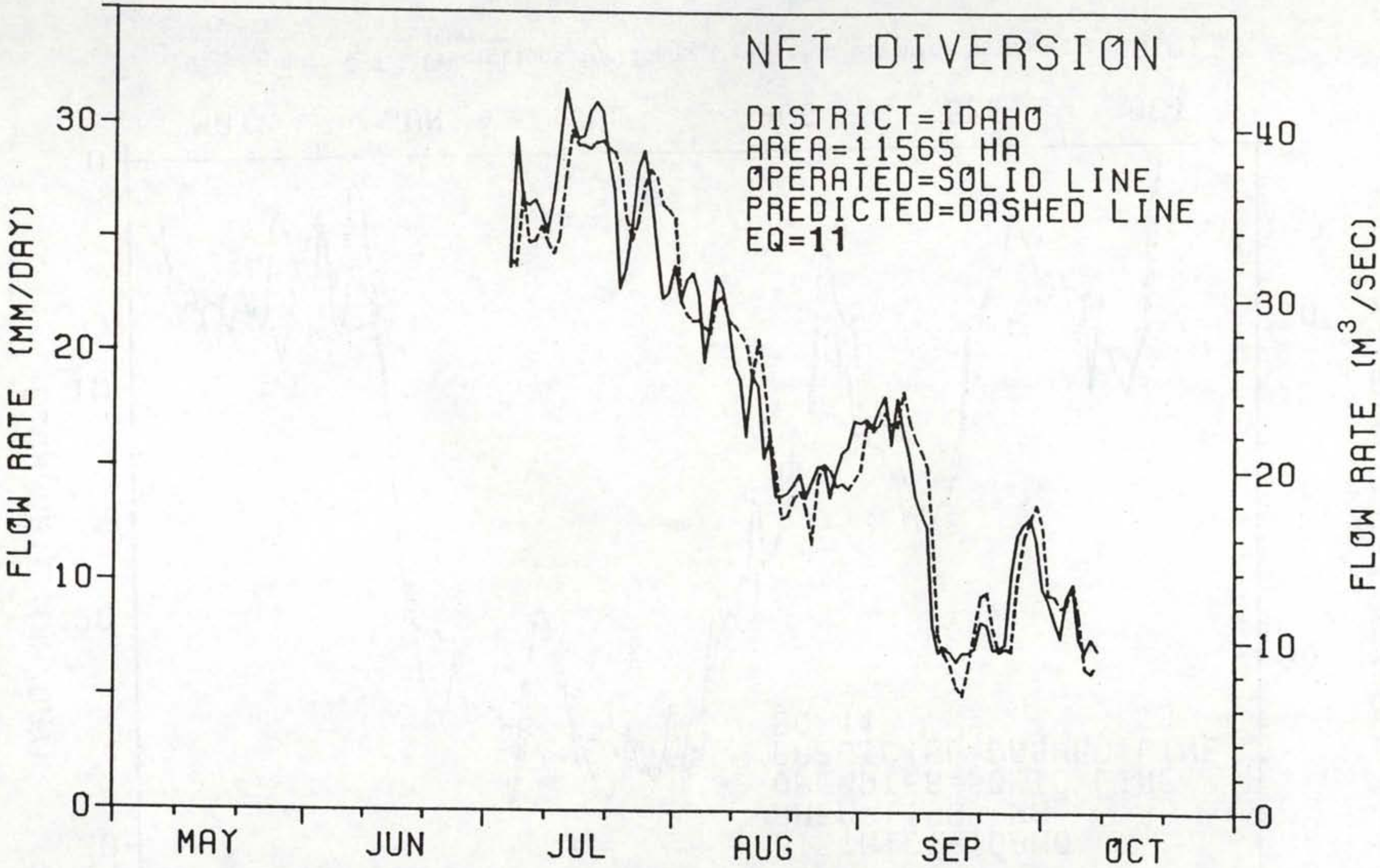

Figure C-3. Predictions for Idaho Irrigation District using equation [11]; 1978.

