

**Evaluation of the 2003 Predictions of the  
Run-Timing of Wild Migrant Yearling Chinook,  
Subyearling Chinook and Steelhead  
and Water Quality at Multiple Locations on the  
Snake and Columbia Rivers using CRiSP/RealTime**

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## **Executive Summary**

This report is a post-season analysis of the performance of the CRiSP portion of the Real-Time/CRiSP complex. Observed 2003 data are compared to predictions made by CRiSP/Real-Time during the 2003 outmigration for arrival timing, water temperature, total dissolved gas, flow and spill.

CRiSP model runs consistently demonstrate that basic mechanisms of migration can be applied to Columbia River fish movements and their survival tracked downstream. As a part of RealTime/CRiSP, CRiSP is absolutely dependent on the arrival distributions predicted by the RealTime portion of the model and other river environment inputs such as flow and spill data.

New this year, additional stocks are tracked in addition to the yearling chinook of previous years. Snake River fish are tracked from Lower Granite Dam downstream. Some Snake and Columbia river ESU stocks are tracked from McNary Dam downstream.

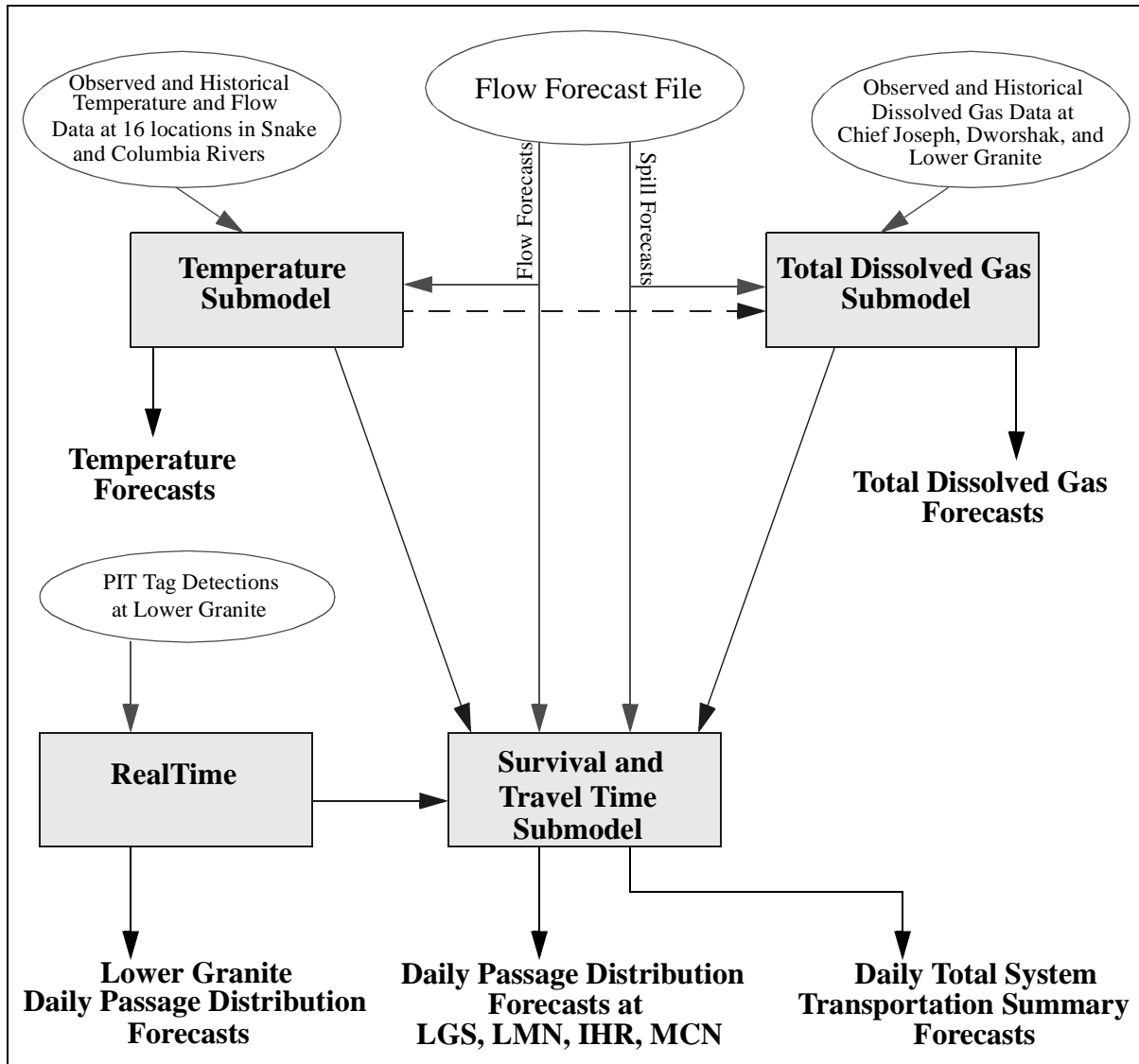
# 1 Introduction

Since 1988, wild salmon have been PIT-tagged through monitoring and research programs conducted by the Columbia River fisheries agencies and Tribes. The detection of tagged individuals at Lower Granite Dam provides a measure of the temporal and spatial distribution of the wild salmonids populations. Program RealTime was developed by researchers at the University of Washington to take advantage of this historical data to predict the proportion of a particular population that had arrived at the index site in real-time and to forecast the elapsed time to some future percentile in a migration at the site (Townsend et al. 1996, 1997; Burgess et al. 1999, 2000). The Columbia River Salmon Passage (CRiSP) model predicts downstream migration and survival of individual stocks of wild and hatchery spawned juvenile fish from the tributaries and dams of the Columbia and Snake rivers to the estuary. The model describes in detail fish movement, survival, and the effects of various river operations on these factors. Fish travel time in CRiSP has been calibrated using the PIT tag data.

During the 1996 migration season, Columbia Basin Research launched a prototype run timing system, CRiSP/RealTime, with results updated on the World Wide Web. This project was launched in an effort to provide real-time inseason projections of juvenile salmon migration to managers of the Columbia-Snake River hydrosystem to assist the managers in decisions about mitigation efforts such as flow augmentation, spill scheduling and fish transportation. CRiSP/RealTime utilizes two separate programs to generate downstream passage distributions. The program RealTime uses an empirical pattern matching routine to predict the arrival distributions for a wide variety of wild salmon stocks at the first detection point in the migratory route, Lower Granite Dam. The CRiSP model takes the predictions from RealTime and uses hydrological, fish behavioral and dam geometry information to simulate the movement and survival of juvenile salmonids through Little Goose, Lower Monumental, and Ice Harbor dams on the Snake River and McNary Dam on the Columbia River. At the same time, CRiSP produces estimates of the fraction of the run arriving at Lower Granite dam which was subsequently transported at the four transport projects: Lower Granite, Little Goose, Lower Monumental, and McNary dams.

This report is a postseason analysis of the accuracy of the 2003 predictions from the CRiSP model as part of the CRiSP/RealTime complex. In the CRiSP model, water quality affects fish

migration and survival, temperature, and dissolved gas levels which are modeled from flow and spill forecasts, historical data, and year-to-date data. The effectiveness of these modeling efforts are compared to observations of passage and river conditions at the end of the season. The analyses and graphic presentations herein demonstrate changes in accuracy of the models throughout the season.



**Figure 1** Simplified schematic of RealTime and CRiSP complex. Prior to migration year 2000, model generated gas was not updated with observed values for the production of daily passage distribution forecasts. PIT Tag data courtesy of Pacific States Marine Fisheries Commission. Water Quality Data courtesy U.S. Army Corps of Engineers. Flow Forecast File provided by Bonneville Power Administration and U.S. Army Corps of Engineers.

## 2 Methods

### 2.1 Data

#### 2.1.1 Travel Time Data

The fish analyzed in this report are individual yearling chinook stocks from tributaries of the Snake River and specific populations of yearling chinook, subyearling chinook and steelhead from the Snake and the Upper Columbia rivers. Forecasts for 2003 are based on two program RealTime index sites: Lower Granite and McNary dams. Table 1 describes these stocks and shows the abbreviations we use throughout this analysis.

**Table 1 Abbreviations used for stocks, their origin and description**

Stock Code	Stock Description / Origin	Species	Index Site
COMPOSITE	Next 4 stocks taken together	Yearling Chinook	Lower Granite <sup>a</sup>
CATHEC	Catherine Creek	Yearling Chinook	Lower Granite
IMNAHR	Imnaha River	Yearling Chinook	Lower Granite
SALRSF	South Fork Salmon River	Yearling Chinook	Lower Granite
MINAMR	Minam River	Yearling Chinook	Lower Granite
SNAKER	Snake River	Subyearling Chinook	Lower Granite
lgrStlhd	Snake River	Steelhead	Lower Granite
mcnChin1S	Snake R Spring/Summer Chinook ESU	Yearling Chinook	McNary <sup>b</sup>
mcnChin0S	Snake R Fall Chinook ESU	Subyearling Chinook	McNary
mcnChin0C	Upper Columbia R Fall Chinook ESU	Subyearling Chinook	McNary
mcnStlhdS	Snake R Steelhead ESU	Steelhead	McNary
mcnStlhdC	Upper Columbia R Steelhead ESU	Steelhead	McNary

a. For the stocks with the Lower Granite Index Site, program RealTime forecasts passage distribution of the stock at Lower Granite and this forecast is used as input to the CRiSP model to project the run-timing of the stock at Little Goose, Lower Monumental, Ice Harbor, and McNary dams.

b. For the stocks with the McNary Index Site, program RealTime forecasts passage distribution of the stock at McNary and this forecast is used as input to the CRiSP model to project the run-timing of the stock at John Day, The Dalles, and Bonneville dams.

Previous postseason analyses generally included only the COMPOSITE stock and its component stocks. The fish were tagged in their natal streams with passive integrated transponder (PIT)

tags. PIT-tagging of wild salmon is part of on-going monitoring and research programs conducted by the Columbia River fisheries agencies and Tribes. Information from PIT tag studies and other fish monitoring programs is presented in reports by the Fish Passage Center, National Marine Fisheries Service (Achord et al. 1992, 1994, 1995a, 1995b, 1996, 1997), Idaho Department of Fish and Game (Kiefer et al. 1993, 1994), Oregon Department of Fish and Game (Keefe et al. 1994; Walters et al. 1997) and the Nez Perce Tribe (Ashe et al. 1995). PIT tags provide instantaneous passage times for individual fish at interrogation sites (Prentice et al. 1990). This year, we are focusing on the passage at McNary Dam for the Lower Granite Index Site stocks and John Day Dam for McNary Index Site stocks.

For the CRiSP downstream projections, we are limited to using historical data since 1993 in order to estimate fish travel time parameters and confidence intervals. Although fish were PIT-tagged previous to these years, there was no provision made to return detected PIT-tagged fish to the river. Consequently, the majority of fish observed at Lower Granite Dam were removed from the river by transport operations. Too few fish were subsequently observed at downstream interrogation sites to generate passage distributions and travel time estimates. In 1993, slide gates were installed which selectively diverted PIT-tagged fish back into the river, allowing for adequate sample sizes at the downstream interrogation sites.

### **2.1.2 Flow, Spill and Other System Operation Data**

Any forecast of fish movement relies critically on accurate forecasts of flow, spill, transportation, and other key system operations. The U.S. Army Corps of Engineers generates flow, spill, and reservoir surface elevation forecasts at all projects on the Columbia and Snake Rivers where there is fish passage. Water supply forecasts are based on a number of factors: the National Weather Service's Northwest River Forecast Center predictions, flood control requirements from the Army Corps, electrical power demand forecasts, and other criteria. The substantial uncertainty associated with springtime conditions often results in frequent and marked changes in these forecasts during April and May. Moreover, attempts to reduce the biological impacts of dissolved gas generated from high spill levels also results in a shifting of spill between projects within as well as outside the basin. Although the forecasts covered as much as 90 days into the future, it must be

recognized that their principal use was in deciding operations for the next week. Forecast accuracy beyond even a few days was itself uncertain. Bonneville Power Administration processes the Army Corps forecasts and makes them available to CBR staff throughout the migration season.

Forecasts for flow, spill, and elevation were replaced with observations on a daily basis with a query to the Columbia River DART database, which downloads water quality data from the Army Corps for the majority of monitoring sites in the Columbia Basin. This method was begun in 2001 and was a significant improvement over the 2000 in-season forecasts that relied on the forecasts alone. Subsequent fish arrival predictions were therefore based on the forecasted values for flow and spill and the latest available observed data.

Flow and spill forecasts provided by the Army Corps did not include forecasted spill values for the Upper Columbia projects (Wanapum, Priest Rapids, Rocky Reach, Rock Island, and Wells). Fixed target spill percents were substituted as forecast values for these dams.

**Table 2 Targeted spill percents used for Upper Columbia dam spill forecasts from mid-May through mid-June.**

dam	PRD	WAN	RIS	RRH	WEL
spill percent	61	35	20	24	7

### 2.1.3 Temperature Data

The temperature time series used in the CRiSP analysis is a combination of year-to-date temperature data and forecasted temperatures. The forecasts are based on observed year-to-date temperature and flow data, historical average temperature and flow profiles for 15 locations in the Snake and Columbia rivers, and the flow forecasts. Historic and observed year-to-date data was obtained from the DART database. Temperature predictions are made by applying a three-day moving window to fit predicted temperature time series to historical average patterns of temperature change; this method is described in detail in section 3.2.

**Table 3 U.S. Army Corps of Engineers fixed monitoring sites and USGS gaging stations used by CRiSP for Temperature forecasts.**

Monitoring Locations	CRiSP Model Input Locations
Chief Joseph Forebay	Columbia Headwater

**Table 3 U.S. Army Corps of Engineers fixed monitoring sites and USGS gaging stations used by CRiSP for Temperature forecasts.**

Monitoring Locations	CRiSP Model Input Locations
Wells Forebay	Methow Headwater
Rock Island Forebay	Wenatchee Headwater
The Dalles Forebay	Deschutes Headwater
Anatone, WA USGS	Snake Headwater
Peck, ID USGS	Clearwater Headwater
Peck, ID USGS	North Fork Clearwater Headwater
Peck, ID USGS	Middle Fork Clearwater Headwater
Anatone, WA USGS	Salmon Headwater
Wells Forebay	Wells Pool
Rocky Reach Forebay	Rocky Reach Pool
Rock Island Forebay	Rock Island Pool
Wanapum Forebay	Wanapum Pool
Priest Rapids Forebay	Priest Rapids Pool
Lower Granite Forebay	Lower Granite Pool
Little Goose Forebay	Little Goose Pool
Lower Monumental Forebay	Lower Monumental Pool
Ice Harbor Forebay	Ice Harbor Pool
McNary Forebay	McNary Pool
John Day Forebay	John Day Pool
The Dalles Forebay	The Dalles Pool
Bonneville Forebay	Bonneville Pool

#### **2.1.4 Total Dissolved Gas Data**

Total dissolved gas (TDG) data are collected at Army Corps fixed monitoring sites below the



Columbia and Snake River dams. The observed year-to-date TDG data for Chief Joseph, Lower Granite, and Dworshak is obtained daily by a query to the Columbia River DART database. The data is downloaded daily from the primary source, the Army Corps, and quality assurance is not always guaranteed. Anomalies in observed TDG data are indicators of suspicious data.

The modeled gas production predicts the gas observed at the Army Corps fixed monitors. For a map of the dissolved gas monitoring system, see the Water Management Division, U.S. Army Corps of Engineers web document, <http://www.nwd-wc.usace.army.mil/report/pdf/gasmap.pdf>. It should be noted that the nearest downstream monitor to Bonneville Dam is 6 miles downstream, so it is expected that the gas levels at this monitor (WRNO) will be lower than those generated at the dam.

**Table 4 U.S. Army Corps of Engineers total dissolved gas fixed monitoring sites used by CRiSP for Total Dissolved Gas forecasts.**

Fixed Monitoring Station Name	Station Code	Location facing downstream
Chief Joseph Tailwater	CHQW	Right Bank
Wells Tailwater	WELW	Left Bank
Rocky Reach Tailwater	RRDW	Mid Channel
Rock Island Tailwater	RIGW	Left Bank
Wanapum Tailwater	WANW	Mid Channel
Priest Rapids Tailwater	PRXW	Mid Channel
Dworshak Tailwater	DWQI	Left Bank
Lower Granite Tailwater	LGNW	Right Bank
Little Goose Tailwater	LGSW	Right Bank
Lower Monumental Tailwater	LMNW	Left Bank
Ice Harbor Tailwater	IDSW	Right Bank
McNary Tailwater	MCPW	Right Bank
John Day Tailwater	JHAW	Right Bank
The Dalles Tailwater	TDDO	Left Bank

**Table 4 U.S. Army Corps of Engineers total dissolved gas fixed monitoring sites used by CRiSP for Total Dissolved Gas forecasts.**

Fixed Monitoring Station Name	Station Code	Location facing downstream
Bonneville Tailwater	WRNO	Left Bank

### 2.1.5 Archives of Model Predictions

The results of the RealTime and CRiSP model runs are stored on the Columbia Basin Research web site. Graphs and text reports based on the results are available through a variety of web-based query tools at <http://www.cbr.washington.edu/crisprt/>. Runs are made several times per week. Archives include daily passage distribution forecasts at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, and McNary dams for each stock of interest and water quality predictions for selected dams on the Columbia and Snake Rivers.

## 2.2 Models

### 2.2.1 CRiSP

CRiSP is a mechanistic model that describes the movement and survival of juvenile salmon in the Columbia and Snake Rivers. The theory and calibration of the model is described in detail in Anderson et al. (2000). We include only a brief summary of the model here, but we note that it has been extremely successful in fitting all of the yearling chinook survival data collected in the Columbia Basin, from 1966 through the present day.

Modeled factors that affect survival of hatchery and wild juvenile stocks include daily flow, river temperature, predator activity and density, total dissolved gas (TDG) supersaturation, and river operations such as spill, fish transportation and bypass systems. For CRiSP model runs, flow and spill were provided by BPA. Temperature and TDG forecasts were developed based on those flow and spill estimates and year-to-date observed data. All other relevant parameters were determined at CBR, based on a variety of different sources.

Dam passage changes with fish guidance efficiency, passage mortalities, and diel passage behavior. These factors are modeled on a species and dam-specific basis. Relevant model parameters for inseason modeling of all stocks are given in Appendix B. These parameters are generally

drawn from the literature or are calibrated from related data (e.g. PIT tag detection rates at various projects). Reservoir mortality depends on several factors: fish travel time, predator density and activity, total dissolved gas supersaturation levels, and water temperature. Predator densities used in CRiSP were estimated from several published sources (Beamesderfer and Rieman 1991; Vigg et al. 1991; Ward et al. 1995; Zimmerman and Parker 1995; Zimmerman et al. 1997). Total dissolved gas production equations are based on research conducted by the Waterways Experiment Station (WES), U.S. Army Corps of Engineers on eight Columbia Basin dams and fitted to other dams in the Columbia Basin system by CBR (U.S. Army Corps of Engineers 1996, 1997; Anderson et al. 2000).

### 2.2.2 Travel Time Components

The main factors determining predicted arrival distributions of fish at the downstream dams are migration travel time and reach mortality. The river is divided into a series of reaches, and fish move through the reaches sequentially. In each reach, the travel time distribution is determined by the migration rate ( $r_t$ ) and the rate of spreading ( $V_{VAR}$ ) (Zabel and Anderson 1997). These vary between the two reach classes defined for 2003, a new feature in CRiSP1.7. The "Lower" class includes the John Day pool on downstream. The "Upper" class includes McNary pool and upstream pools on both the Snake and the Columbia.

Migration rate varies by reach and by time step and is stock and reach class specific. The CRiSP migration rate equation takes into account fish behavior related to river velocity, seasonal effects, and fish experience in the river (Zabel et al. 1998). The full migration model is:

$$r_t = \beta_0 + \beta_1 \left[ \frac{1}{1 + \exp(-\alpha_1(t - T_{RLS}))} \right] + \beta_{FLOW} \cdot \left[ \frac{\bar{V}_t}{1 + \exp(-\alpha_2(t - T_{SEASON}))} \right] \quad (1)$$

where:

$r_t$  = migration rate

$t$  = Julian date

$T_{RLS}$  = Julian Date of passage at index site: Lower Granite or McNary

$T_{SEASON}$  = inflection point of flow-dependent term that has the effect of shifting the flow effect through the season

$\beta_0$  and  $\beta_1$  = flow-independent parameters

$\alpha_1$  = a slope parameter that determines the rate of change of the experience effect

$\alpha_2$  = a slope parameter that determines how quickly the flow effects shift from early-season to late-season behaviors

$\beta_{FLOW}$  = parameter that determines the proportion of river velocity used for migration

$V_t$  = the average river velocity during the average migration period, for each reach.

The flow-independent part of the equation starts fish at a minimal migration rate ( $\beta_{MIN}$  at  $t=T_{RLS}$ ) with fish increasing their flow-independent migration rate to a maximal migration rate ( $\beta_{MAX}$  as  $t \gg T_{RLS}$ ). These rates are determined as follows:

$$\beta_{MIN} = \beta_0 + \beta_1/2 \quad (2)$$

$$\beta_{MAX} = \beta_0 + \beta_1. \quad (3)$$

The parameter  $\alpha_1$  determines the rate of change from  $\beta_{MIN}$  to  $\beta_{MAX}$ . For each stock, the rate of spreading parameter ( $V_{VAR}$ ) is estimated, along with the three migration rate parameters:  $\beta_{MIN}$ ,  $\beta_{MAX}$ , and  $\beta_{FLOW}$ .

A reduced model eliminates the transition from  $\beta_{MIN}$  to  $\beta_{MAX}$  by setting  $\beta_1 = 0$ , which is more appropriate for fish without flow-independent terms:

$$r_t = \beta_{Min} + \beta_{FLOW} \cdot \left[ \frac{\bar{V}_t}{1 + \exp(-\alpha_2(t-T_{SEASON}))} \right]. \quad (4)$$

Similarly, a two parameter model suffices for some stocks where the velocity is the determining factor alone:

$$r_t = \beta_{Min} + \beta_{FLOW} \cdot \bar{V}_t. \quad (5)$$

### 2.2.3 Parameter Estimation

The spread parameter (VVAR) was estimated for each stock from historical observations. Migration rate parameters were estimated from the historical data using an optimization routine.

that compares model predicted passage distributions to observed ones. The first step is to use the passage distribution at Lower Granite as a release distribution in the CRiSP model. Based on an initial set of parameters, arrival distributions are generated at the downstream observation sites through McNary Dam. The model predictions are compared to the observations, and then the optimization routine selects a new set of parameters to try. This procedure iterates until the parameters are selected that minimize the difference between the observations and the predictions. Once the upper river reaches are calibrated, The lower reaches are assigned a different reach class and the migration parameters are optimized for them.

The modeled mean travel times are a function of the migration submodel chosen and the particular parameter values selected. The migration rate parameters were estimated by a least-squares minimization (with respect to the parameters) of the following equation:

$$SS = \sum_{i=1}^O \sum_{k=1}^C (\hat{T}_{i,k} - \overline{T}_{i,k})^2, \quad (6)$$

where:

$O$  = the total number of observation sites,

$C$  = the total number of cohorts,

$\hat{T}_{i,k}$  = the modeled mean travel time to the  $i$ -th site by the  $k$ -th cohort, and

$\overline{T}_{i,k}$  = the observed mean travel time to the  $i$ -th site by the  $k$ -th cohort.

Parameters used during the 2003 migration season can be found in Appendix B.

#### 2.2.4 Assessment of Predictions

To assess the performance of the passage and other predictions, we apply the same measure used to assess RealTime predictions (Townsend et al. 1996). For each stock at each observation site, we compute the Mean Absolute Deviation (MAD) for the day ( $j$ ) on which the prediction was made. This measure is based on the average deviation between predicted and observed cumulative passage on prediction dates during the season. MAD is computed as:

$$MAD_j = \frac{1}{N} \sum_{t=1}^N \left| F_{Day_t} - \hat{F}_{Day_{tj}} \right| \times 100 \quad (7)$$

where:

$j$  = forecast day on which MAD is calculated;

$t$  = index of prediction day (from 1 to  $N$ );

$N$  = number of days on which a prediction and observation were made for the stock at the site during the season;

$Day$  = vector of length  $N$  which identifies the Julian days from first observation of the stock at the site until two weeks past last observation (this is fixed for each site and each stock);

$F_{Day_t}$  = observed cumulative passage on  $Day_t$ ; and

$F_{Day_{tj}}$  = predicted cumulative passage on  $Day_t$ .

For each stock/site combination, the season length is determined as the time from when the first fish for the particular stock is observed at the site until two weeks after the last fish is observed at the site. This arbitrary "tail" of the distribution accounts for the possibility that fish may subsequently pass without being detected; the same two-week tail is used to generate MADs for RealTime.

The summation in Equation (7) is performed over each of the dates on which model predictions were implemented – approximately every day during the season. This provides a snapshot of how well the model performs as the season progresses based on the final, "true" data. Ideally, there would be general decrease in MAD as  $j$  goes from 1 to  $N$  because the true distribution of the run should be better known and the true state of the flow and spill profiles should be known.

### 2.2.5 Temperature Algorithm

A temperature forecasting algorithm was developed to predict the current year's water temperatures on the Snake and Columbia Rivers based on historical data, year-to-date data, and the flow forecast file. The forecasted river temperatures in the near future are based on the current trend in temperature; however, far into the future, the algorithm relies on mean temperature profiles and adjusts this mean according to the amount of flow. Mean temperature and flow profiles were computed for all locations found in Table 5 using data from 1976 to the present. We queried the

Columbia River DART database for current year-to-date temperature and flow data each time a prediction was made. CRiSP used the temperature forecasts at the locations listed in Table 3 for the generation of total dissolved gas forecasts and passage distribution forecasts. Temperature forecasts at Lower Granite (LWG), Priest Rapids (PRD), and The Dalles (TDA) are published on the web site as representative of the Snake, Mid-Columbia and Lower Columbia temperatures, respectively.

The forecast algorithm begins by setting the daily temperature to the mean for that day and then replacing the mean temperatures where year-to-date information is available. The last 3 days of available temperatures are looked at to predict the next day's temperature. Averaging over the last three days is an attempt to smooth out some of the day to day variation and to provide a safeguard against bad data giving the algorithm a faulty starting point. Given the averaged starting point, the next 4 weeks of temperatures are calculated by taking the previous day's temperature and adding to it the average daily temperature increment for that day.

Over time, the current trend of temperature becomes less and less useful and eventually uncorrelated with future temperatures. Thus after four weeks, this predictor is phased out of the calculation. This is when the flow forecast information enters into the algorithm. The flow forecast together with the mean profiles of flow and temperature predict what temperatures a month or more from reliable data will be. The relationship between flow and temperature is the following:

$$T_i = tempmean_i + B_0 + B_1 \cdot (F_i - flowmean_i) \quad (8)$$

where:

$T_i$  = temperature prediction value for day  $i$ ,

$tempmean_i$  = mean temperature on day  $i$  from mean temperature profile,

$B_0$  and  $B_1$  = flow coefficients,

$F_i$  = flow forecast value for day  $i$ ,

$flowmean_i$  = mean flow on day  $i$  from mean flow profile.

Temperature was measured in Celsius and flow in kcfs. A separate analysis for the flow coefficients was conducted early in 2002 and the results are presented in Table 5.

**Table 5 Values used for the flow coefficient  $B_1$  during the 2003 migration season were the same for 2002. The flow coefficient  $B_0$  was set to 0 at all locations.**

Location	$B_1$
Bonneville	-0.0043770060
The Dalles	-0.0015191452
John Day	-0.0055892750
McNary	-0.0076976137
Ice Harbor	-0.0145351785
Lower Monumental	-0.0099626503
Little Goose	-0.0160505825
Lower Granite	-0.0152362973
Priest Rapids	-0.0085965643
Wanapum	-0.0025145659
Rocky Reach	-0.0102809333
Rock Island	-0.0079651068
Wells	-0.0009238544
Chief Joseph	0.00187884532
Anatone, WA (13334300)	-0.00001908619
Peck, ID (13341050)	-0.00007100836

### 2.2.6 Total Dissolved Gas Modeling

The gas production equations are an empirical fit of spill data collected by the Army Corps (ACOE). These equations were modified as necessary to accommodate CRiSP function formats and the curves generated by CRiSP compatible functions were adjusted to minimize the difference with the ACOE's curves. The percent of total dissolved gas (TDG) exiting the tailrace of a dam is predicted as a function of the amount of discharge in kcfs. This level of TDG is not necessarily the highest level of gas reached, but rather the level of gas in the spill water after some of the more turbulent processes have stabilized. The calibration for each dam was fit to the nearest



downstream monitor. These are typically about a mile downstream of the dam.

In the past CRiSP has been formulated to accommodate any one of several TDG production models. Currently, all dams are modeled with a bounded exponential model requiring three parameters.

$$\%TDG = a + b \cdot \exp(c \cdot Q_s) \quad (9)$$

The TDG production parameters are shown in Table 6. The MAD value refers to the mean absolute deviation of all the available data to the prediction of the the equation. The parameter set that minimized MAD is the equation we utilize.

