Evaluation of the 2002 Predictions of the Run-Timing of Wild Migrant Yearling Chinook and Water Quality at Multiple Locations on the Snake and Columbia Rivers using CRiSP/RealTime

Prepared by:

W. Nicholas Beer
Susannah Iltis
Chris Van Holmes
James J. Anderson

Columbia Basin Research
School of Aquatic and Fishery Sciences
University of Washington
Box 358218
Seattle, Washington 98195

Prepared for:

U.S. Department of Energy
Bonneville Power Administration
Environment, Fish and Wildlife
P.O. Box 3621
Portland, OR 97283-3621

Project Number 89-108
Contract Number DE-BI79-89BP02347

July 18, 2003

Executive Summary

This report is a post-season analysis of the performance of the CRiSP portion of the Real-Time/CRiSP complex. Observed 2002 data are compared to predictions made by CRiSP/Real-Time during the 2002 outmigration for arrival timing, water temperature, and total dissolved gas. Also, flow and spill predictions made during the season at various dams are compared to data.

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.

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 elapsed time to some future percentile in a migration (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 2002 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.

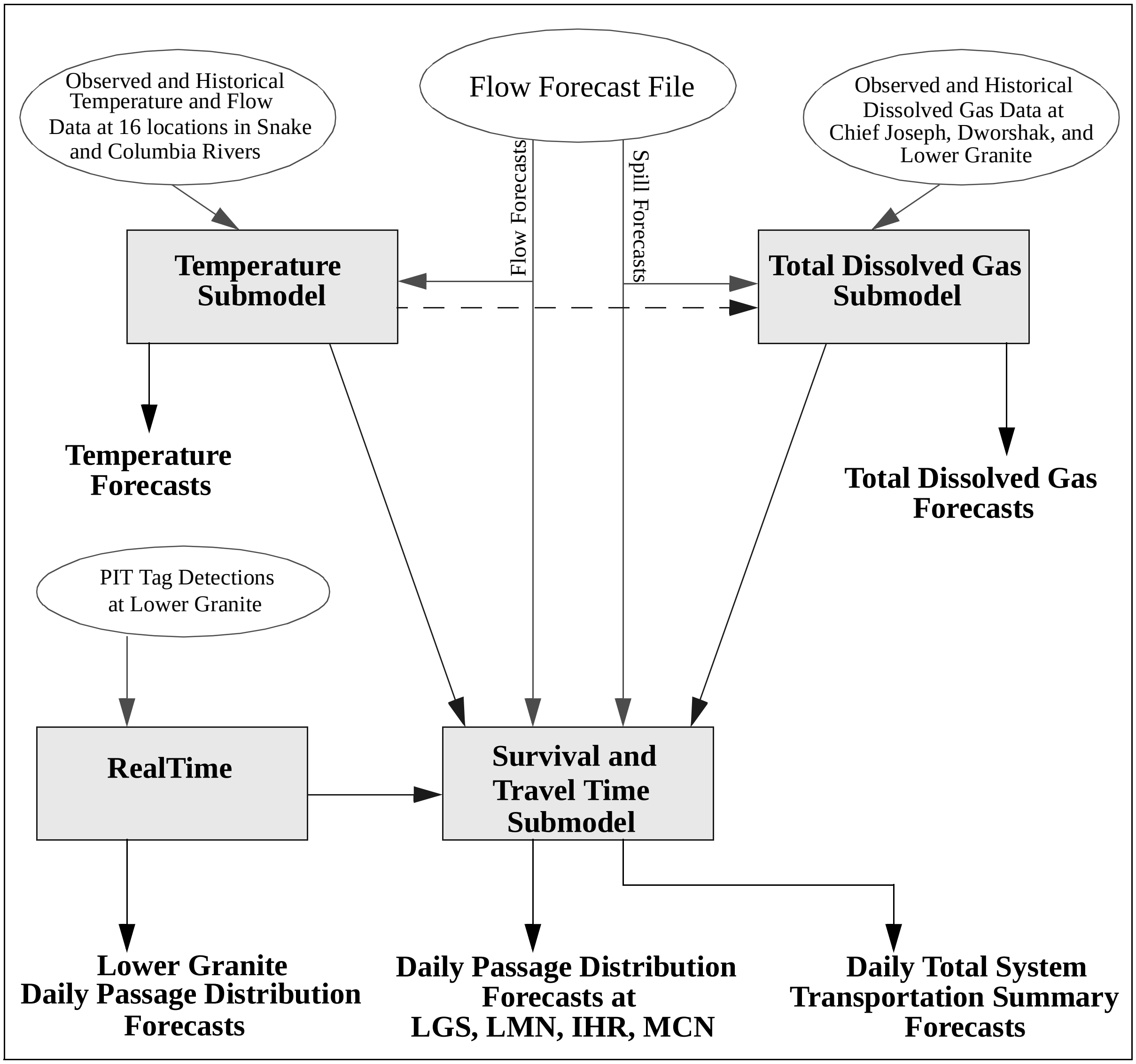


Figure 1 Simplified schematic of RealTime and CRiSP complex. Prior to migration year 2000, model generated gas was not updated with observed values for the production of daily passage distribution forecasts. PIT Tag data courtesy of Pacific States Marine Fisheries Commission. Water Quality Data courtesy 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 spring/summer chinook which originate from several tributaries of the Snake River: Catherine Creek, Imnaha River, Minam River, and South Fork Salmon River abbreviated as CATHEC, IMNAHR, MINAMR, and SALRSF, respectively. Previous post-season analyses also included Lostine River (1997) and South Fork Wenaha River (1996, 1997) 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). The four observation sites addressed in this report are Lower Granite, Little Goose and Lower Monumental Dams on the Snake River and McNary Dam on the Columbia River.

In addition to the individual stocks, a “composite” stock was formed by combining all four stocks together, weighting each stock equally, as in previous analyses.

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.

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 1 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
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 2 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

Table 2 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
John Day Tailwater	JHAW	Right Bank
The Dalles Tailwater	TDDO	Left Bank
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 yearling chinook 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).

Migration rate varies by reach and by time step and is stock 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). For the yearling chinook analyzed here, we use a full migration model:

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

where:

r_t = migration rate

t = Julian date

T_{RLS} = Julian Date of passage at Lower Granite

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

β_0 and β_1 = flow-independent parameters

α_1 = a slope parameter that determines the rate of change of the experience effect

α_2 = a slope parameter that determines how quickly the flow effects shift from early-season to late-season behaviors

β_{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 (β_{MIN} at $t=T_{RLS}$) with fish increasing their flow-independent migration rate to a maximal migration rate (β_{MAX} as $t \gg T_{RLS}$). These rates are determined as follows:

$$\beta_{MIN} = \beta_0 + \beta_1 / 2 \tag{2}$$

$$\beta_{MAX} = \beta_0 + \beta_1 . \tag{3}$$

The parameter α_1 determines the rate of change from β_{MIN} to β_{MAX}. For each stock, the rate of spreading parameter (V_{VAR}) is estimated, along with the three migration rate parameters from the above equations: β_{MIN}, β_{MAX}, and β_{FLOW}. Parameters used during the 2002 migration season can be found in Appendix B.

2.2.3 Parameter Estimation

Migration rate parameters and the spread parameter (V_{VAR}) 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. 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.