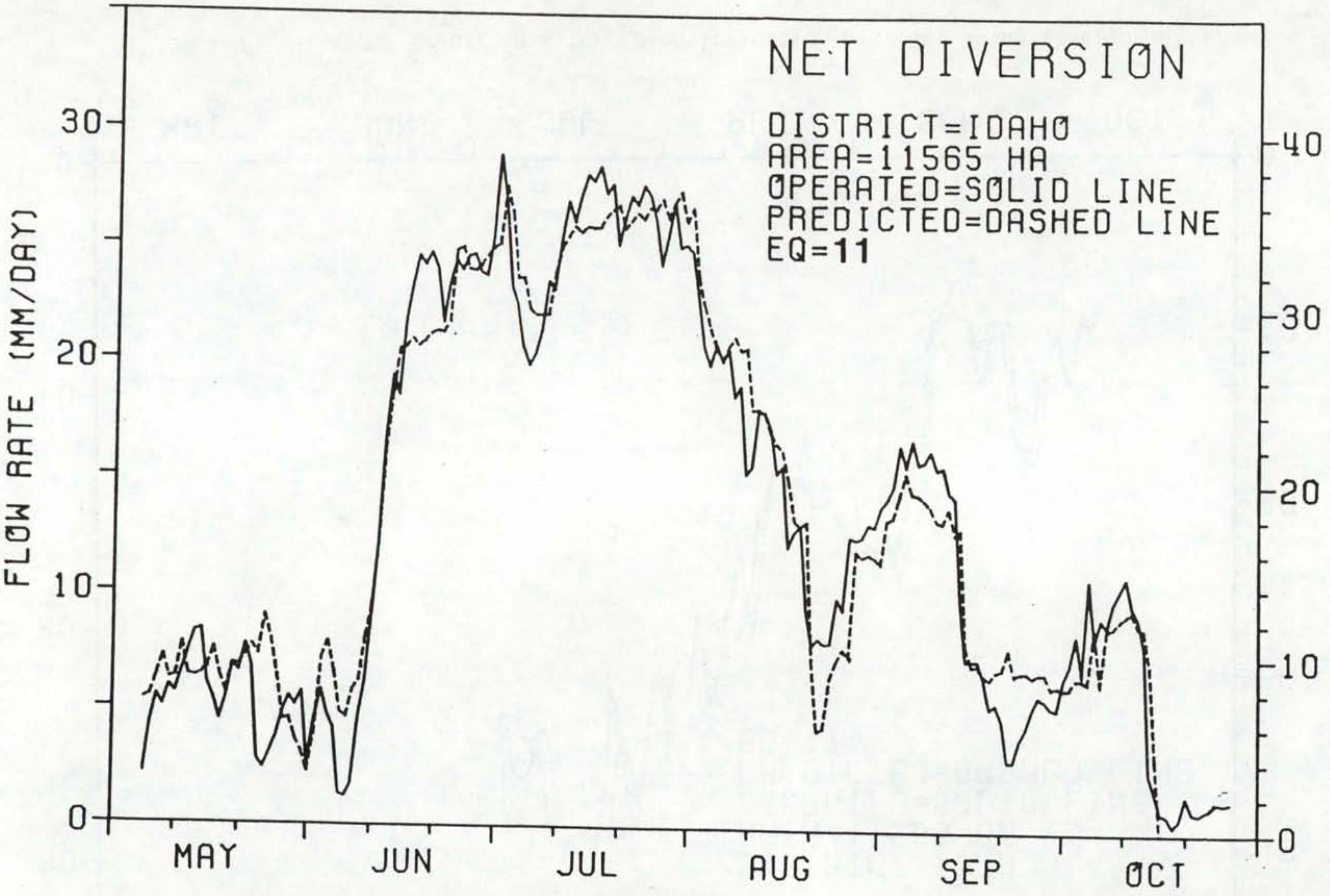

Figure C-4. Predictions for Idaho Irrigation District using equation [11]; 1980.