**Table 6 Calibrated spill production parameters for 14 sites based on 2000, 2001, and 2002 observed TDG. Columns "low" and "high" are the bounds of applicable spills.**

sites	MAD	a	b	c	low	high
BON	3.060	17.2	-30.9	-0.03070	0	400
TDA	1.140	19.9	-19.1	-0.01850	0	400
JDA	1.390	24.1	-21.4	-0.01350	0	400
MCN	1.230	23.8	-17.8	-0.00987	0	400
IHR	1.000	36.3	-36.3	-0.00837	0	200
LMN	1.270	57.0	-48.6	-0.00589	0	200
LGS	0.931	33.1	-26.2	-0.01260	0	200
LWG	1.270	38.8	-37.2	-0.01220	0	200
PRD	1.610	22.3	-20.4	-0.01960	0	200
RIS	3.100	19.4	-19.4	-0.07750	0	200
RRH	3.520	20.2	-20.2	-0.03780	0	200
WAN	1.380	26.6	-21.8	-0.01140	0	200
WEL	1.820	47.6	-40.0	-0.00642	0	200
CHJ	4.420	21.4	-21.4	-0.09130	0	100
DWR	2.330	51.5	-51.5	-0.04110	0	100

### 2.2.7 Assessment of Temperature and TDG Predictions

Similar to the passage prediction assessment, we computed MAD between predicted tempera-

ture or TDG values and the observed values for each observation site. Hindcasts may change throughout the prediction period as observations were corrected and updated information was used.

## **3 Results**

The joint effort of RealTime and CRiSP produced many inseason forecasts products, including:

- Daily Fish Passage (joint product)
- Passage and Transport Summary (joint product)
- Smolt Passage Predictions w/Historical Timing Plots (RealTime only product)
- Total Dissolved Gas (TDG) Forecasts (CRiSP only product)
- Temperature Forecasts (CRiSP only product).

These products are presented graphically via the World Wide Web at

<http://www.cbr.washington.edu/crisprt/>. In this report, selected CRiSP/Realtime predictions are analyzed and graphic presentation of these results follow in the various appendices.

### **3.1 Flow and Spill Forecasts**

Forecasts of flow and spill were made available approximately every two weeks during the season and affected the accuracy of passage predictions. The timing of the updated flow and spill forecast files sometimes corresponds with sudden changes in the passage predictions and hence MAD values. In the past, these files have been made available more frequently. Forecasted flows and spills for April 7, June 9 and Aug 6 at LWG, PRD, TDA, and BON are shown in Appendix C.

Early forecasts of daily-averaged flow over the entire season at LWG were moderately accurate. Since migration year 2001, the flow forecast files no longer contain spill forecasts at the Upper Columbia dams operated by the PUDs. For the 2003 season as in years past, we used a target spill percent value of 61% at PRD (Table 2 contains the target spill values for these Upper Columbia dams). The trend for the last three years is in Appendix D. Flow and spill forecasts affect fish passage, total dissolved gas, and temperature. Errors in these forecasts have to be propagated through the model and do affect model results.

### **3.2 Temperature Prediction**

The temperature prediction algorithm begins by setting the daily temperature to the historical mean value for that day and then replacing the mean temperatures where year-to-date information is available. Given an averaged starting point from the previous few days of current data, the next four weeks of temperatures are calculated by taking the previous day's temperature and adding to it the historically averaged daily temperature increment for that day. Over the forecast period, the current trend of temperature becomes less and less useful and eventually uncorrelated with future temperatures. Thus for the long term forecaster (over four weeks), this predictor is phased out of the calculation. At this point, a simple linear regression against predicted flow is used to predict temperatures a month or more away from reliable data.

A general trend of negative correlation between flow and water temperature can be seen in data from the Snake and Columbia Rivers. Years with higher (lower) than average flows have lower (higher) than average water temperatures. Using a flow forecast file for the current year, a prediction of temperature can be made using the flow/temperature relationship (see 2.2.5 for details). It should be noted that water temperature data are very noisy and are influenced by several variables: air temperature and other weather conditions, water volume and reservoir geometry, snowpack, upstream water releases, etc. Consequently, the flow/temperature relationship only explains a small amount of the variation of water temperature within a year and between years. As a result, averaged historical data plays a large part in the predictions made, with the flow/temperature relationship only predicting a small amount of variation about the mean.

The algorithm developed for temperature has many desirable features. It concurs with the most up-to-date data, it is consistent with historical seasonal patterns in temperature, and it uses predicted flows to make moderate adjustments. Temperature predictions were generated about every three weeks during the migration season, coinciding with the generation of a new flow forecast file.

Sample predictions versus the 2003 observed temperatures for three reservoirs are shown in Appendix E. For all three reservoirs, the predictions became more accurate as the season went on and more observed data for 2003 became available. Initially, the forecasts looked smooth, anticipating a change in temperature that roughly corresponded to the natural annual cycles of flow and air temperatures. However, there was a great deal of variability in the observed temperatures that

the forecaster could not anticipate.

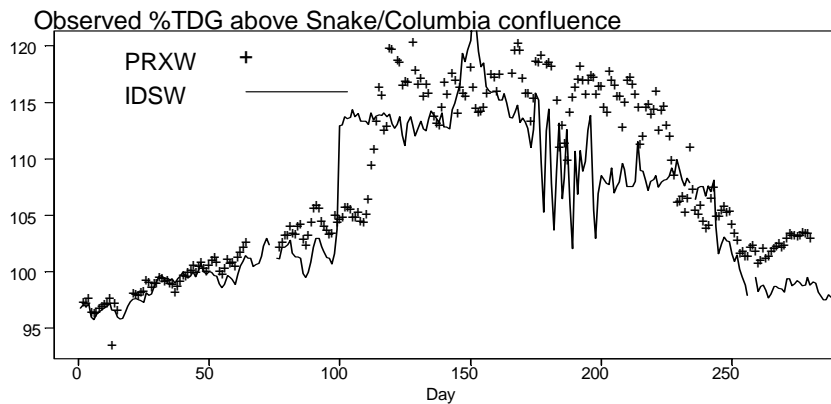
Appendix F shows, for each of the three dams, a time series of how accurate the predictions were on each day. In each of the plots, MAD is plotted for the forecast made on that day compared to the data (see '2.2.4 Assessment of Predictions').

In general, short-term predictions (i.e. for the next week) are no better than long-term predictions (for the next several weeks); this is a consequence of lack of quality assurance for year-to-date temperature data. Since predicted temperatures take as their starting point the most recent "observed" temperatures, any inaccuracy in recent temperature records will be reflected in the short-term predictions of temperature. CRiSP, while sensitive to temperature variation, does not produce strongly different results for differences of a few °C, and these inaccuracies are unlikely to have contributed significantly to any model error.

### **3.3 Total Dissolved Gas Prediction**

The Total Dissolved Gas (TDG) predictions used observed dissolved gas data, predicted spill at upstream dam(s), and temperature profile output from the temperature algorithm to anticipate dissolved gas concentrations. Predictions begin with querying the Columbia River DART database for dissolved gas percentage data for Chief Joseph (CHJ), Lower Granite (LWG), and Dworshak (DWR) dams, and observed spill data for DWR. This observed data is used in conjunction with historical monthly TDG mean values at CHJ, LWG and DWR to produce output gas profiles for each of these dams for the whole year. Missing or invalid data points at the beginning of the series are filled in using the first valid data point; holes between valid data points are linearly interpolated between the two surrounding data points; and missing data after the last valid data point are filled in with historical mean values. The output gas profiles are used as direct input to the CRiSP model of dissolved gas at several headwater locations: Columbia Headwater, Lower Granite Pool, and North Fork Clearwater Headwater. The TDG forecasts rely on the results of the temperature predictions for temperature data and the flow forecast files for the flow and spill. The TDG forecasts in particular are sensitive to predicted flows and planned spill. The TDG forecasts are produced for each dam by running CRiSP and generating gas production at all the dams in the basin.

TDG forecasts were made each time a new flow forecast file was made available to CBR. Sample predictions versus the 2003 observed total dissolved gas data for five monitoring sites are shown in Appendix G. The gas levels in the Columbia are higher than in the Snake River. Below the confluence with the Snake mixing serves to help equilibrate these dynamics.



Generally, the predictions became more accurate as the season progressed and more observed data became available. The five sites shown are typical with predictions generally all with less than 3% TDG error. This is shown by the plots in Appendix H that are analogous to the prediction success plots shown for temperature.

### 3.4 Passage Distribution Prediction

Plots of predicted passage distributions compared to the observations of PIT-tagged fish are provided in Appendix I. The entire passage distribution predictions are presented for three representative dates: April 27, May 15, and June 17 to span the early, middle and late portions of the run. Previous to the date of prediction (vertical line) the model predictions are based on hindcast passage for the best available river conditions. Ahead of the prediction date is the forecast passage based on anticipated river conditions (discussed in other sections: see 3.1, 3.2, 3.3). Complete plots showing the current forecast with historic conditions are available on our web site at <http://www.cbr.washington.edu/crisprt/>.

**Table 7 Number of PIT-tagged fish<sup>a</sup> used for RealTime and CRiSP modeling at selected observation sites.**

Stock	Number of fish with PIT tags observed at:					
	Lower Granite	Little Goose	Lower Monument	McNary	John Day	Bonneville
COMPOSITE	232	182	96	142	85	82
CATHEC	99	80	46	49	34	36
IMNAHR	43	35	27	38	23	14
SALRSF	12	12	4	10	8	3
MINAMR	78	55	19	45	20	29
SNAKER	316	340	159	205	48	33
lgrStlhd	5717	20995 <sup>b</sup>	9264	3980	2183	3602
mcnChin1S	NA	NA	NA	16123	7987	6660
mcnChin0S	NA	NA	NA	625	153	88
mcnChin0C	NA	NA	NA	1311	291	183
mcnStlhdS	NA	NA	NA	4035	2200	3634
mcnStlhdC	NA	NA	NA	18835	22724	15590

a. The RealTime/CRiSP complex uses a subset of all available PIT-tagged fish for the stocks of interest.

b. From April 10 to June 7, 31538 PIT-tagged wild summer steelhead were released at LGRRRR, which is defined as release below the PIT-Tag Diversion System Gate at Lower Granite with subsequent return to the river. These fish are not included in the detections at Lower Granite nor the program RealTime arrival distribution forecast.

In the plots in Appendix I, the predictions at McNary and John Day are based on CRiSP projected passage of program RealTime forecasted arrival distributions at Lower Granite and McNary Dam, respectively. Any error in the prediction at the index site is propagated to the downstream sites. Failure to detect, or report all PIT-tagged fish passing the detectors at Lower Granite Dam meant that their continued downstream movement could not be modeled accurately. Obviously, some fish escaped detection at one site only to be observed at another site downstream as is illustrated with the cumulative returns of some stocks at some dams as shown by the plots in Appendix J and by the counts shown in Table 7. Thus the apparent arrival time distributions do

not match the population's observed distribution simply because they are counting overlapping but different groups of fish. The simple fact that more fish are observed downstream distorts the ability of CRiSP to predict downstream travel.

The MAD results for RealTime and the downstream predictions are presented in Table 8 for the end of the season. For example, the model predicted 50% passage of CATHEC fish at MCN on day 148 but the observed day of 50% passage was day 143, so the error is -5 days.

**Table 8 Difference of observed passage - predicted passage times for designated percentages of stocks at six different dams at the end of the season. Negative numbers mean that the prediction is late. Positive numbers mean the prediction is early.**

5 % Passage	LWG	LGS	LMN	MCN	JDA	BON
CATHEC	-1	-2	2	-6	4	-3
IMNAHR	0	1	1	-5	-4	-7
MINAMR	0	2	-3	5	3	2
SALRSF	0	-1	32	2	24	33
COMPOSITE	-6	-1	1	0	0	0
SNAKER	3	-2	-6	-6	-17	-20
mcnChin0S	NA	NA	NA	3	1	4
mcnChin0C	NA	NA	NA	0	-2	-8
mcnStlhdS	NA	NA	NA	1	6	5
mcnStlhdC	NA	NA	NA	5	7	5
mcnChin1S	NA	NA	NA	0	7	9
lgrStlhd	1	4	5	3	8	7
50%	LWG	LGS	LMN	MCN	JDA	BON
CATHEC	-1	2	2	-5	8	9
IMNAHR	0	5	11	-4	6	2
MINAMR	0	-2	26	1	-2	-2
SALRSF	0	-2	0	1	14	27
COMPOSITE	-1	5	14	0	14	6
SNAKER	3	-4	-1	-10	-4	-25
mcnChin0S	NA	NA	NA	7	17	3
mcnChin0C	NA	NA	NA	0	5	-18
mcnStlhdS	NA	NA	NA	0	2	2
mcnStlhdC	NA	NA	NA	9	10	9
mcnChin1S	NA	NA	NA	0	15	11
lgrStlhd	2	11	11	9	12	13
95%LWG	LGS	LMN	MCN	JDA	BON	
CATHEC	-1	-1	4	4	-5	-1
IMNAHR	-2	1	2	0	-3	-1
MINAMR	-2	0	5	0	-3	6
SALRSF	-9	-17	-16	-4	-8	2
COMPOSITE	-2	-2	0	4	-5	3
SNAKER	0	-7	2	-3	-9	-31
mcnChin0S	NA	NA	NA	-2	1	-19
mcnChin0C	NA	NA	NA	-2	-10	-13
mcnStlhdS	NA	NA	NA	3	0	5
mcnStlhdC	NA	NA	NA	3	0	3

**Table 8 Difference of observed passage - predicted passage times for designated percentages of stocks at six different dams at the end of the season. Negative numbers mean that the prediction is late. Positive numbers mean the prediction is early.**

5 % Passage	LWG	LGS	LMN	MCN	JDA	BON
mcnChin1S	NA	NA	NA	1	-5	0
lgrStlhd	2	8	9	6	3	8

## 4 Discussion

### 4.1 Accuracy of Predictions

#### 4.1.1 Flow/Spill Predictions

Flow and spill forecasts provided by Army Corps improved in accuracy as the season progressed; however, the accuracy of early predictions is always problematic. Early season forecasts are potentially very poor (see Appendix D for comparison of early-season predictions in 2001, 2002 and 2003 to observed data). The more anomalous the season, the more difficult it is to create accurate predictions the more difficult is the task of predicting the movements of the fish.

Estimates of the fraction of fish transported at Snake River projects will be sensitive to estimated spill fractions: fish that are "spilled" are not collected for transportation. For accurate long-term projections of transport fractions, more accurate long-term projections of spill fraction will be required. Even when spill fraction is accurately measured, variability in spill efficiency and FGE can produce errors in estimated transport fractions.

#### 4.1.2 Temperature Prediction

The temperature forecasting algorithm was successful in creating an appropriate temperature profile for each of the reservoirs. The MAD values decreased throughout the season as shown in the figures in Appendix F.

Because yearling chinook migrate in the spring and early summer, they are not particularly vulnerable to temperature extremes. Subyearling fish are the most vulnerable to temperature effects since in-river temperatures can exceed their preferences and often fall within the optimal



temperatures for predators such as Northern pikeminnow. At 18°C chinook feeding efficiency drops precipitously from its optimal temperature range near 12-16°C while the pikeminnow's consumption rates (of smolts) reaches within 10% of its maximum.

In CRiSP, although predation and gas saturation dynamics are somewhat temperature-dependent, the difference in estimated survival resulting from temperature variations of one or two °C are minimal. The overwhelming majority of temperature predictions fell well within the two-degree window, and thus we do not believe that inaccuracies in temperature forecasts contributed significantly to errors in projections of fish passage.

#### **4.1.3 Total Dissolved Gas Predictions**

The MAD results for total dissolved gas (TDG) predictions are shown in Appendix H. The trend toward improvements in MAD are obvious as the season progresses. There are small differences between the data and the predictions in hind-casts. Most MAD values are below 3.0 percentage points with a few exceptions of early season predictions especially at LGS. There are many sources and sinks of TDG that are unmodeled including major tributaries between modeled confluences.

#### **4.1.4 Passage Timing Predictions**

The RealTime MAD is calculated from RealTime output files at the end of the season. The reported 2003 "run" and "prediction" percentages are used according to the method in Equation (7). The downstream MAD values are based on CRiSP output files for PIT-tagged fish.

The "Composite" stock is processed differently than the individual stocks. Program RealTime produces run predictions for the Composite stock as if it were an individual stock. There is no corresponding CRiSP run for the Composite stock. The values for the downstream dams are derived by a post-processing script that averages the run results for the four individual stocks into one stock. In principle, the composite stock is easier to predict than individual stocks, as the composite stock represents a substantially larger number of fish; however, their distribution is least likely to be statistically normal. There are differences between stocks in how well CRiSP/RealTime performed. Some examples of these are shown in more detail in graphs in Appendix I on a stock-by-stock basis.

Seasonal variation in MAD values are plotted for select sites and stocks in Appendix K. It is readily apparent that upstream prediction errors are "propagated" downstream. Note how the patterns of MAD (though not necessarily the values) move in step through the season.

Another measure of success in predicting stock travel time is to examine the differences in the number of days between the observed passage of a certain proportion of the run (10%, 50% or 90%) and the predicted passage of that same proportion of the run. Table 8 shows those differences for the stocks at six dams. Perfect correspondence would result in 0 in all cells. Consistent errors in modeling would result in a bias either advancing or retarding all predictions, but that does not seem to be the case for this year. Observed cumulative passage is potentially biased late (especially for low numbers) because fish passage is a discrete process.

More interesting is the differences in travel times between the stocks in a given reach of the river. Sudden shifts in the numbers as the population moves downstream suggest an intervening cause for their delay or acceleration between two dams. Differences of passage for the stocks at various dams can be seen in Appendix J which shows some of the anomalies that give rise to prediction problems. For example, cumulative passage of IMNAHR fish at MCN begins almost simultaneously with LMN observations and both precedes and exceeds it all season. When there are only 40 fish total, the timing of observations of even a few of them can dramatically alter the perceived distribution of the population.

Here is a summary of the causes of errors between the observations and predictions.

1) Actively migrating fish have migration parameters that are calibrated to their historical travel time between LWG and downstream dams. These parameters give fish the best possible "running start" given that they have been migrating for days or weeks prior to arrival at Lower Granite. Fish are increasing in speed with their "experience" in the river as the season proceeds. These migration parameters are updated annually. It is not feasible to have separate parameters for each reach even though there are significant between-reach differences in velocity.

2) RealTime does not provide absolutely accurate estimates of arrival timing at Lower Granite Dam or McNary Dam; to the extent that there are errors in RealTime predictions, those errors are propagated downstream by CRiSP.

3) RealTime is a statistical procedure, and there is some degree of variation from the particular conditions observed in any given year. There is no reason to expect predictions made on any particular date to perfectly fit the arrival distribution preceding that date, because the final arrival distribution is contingent on arrivals through the entire system. If the run is 50% complete but RealTime estimates only 40% completion, for example, that will necessarily produce error both before the prediction date (underestimating) and after it (overestimating, to catch up).

4) RealTime uses a conversion factor to estimate the true passage of PIT-tagged fish. This is based on spill efficiency and FGE (Burgess et al. 1999). The conversion is supposed to account for unobserved fish that pass the PIT-tag detectors. It does not attempt to make a correction for fish passing the dam through the turbines and ignores any transported fish that may be inadvertently removed from the river. This may be the cause of anomalies in the release dam predictions.

5) Some data is missing and is never updated because data records are missing. Most likely this is due to fish passing the dam without triggering a detector. The observed passage at a downstream dam is then skewed because the fish that escape the detectors at an upstream dam may not be random selections from the population of all fish in that stock that pass the dam. Changes in dam operations, hydrologic conditions and mortality can skew the counts by either increasing or decreasing the detections even under the best conditions because of biases in mortality coupled with low numbers of passing smolts. This can have an impact on the results of the analysis because all downstream modeling efforts are going to be dependent on the initial "release" of fish at the first dam and the data collected at downstream dams.

Ideally, we would limit the analysis of downstream passage ONLY to fish that were observed at the uppermost dam and would then have a better estimate of the travel time and survival between dams. This has been a particular problem in the past with LGS observed passage exceeding LWG passage. This year, it is acute for several locations and stocks. Appendix J illustrates the problem with upstream cumulative numbers much lower than downstream passage for certain stocks and locations.

6) CRiSP travel time parameters are based on historical conditions. A strong deviation from the migratory behavior of their predecessors means that these migrants will not be modeled as accurately. Once the fish have entered the system, the model is mostly able to track their move-

ments but the errors are propagated downstream. Based on the differential mortality and passage times, there may be significant inter-dam differences in travel time and survival.

7) Some errors are a fundamental result of using a model and relying on parameters to describe basic relationships. The two main functions of CRiSP in this application are to move fish downstream and to keep track of survival and passage routes of fish. The primary model inputs are forecasts of flow and spill fractions. Flow is an important input because it influences the downstream migration rate of the fish. Behavior-dependent migration rate parameters are based on data and the downstream passage distributions are based on modeled numbers of fish passing the PIT tag detectors. Diversion of migrating fish into sampling systems that detect PIT-tagged fish depends upon the efficiency of spillways and fish diversion screens. The accuracy of CRiSP also depends upon our correctly estimating the values of these parameters. In recent years, we had to rely more and more on forecast data of flow and spill, but in 2003, this information was updated as often as weekly and included historical data from DART when it was available. Some of the sudden jumps and changes in the MAD profiles can be attributed to changes in the forecasts; however, this is a considerable improvement over recent years. Table 9 shows the number of flow/spill archive files used during each year since 1996.

**Table 9 Counts of flow/spill archive files available for use in predicting smolt passage from 1996 through 2003.**

Year	Number of flow/spill archive files
1996	18
1997	19
1998	22
1999	14
2000	6
2001	8
2002	8
2003	18

Spill has several effects on model output. First, it affects the passage routes of the fish – with higher spills, fewer fish pass through the bypass system where PIT-tagged fish can be detected. Survival of migrating fish is also affected by spill: high levels of spill lead to high dissolved gas

levels, causing potentially lethal gas bubble trauma, behavioral alteration, and vulnerability to predation. This problem has been addressed to a certain extent with structural changes to the dams over the last 10 years that limit the entrainment of air in the tailrace during spill operations. Gas levels over 120% are fairly rare. Snake and Columbia River TDG levels were more typically near 115% at Priest Rapids Dam (PRXW) during the higher-spill season, and somewhat less below Ice Harbor Dam (IDSW).

8) There are some unmodeled effects that influence the passage of the fish through the system. At the end of 2001, we performed several comparisons of different predictions under the assumptions of various in-season knowledge (Beer et al. 2002). We concluded:

"Overall there is little to be gained from such efforts except to demonstrate that even with perfect knowledge of the travel-time parameters and environmental conditions, the model can not account for the variability in travel time from un-modeled causes... it means that the overall evaluation of model performance should allow for at least this much error (2.-13.3 % in this evaluation). In practice, a calibration of travel-time parameters within a season is difficult and speculative. Prediction of environmental variables is best accomplished by having up-to-date observations whenever possible and using CRiSP's internal modeling mechanisms for future dates."

## **4.2 Utility of CRiSP/RealTime Predictions in Management**

CRiSP has been continuously evolving to accommodate new data, and meet river managers needs by including sub-models of previously un-modeled processes. CRiSP1.7 was used in 2003 which allows for "reach classes" in which parameters distinguished between certain reach environments. For example, the variation in travel velocity is distinct for yearling chinook above and below McNary Dam which separates the lower river class from the upper river class. On-going developments such as tracking the exposure of fish to environmental conditions will allow the user to assess the exposure of fish populations to various environmental conditions such as temperature, turbidity, total dissolved gas, etc. Currently, the CBR web site allows certain types of

queries to the data. The inclusion of data queries and fish exposure tracking processes into the downstream passage model will allow an user to generate detailed output of the processes as a result of any scenario they design.

Flow augmentation for control of discharge, temperature, spill timing and fraction, transportation operations, etc. are some of the many examples of how managers can adjust the hydrosystem for the benefit of salmon. However, this requires accurate assessments of the status of salmon out-migration and planned responses to various contingencies. For example, one might elect to transport juvenile chinook at collection facilities, but separate fish when flows fall below some target value until the run has reached 80%. This policy requires an accurate assessment of when that 80% level is reached. Similarly, a policy that seeks to transport a given fraction of the run, say 50%, can only be done if one has estimates of the state of the run and the fraction transported to date.

The cumulative passage forecasts provide managers with estimates of the fraction of a given run that will be exposed to expected spill, flow, dissolved gas levels, and transportation during a given period of interest - generally the next one to two weeks. This allows both quantitative and qualitative assessment of the exposure these fish will experience to the conditions. Within limits, the managers can choose to modify operational conditions. If spill is to be targeted for particular stocks, the CRiSP/RealTime estimates of arrival distributions would allow managers to direct spill at the projects where the bulk of the run is passing and reduce spill at projects where few fish are passing, in order to control dissolved gas levels.

Since in-season calibrations would be difficult and not necessarily helpful (Beer et al. 2002), we are continuing to seek improvements in model predictions by focusing our efforts on improving environmental data and clarifying the role of various river environments in characterizing the survival and movements of the fish.

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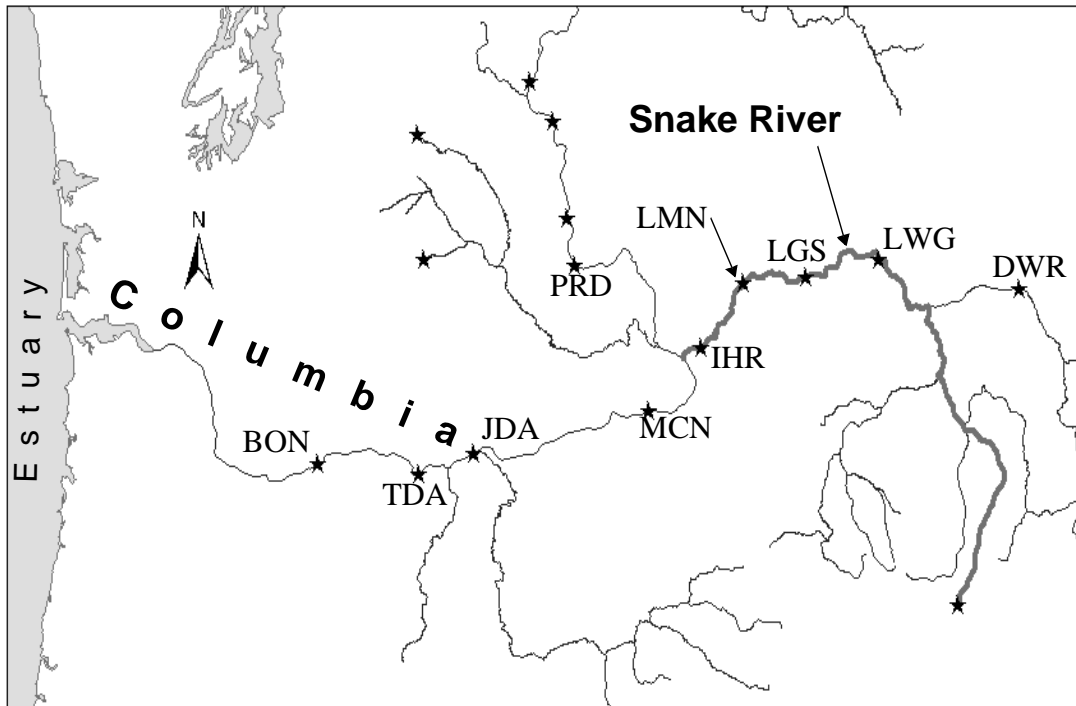
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## Appendix A Map of Columbia and Snake River Locations



**Figure A-1** Map of CRiSP locations

The stars are dam locations, and some are labeled with their three character code. Spill, elevation and flow predictions are made by BPA at *all* shown dams. Temperature predictions are made at Lower Granite (LWG), Priest Rapids (PRD) and The Dalles (TDA). Total dissolved gas is monitored at sites downstream of all dams shown and analyzed for sites below Lower Granite-LWG (LGNW), Little Goose-LGS (LGSW), McNary-MCN (MCPW), Ice Harbor-IHR (IDSW), and John Day-JDA (JHAW). The stocks analyzed in this report pass Lower Granite Dam or McNary Dam (their arrivals predicted by RealTime) and CRiSP results are presented for their arrivals at downstream locations.

## Appendix B CRiSP Parameters

This is a selection of parameters used for passage and travel time modeling. The full characterization of the model could result in tens of thousands of lines of input.

**Table B-1** Dam Specific Parameters used for CRiSP runs.

Dam	FGE	FGE	FGE
	Chinook 0	Chinook 1	Steelhead
Bonneville	0.09	0.39	0.41
Bonneville II	0.28	0.48	0.48
The Dalles	0.10	0.12	0.03
John Day	0.32	0.73	0.85
McNary	0.62	0.83	0.89
Ice Harbor	0.54	0.54	0.93
Lower Monumental	0.49	0.49	0.82
Little Goose	0.53	0.78	0.81
Lower Granite <sup>a</sup>	1.0	1.0	1.0

a. CRiSP uses output from the RealTime program for passage at Lower Granite Dam, which in effect has already accounted for FGE.

**Table B-2** Species Specific Parameters used for CRiSP runs

Species	Reach Predation Coefficient	Forebay Predation Coefficient	Tailrace Predation Coefficient
All	12.70	15.60	0.00

**Table B-3** Dam and Species Specific Parameters used for CRiSP runs: Spill Mortality, Bypass Mortality, and Turbine Mortality as determined by the 2000 NMFS BiOp.