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:

$$SS = \sum_{i=1}^{O} \sum_{k=1}^{C} \left(\hat{\overline{T_{i,k}}} - \overline{T_{i,k}}\right)^2 , \tag{4}$$

where:

O = the total number of observation sites,

C = the total number of cohorts,

$\hat{\overline{T_{i,k}}}$ = 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.

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:

$$MAD_j = \frac{1}{N} \sum_{t=1}^{N} \left| F_{Day_t} - \hat{F}_{Day_{tj}} \right| \times 100 \tag{5}$$

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 (5) 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. The last MAD value (MAD_N) is used in Table 7 as the final analysis of model success.

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 3 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 1 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:

$$T_i = tempmean_i + B_0 + B_1 \cdot (F_i - flowmean_i) \quad (6)$$

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 3.

Table 3 Values used for the flow coefficient B_1 during the 2002 migration season. 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

Table 3 Values used for the flow coefficient B_1 during the 2002 migration season. The flow coefficient B_0 was set to 0 at all locations.

Location	B_1
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 calibrated gas production equations used in CRiSP are based on the work of the Waterways Experiment Station (WES), U.S. Army Corps of Engineers (1996, 1997) and Columbia Basin Research (Anderson et al. 2000) as a part of the Dissolved Gas Abatement Study for the U.S. Army Corps of Engineers. The gas production equations are an empirical fit of spill data collected by the Army Corps. 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, which is typically about a mile downstream of the dam.

For the eight lower Snake and lower Columbia dams that were studied by WES, the gas production equation may take one of three forms: linear function of total spill, a bounded exponential function of total spill, or a bounded exponential function of the spill on a per spillbay basis. These equations were adopted for all dams in CRiSP.

Linear Saturation Equation

$$\%TDG = m \cdot Q_s + b \tag{7}$$

where:

%TDG = the % total dissolved gas saturation, where 100% is equilibrium,

Q_s = the total amount of spill in kcfs, and

m, b = the empirically fit slope and intercept parameters.

Bounded Exponential Equations

$$\%\mathrm{TDG} = \mathrm{a} + \mathrm{b} \cdot \exp(c \cdot Q_s) \tag{8}$$

OR

$$\%\mathrm{TDG} = \mathrm{a} + \mathrm{b} \cdot \exp(c \cdot q_s) \tag{9}$$

where:

q_s = the amount of spill through an individual spillbay, and

a,b,c = the empirically fit model parameters.

For Lower Granite Dam (LWG) and The Dalles Dam (TDA), the WES (1997) reference gave the production curves in the terms of q_s, discharge per spillbay. For implementation into CRiSP, Equation (9) is converted into the form of Equation (8) by the relation $q_s = Q_s/n$ (assuming the total discharge Q_s was uniformly distributed between the n number of spillbays) and absorbing n into a new value for c.

Table 4 Gas production curves used by CRiSP during 2002.

Project	%TDG =		Reference
BON	$0.12 \cdot Q_s + 105.61$		WES 1996
TDA	$124.3 - 9 \cdot \exp(-0.023 \cdot Q_s)$	Night	WES 1997[a]
	$124.3 - 9 \cdot \exp(-0.012 \cdot Q_s)$	Day	WES 1997[a]
JDA	$121.1 - 17.7 \cdot \exp(-0.016 \cdot Q_s)$	Night	Anderson et al. 2000
	$128.4 - 24.4 \cdot \exp(-0.024 \cdot Q_s)$	Day	Anderson et al. 2000
MCN	$0.0487 \cdot Q_s + 114.9$		WES 1997
IHR	$120.9 - 20.5 \cdot \exp(-0.023 \cdot Q_s)$		Anderson et al. 2000
LMN	$132.7 - 24.56 \cdot \exp(-0.0225 \cdot Q_s)$	Night	Anderson et al. 2000
	$131.2 - 36.1 \cdot \exp(-0.0592 \cdot Q_s)$	Day	Anderson et al. 2000

Table 4 Gas production curves used by CRiSP during 2002.

Project	%TDG =		Reference
LGS	$131.3 - 32.0 \cdot \exp(-0.01985 \cdot Q_s)$	Night	WES 1997
	$0.53 \cdot Q_s + 100.5$	Day	WES 1996
LWG	$138.0 - 35.8 \cdot \exp(-0.013 \cdot Q_s)$		WES 1997[a]
PRD	$130.9 - 25.15 \cdot \exp(-0.01045 \cdot Q_s)$		Anderson et al. 2000
WAN	$139.45 - 26.87 \cdot \exp(-0.00915 \cdot Q_s)$		Anderson et al. 2000
RIS	$141.1 - 26.9 \cdot \exp(-0.00874 \cdot Q_s)$		Anderson et al. 2000
RRH	$137.6 - 21.4 \cdot \exp(-0.00733 \cdot Q_s)$		Anderson et al. 2000
WEL	$0.15 \cdot Q_s + 107.2$	Night	Anderson et al. 2000
	$0.47 \cdot Q_s + 107.9$	Day	Anderson et al. 2000
CHJ	$140.1 - 34.8 \cdot \exp(-0.0241 \cdot Q_s)$		Anderson et al. 2000
DWR	$135.95 - 71.1 \cdot \exp(-0.4787 \cdot Q_s)$		Anderson et al. 2000

a. The original WES equation was a bounded exponential function of spill on a per spillbay basis q_S. It has been converted into a bounded exponential function of total spill.

Different day and night spill patterns for adult and juvenile fish passage at the dams require different production equations. In the case where there is no discernible difference between night and day gas production, the day and night equations are set to be the same. In practice during future years, the day and night patterns will be identical under most circumstances since virtually all used spill gates on the system have structures to deflect spilled water.

2.2.7 Assessment of Temperature and TDG Predictions

Similar to the passage prediction assessment, for each observation site we computed MAD between predicted temperature or TDG values and the observed values. 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 three weeks during the season and affected the accuracy of passage predictions. The timing of the updated flow and spill forecast files 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 4, May 23 and July 17 at LWG, PRD, TDA, and BON are shown in Appendix E.

Early forecasts of daily-averaged flow over the entire season at LWG were moderately accurate. The mid-season spike in the flows was anticipated but was not as large as anticipated. This reflects the uncertainty associated with weather conditions, snow melt, and runoff from the Snake River basin.

Since migration year 2001, the flow forecast files no longer contain spill forecasts at the Upper Columbia dams operated by the PUDs. For the 2002 season, we used a target spill percent value of 61% at PRD (Table 6 contains the target spill values for these Upper Columbia dams). The trend for the last three years is in Appendix F. 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 than average flows have lower than average water temperatures, and years with lower than average flow have 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 2002 observed temperatures for three reservoirs are shown in Appendix G. For all three reservoirs, the predictions became more accurate as the season went on and more observed data for 2002 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 H 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'). For example, the prediction made on Julian Day 110 in the early season at Lower Granite was off by 0.7 °C.

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 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 2002 observed total dissolved gas data for five monitoring sites are shown in Appendix I. Generally, the predictions became more accurate as the season went on and more observed data for 2002 became available. This is shown by the plots in Appendix J that are analogous to the prediction success plots shown for temperature. The forecasts used observed dissolved gas data, predicted spill at upstream dam(s), and temperature profile output from the temperature algorithm to anticipate dissolved gas concentrations.