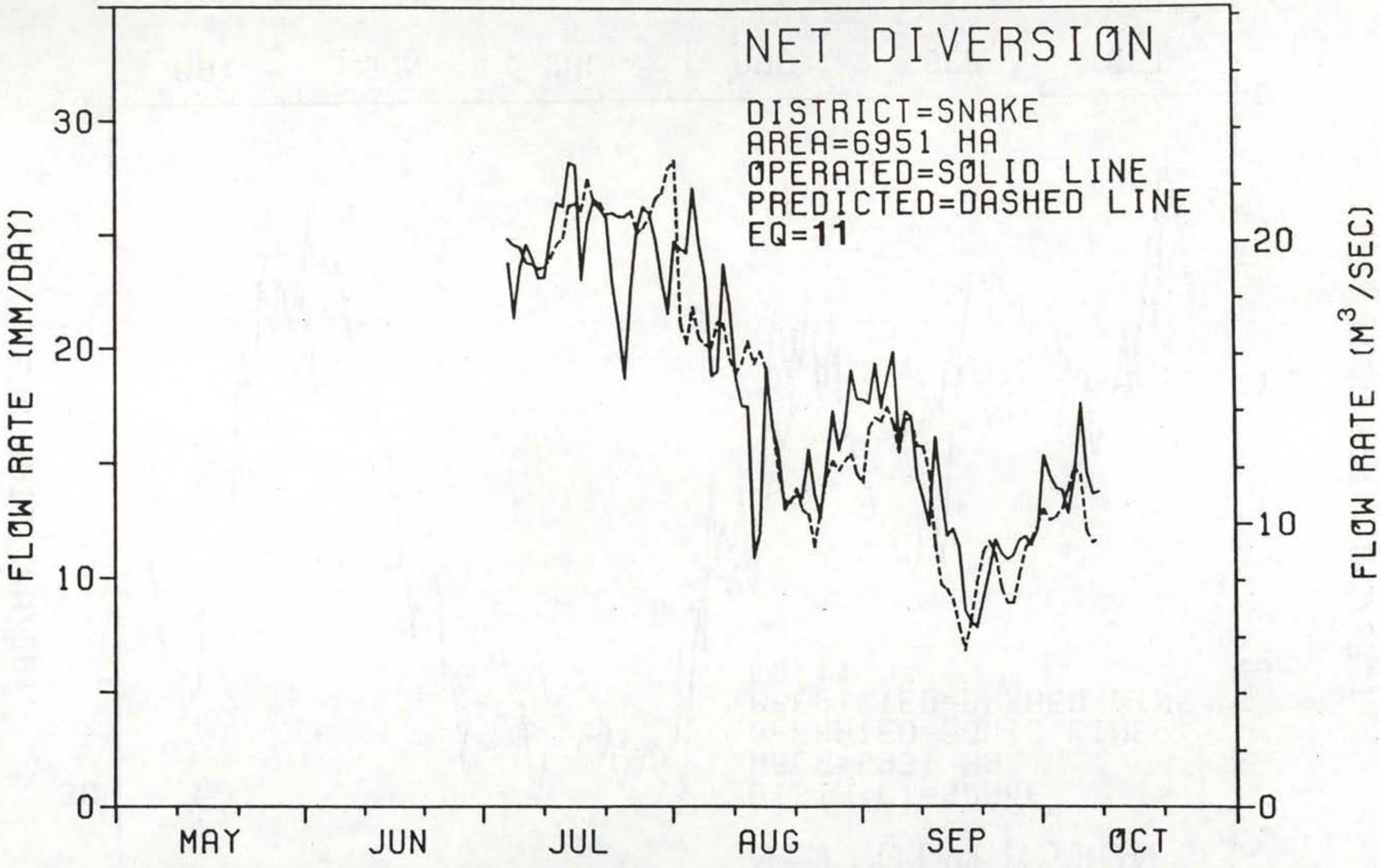

Figure C-5. Predictions for Snake River Valley Irrigation District using equation [11]; 1978.