Dam	Species	Spill Mortality	Bypass Mortality	Turbine Mortality
Bonneville	Chinook 0	0.02	0.18	0.10
	Chinook 1	0.02	0.10	0.10
	Steelhead	0.02	0.10	0.10
Bonneville II	Chinook 0	0.00	0.02	0.06
	Chinook 1	0.00	0.02	0.10
	Steelhead	0.00	0.02	0.10
The Dalles	Chinook 0	0.06	0.07	0.16
	Chinook 1	0.05	0.04	0.19
	Steelhead	0.05	0.05	0.19
John Day	Chinook 0	0.02	0.02	0.10
	Chinook 1	0.02	0.02	0.10
	Steelhead	0.02	0.02	0.10
McNary	Chinook 0	0.02	0.03	0.10
	Chinook 1	0.02	0.02	0.10
	Steelhead	0.02	0.02	0.10
Ice Harbor	Chinook 0	0.05	0.02	0.10
	Chinook 1	0.02	0.02	0.10
	Steelhead	0.02	0.02	0.10
Lower Monumental	Chinook 0	0.02	0.02	0.10
	Chinook 1	0.03	0.05	0.08
	Steelhead	0.03	0.07	0.07
Little Goose	Chinook 0	0.02	0.02	0.10
	Chinook 1	0.00	0.01	0.08
	Steelhead	0.00	0.05	0.08
Lower Granite	Chinook 0	0.02	0.02	0.10
	Chinook 1	0.02	0.02	0.07
	Steelhead	0.02	0.02	0.07

**Table B-4** Reservoir and Species Specific Parameters used for CRiSP runs.

Reservoir	Predator Density Chinook 0	Predator Density Chinook 1	Predator Density Steelhead
Estuary	3079	1950	1950
Jones Beach	2966	1950	1950
Columbia Gorge	2815	1950	1950
Bonneville Tailrace	7367	1950	1950
Bonneville Pool	3254	1014	1014
The Dalles Pool	2074	1014	1014
Deschutes Confluence	2074	1014	1014
John Day Pool	611	1014	1014
McNary Pool	899	1014	1014
Lower Snake River	1344	809	809
Ice Harbor Pool	877	809	809
Lower Monumental Pool	1455	809	809
Little Goose Pool	1137	809	809
Lower Granite Pool	2590	809	809



**Table B-5** Stock Specific Migration Parameters used for CRiSP runs

Stock	Reach	Eqn (#)	Parameters					
			Full (1)	$\beta_{MIN}$	$\beta_{MAX}$	$\beta_{FLOW}$	$\alpha_1$	$T_{seas}$
		Reduced (4)	$\beta_{MIN}$	--	$\beta_{FLOW}$	—	$T_{seas}$	$\alpha_2$
		Flow (5)	$\beta_{MIN}$	--	$\beta_{FLOW}$	—	--	--
CATHEC	Both	Reduced	-3.5351	--	1.756	--	104.70	0.1992
IMNAHR	Both	Reduced	1.9479	--	1.1874	--	106.43	0.1573
SALRSF	Both	Full	0.1991	2.9322	1.0176	0.1992	90.00	0.1969
MINAMR	Both	Reduced	-2.696	--	1.442	--	87.26	0.1118
SNAKER	Both	Full	0.1218	0.2032	1.9345	0.0861	182.1	0.618
lgrStlhd	Upper <sup>a</sup>	Reduced	-8.262	--	2.8579	--	72.544	0.234
	Lower <sup>b</sup>	Flow	0.1601	--	3.5729	--	--	--
mcnChin0S	Lower	Flow	-5.0161	--	3.931	--	--	--
mcnChin0C	Lower	Reduced	0.0993	--	2.2192	--	173.2	0.0669
mcnStlhdS	Lower	Flow	0.1601	--	3.5729	--	--	--
mcnStlhdC	Lower	Full	0.031	23.146	3.262	0.4531	120.92	0.7838
mcnChin1S	Lower	Reduced	0.6891	--	1.5871	--	99.11	0.1645

a. The “Upper” reach class is assigned to all CRiSP defined reaches above McNary Dam, including McNary Pool.

b. The “Lower” reach class is assigned to all CRiSP defined reaches below McNary Dam.

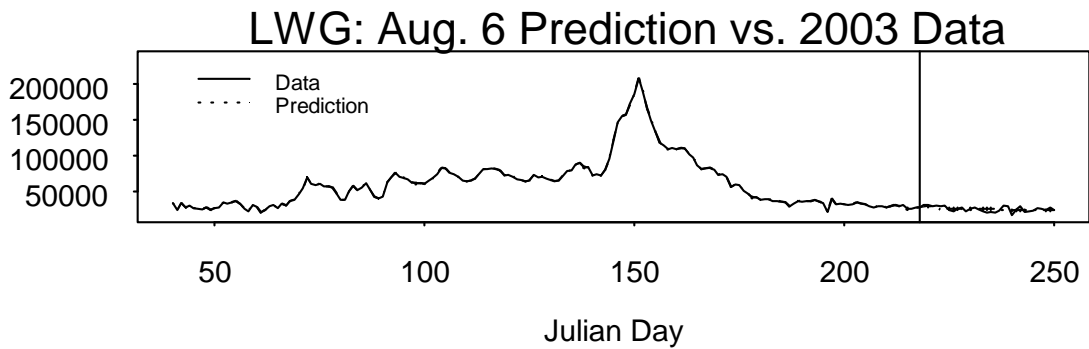
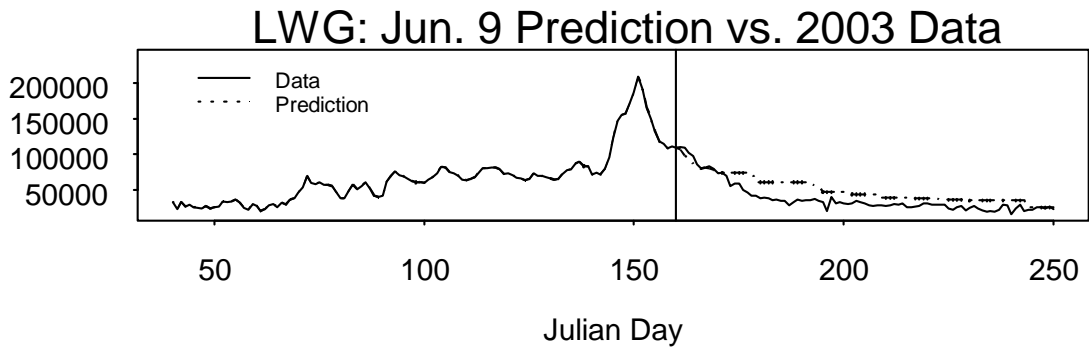
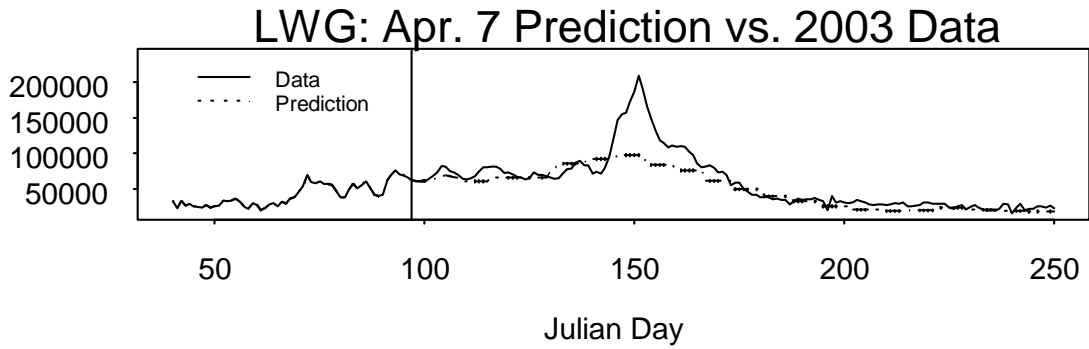
**Table B-6** Stock Specific Rate of Spread Parameter ( $V_{VAR}$ ) used for CRiSP runs.

Stock	$V_{VAR}$ Upper Reach Class	$V_{VAR}$ Lower Reach Class
CATHEC	86.66	179.16
IMNAHR	53.27	179.16
SALRSF	100.31	179.16
MINAMR	75.45	179.16
SNAKER	216.56	216.56
lgrStlhd	174.25	226.55
mcnChin0S	--	243.98
mcnChin0C	--	242.06
mcnStlhdS	--	226.55
mcnStlhdC	--	225.53
mcnChin1S	--	179.16

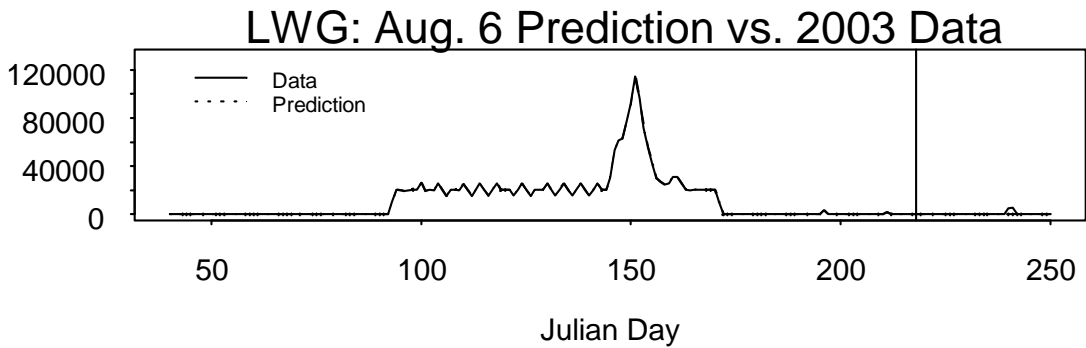
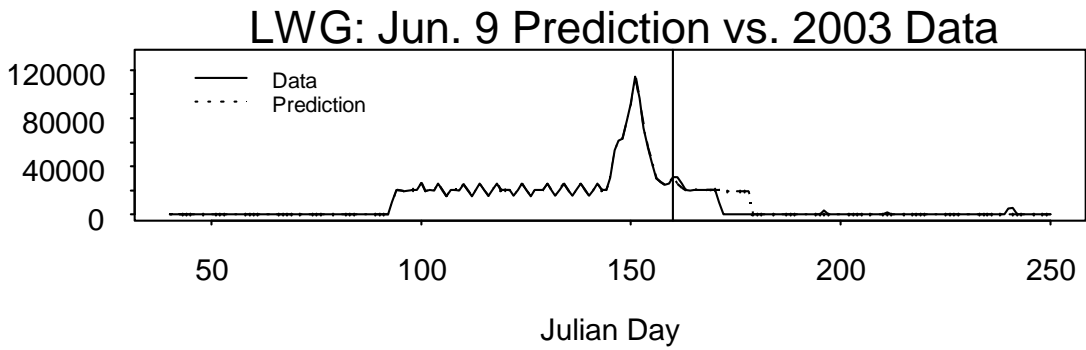
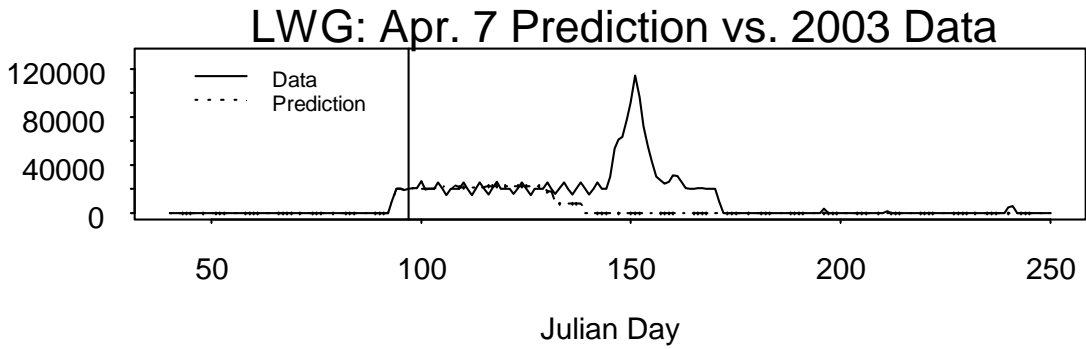
## **Appendix C Flow/Spill Forecast Plots**

Flow and Spill plots for four dams: Lower Granite (LWG), Priest Rapids (PRD), The Dalles (TDA), and Bonneville (BON). The Y axis on the graphs is cubic feet per second (CFS). The vertical line in the plot marks the date of the prediction.

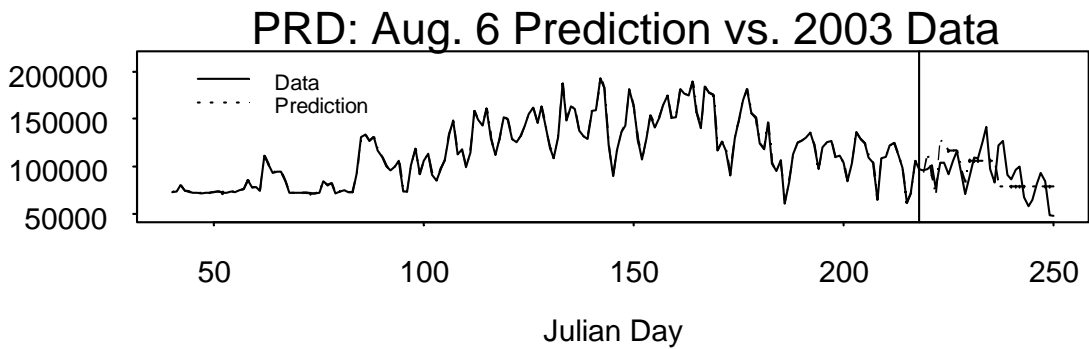
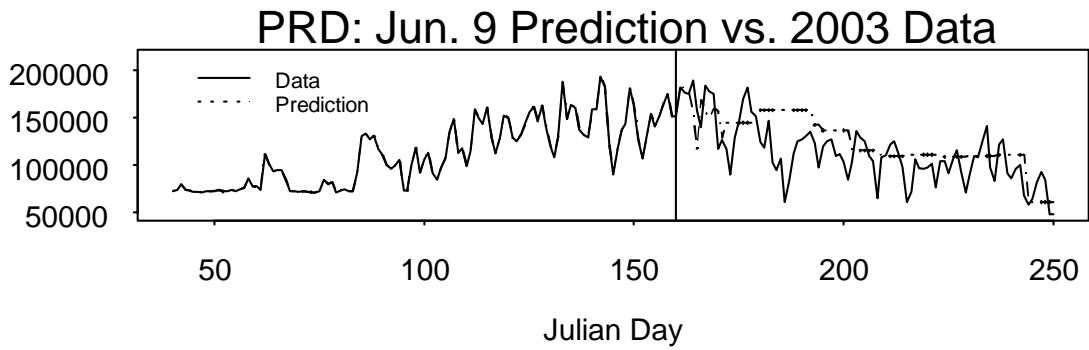
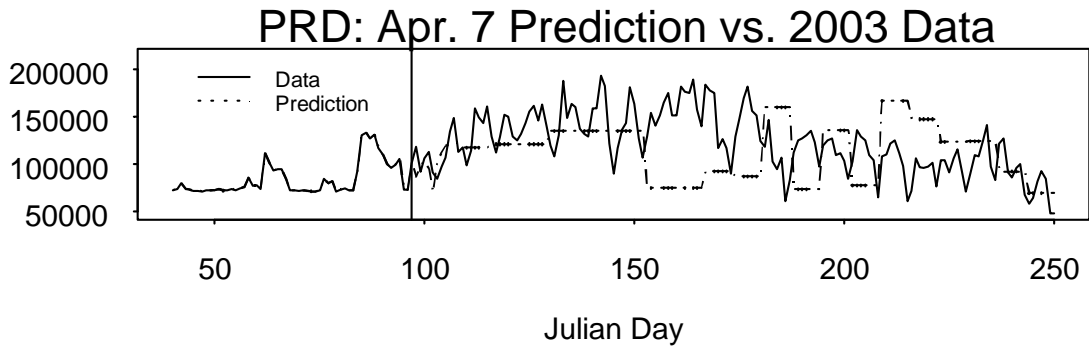
The PRD flow forecast values are those forecast by ACOE; however, the PUDs that operate the Mid-Columbia dams attempted to spill a fixed percentage of the flow during the season. See Table 2 for the target percent values used by CRiSP as forecasted values for the Mid-Columbia dams. The values in the plots are spill volume not percent (Figure C-4).



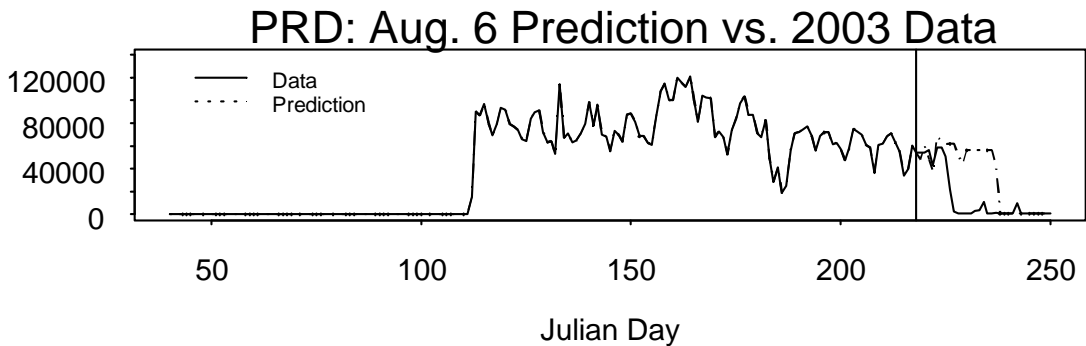
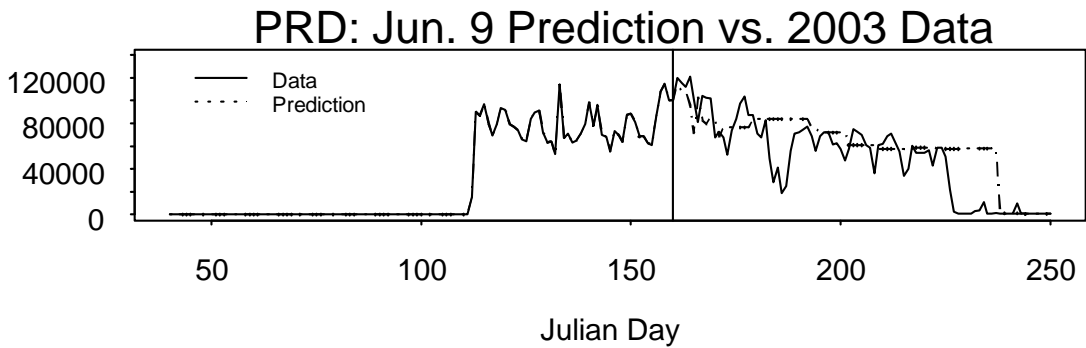
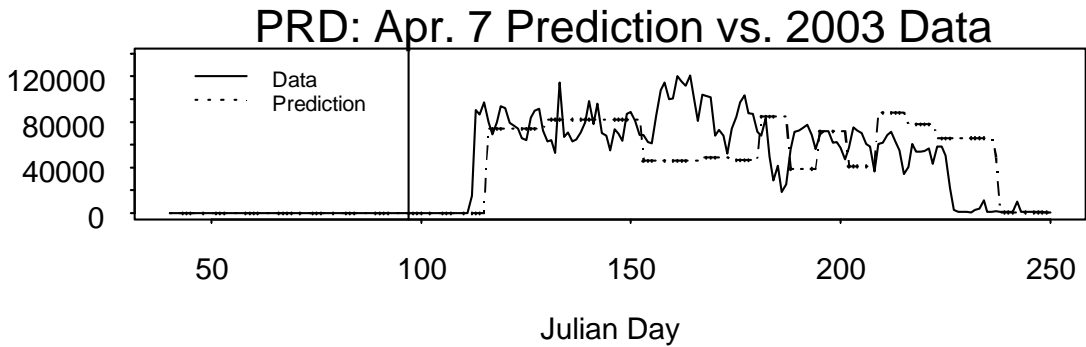
**Figure C-1** Flow predictions and observations for Lower Granite Dam. Y axis shows CFS.



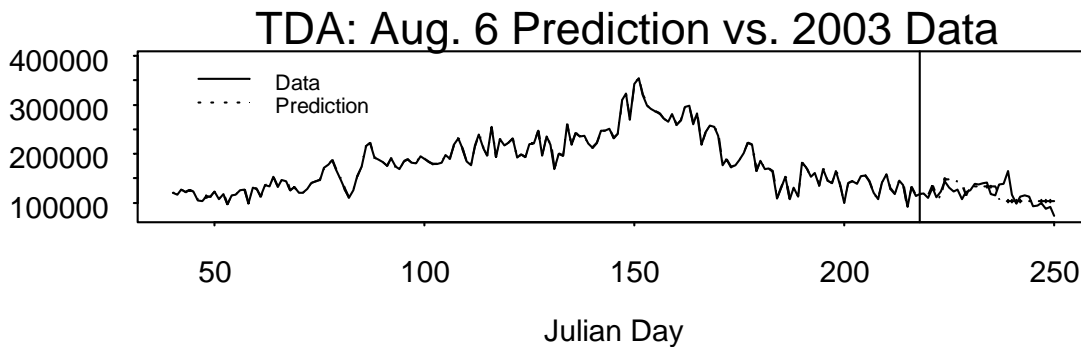
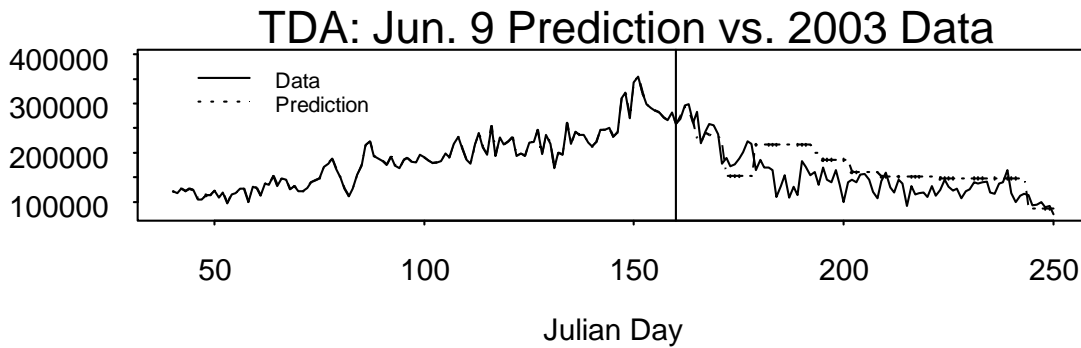
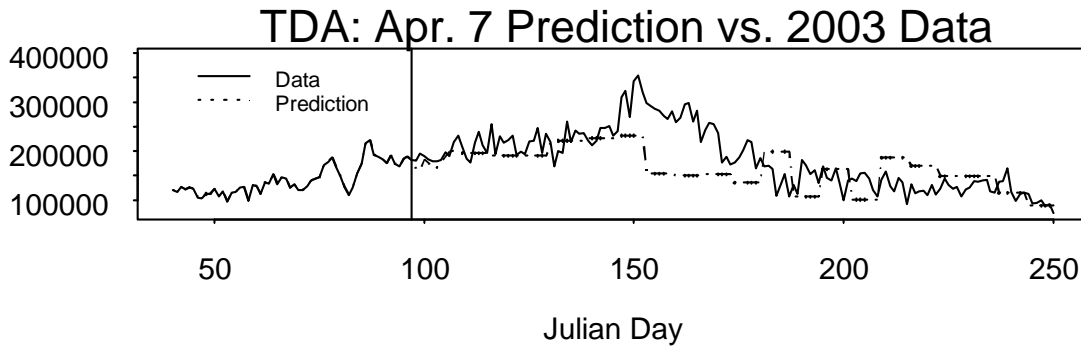
**Figure C-2** Spill predictions and observations for Lower Granite Dam. Y axis shows CFS.



**Figure C-3** Flow predictions and observations for Priest Rapids Dam. Y axis shows CFS.

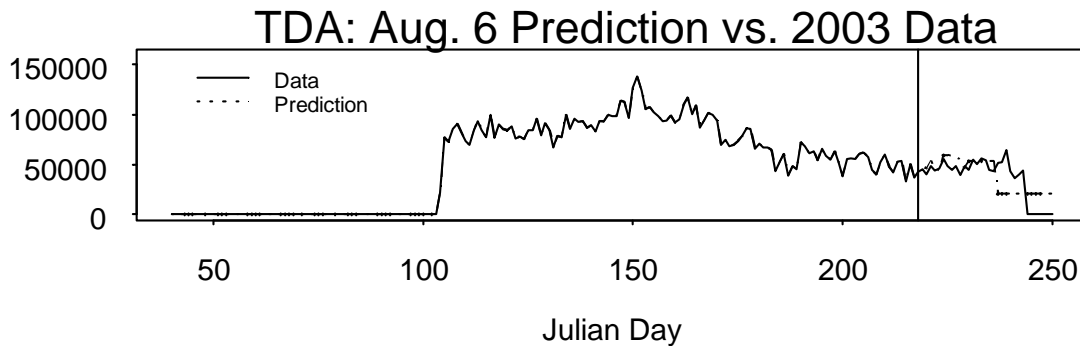
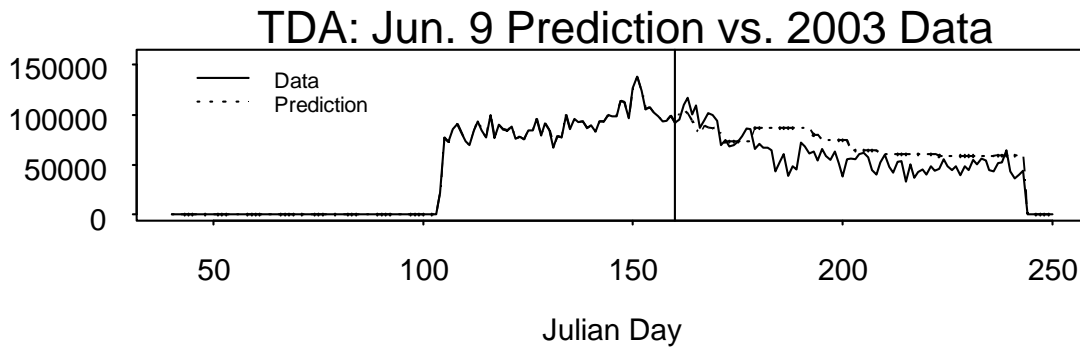
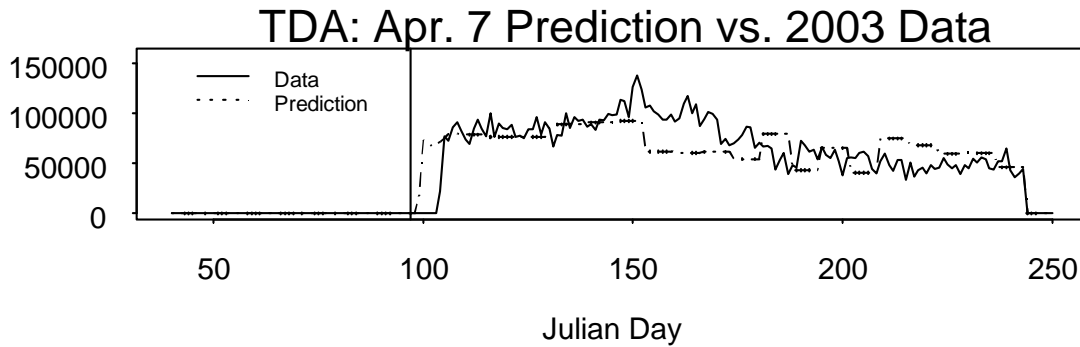


**Figure C-4** Spill predictions based on forecasts and observations for PRD. Mid-Columbia PUDs used fixed spill percentage targets during the season. Y axis shows CFS.