3.4 Passage Distribution Prediction

Plots of predicted passage distributions compared to the observations of PIT-tagged fish are provided in Appendix C. The entire passage distribution predictions are presented for four representative dates: April 25, May 22, and June 20 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 5 Number of PIT-tagged fish[a] used for RealTime and CRiSP modeling at selected observation sites.

Stock	Number of wild spring and summer chinook used for observations with PIT tags observed at:					
	Lower Granite	Little Goose	Lower Monument	McNary	John Day	Bonneville
Catherine Creek	36	46	38	37	15	8
Imnaha River	15	32	41	34	21	16
Minam River	65	73	77	73	34	33
S. Fork Salmon River	29	42	45	26	21	19
Composite	145	193	201	170	91	76

a. The RealTime/CRiSP complex uses a subset of all available PIT-tagged fish for the stocks of interest. For the 2002 migration season, we used stocks determined by P. Poe, Fish Biologist, Bonneville Power Administration.

In the plots in Appendix C, the predictions at Lower Granite Dam are based on RealTime results, and the predictions at the downstream sites are CRiSP projections. Any error in the prediction at Lower Granite Dam is propagated to the downstream sites. Failure to detect, or report all PIT-tagged fish passing the detectors at Lower Granite Dam means that their continued downstream movement cannot be modeled accurately. Obviously, some fish escape detection at a site only to be observed downstream as is illustrated with the increase in the number of Imnaha River fish at Little Goose Dam compared to Lower Granite Dam. This is likely also happening even if the numbers are maintaining or decreasing due to mortality, and thus the apparent arrival time distributions do not match the population’s true distribution. The simple fact that more fish are observed at LGS than at LGR distorts the ability of CRiSP to predict downstream travel.

4 Discussion

4.1 Accuracy of Predictions

4.1.1 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 H.

Because yearling chinook migrate in the spring and early summer, they are not particularly vulnerable to temperature extremes. 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.

4.1.2 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 F for comparison of early-season predictions in 2000, 2001 and 2002 to observed data).

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.

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 6 Targeted spill percents for Upper Columbia dam spill forecasts from mid-April through mid-June.

dam	PRD	WAN	RIS	RRH	WEL
spill percent	61	40	15	30	20

4.1.3 Total Dissolved Gas Predictions

The MAD results for total dissolved gas (TDG) predictions are shown in Appendix J. 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. The final MAD values are all below 3.6 percentage points for each dam and a recalibration of the gas model is now using the latest TDG generation equations as provided by the ACOE. There are many sources and sinks of TDG that are unmodeled including major tributaries between modeled confluences.

4.1.4 Passage Timing Predictions

The MAD results for RealTime and the downstream predictions are presented in Table 7 for the end of the season. The RealTime MAD is calculated from RealTime output files at the end of the season. The reported 2002 “run” and “prediction” percentages are used according to the method in Equation (5). The downstream MAD values are based on CRiSP output files for PIT-tagged fish.

Table 7 Mean absolute deviations (MAD) in smolt run timing predictions at the four observation sites for the end of 2002. MAD at Lower Granite is from archived RealTime run results and the other three are from archived CRiSP run results.

Stock	MAD at LWG	Downstream MAD		
		LGS	LMN	MCN
Catherine Creek	1.8	4.4	4.9	4.2
Imnaha River	2.5	9.6	10.3	16.9
Minam River	1.6	8.1	6.8	10.5
S. Fork Salmon River	2.4	10.1	13.4	8.3
Composite	2.2	7.2	5.0	4.6

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 C on a stock-by-stock basis.

Seasonal variation in MAD values are plotted for select sites and stocks in Appendix D. 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.

Table 8 Differences in predicted passage times for designated percentages of four individual stocks at five different dams.

Run	**Observed day - Predicted day**				
10%	LWG	LGS	LMN	MCN	BON
CATHEC	0	11	12	11	15
IMNAHR	0	6	11	6	9
MINAMR	0	6	14	8	8
SALRSF	-1	14	15	8	11
50%	LWG	LGS	LMN	MCN	BON
CATHEC	0	2	0	1	-1
IMNAHR	0	-8	-5	-7	-4
MINAMR	-6	-2	2	1	3
SALRSF	0	13	14	6	5
90%	LWG	LGS	LMN	MCN	BON
CATHEC	0	0	12	2	11
IMNAHR	0	-8	-9	-13	-8
MINAMR	0	-1	0	-9	-8
SALRSF	0	4	3	3	5

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 four stocks at five 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 Figure 2 which shows some of the anomalies that give rise to prediction problems. For example, SALRSF stock passage at Lower Granite dam (LWG) is shown as a black line. Little Goose dam (LGS), the next downstream dam is a dotted line. There is significant delay for some SALRSF fish which is depicted by the wide gap between the two curves early in their passage. Based on the median arrival (50%) day at the upstream dam (LWG), the run is predicted to arrive at LGS dam 13 days earlier than the true observation.

There are several fundamental issues that contribute to high MAD values.

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. The modeled fish are increasing in speed with their "experience" in the river and the more rapid velocity reaches closer to the historic level of travel speed as the season and their downstream migration 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; to the extent that there are errors in RealTime predictions, those errors are propagated downstream by CRiSP.