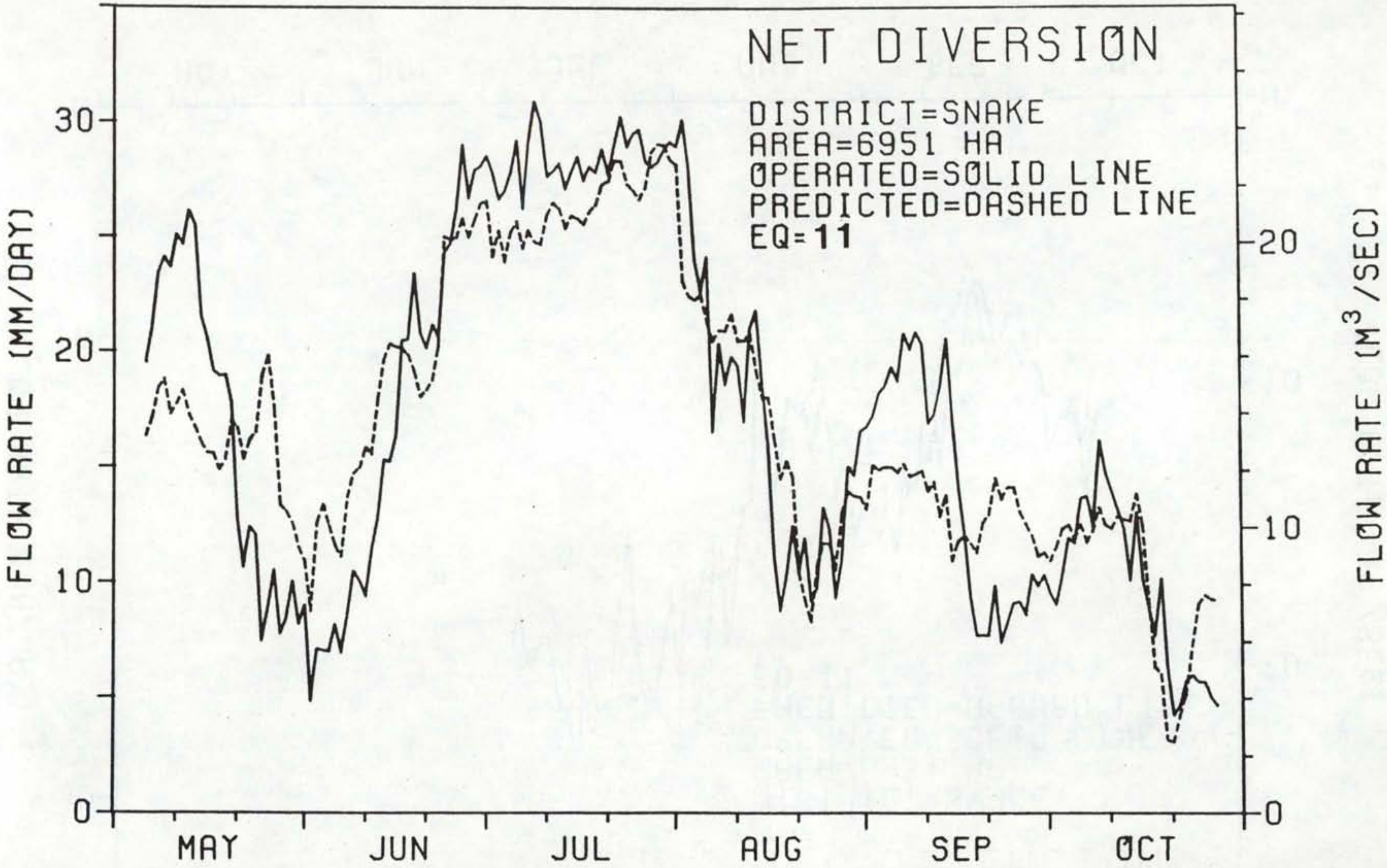

Figure C-6. Predictions for Snake River Valley Irrigation District using equation [11]; 1980.

Table C-5. Statistics for Idaho Irrigation District using equation [15].

$$QNETdiv(t) = \alpha + \beta_i * DMON_i(t) + \eta_1 * DWEEK(t) * MAQdiv(t-1) + \eta_2 * MAET(t-1) + \eta_3 * MAPC(t-1) + \eta_4 * Qdiv(t-1) + Error(t) \qquad [15]$$

Years	1978, 1979
No. of Observations	264
R^2	0.911
Standard Error	2.325

Coefficient	Value	Standard Error	T-statistic
α	2.981	0.8921	3.341
β June	0.5135	0.5373	0.9557
β July	1.011	0.6267	1.613
β August	-2.664	0.5129	-5.195
β October	-3.575	0.5575	-6.413
η_1	0.02690	0.01327	2.027
η_2	0.8996	0.1826	4.926
η_3	-1.5311	0.1686	-9.080
η_4	0.5726	0.05040	11.36