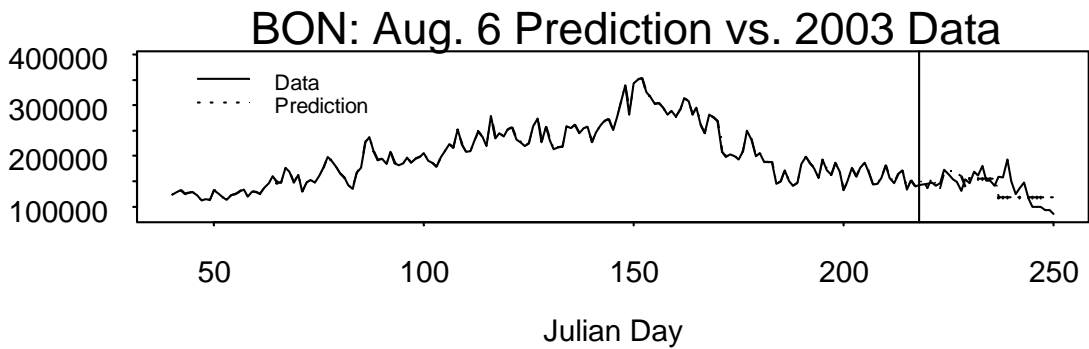
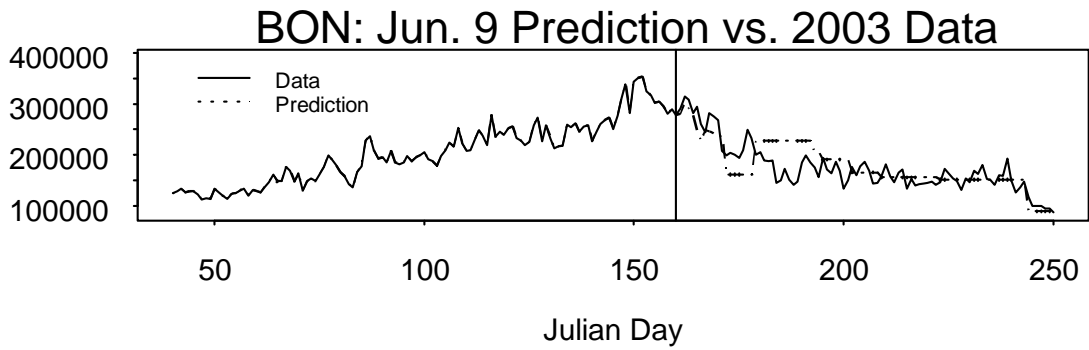
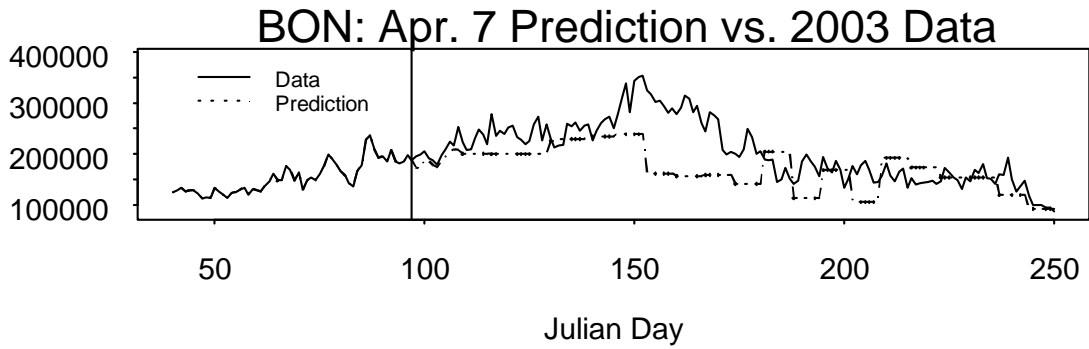


**Figure C-5** Flow predictions and observations for The Dalles Dam. Y axis shows CFS.

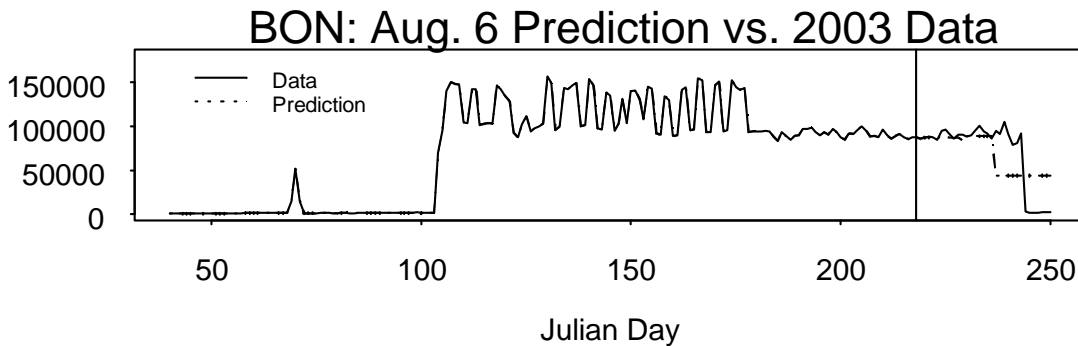
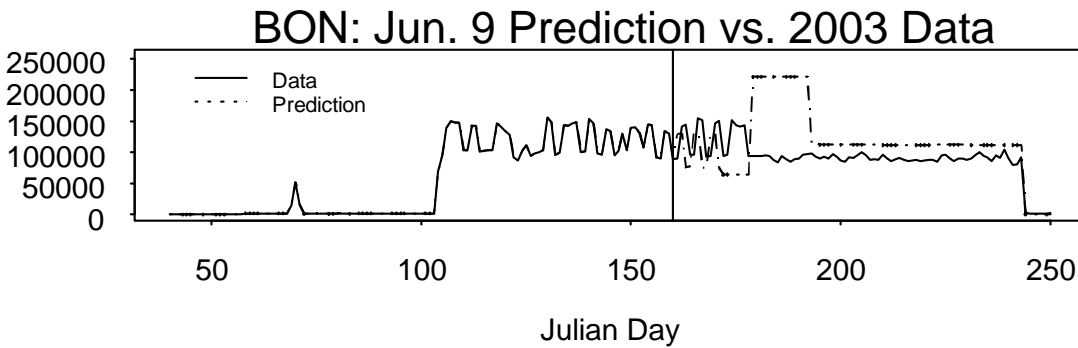
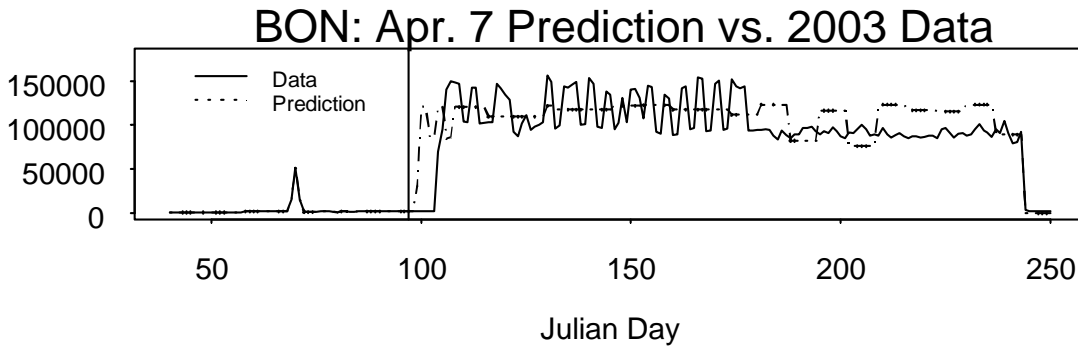




**Figure C-6** Spill predictions and observations for The Dalles Dam. Y axis shows CFS.



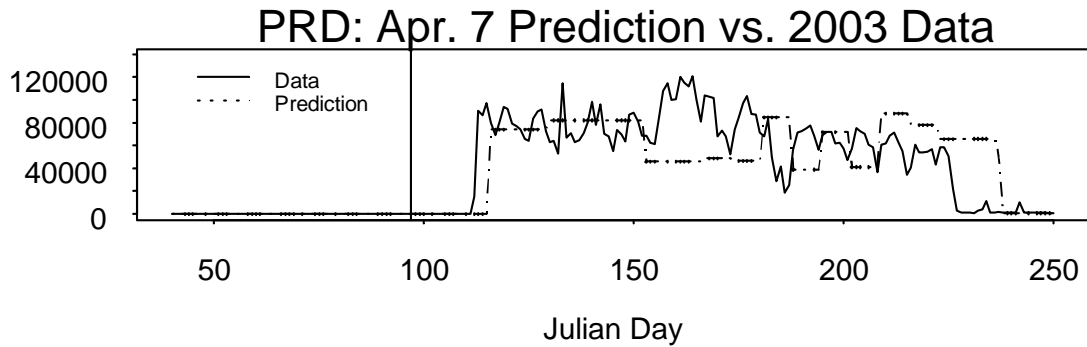
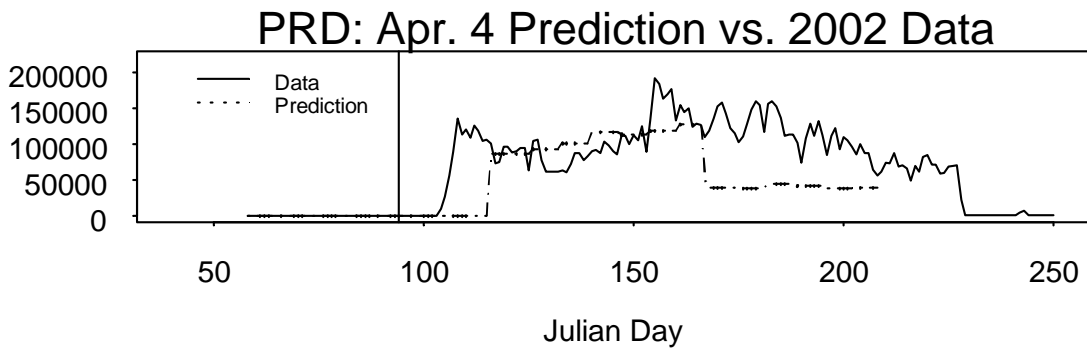
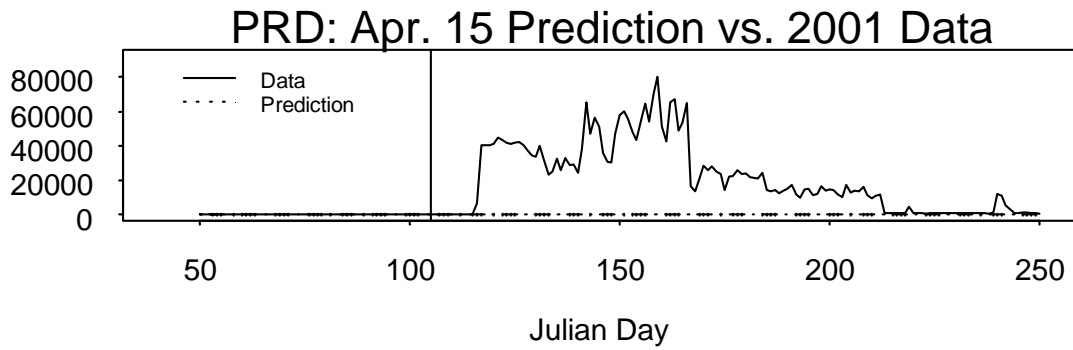
**Figure C-7** Flow predictions and observations for Bonneville Dam. Y axis shows CFS.



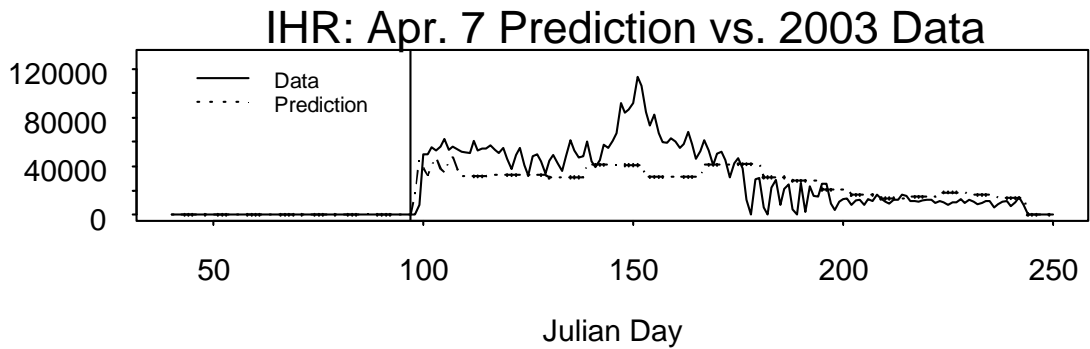
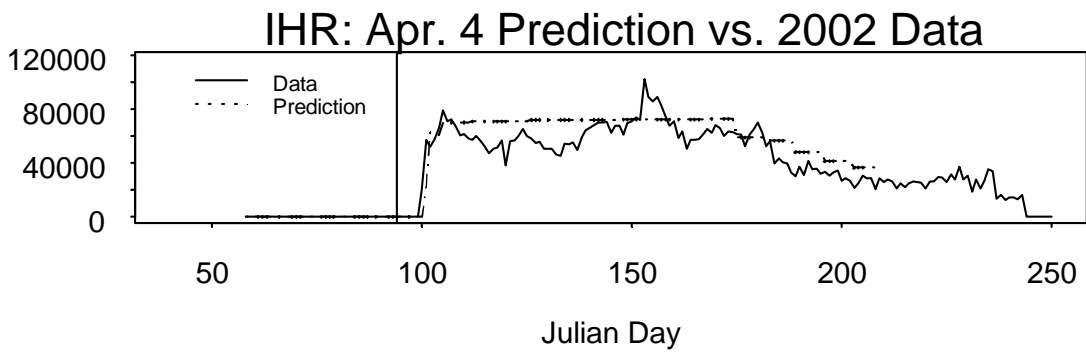
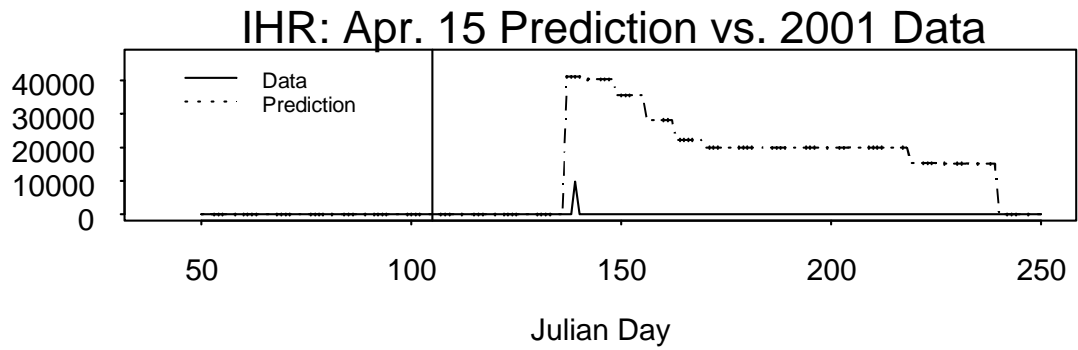
**Figure C-8** Spill predictions and observations for Bonneville Dam. Y axis shows CFS.

## **Appendix D Spill Forecast History Plots**

Spill predictions during the early season are difficult to make. Shown here are the early April predictions of spill compared to data for Priest Rapids and Ice Harbor over the last three years.

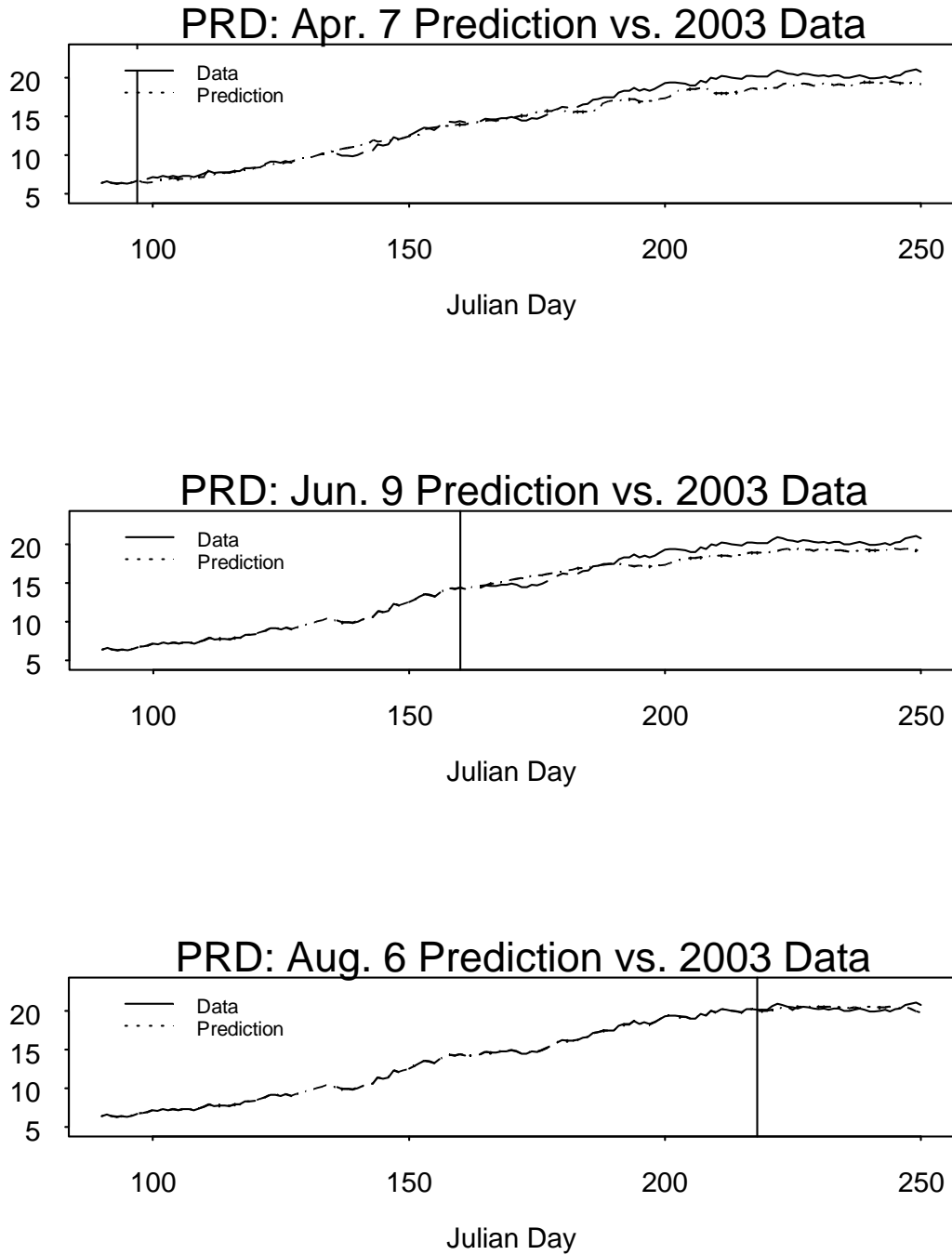


**Figure D-1** Early season spill predictions for three previous years compared to data at Priest Rapids Dam.

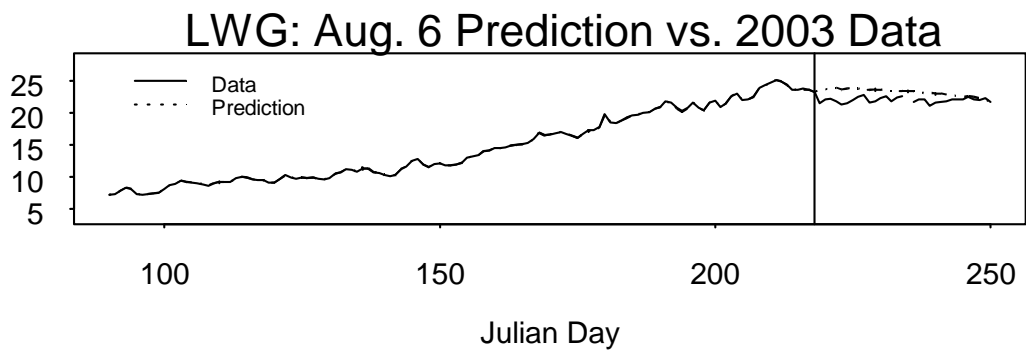
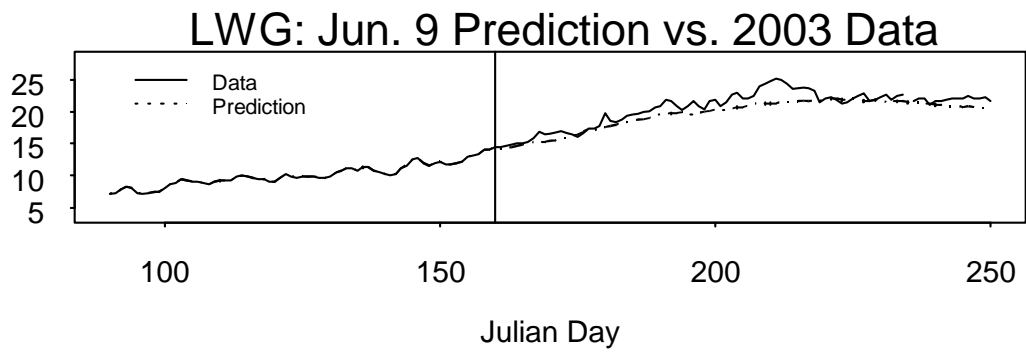
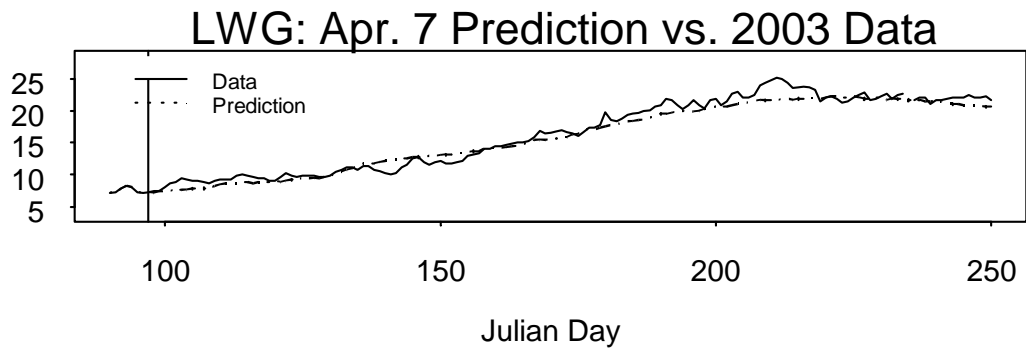


**Figure D-2** Early season spill predictions for three previous years compared to data at Ice Harbor dam.

## Appendix E Temperature Forecast Plots

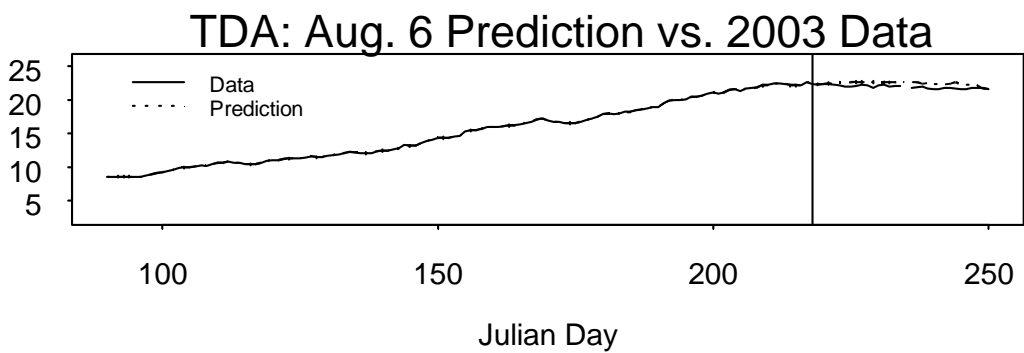
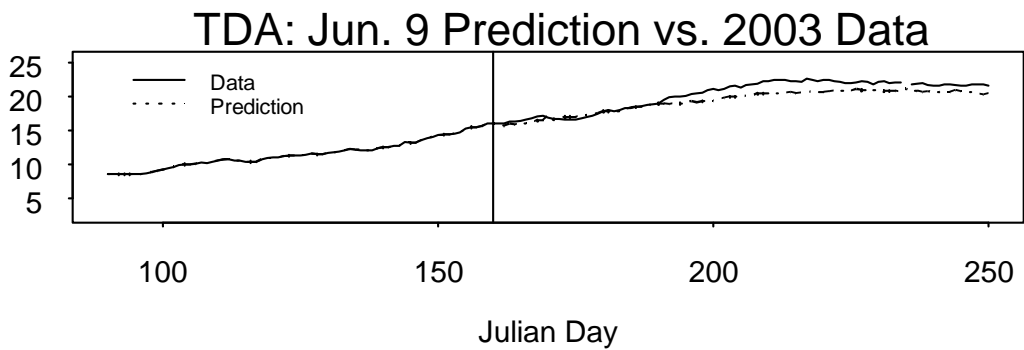
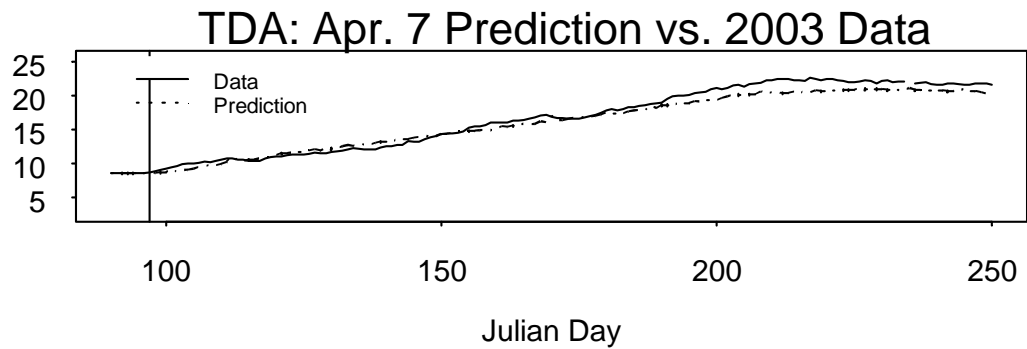


**Figure E-1** Temperature predictions and observations for Priest Rapids Dam. Y axis is °C.



**Figure E-2** Temperature predictions and observations for Lower Granite Dam. Y axis is °C.



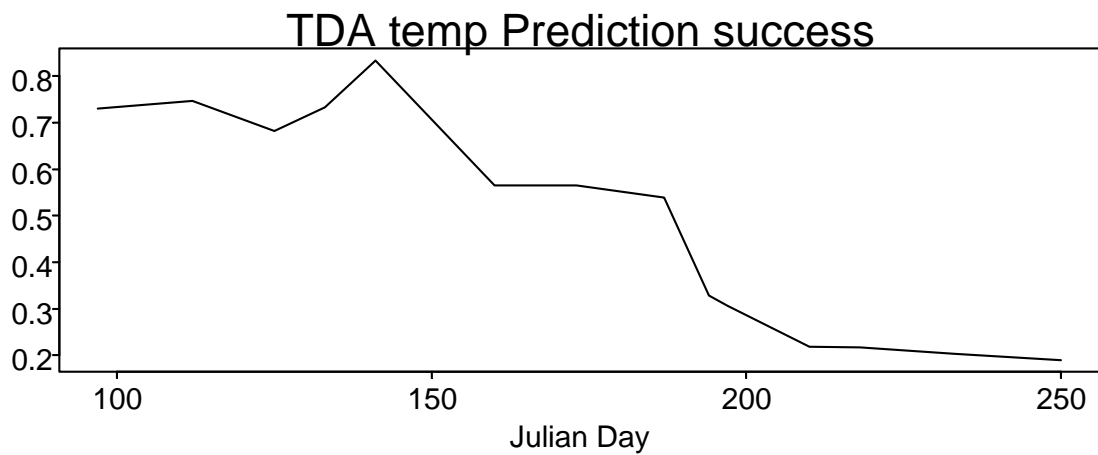
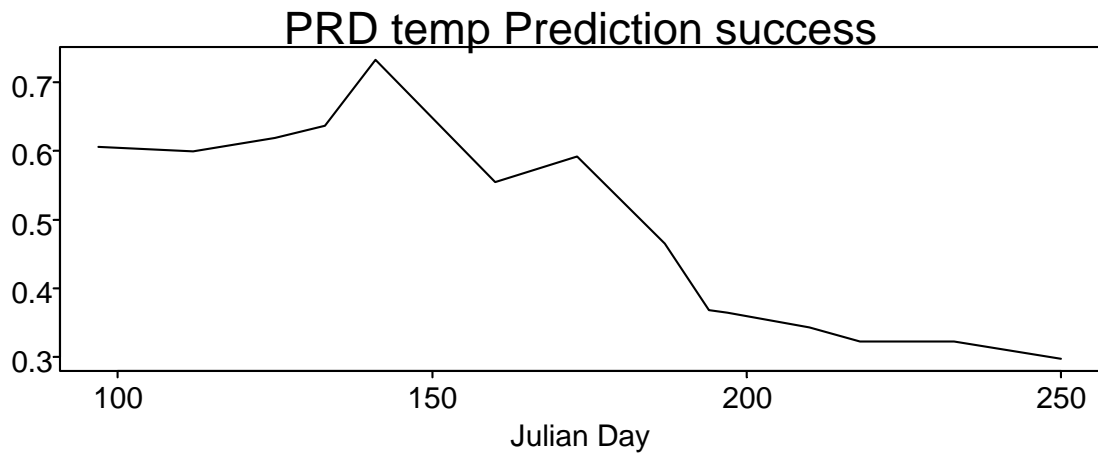
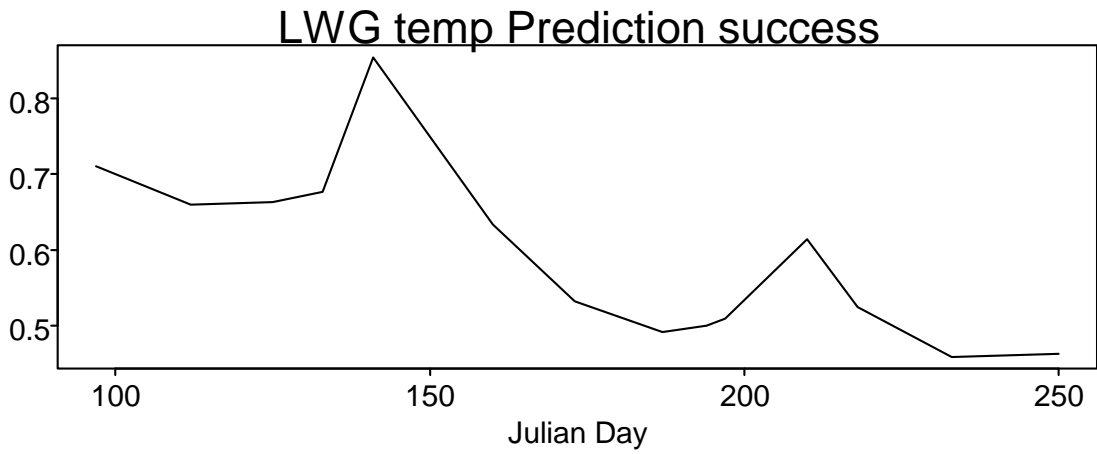


**Figure E-3** Temperature predictions and observations for The Dalles Dam. Y axis is °C.

## **Appendix F Seasonal Variation in Temperature Forecasts**

For each day that a prediction was made, the Mean Absolute Deviation was calculated for each day in the season for which there was both an observation and a prediction. (See text: “Assessment of Predictions” on page 13.)