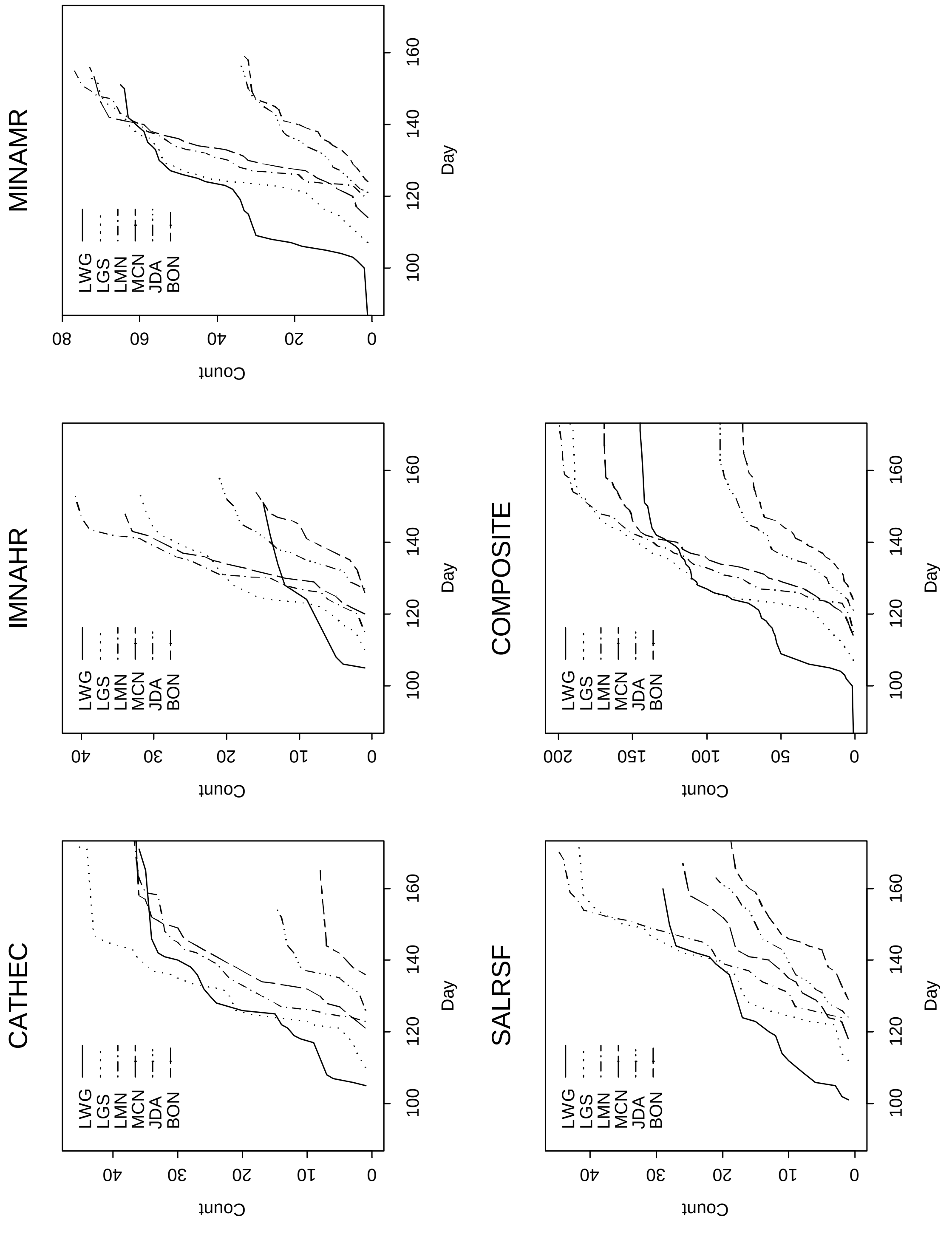


Figure 2 Cumulative passage patterns for four stocks and the composite stock as they move downstream and cross six dams.

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 give CRiSP the passage distribution at the dam and the CRiSP runs proceed from a hypothetical release just above Lower Granite Dam so that CRiSP can calculate the mortality associated with the dam passage. The conversion is supposed to account for unobserved fish that go over the spillway. 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 LWG passage prediction.

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 above Lower Granite Dam and the data collected at downstream dams.

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 movements but the errors are propagated downstream. Based on the differential mortality and passage times, there seemed to have been 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 have had to rely more and more on forecast data of flow and spill. In 2002, these files were updated every few weeks 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 this problem. 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 2002.

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

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.

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 assump-

tions 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

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 outmigration 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.

Receipt of flow forecasts on a more frequent schedule would be advantageous because we would use actual observations for the days available, and we would be able to predict flows more accurately because predictions for the near-term are inherently more accurate than those made far into the future. The use of historical data was very beneficial for accurately portraying the river over historical periods.

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. For 2002, on each day that a CRiSP-RealTime run was made, a database query updated CRiSP's input files to include the latest available environmental information.

Further improvements will require updates to CRiSP's survival and travel-time algorithms to accommodate other processes. A newer version of the model (CRiSP1.7) is being developed and is intended to expand un-modeled processes.

5 References

Achord, S., J. Harmon, D. Marsh, B. Sandford, K. McIntyre, K. Thomas, N. Paasch, and G. Matthews. 1992. Research Related to Transportation of Juvenile Salmonids on the Columbia and Snake Rivers, 1991. National Marine Fisheries Service. Seattle, WA.

Achord, S., G. Matthews, D. Marsh, B. Sandford, and D. Kamikawa. 1994. Monitoring the Migrations of Wild Snake River Spring and Summer Chinook Salmon Smolts, 1992. Annual Report 1992. National Marine Fisheries Service. DOE/BP-18800-1. Bonneville Power Administration. Portland, OR. 73 pp.

Achord, S., D. Kamikawa, B. Sanford, and G. Matthews. 1995a. Monitoring the Migrations of Wild Snake River Spring/Summer Chinook Salmon Smolts, 1993. Annual Report 1993. National Marine Fisheries Service. DOE/BP-18800-2. Bonneville Power Administration. Portland, OR. 88 pp.

_________________. 1995b. Monitoring the Migrations of Wild Snake River Spring/Summer Chinook Salmon Smolts, 1994. Annual Report 1994. National Marine Fisheries Service. DOE/BP-18800-3. Bonneville Power Administration. Portland, OR.100 pp.

Achord, S., M. Eppard, B. Sanford, and G. Matthews. 1996. Monitoring the Migrations of Wild Snake River Spring/Summer Chinook Salmon Smolts, 1995. Annual Report 1995. National Marine Fisheries Service. DOE/BP-18800-5. Bonneville Power Administration. Portland, OR.

Achord, S., M. Eppard, E. Hockersmith, B. Sanford, and G. Matthews. 1997. Monitoring the Migrations of Wild Snake River Spring/Summer Chinook Salmon Smolts, 1996. Annual Report 1996. National Marine Fisheries Service. DOE/BP-18800-6. Bonneville Power Administration. Portland, OR.

Anderson, J., W. Beer, J. Hayes, S. Iltis, M. Moore, D. Salinger, P. Shaw, C. Van Holmes, and R. Zabel. 2000. Columbia River Salmon Passage Model, CRiSP.1.6: Theory and Calibration. Columbia Basin Research, University of Washington. Seattle, WA. 238 pp.

Ashe, B., A. Miller, P. Kucera, and M. Blenden. 1995. Spring Outmigration of Wild and Hatchery

Chinook Salmon and Steelhead Trout Smolts from Imnaha River, March 1 - June 15, 1994. Nez Perce Tribe, Department of Fisheries Resources Management, Lapwai, Idaho. DOE/BP-38906-4. Bonneville Power Administration. Portland, OR. 76 pp.

Beamesderfer R.C. and B.E. Rieman. 1991. Abundance and distribution of northern squawfish, walleye and smallmouth bass in John Day Reservoir, Columbia River. *Transactions of the American Fisheries Society* 120:439-447.

Beer, W.N. S. Iltis, C. VanHolmes, and J.J. Anderson. 2002. Evaluation of the 2001 Predictions of the Run-Timing of Wild Migrant Yearling Chinook and Water Quality at Multiple Locations on the Snake and AColumbia Rivers using CRiSP/RealTime. Columbia Basin Reasearch, UW School of Aquatic and Fisheries Science. Box 358218 Seattle, WA 98195.

Burgess, C., R. Townsend, J. Skalski, and D. Yasuda. 1999. Monitoring and Evaluation of Smolt Migration in the Columbia Basin, Volume III: Evaluation of the 1998 Prediction of the Run-Timing of Wild Migrant Yearling and Subyearling Chinook and Steelhead, and Hatchery Sockeye in the Snake River Basin using Program RealTime. Columbia Basin Research, University of Washington. Seattle, WA.

Cramer, Steven P. 1996. Seasonal Changes During 1996 in Survival of Yearling Chinook Smolts Through the Snake River as Estimated from Detections of PIT Tags. Report prepared for Direct Services Industries.

Fish Passage Center of the Columbia Basin Fish and Wildlife Authority. Annual Report. Portland, OR.

Hayes, J., P. Shaw, R. Zabel, and J. Anderson. 1996. Evaluation of the 1996 Predictions of the Run-timing of Wild Migrant Yearling Chinook in the Snake River Basin Using CRiSP/RT. University of Washington, Columbia Basin Research. Seattle, WA.