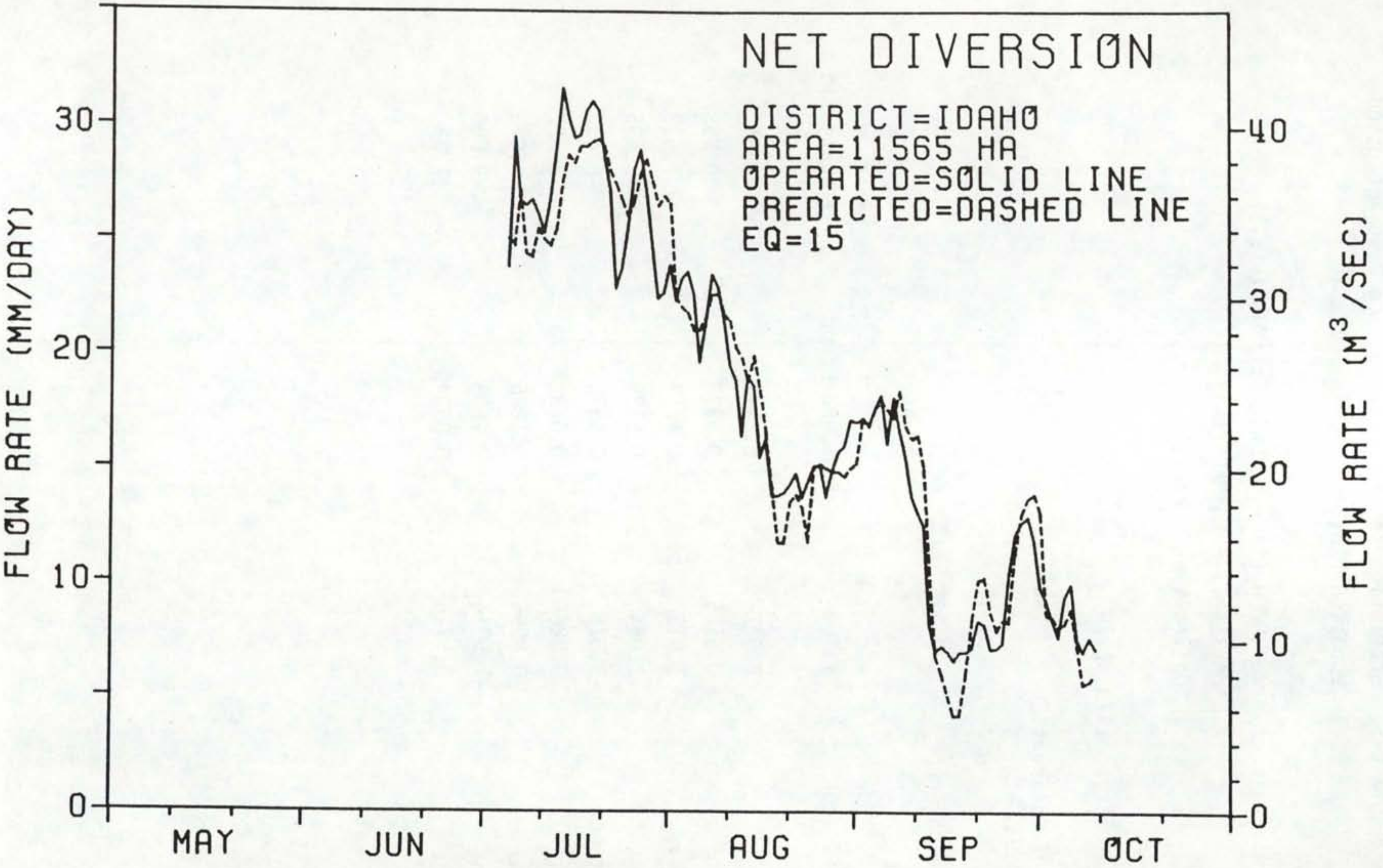

Figure C-7. Predictions for Idaho Irrigation District using equation [15]; 1978.