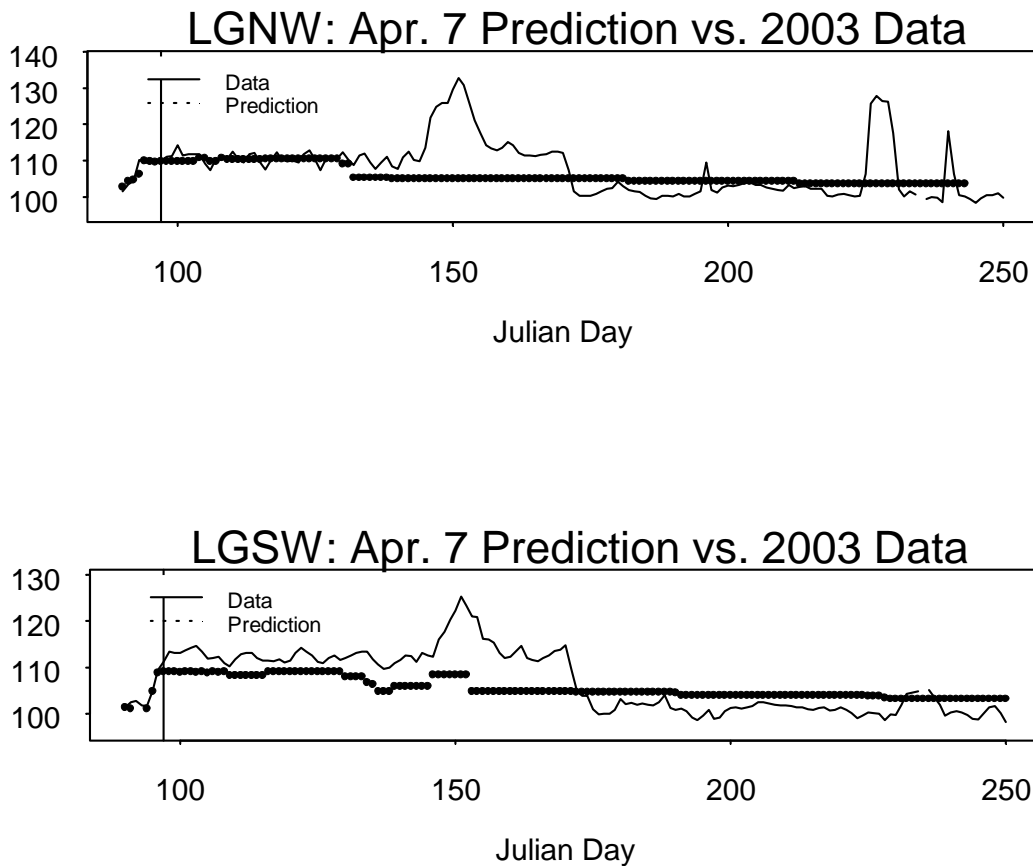
These MAD values are plotted as a time series to see how the predictions changed through the season. If the predicted values exactly matched the observations, the MAD for that day would be zero. In the plots that follow, the MAD value is on the Y-axis and the Julian day is on the X-axis.



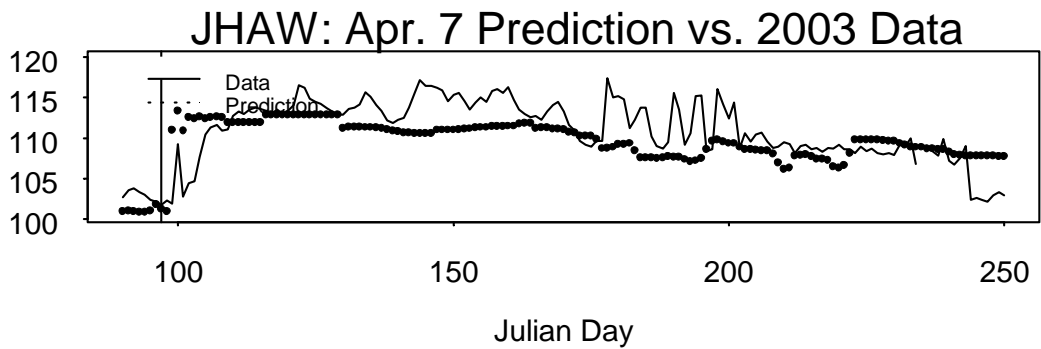
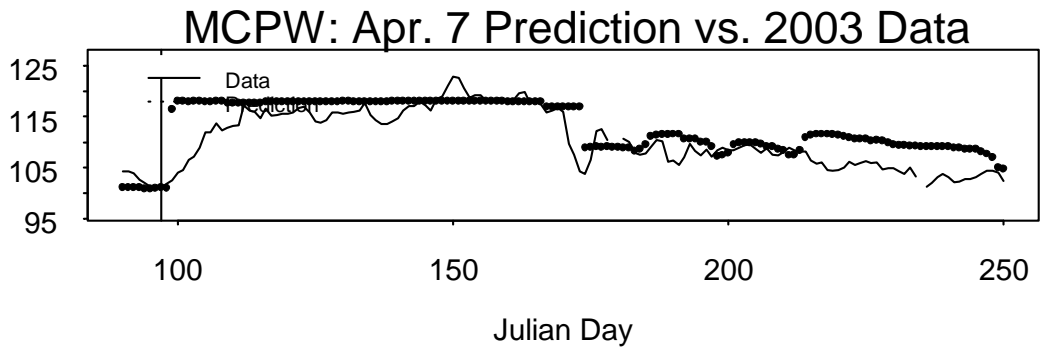
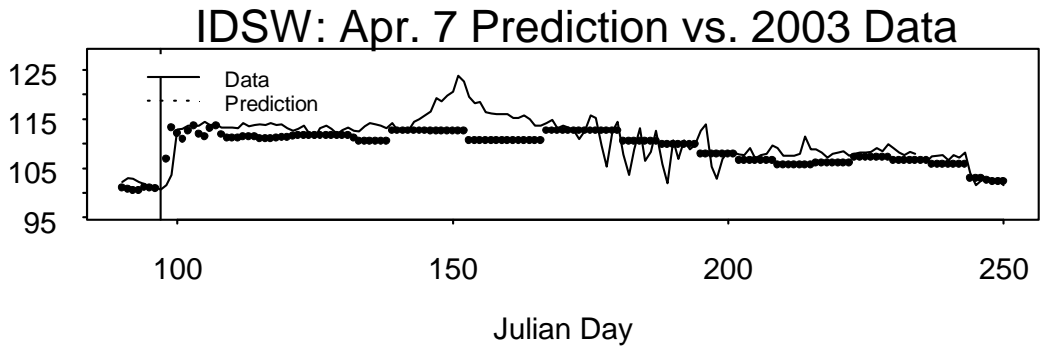
**Figure F-1** Seasonal variation in temperature prediction success at three locations as measured by MAD (Y-axis).

## Appendix G Dissolved Gas Forecast Plots

Total dissolved gas predictions and observations are shown in the following plots for five monitoring sites downstream from dams. The X-axis is the Julian day and the Y-axis is the percentage super-saturation.

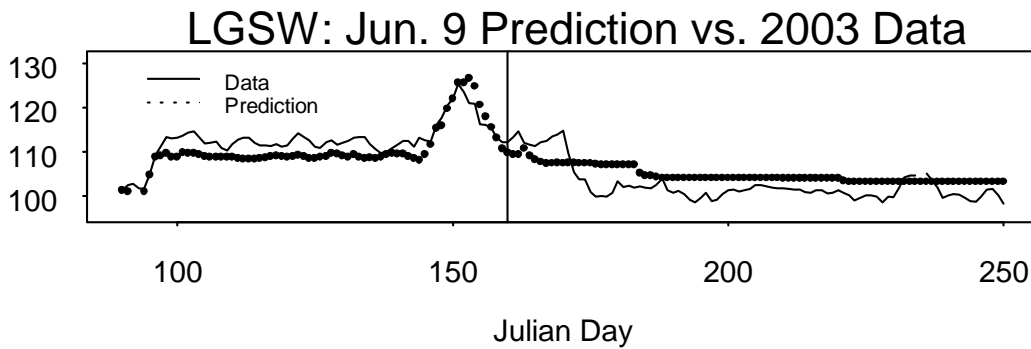
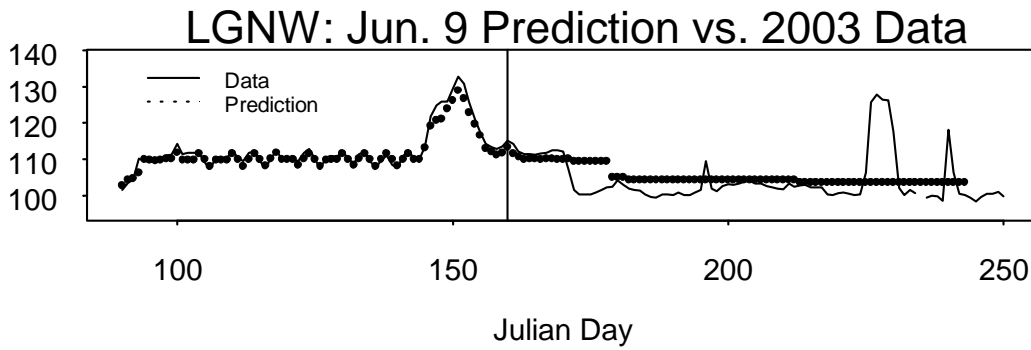


**Figure G-1** Total Dissolved Gas predictions and observations for Lower Granite Dam (LGNW) and Little Goose Dam (LGSW). Y axis is the percent saturation.

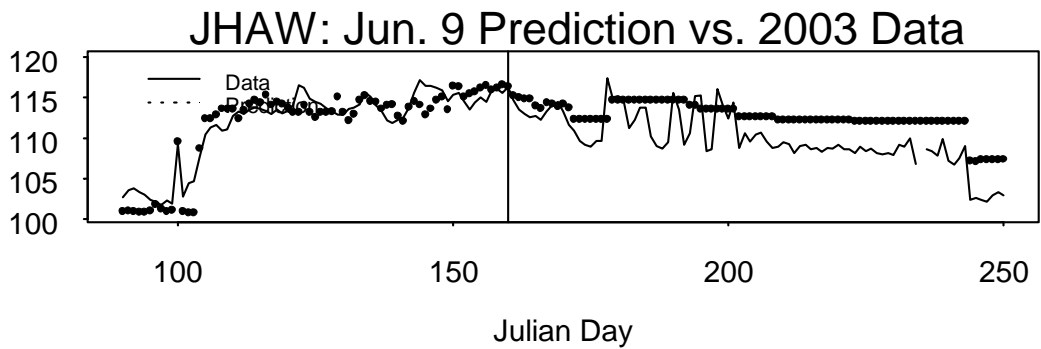
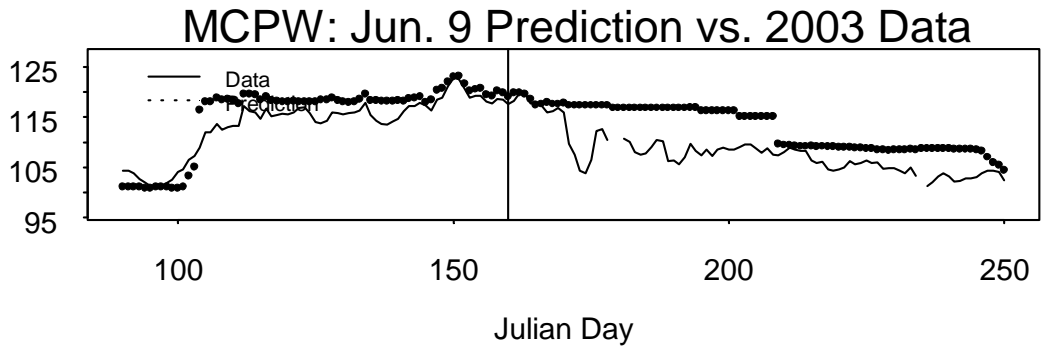
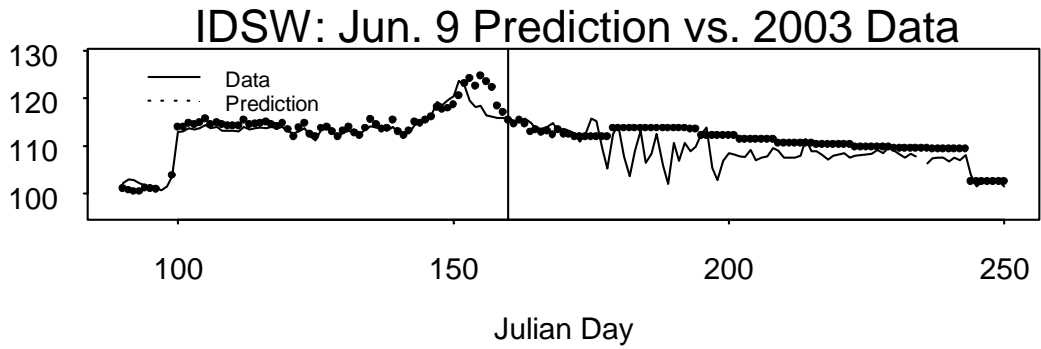


**Figure G-2** Total Dissolved Gas predictions and observations for Ice Harbor (IDSW), McNary (MCPW), and John Day (JHAW) dams. Y axis is the percent saturation.

intentionally blank to match layout of April plots



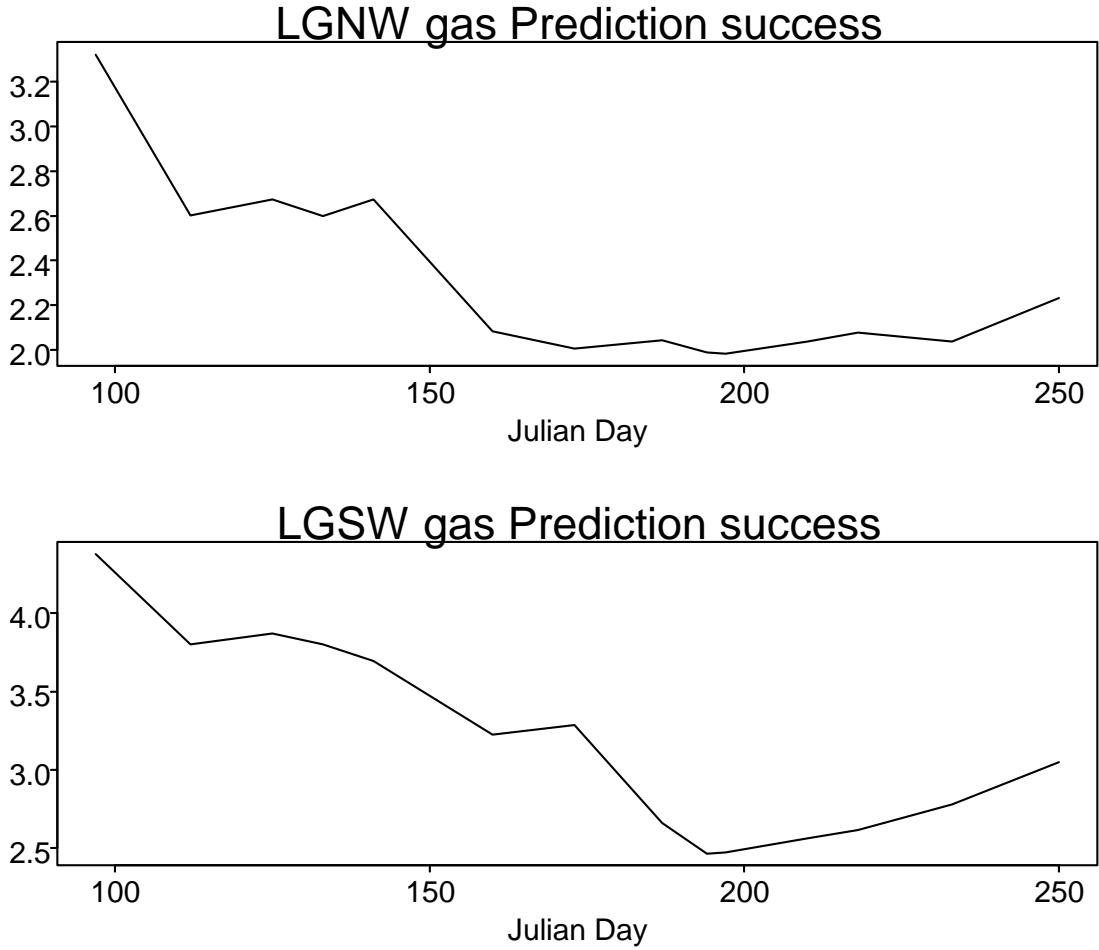
**Figure G-3** Total Dissolved Gas predictions and observations for Lower Granite Dam (LGNW) and Little Goose Dam (LGSW). Y axis is the percent saturation.



**Figure G-4** Total Dissolved Gas predictions and observations for Ice Harbor (IDSW), McNary (MCPW), and John Day (JHAW) dams. Y axis is the percent saturation.

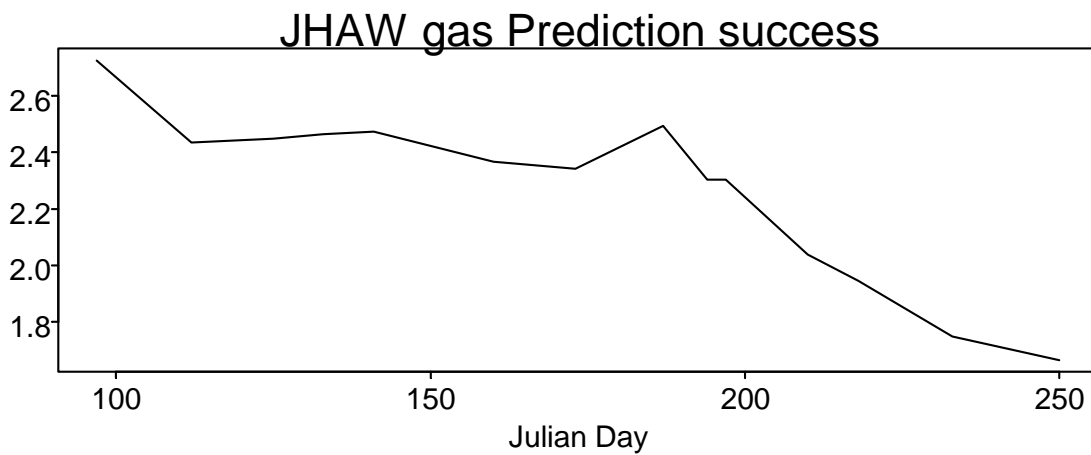
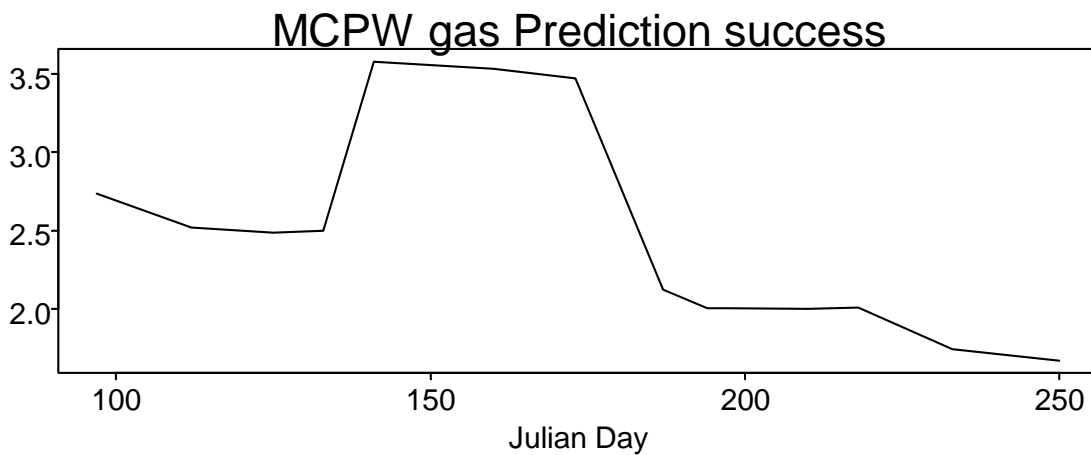
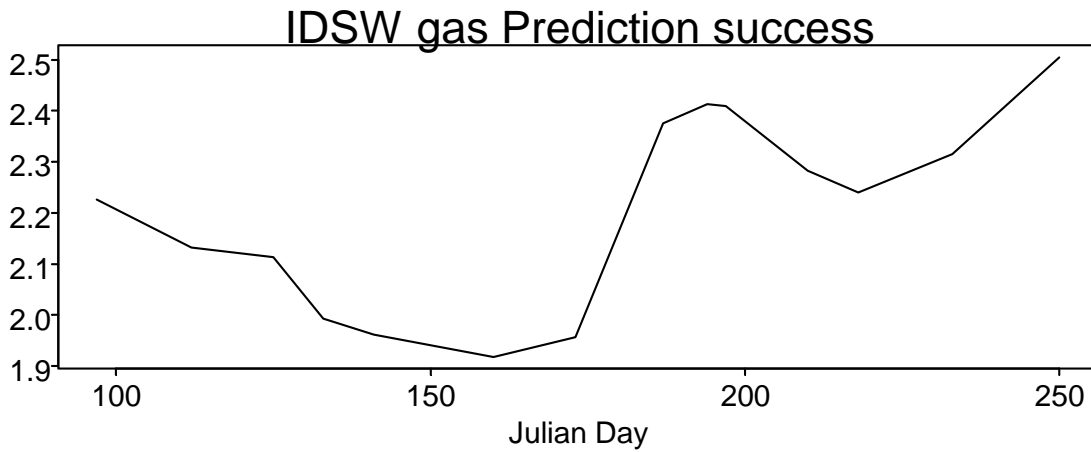
# Appendix H Seasonal Variation in TDG Forecasts

Prediction success for Total Dissolved Gas throughout the season is shown for five monitoring sites below dams. The X-axis is the Julian day and the Y-axis is the average daily error in percentage (points) for the prediction made on that day compared to the data for the entire season.



**Figure H-1** Season variation in Total Dissolved Gas prediction at two monitoring sites below Lower Granite Dam and Little Goose Dam (top to bottom respectively).





**Figure H-2** Season variation in Total Dissolved Gas prediction at three monitoring sites below Ice Harbor, McNary, and John Day dams (top to bottom respectively).

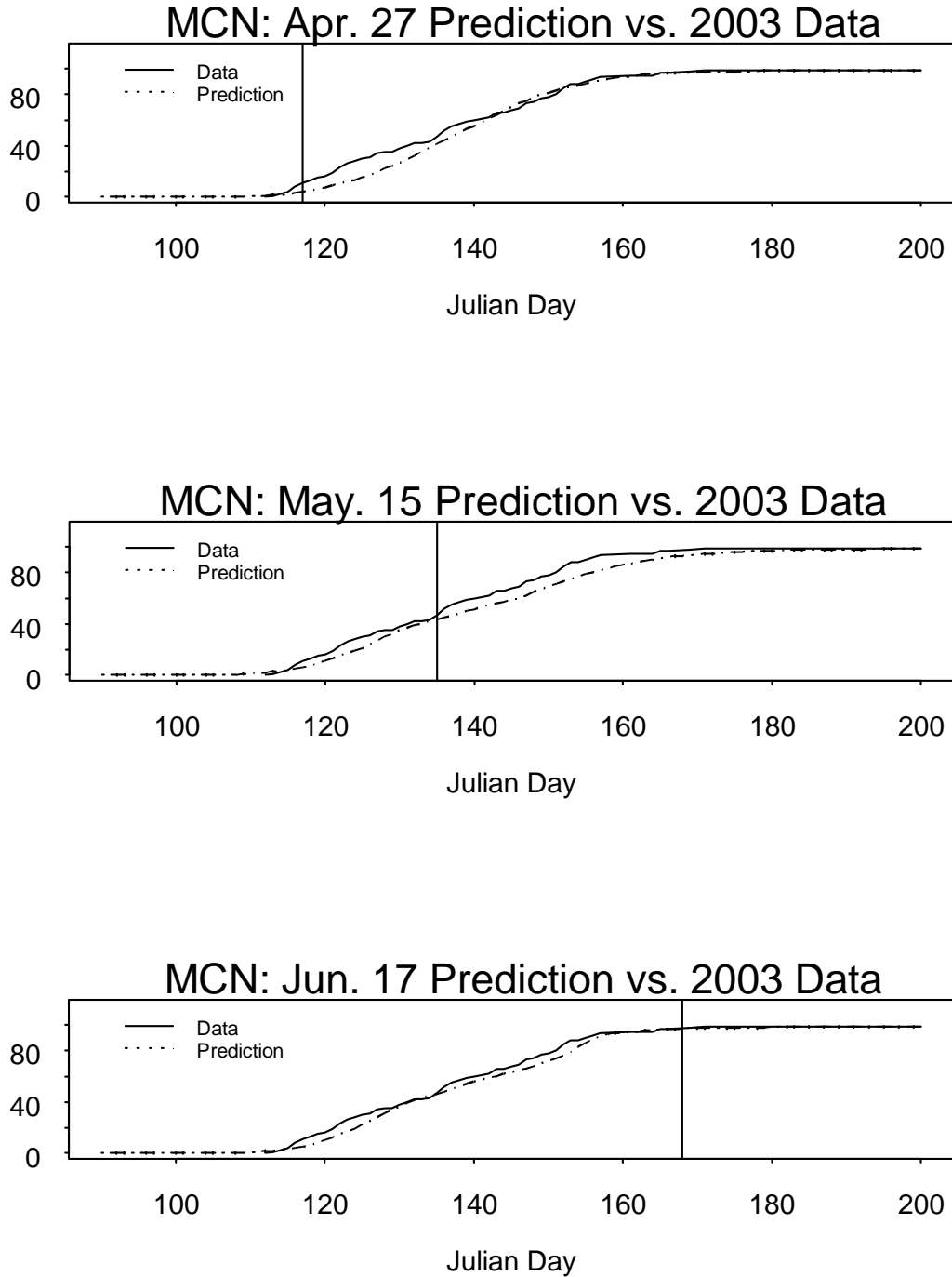
## Appendix I Arrival Time Distribution plots

The following figures present the CRiSP/RealTime predictions and observations of multiple stocks at multiple locations. The predicted distribution at the Index Site is generated by the Real-Time program. For stocks with the Lower Granite Index Site, the predicted distributions at Little Goose, Lower Monumental, and McNary are CRiSP projections based on the arrival time predictions at Lower Granite Dam. For stocks with the McNary Index Site, the predicted distributions at John Day and Bonneville are CRiSP projections based on the arrival time predictions at McNary Dam. The vertical line in each plot is the date of the prediction. The historical runs can be accessed from the web site at <http://www.cbr.washington.edu/crisprt/archive/>.