Keefe, M., R. Carmichael, B. Jonasson, R. Messmer, and T. Whitesel. 1994. Fish Research Project Oregon-Investigations into the Life History of Spring Chinook in the Grande Ronde River Basin. Annual Report 1994. Oregon Department of Fish and Wildlife. DOE/BP-33299-1A. Bonneville Power Administration. Portland, OR.

Kiefer, R. and J. Lockhart. 1993. Idaho Habitat and Natural Production Monitoring: Part II. Idaho Department of Fish and Game. DOE/BP-21182-2. Bonneville Power Administration. Portland, OR. 67 pp.

_________________. 1994. Intensive Evaluation and Monitoring of Chinook Salmon and Steelhead Trout Production, Crooked River and Upper Salmon River Sites. Idaho Department Fish and Game. Annual Report. DOE/BP-21182-5. Bonneville Power Administration. Portland, OR. 70 pp.

Parker, R., M. Zimmerman, and D. Ward. 1994. Report G. Development of a System Wide Program: Indexing and Fisheries Evaluation. In Nigro (ed.): Development of a System Wide Program: Stepwise Implementation of a Predation Index, Predator Control Fisheries, and Evaluation Plan in the Columbia River Basin, Volume II. Annual Report 1992. DOE/BP-07084-4. Bonneville Power Administration. Portland, OR.

Prentice, E., T. Flagg, and C. McCutcheon. 1990. Feasibility of Using Implantable Passive Integrated Transponder (PIT) Tags in Salmonids. *American Fisheries Society Symposium*. 7:317-322.

Townsend, R., P. Westhagen, D. Yasuda, J. Skalski, and K. Ryding. 1996. Evaluation of the 1995 Predictions of the Run-timing of Wild Migrant Yearling Chinook in the Snake River Basin Using Program RealTime. DOE/BP-35885-9. Bonneville Power Administration. Portland, OR.

Townsend, R., D. Yasuda, and J. Skalski. 1997. Evaluation of the 1996 Predictions of the Run-timing of Wild Migrant Yearling Chinook in the Snake River Basin Using Program RealTime. DOE/BP-91572-1. Bonneville Power Administration. Portland, OR.

U.S. Army Corps of Engineers. 1996. Appendix K: Evaluation and Analysis of Historical Dissolved Gas Data from the Snake and Columbia Rivers. In: Dissolved Gas Abatement Study, Phase I, Technical Report. U.S. Army Corps of Engineers. Portland, OR.

U.S. Army Corps of Engineers. 1997. Total Dissolved Gas Production at Spillways on the Snake and Lower Columbia Rivers: Memorandum for Record, Waterways Experiment Station.

In: Dissolved Gas Abatement Study, Phase II, Technical Report. U.S. Army Corps of Engineers. Portland, OR.

Vigg, S. and C. Burley. 1991. Temperature dependent maximum daily consumption of juvenile salmonids by norther squawfish (*Ptychocheilus Oregonensis*) from the Columbia River. *Canadian Journal of Fisheries and Aquatic Sciences* 48: 2491-2498.

Vigg S., T. Poe, L. Pendergast and H. Hansel. 1991. Rates of consumption of juvenile salmonids and alternative prey fishes by northern squawfish, walleyes, smallmouth bass and channel catfish in John Day Reservoir, Columbia River. *Transactions of the American Fisheries Society* 120:421-438.

Walters, T., R. Carmichael, and M. Keefe. 1997. Fish Research Project Oregon-Smolt Migration Characteristics and Mainstem Snake and Columbia River Detection Rates of Grande Ronde and Imnaha River Naturally Produced Spring Chinook Salmon. Annual Reports 1993-1995. Oregon Department of Fish and Wildlife. DOE/BP-38906-8. Bonneville Power Administration. Portland, OR.

Ward, D., J. Peterson, and J. Loch. 1995. Index of Predation of Juvenile Salmonids by Northern Squawfish in the Lower Columbia and Snake Rivers. *Transactions of the American Fisheries Society*. 124:321-334.

Zabel, R. and J. Anderson. 1997. A Model of the Travel Time of Migrating Juvenile Salmon, with an Application to Snake River Spring Chinook. *N. Amer. J. Fish. Manag.*17:93-100.

Zabel, R. and J. Anderson, and P. Shaw. 1998. A Multiple Reach Model to Describe the Migratory Behavior of Snake River Yearling Chinook Salmon (*Oncorhynchus tshawytscha*). *Can. J. Fish. Aquat. Sci*. 55: 658-667.

Zimmerman, M., and R. Parker. 1995. Relative density and distribution of smallmouth bass, channel catfish, and walleye in the Lower Columbia and Snake Rivers. *Northwest Science* 69:19-28.

Zimmerman, M., D. Ward, T. Friesen, and C. Knutsen. 1997. Development of a Systemwide Predator Control Program: Indexing and Fisheries Evaluation. In F. R. Young (ed.)

Development of a Systemwide Predator Control Program: Stepwise Implementation of a Predation Index, Predator Control Fisheries, and Evaluation Plan in the Columbia River Basin, Section II: Evaluation. 1995 Annual Report. DOE/BP-24514-4. Bonneville Power Administration. Portland, OR.