The stocks are referenced by their codes:

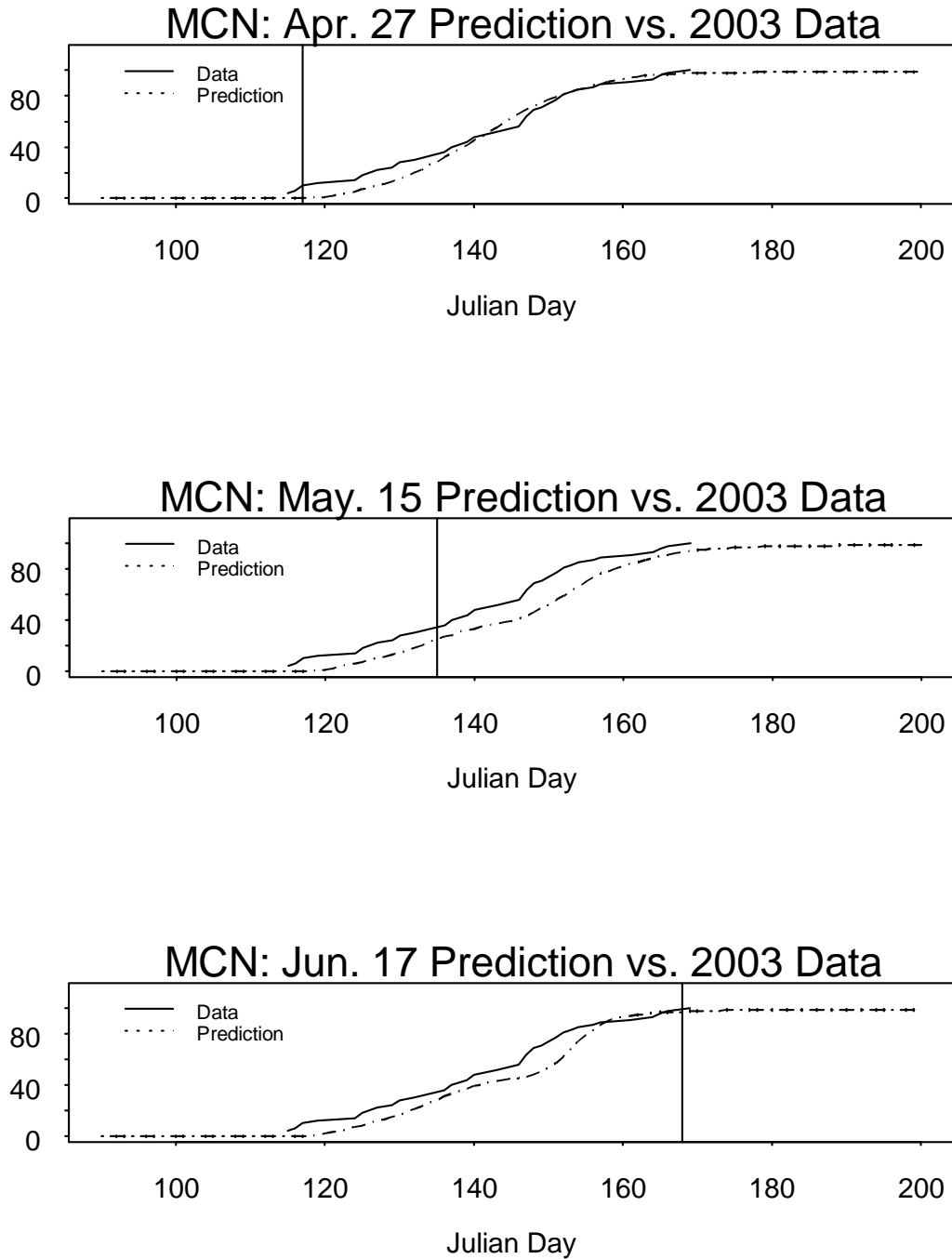
<u>Stock Code</u>	<u>Origin</u>	<u>Species</u>	<u>Index Site</u>	<u>Pass. Site</u>
COMPOSITE	Next 4 stocks taken together	Yearling Chinook	LWG	MCN
CATHEC	Catherine Creek	Yearling Chinook	LWG	MCN
IMNAHR	Imnaha River	Yearling Chinook	LWG	MCN
SALRSF	South Fork Salmon River	Yearling Chinook	LWG	MCN
MINAMR	Minam River	Yearling Chinook	LWG	MCN
SNAKER	Snake River	Subyearling Chinook	LWG	MCN
lgrStlhd	Snake River	Steelhead	LWG	MCN
mcnChin1S	ESU Snake R Spring/Summer	Yearling Chinook	MCN	JDA
mcnChin0S	ESU Snake R Fall	Subyearling Chinook	MCN	JDA
mcnChin0C	ESU Upper Columbia R Fall	Subyearling Chinook	MCN	JDA
mcnStlhdS	ESU Snake R	Steelhead	MCN	JDA
mcnStlhdC	ESU Upper Columbia R	Steelhead	MCN	JDA

## Yearling Chinook Composite stock at McNary



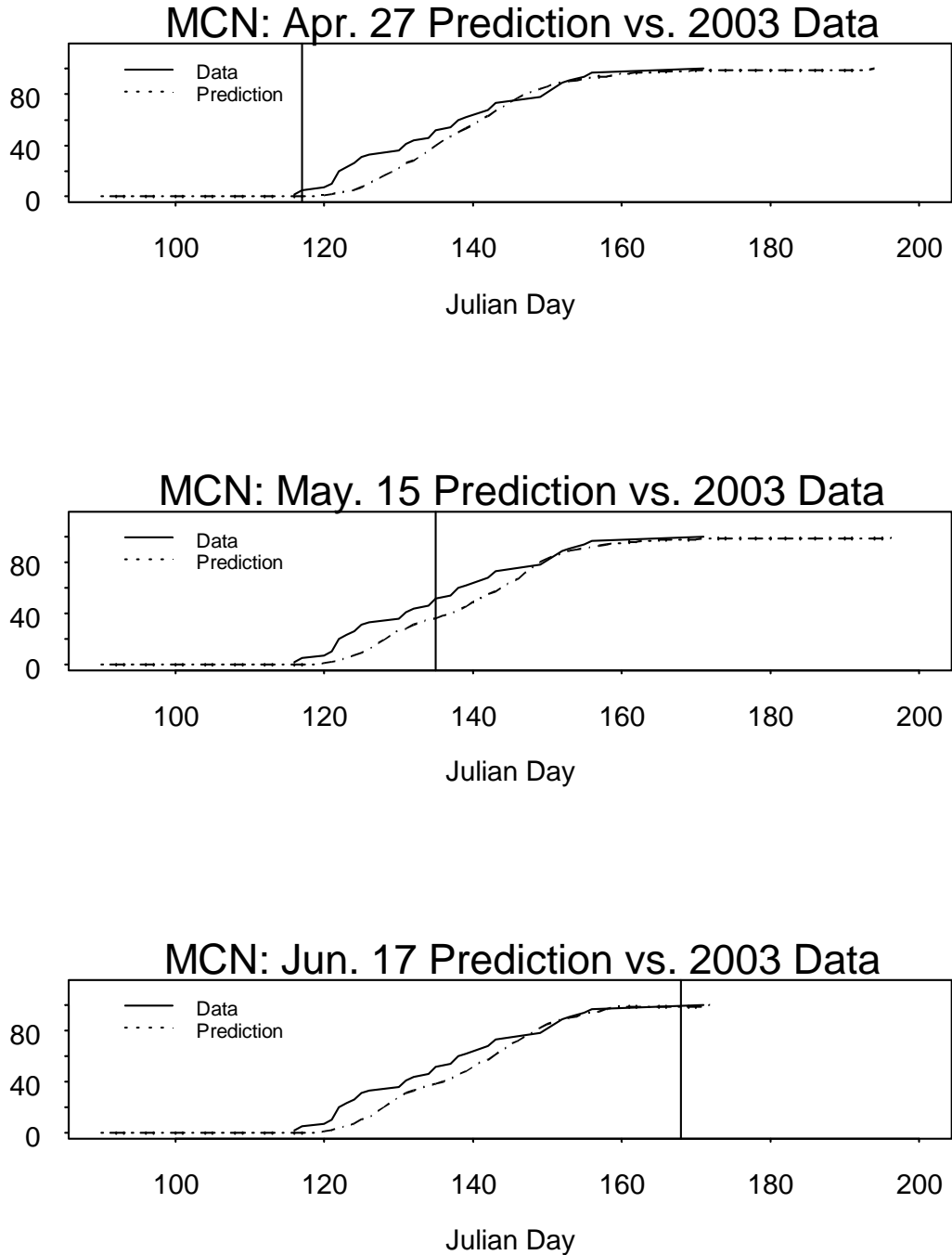
**Figure I-1** Percent passage predictions and observations for Yearling Chinook Composite stock at McNary Dam. Y axis is percent passage.

## Yearling Chinook CATHEC stock at McNary



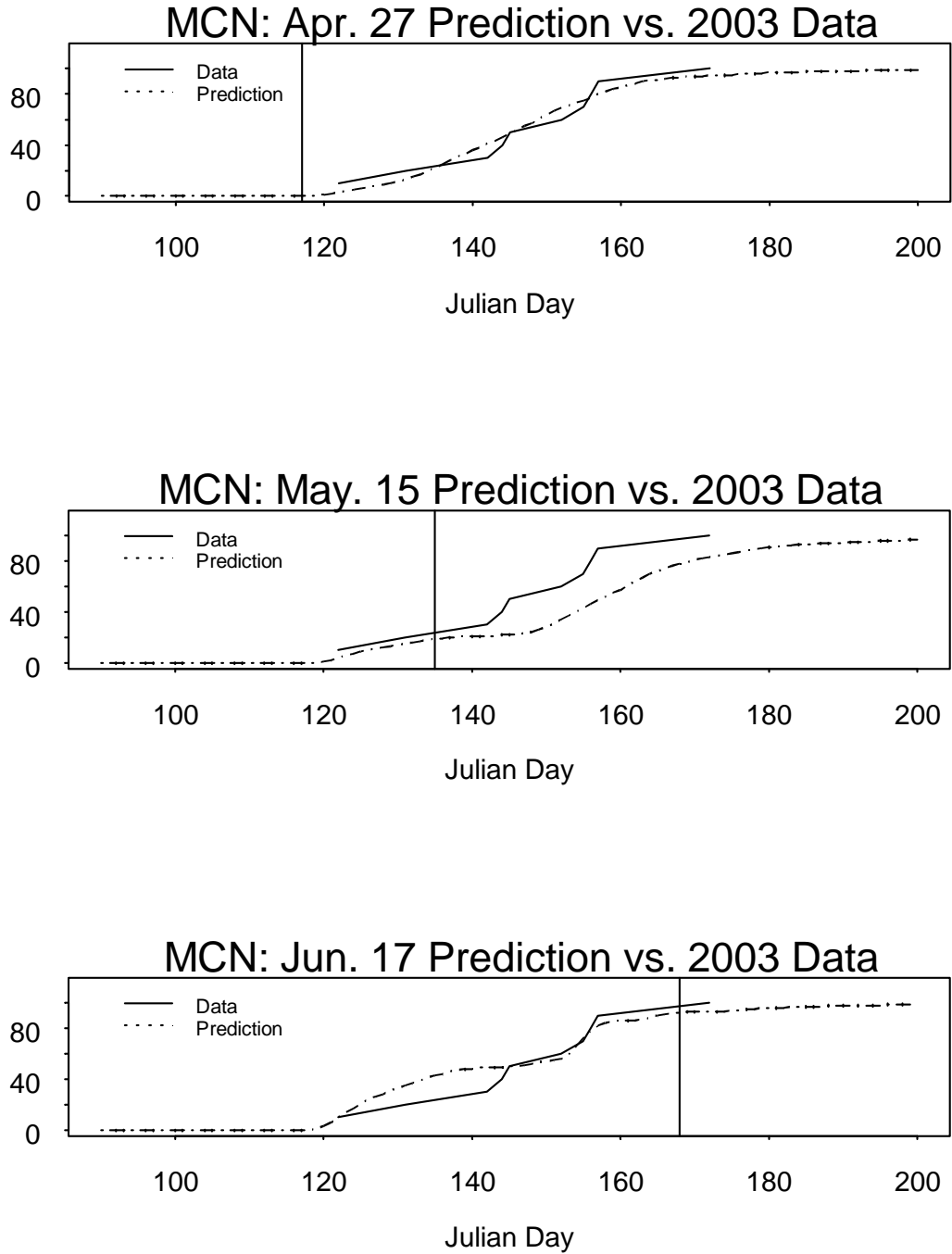
**Figure I-2** Percent passage predictions and observations for Yearling Chinook CATHEC stock at McNary Dam. Y axis is percent passage.

## Yearling Chinook IMNAHR stock at McNary



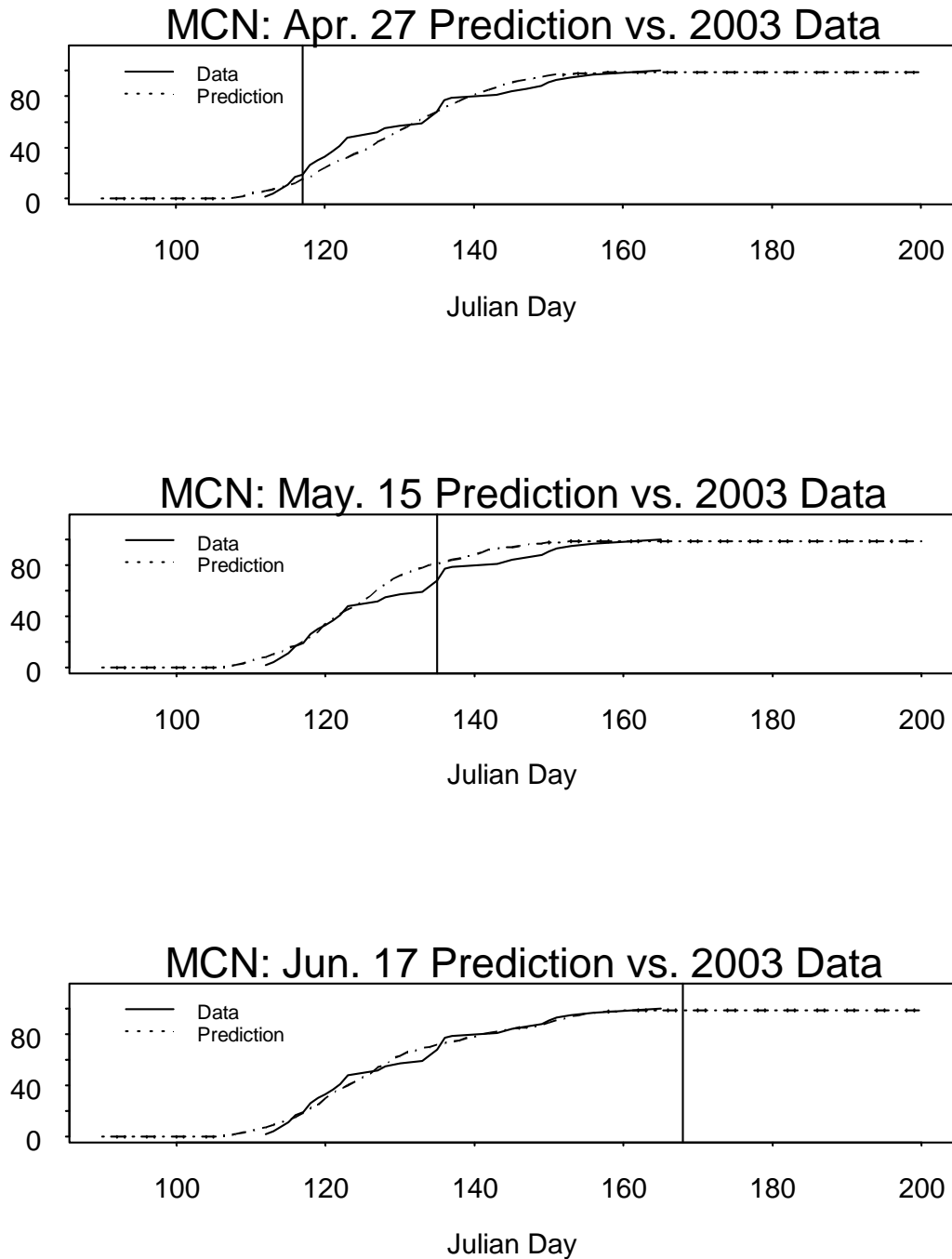
**Figure I-3** Percent passage predictions and observations for Yearling Chinook IMNAHR stock at McNary Dam. Y axis is percent passage.

## Yearling Chinook SALRSF stock at McNary



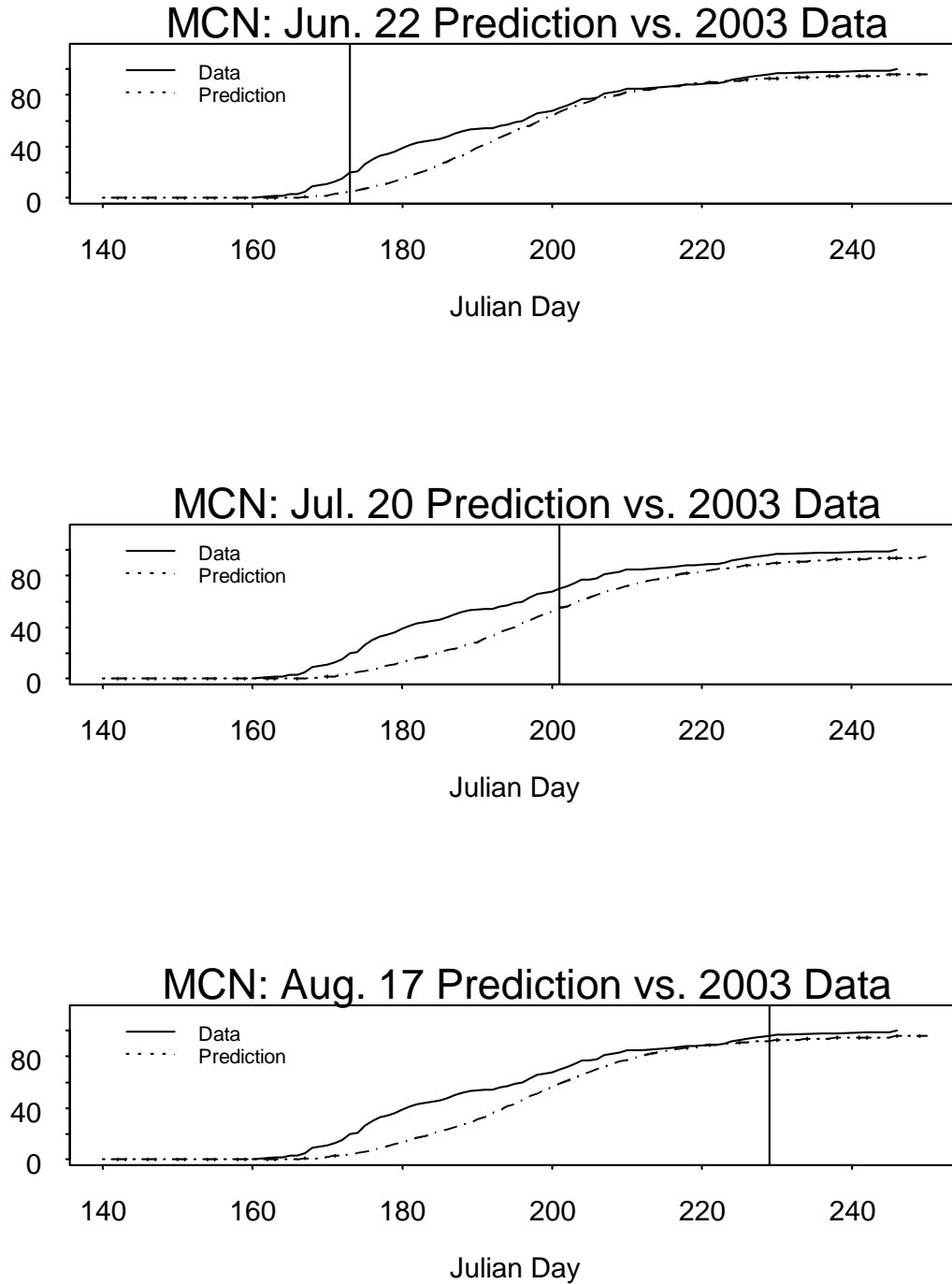
**Figure I-4** Percent passage predictions and observations for Yearling Chinook SALRSF stock at McNary Dam. Y axis is percent passage.

## Yearling Chinook MINAMR stock at McNary



**Figure I-5** Percent passage predictions and observations for Yearling Chinook MINAMR stock at McNary Dam. Y axis is percent passage.

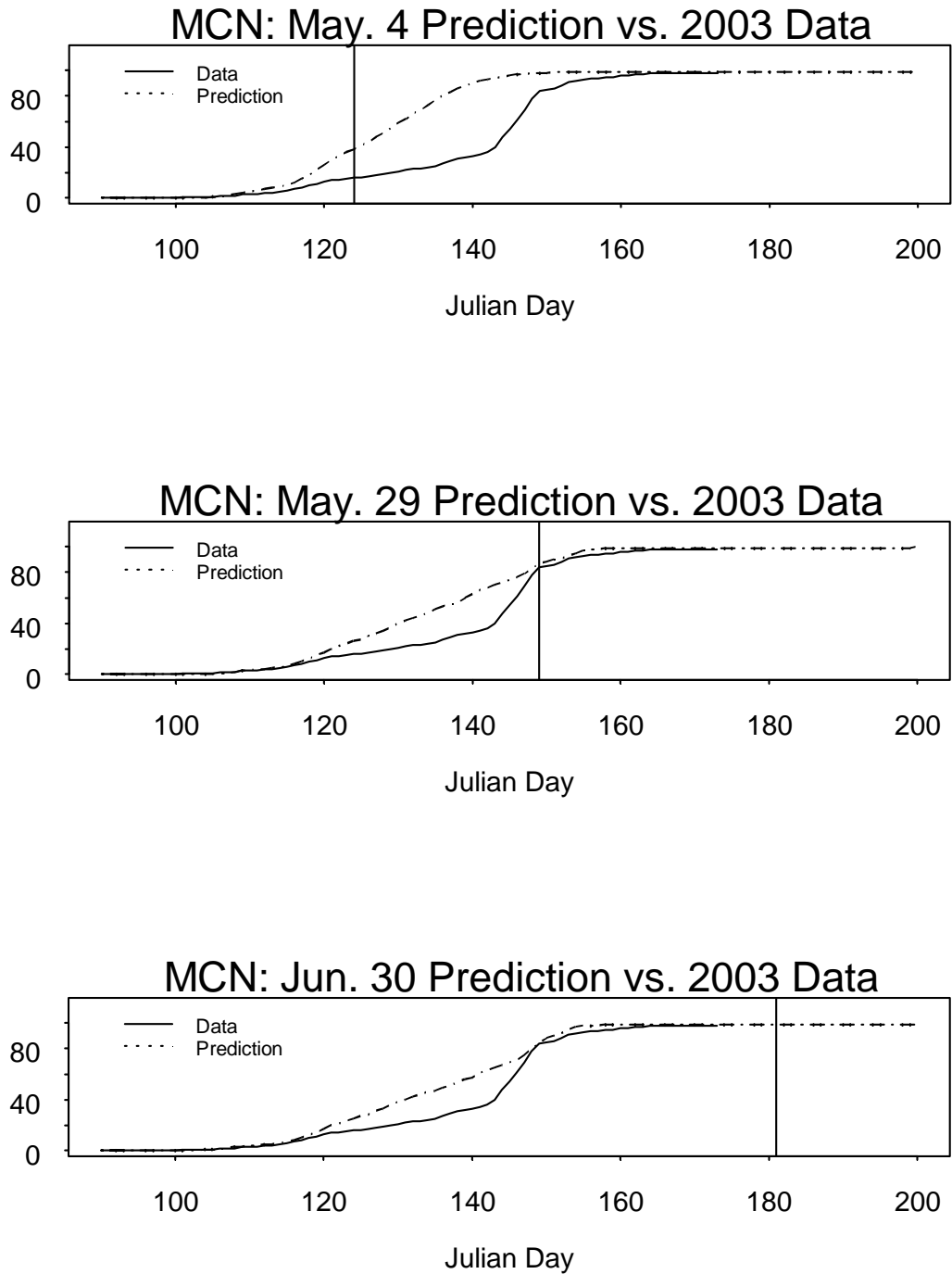
## Subyearling Chinook SNAKER stock at McNary



**Figure I-6** Percent passage predictions and observations for Subyearling Chinook SNAKER stock at McNary Dam. Y axis is percent passage.

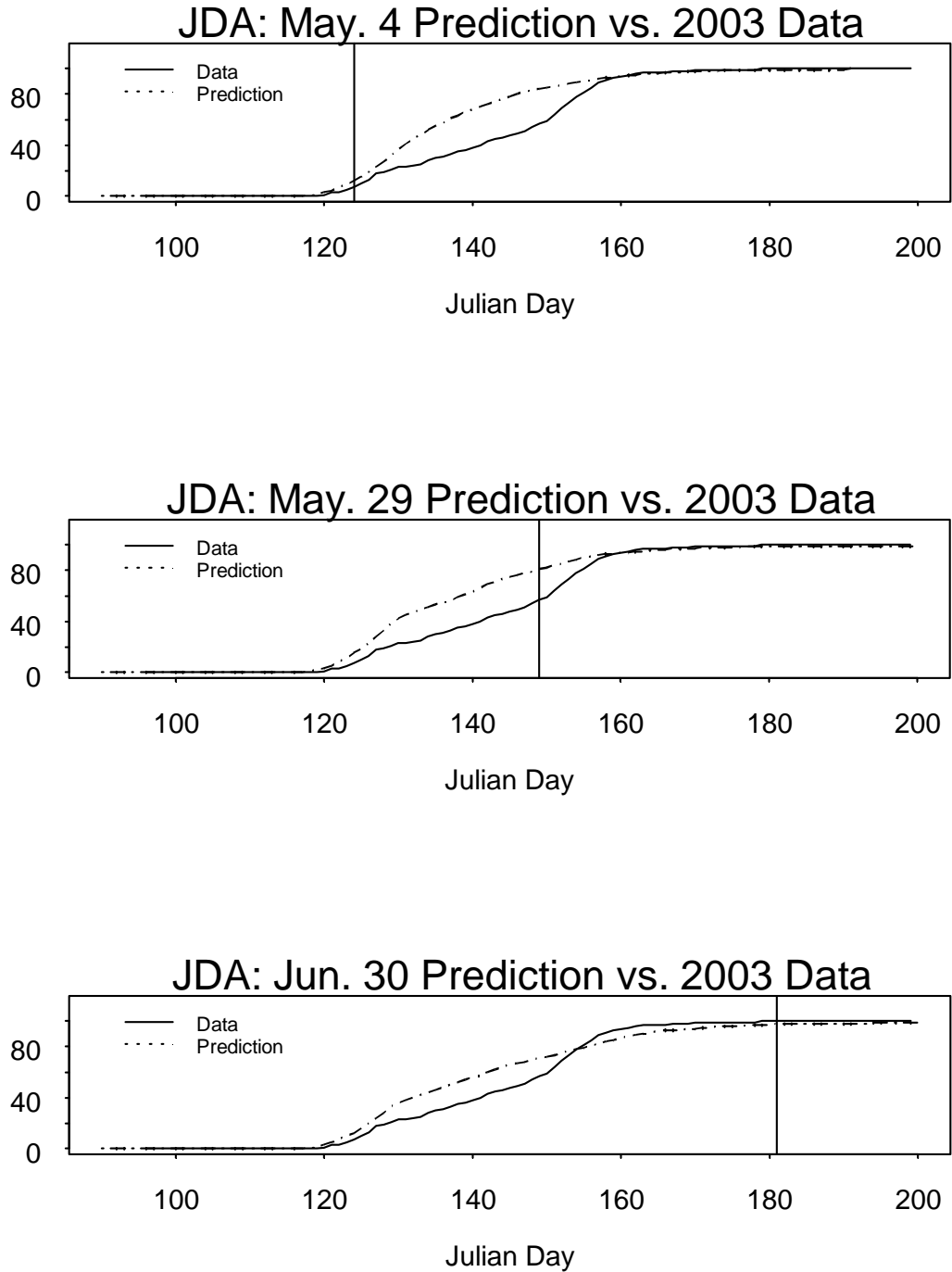


## Steelhead IgrStlhd stock at McNary



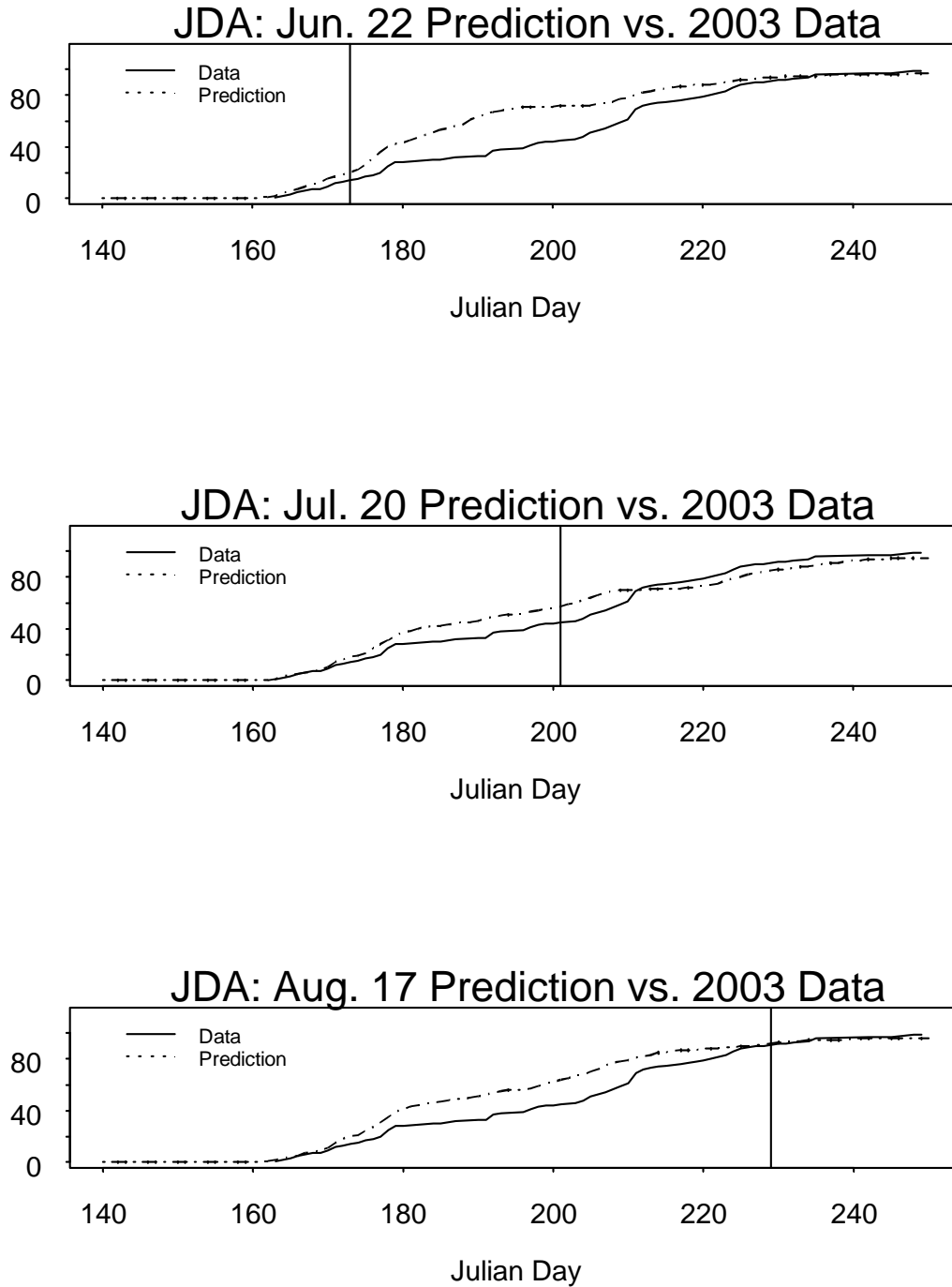
**Figure I-7** Percent passage predictions and observations for Steelhead IgrStlhd stock at McNary Dam. Y axis is percent passage.