Appendix A Map of Columbia and Snake River Locations

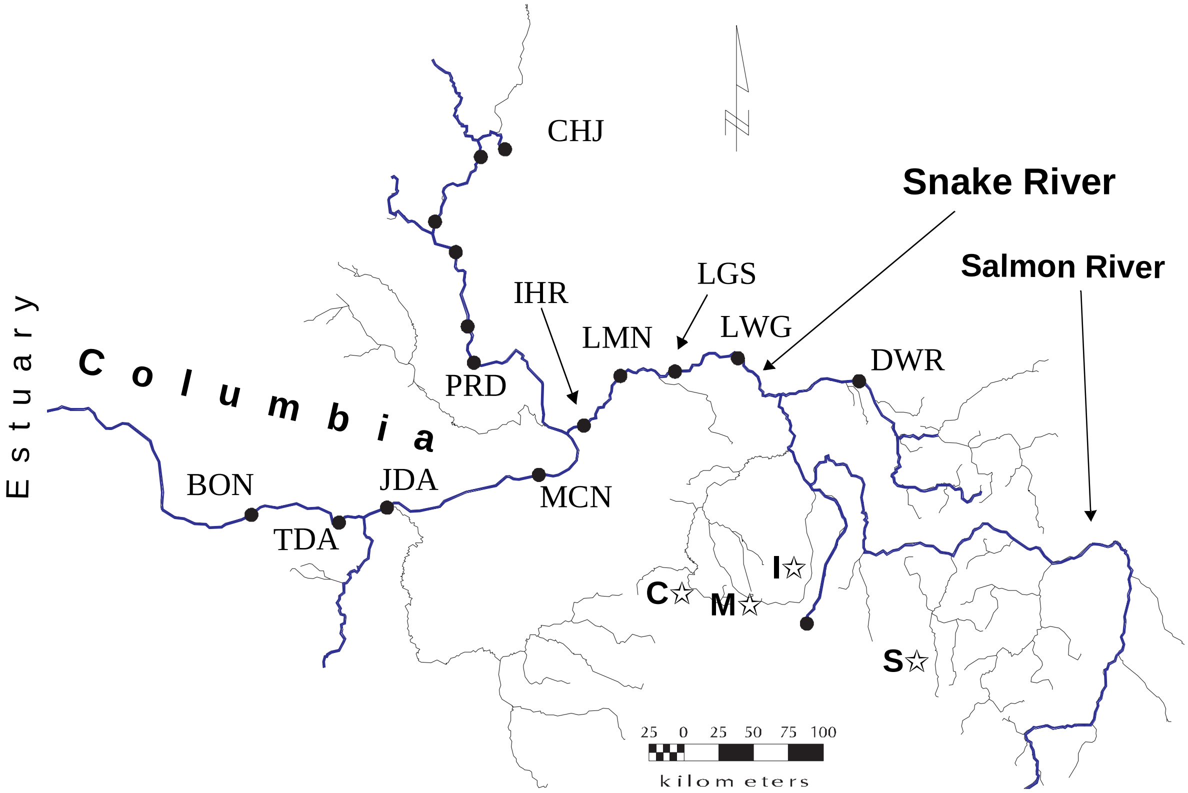


Figure A-1 Map of CRiSP locations

"●" are dam locations (not all are labelled by name). "☆" are approximate release locations with a key letter as follows: S=SALRSF, M=MINAMR, C=CATHEC, and I=IMNAHR. The darker river segments are explicitly modeled in CRiSP. Other segments are shown for reference only. 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 (MCPX), Priest Rapids-PRD (PRXW), and Bonneville-BON (SKAW). The stocks analyzed in this report pass Lower Granite Dam (their arrivals predicted by RealTime) and results are presented for their arrivals at Little Goose (LGS), Lower Monumental (LMN) and McNary (MCN).

Appendix B CRiSP Parameters

Table B-1 Dam Specific Parameters used for CRiSP runs. Spill and bypass mortalities are set at 0.02. Turbine mortality is set at 0.07.

Dam	FGE	Forebay Pred. Density	Tailrace Pred. Density	Spill Efficiency
Bonneville	0.38	1741	13249	1.0
Bonneville II	0.44			
The Dalles	0.46	1741	13249	2.0
John Day	0.64	1741	13249	1.0
McNary	0.95	1741	13249	1.0
Ice Harbor	0.71	547	14094	1.0
Lower Monumental	0.61	547	14094	1.2
Little Goose	0.82	547	14094	1.0
Lower Granite	1.0*	0**	14094	1.0

*CRiSP uses RealTime output which in effect has already accounted for FGE.

**CRiSP does not apply predation to RealTime output.

.

Table B-2 Species Specific Parameters used for CRiSP runs

Species	Reach Pred. Coef.	Forebay Pred. Coef.	Tailrace Pred. Coef.
Chinook 1	12.70	15.6	0.4844

For stock specific parameters used for CRiSP Yearling Chinook (Chinook 1) model runs, see the 2002 values in Table B-4.

Table B-3 Reservoir Specific Parameters used for CRiSP runs

Reservoir	Predator Density
Estuary	1950

Table B-3 Reservoir Specific Parameters used for CRiSP runs

Reservoir	Predator Density
Jones Beach	1950
Columbia Gorge	1950
Bonneville Tailrace	1950
Bonneville Pool	1014
The Dalles Pool	1014
Deschutes Confluence	1014
John Day Pool	1014
McNary Pool	1014
Lower Snake River	809
Ice Harbor Pool	809
Lower Monumental Pool	809
Little Goose Pool	809
Lower Granite Pool	809

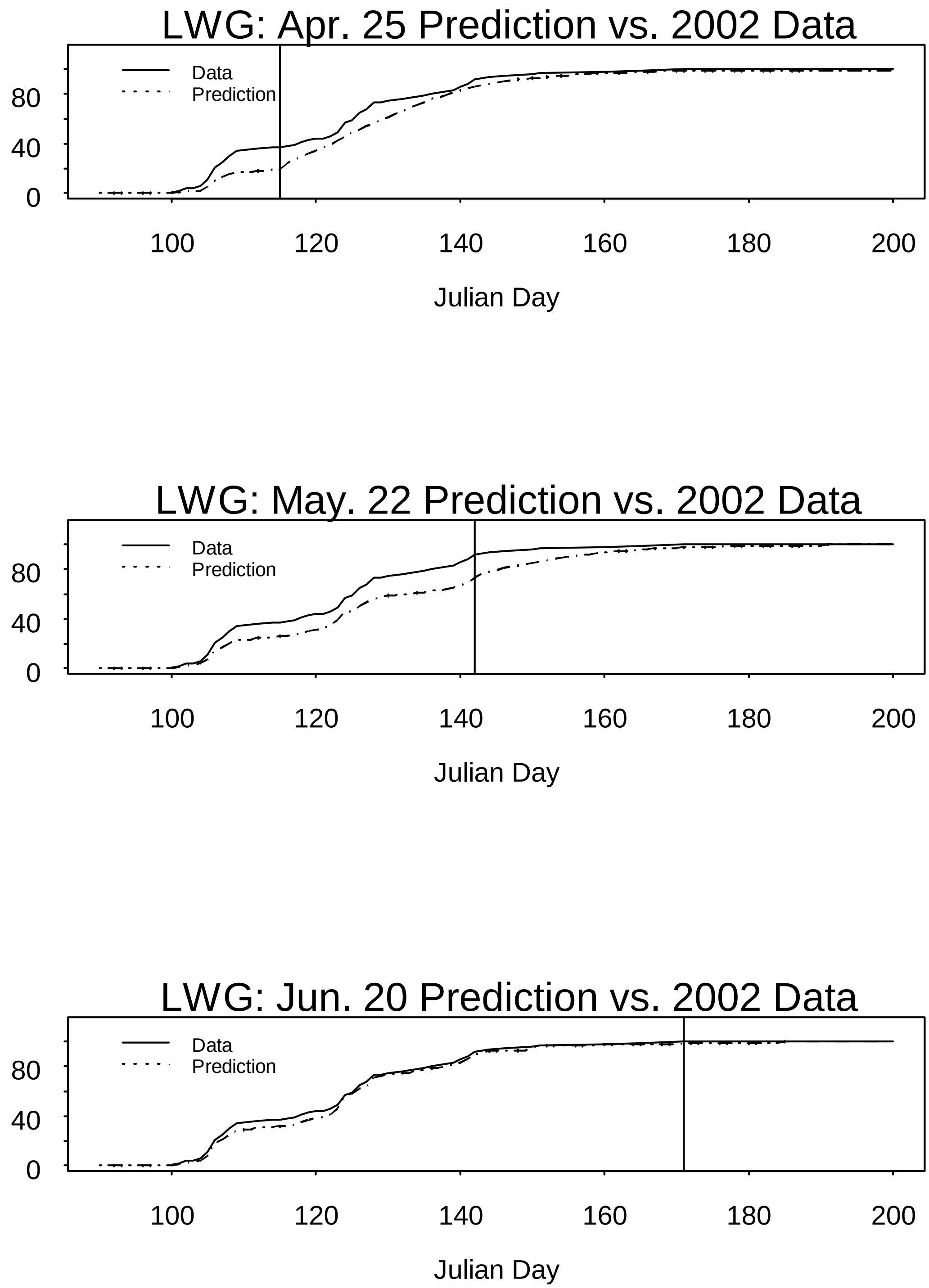
Table B-4 Migration Parameters used by CRiSP

parameter estimates					
β_{MIN}	β_{MAX}	β_{FLOW}	α_1	T_{seas}	α_2
Catherine Creek Spring Chinook					
-6.91	4.75	1.79	0.38	0.08	0.50
Imnaha Spring Chinook					
-8.43	5.05	1.26	0.29	96.17	1.06
Minam River Spring Chinook					
-8.15	4.65	1.44	0.38	92.76	0.5
Salmon River South Fork Spring Chinook					
-2.91	7.82	0.92	0.38	0.02	0.88

Appendix C Arrival Time Distribution plots

The following figures present the CRiSP/RealTime predictions on April 25, May 22, and June 20. The dates represent pre-migration, mid migration and late migration times. The dashed line represent the model predictions and the solid line is the observed distribution of PIT tag arrivals at dam (either Lower Granite, Little Goose, Lower Monumental, McNary and Bonneville). The predicted distribution at Lower Granite Dam is generated by the RealTime program, and the predicted distributions at Little Goose, Lower Monumental, McNary and Bonneville are CRiSP projections based on the Lower Granite prediction. The vertical line in each plot is the date of the prediction. The historical runs can be displayed on world wide web pages devoted to presentation of arrival time data. The home page for the project is found at http://www.cbr.washington.edu/crisprt/.