# Snake River Spring/Summer Chinook ESU mcnChin1S at John Day



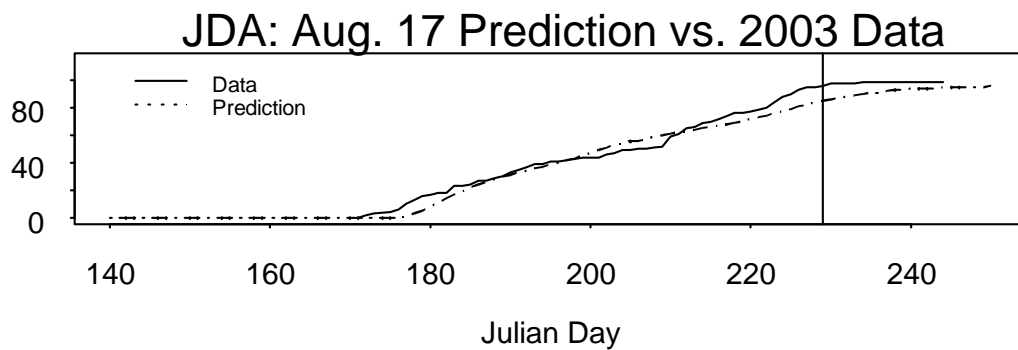
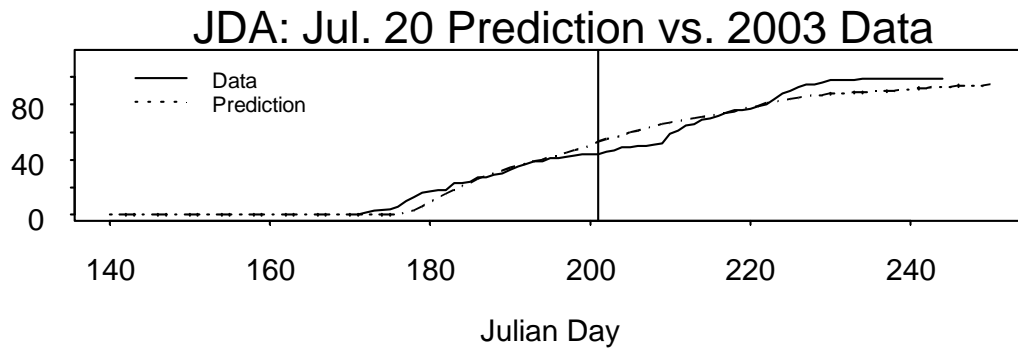
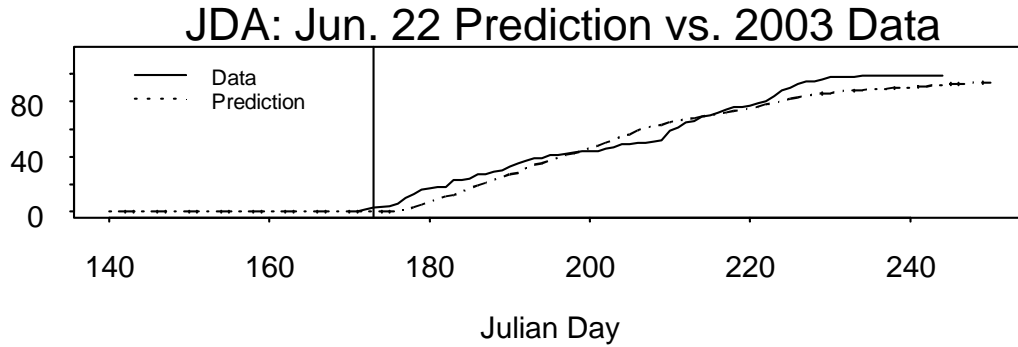
**Figure I-8** Percent passage predictions and observations for Snake River Spring/Summer Chinook ESU mcnChin1S at John Day Dam. Y axis is percent passage.

## Snake R Fall Chinook ESU mcChin0S at John Day



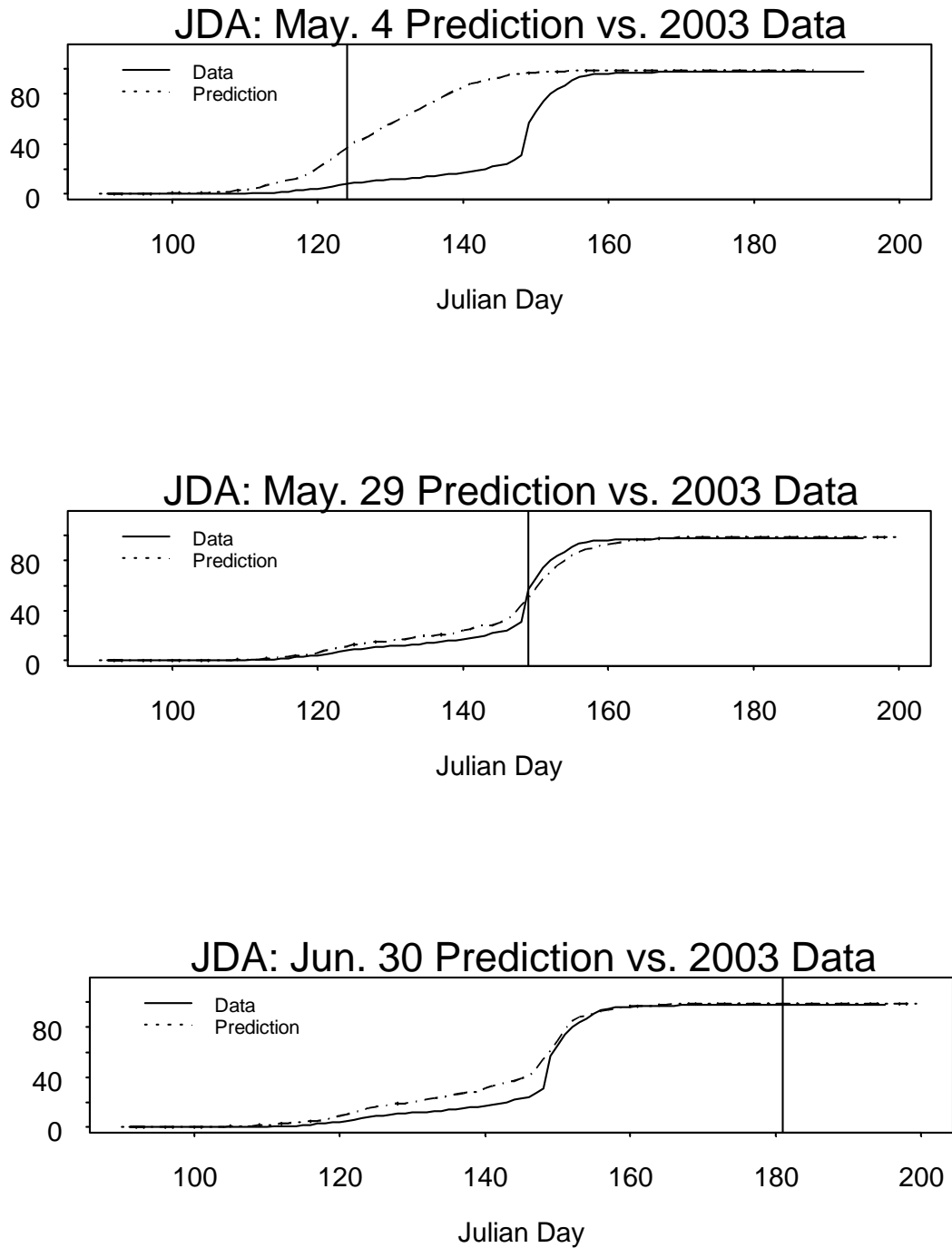
**Figure I-9** Percent passage predictions and observations for Snake River Fall Chinook ESU mcChin0S stock at John Day Dam. Y axis is percent passage.

# Upper Columbia R Fall Chinook ESU mcnChin0C at John Day



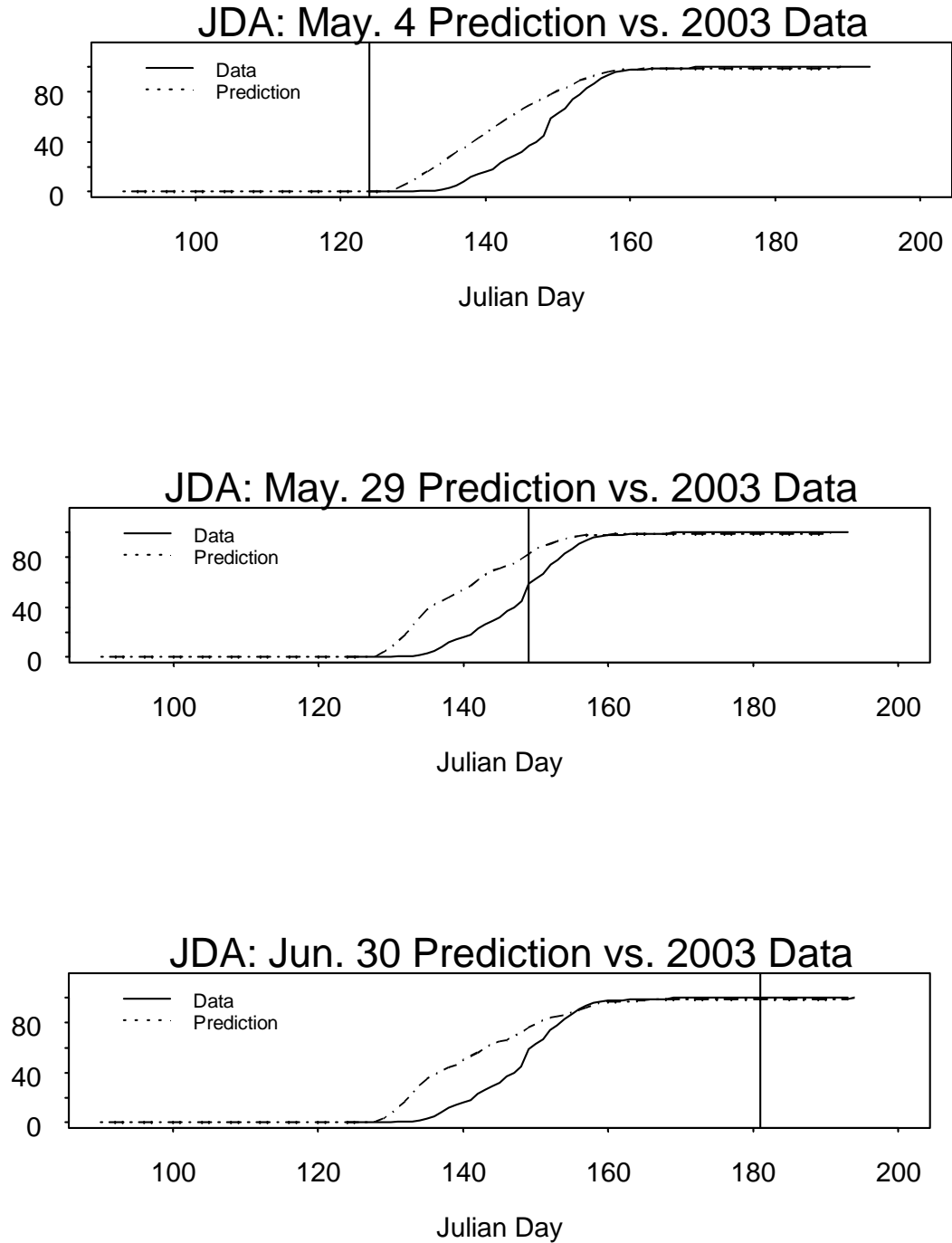
**Figure I-10** Percent passage predictions and observations for Upper Columbia River Fall Chinook ESU mcnChin0C stock at John Day Dam. Y axis is percent passage.

## Snake R Steelhead ESU mcStlhdS at John Day



**Figure I-11** Percent passage predictions and observations for Snake River Steelhead ESU mcStlhdS at John Day Dam. Y axis is percent passage.

# Upper Columbia R Steelhead ESU mcnStlhdC at John Day



**Figure I-12** Percent passage predictions and observations for Upper Columbia River Steelhead ESU at John Day Dam. Y axis is percent passage.

## Appendix J Cumulative Observation plots

The following figures present the CRiSP/RealTime observations of each tracked stock at multiple locations. Note that the counts at any given dam may in fact be greater than at upstream locations<sup>1</sup>. The sequence of passage is LWG, LGS, LMN, MCN, JDA, and BON. This is likely due to different passage routes through the dams, and the efficiency of PIT-tag detectors in identifying fish as they pass. Passage predictions made by CRiSP assume that missing fish have died and are not counted. The observations can vary due to mortality and counting efficiency. Biases in passage routes that vary during the period of fish passage result in biases in counts and passage timing.

The total numbers vary across several orders of magnitude between the stocks.

The stocks are referenced by their codes as they are in Appendix I:

<u>Stock Code</u>	<u>Origin</u>	<u>Species</u>	<u>Index Site</u>	<u>Pass. Site</u>
COMPOSITE	Next 4 stocks taken together	Yearling Chinook	LWG	MCN
CATHEC	Catherine Creek	Yearling Chinook	LWG	MCN
IMNAHR	Imnaha River	Yearling Chinook	LWG	MCN
SALRSF	South Fork Salmon River	Yearling Chinook	LWG	MCN
MINAMR	Minam River	Yearling Chinook	LWG	MCN
SNAKER	Snake River	Subyearling Chinook	LWG	MCN
lgrStlhd	Snake River	Steelhead	LWG	MCN
mcnChin1S	ESU Snake R Spring/Summer	Yearling Chinook	MCN	JDA
mcnChin0S	ESU Snake R Fall	Subyearling Chinook	MCN	JDA
mcnChin0C	ESU Upper Columbia R Fall	Subyearling Chinook	MCN	JDA
mcnStlhdS	ESU Snake R	Steelhead	MCN	JDA
mcnStlhdC	ESU Upper Columbia R	Steelhead	MCN	JDA

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1. From April 10 to June 7, 2003, 31538 PIT-Tagged wild summer steelhead were released at LGRRRR: release below PIT-Tag Diversion System at Lower Granite Dam. The first point of detection for these fish is Little Goose Dam not Lower Granite.

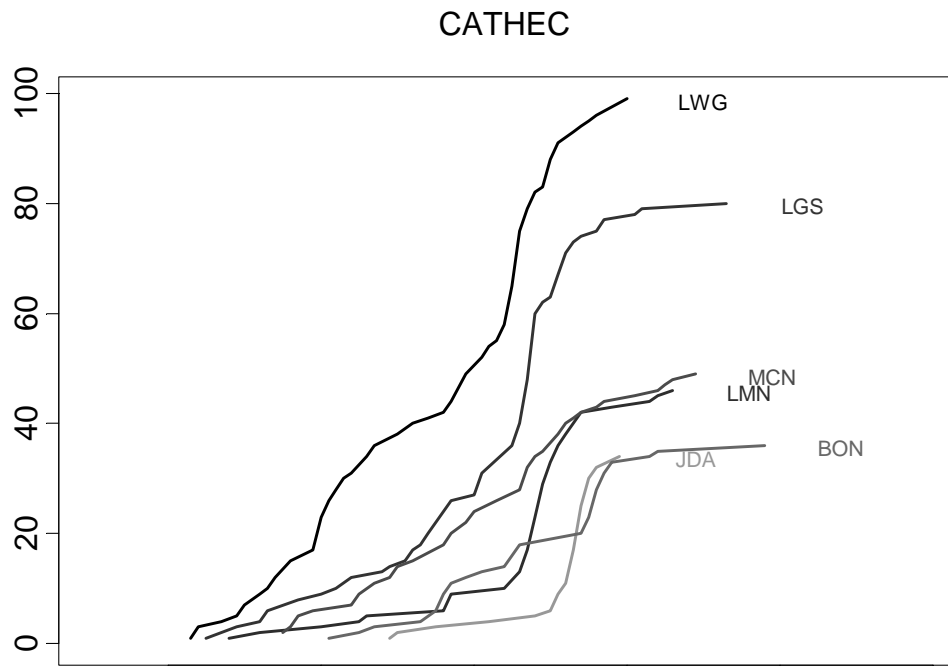
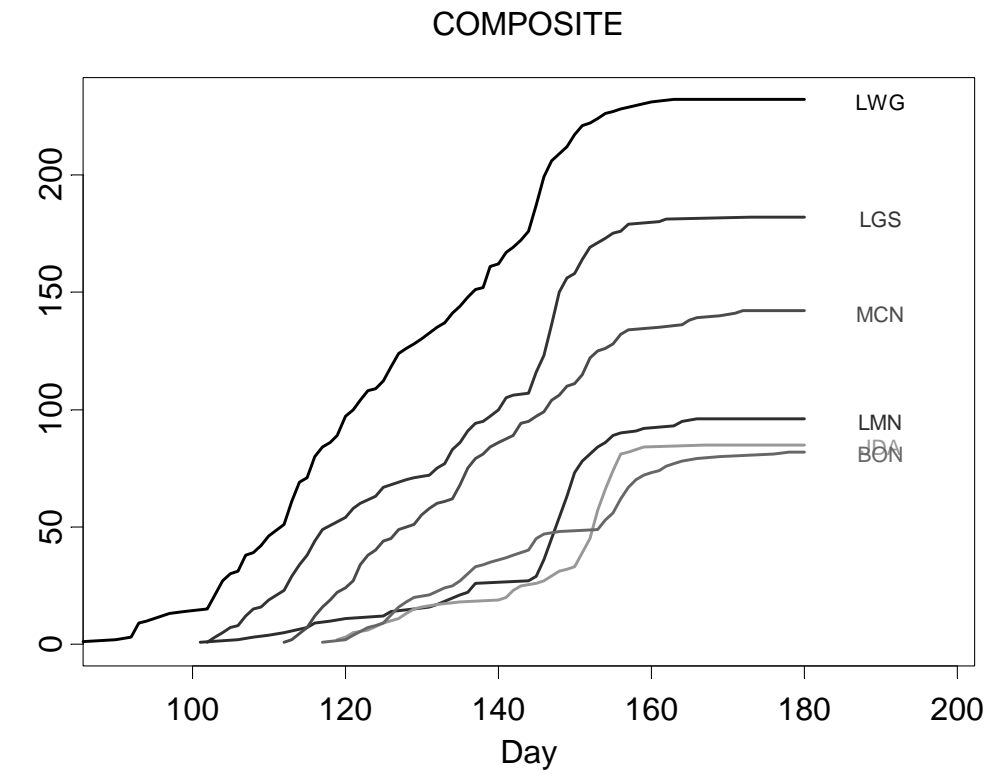


Figure J-1 COMPOSITE and CATHEC cumulative observations at six sites. The sequence of passage is LWG, LGS, LMN, MCN, JDA, and BON.



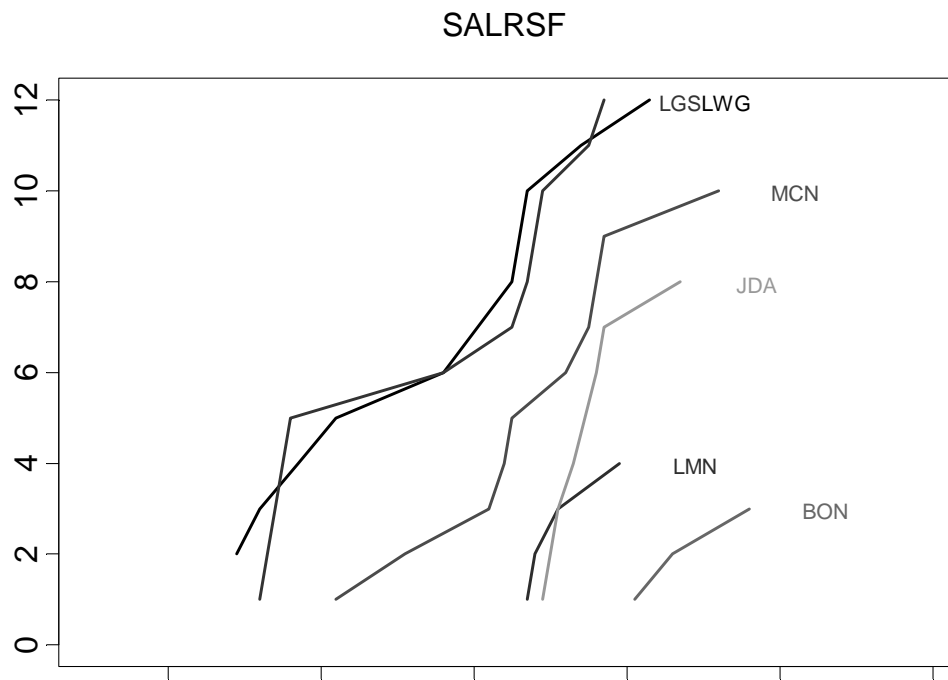
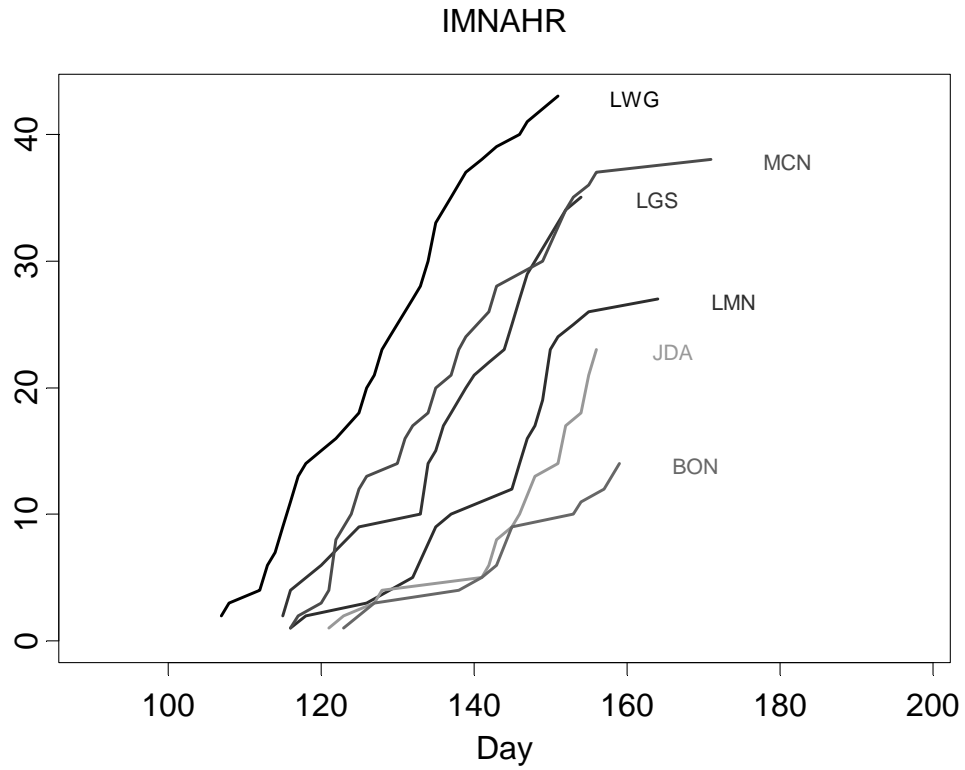


Figure J-2 IMNAHR and SALRSF cumulative observations at six sites. The sequence of passage is LWG, LGS, LMN, MCN, JDA, and BON.

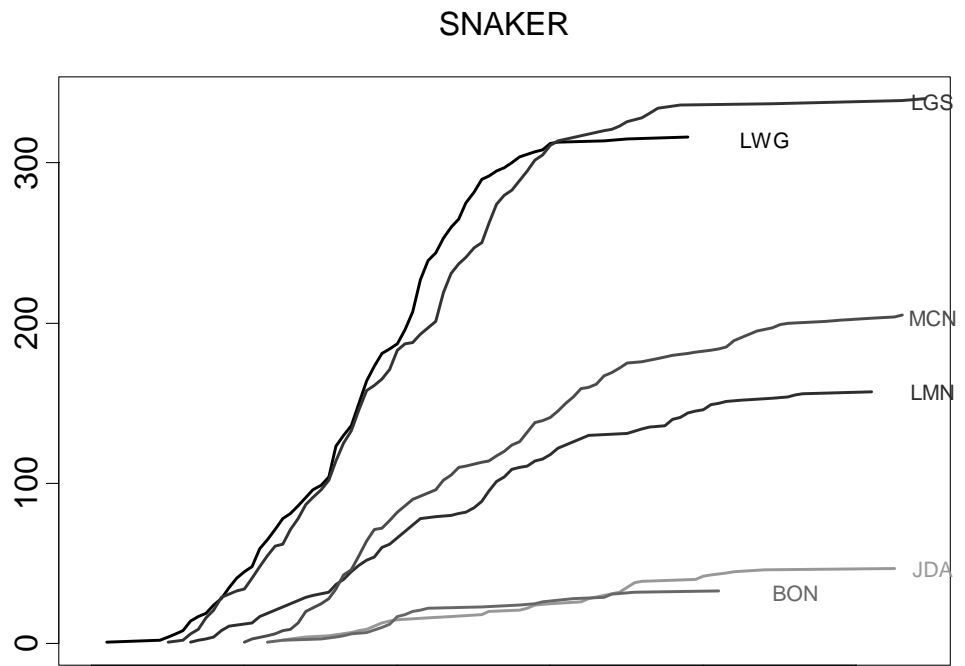
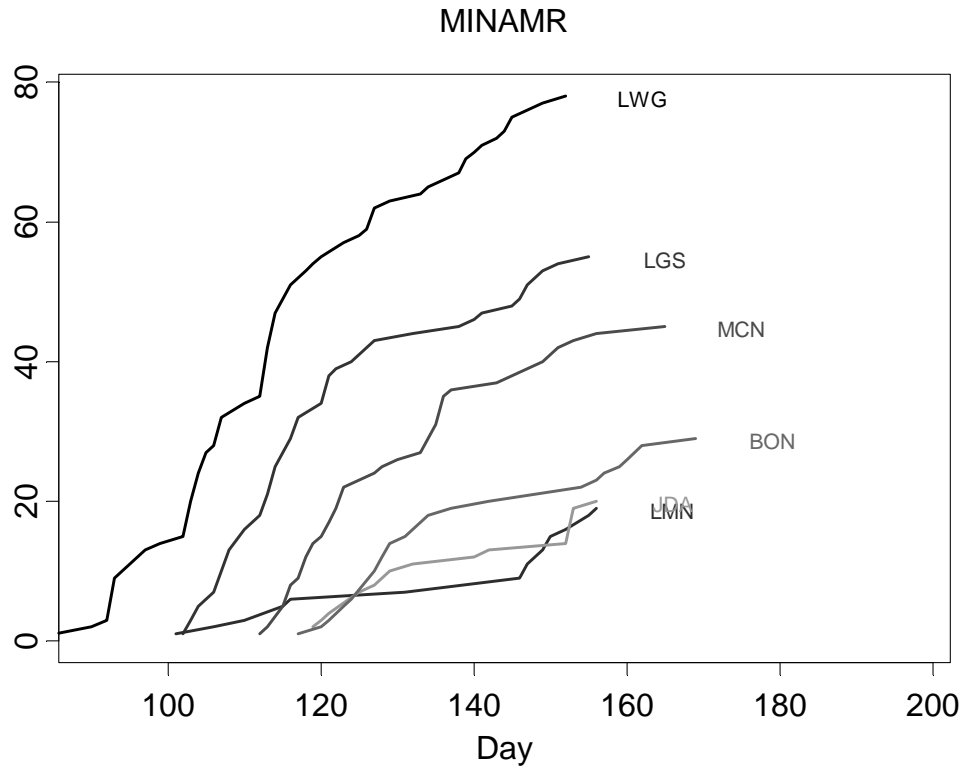


Figure J-3 MINAMR and SNAKER cumulative observations at six sites. The sequence of passage is LWG, LGS, LMN, MCN, JDA, and BON.

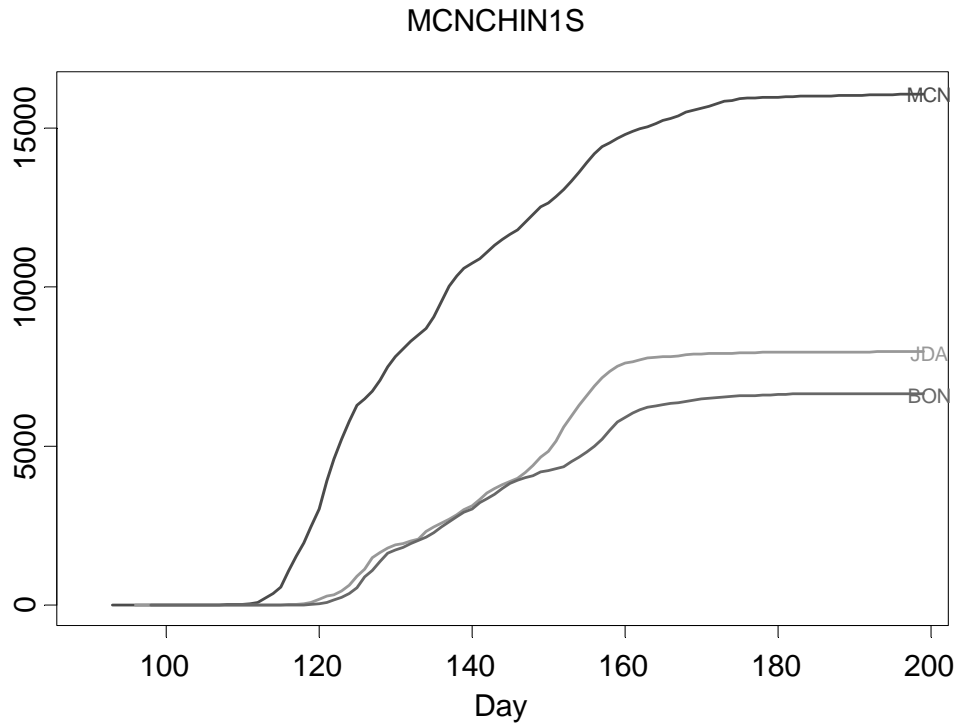
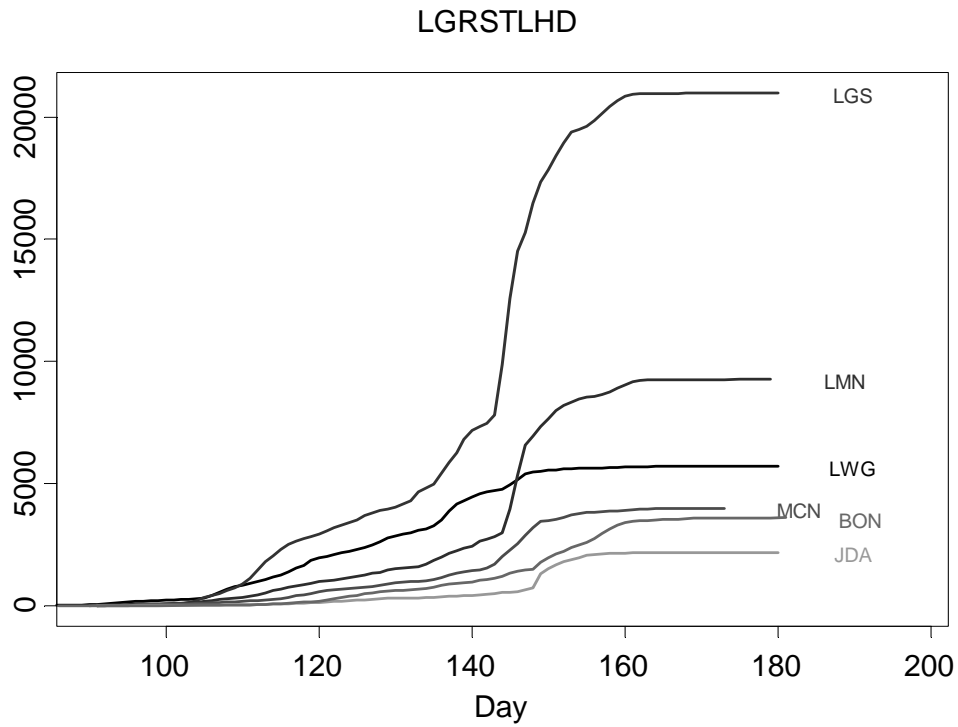
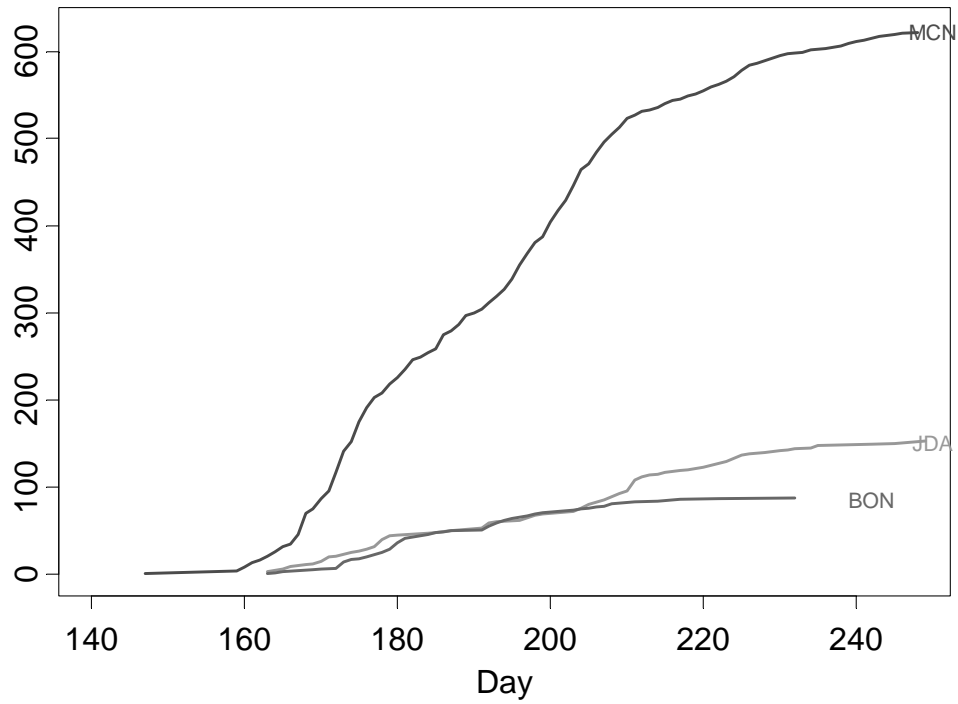


Figure J-4 IgrStlhd cumulative observations at 6 sites; mcnChin1S cumulative observations at 3 sites. The sequence of passage is LWG, LGS, LMN, MCN, JDA, and BON.

### MCNCHIN0S



### MCNCHIN0C



Figure J-5 mcnChin0S and mcnChin0C cumulative observations at three sites. The sequence of passage is MCN, JDA, and BON.

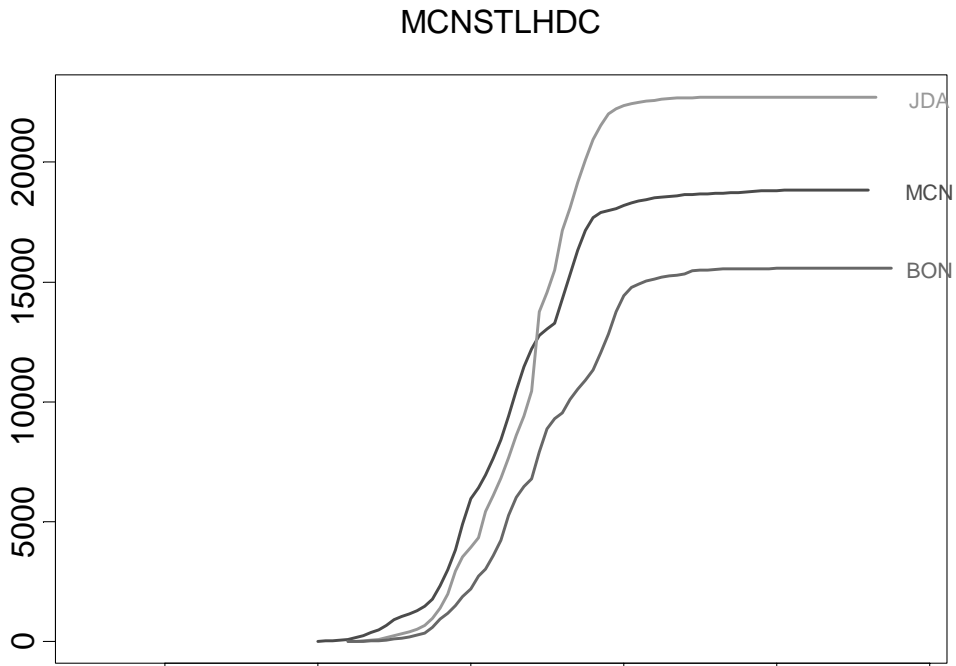
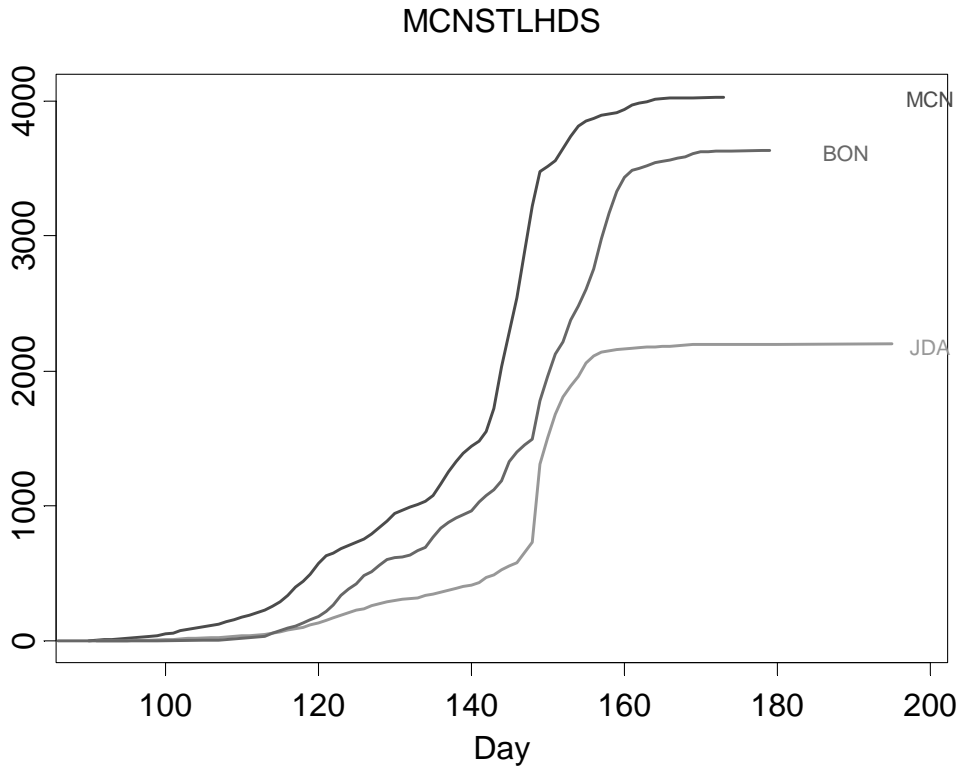


Figure J-6 mcnStlhdS and mcnStlhdC cumulative observations at six sites. The sequence of passage is MCN, JDA, and BON.

## Appendix K Seasonal Variation in Passage Predictions

Passage predictions during the season vary as function of changes in river conditions from past predicted values. RealTime predictions of arrivals at the index sites—Lower Granite Dam and McNary Dam—are used as input to CRiSP which then predicts the arrival of fish at downstream locations. In the figures that follow, *MAD* computations for each modeled day of arrivals are displayed. Patterns of prediction success at an upstream location are propagated downstream.

The stocks are referenced by their codes:

<u>Stock Code</u>	<u>Origin</u>	<u>Species</u>	<u>Index Site</u>	<u>Pass. Site</u>
COMPOSITE	Next 4 stocks taken together	Yearling Chinook	LWG	MCN
CATHEC	Catherine Creek	Yearling Chinook	LWG	MCN
IMNAHR	Imnaha River	Yearling Chinook	LWG	MCN
SALRSF	South Fork Salmon River	Yearling Chinook	LWG	MCN
MINAMR	Minam River	Yearling Chinook	LWG	MCN
SNAKER	Snake River	Subyearling Chinook	LWG	MCN
lgrStlhd	Snake River	Steelhead	LWG	MCN
mcnChin1S	ESU Snake R Spring/Summer	Yearling Chinook	MCN	JDA
mcnChin0S	ESU Snake R Fall	Subyearling Chinook	MCN	JDA
mcnChin0C	ESU Upper Columbia R Fall	Subyearling Chinook	MCN	JDA
mcnStlhdS	ESU Snake R	Steelhead	MCN	JDA
mcnStlhdC	ESU Upper Columbia R	Steelhead	MCN	JDA

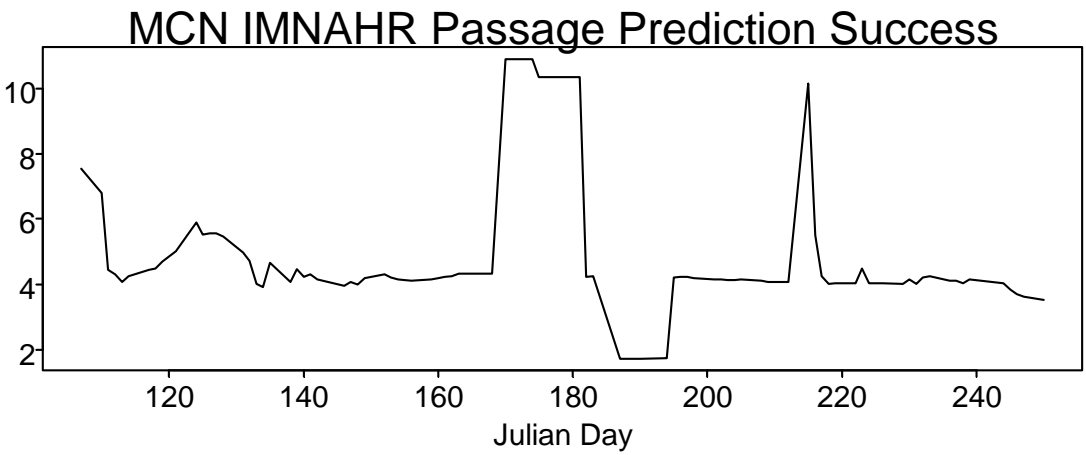
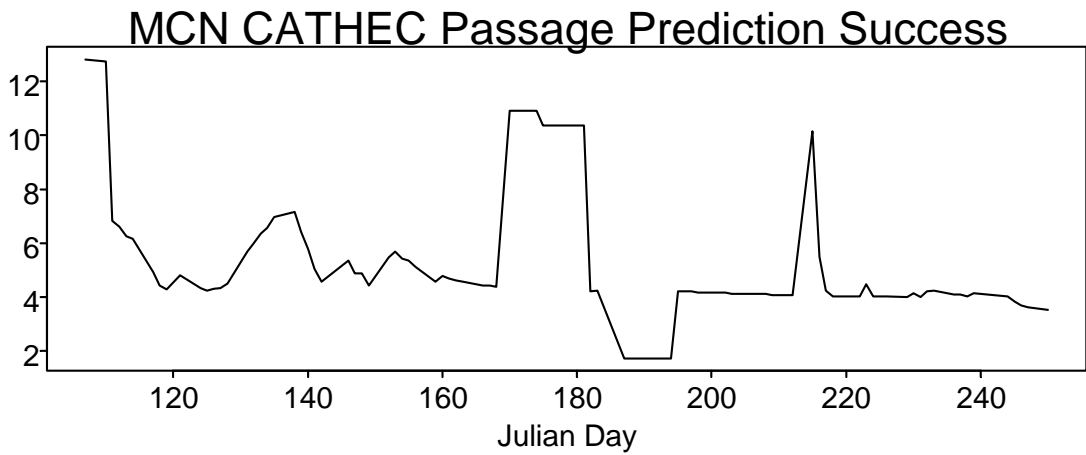
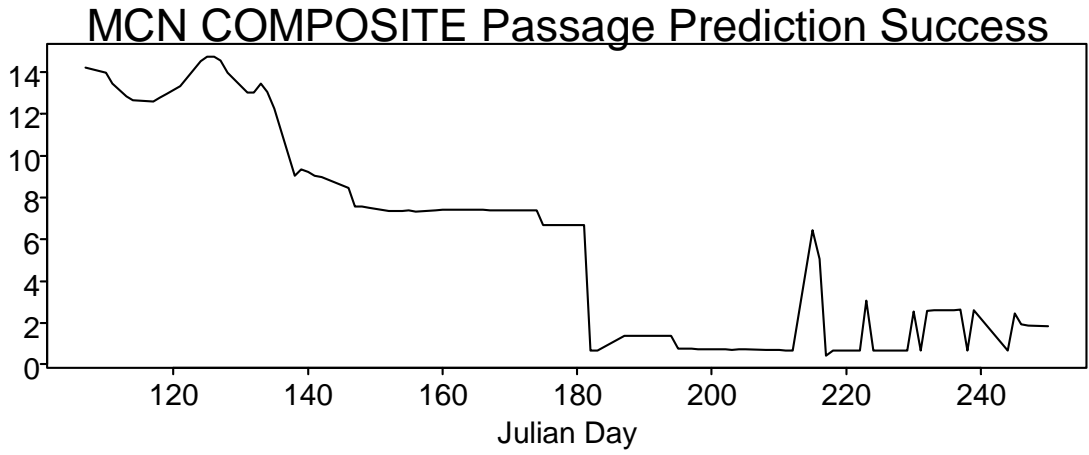


Figure K-1 Seasonal variation in passage prediction success for Catherine Creek stocks at Little Goose, Lower Monumental and McNary Dams. Y axis is the MAD value.

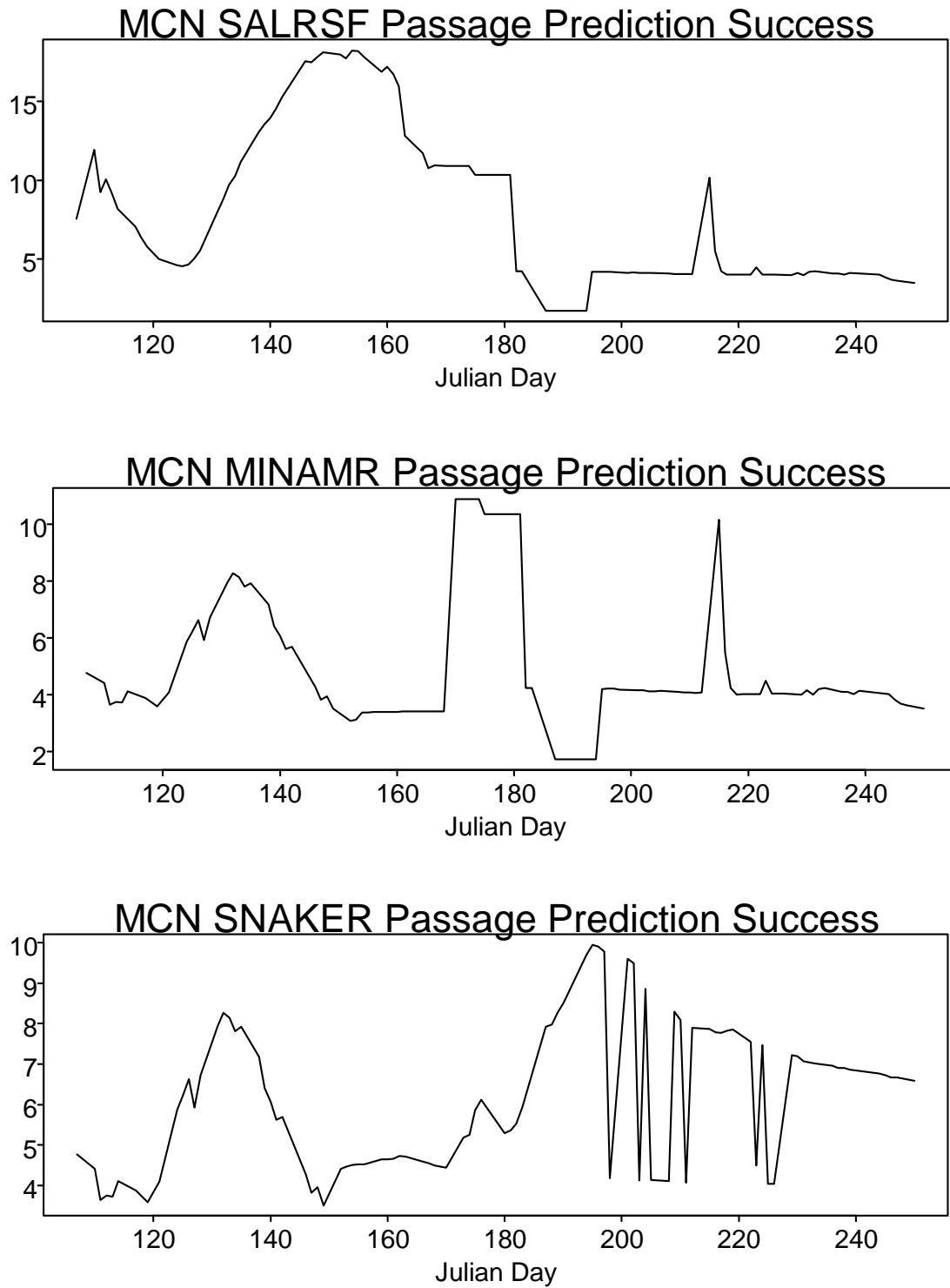


Figure K-2 Seasonal variation in passage prediction success for Catherine Creek stocks at Little Goose, Lower Monumental and McNary Dams. Y axis is the *MAD* value.



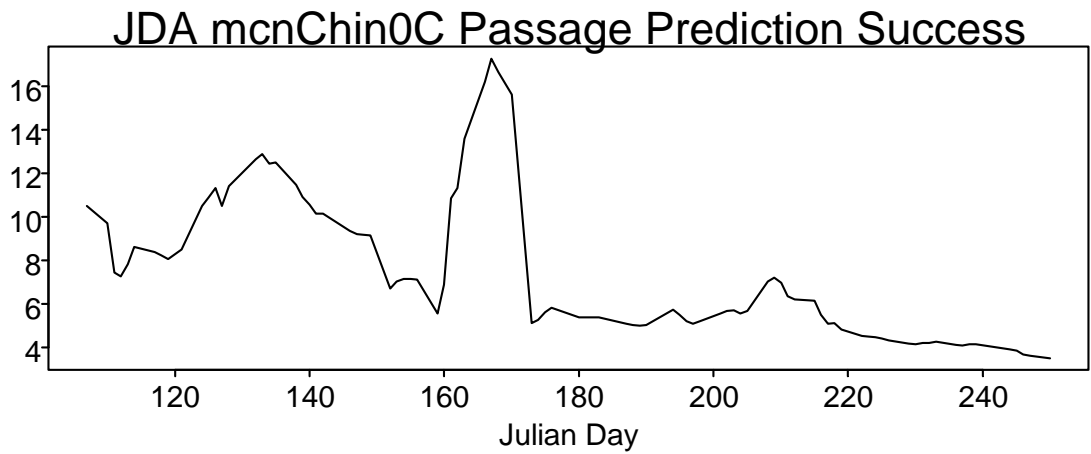
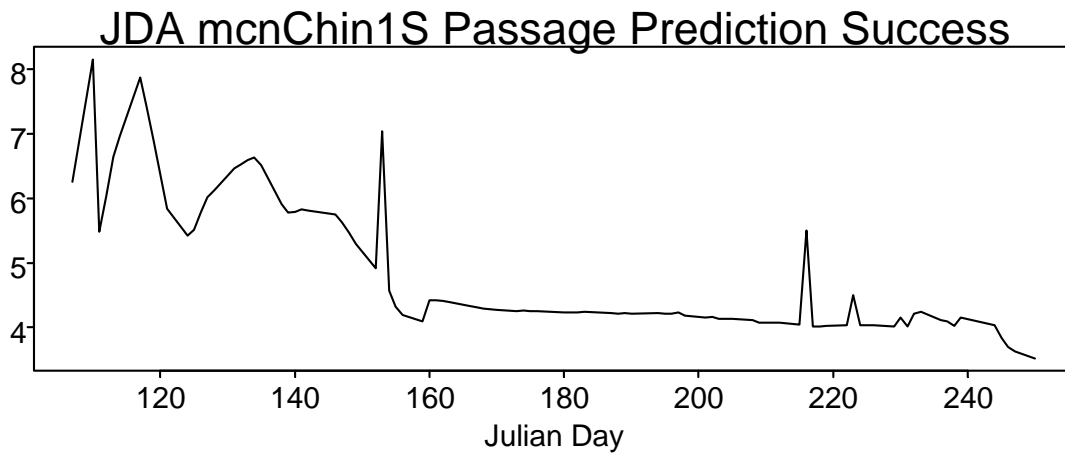
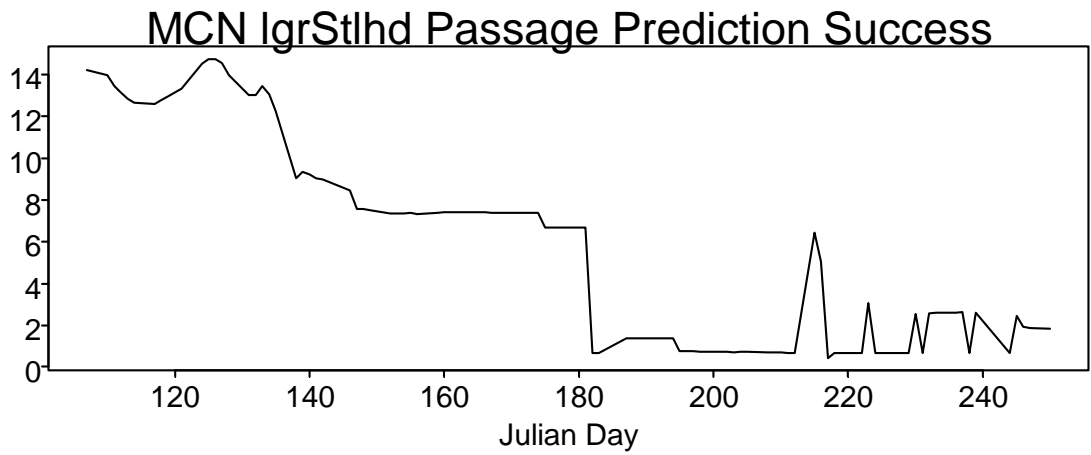


Figure K-3 Seasonal variation in passage prediction success for Catherine Creek stocks at Little Goose, Lower Monumental and McNary Dams. Y axis is the *MAD* value.

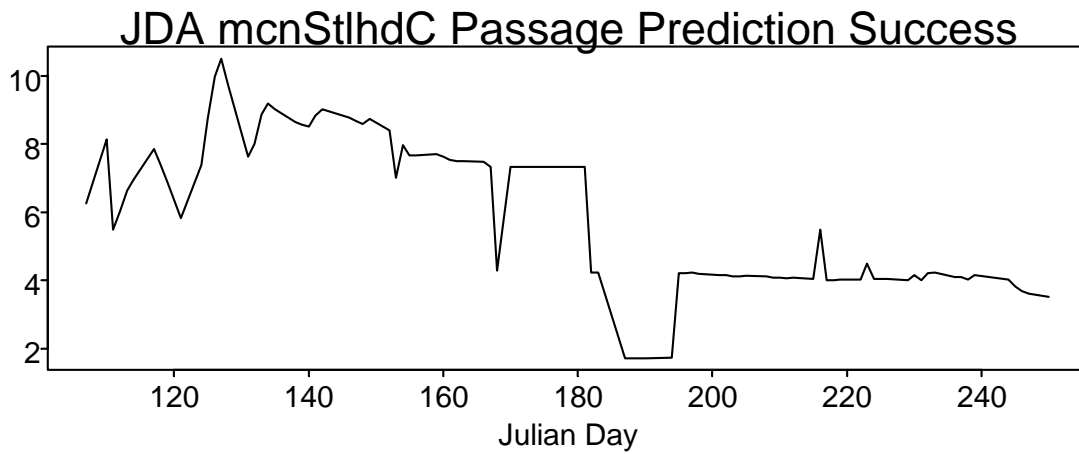
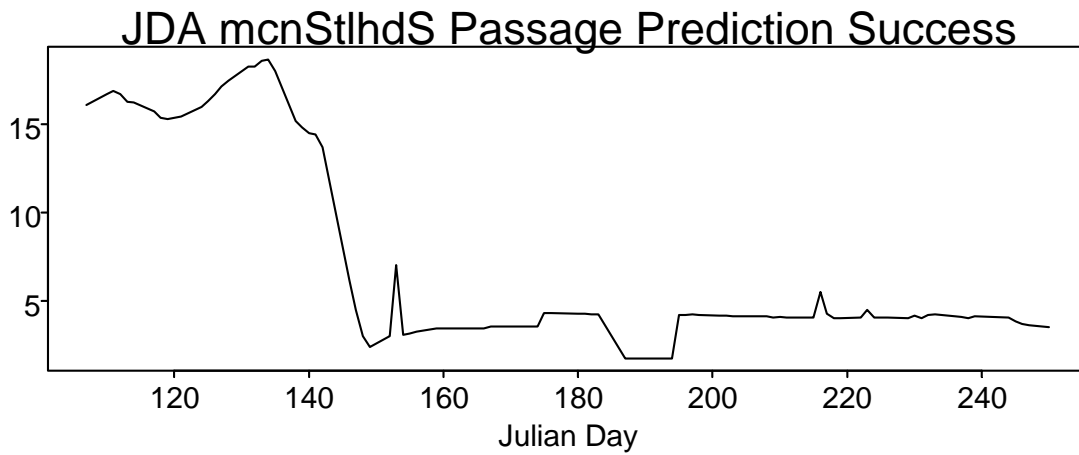
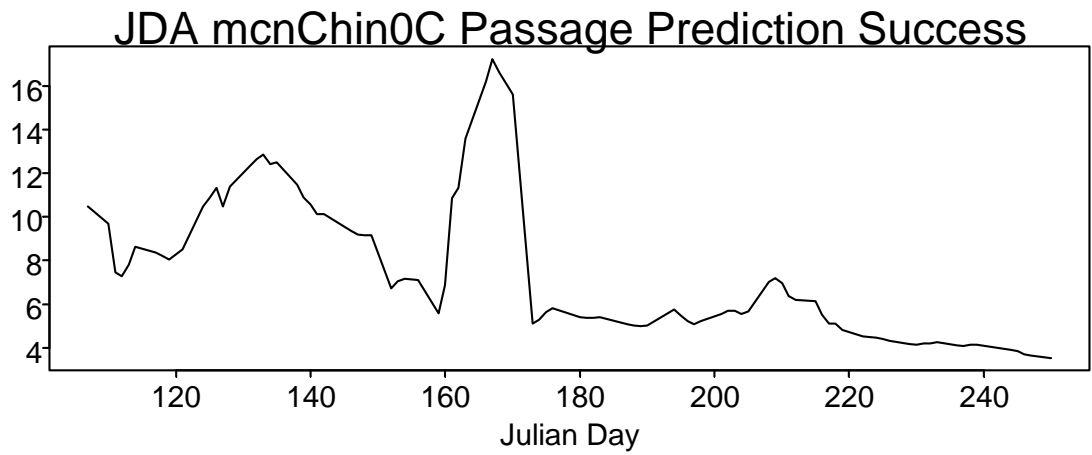


Figure K-4 Seasonal variation in passage prediction success for Catherine Creek stocks at Little Goose, Lower Monumental and McNary Dams. Y axis is the *MAD* value.