Composite Stock - Lower Granite Dam (LWG)


LWG: Apr. 25 Prediction vs. 2002 Data

LWG: May. 22 Prediction vs. 2002 Data

LWG: Jun. 20 Prediction vs. 2002 Data

Figure C-1 RealTime predictions for cumulative distribution of arrivals of the Composite stock at Lower Granite Dam. Y-axis shows percent of total passage.

Composite Stock - Little Goose Dam (LGS)

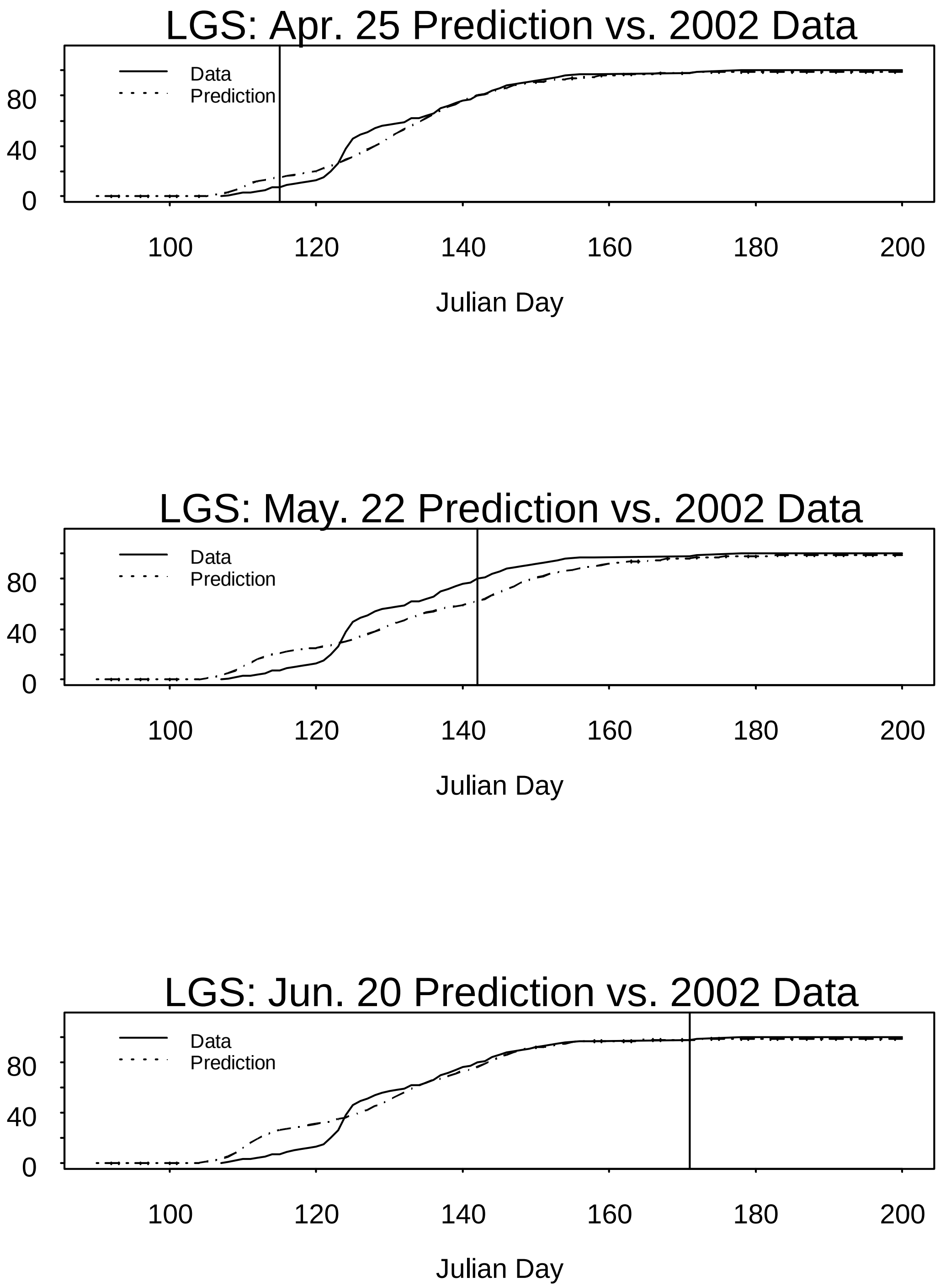


Figure C-2 CRiSP predictions for cumulative distribution of arrivals of the Composite stock at Little Goose Dam. Y-axis shows percent of total passage.

Composite Stock - Lower Monumental Dam (LMN)

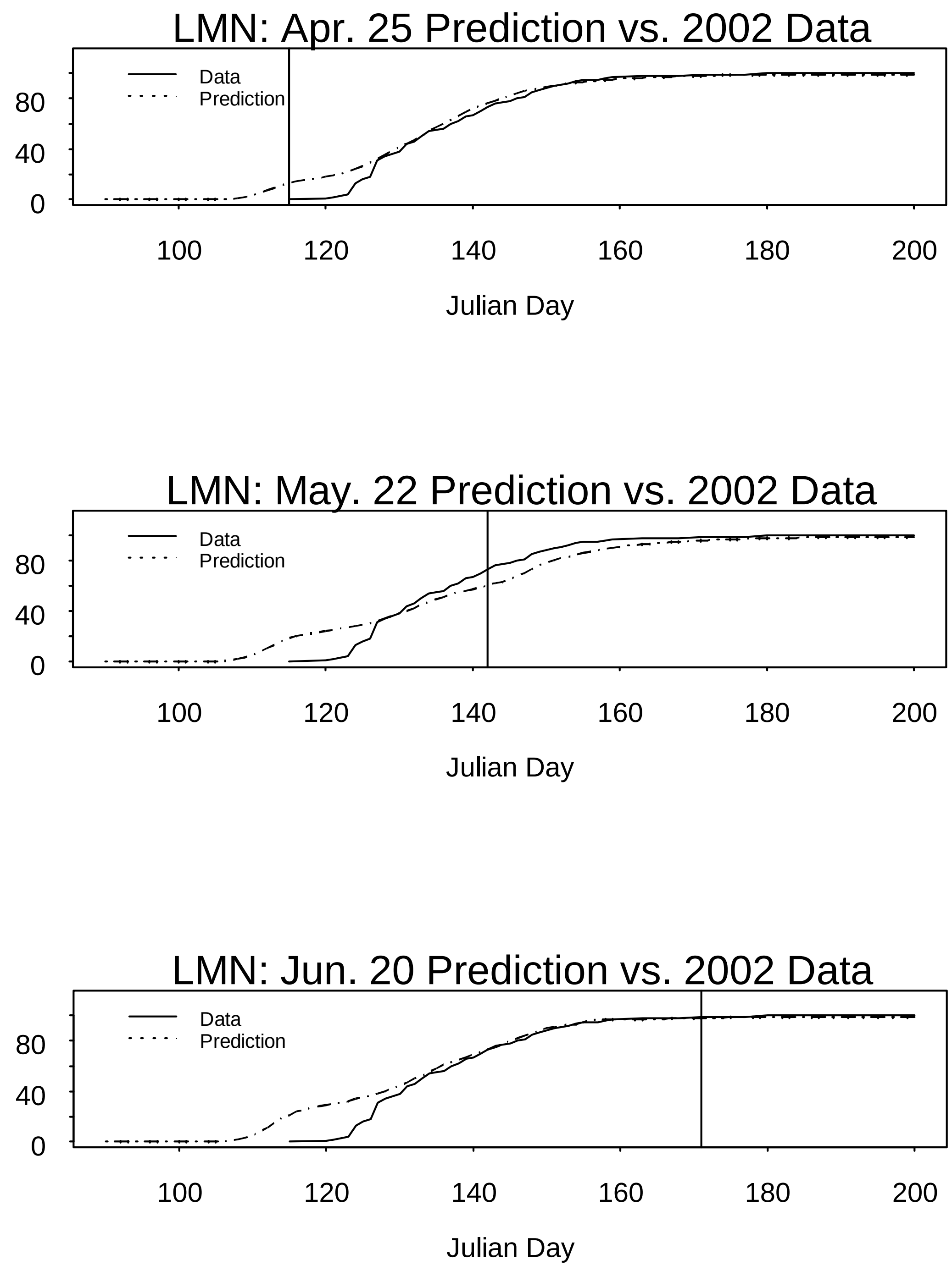


Figure C-3 CRiSP predictions for cumulative distribution of arrivals of the Composite stock at Lower Monumental Dam.Y-axis shows percent of total passage.

Composite Stock - McNary Dam (MCN)

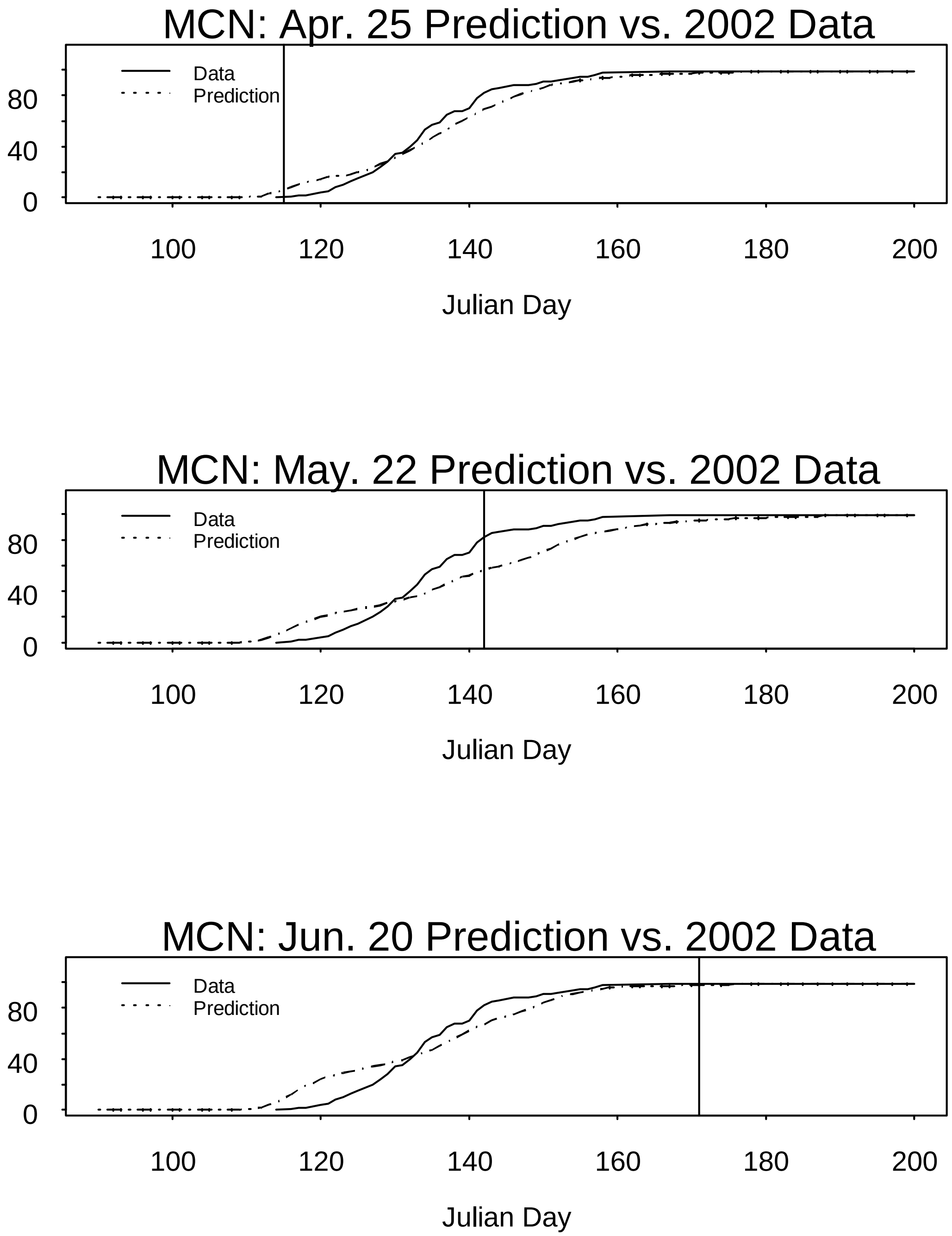
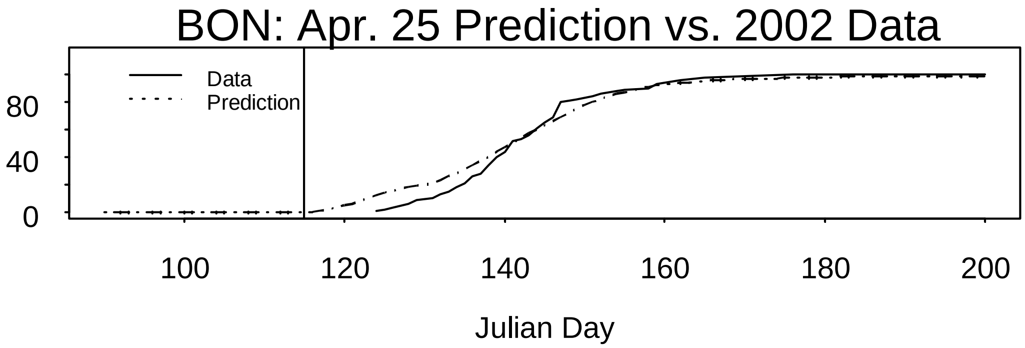
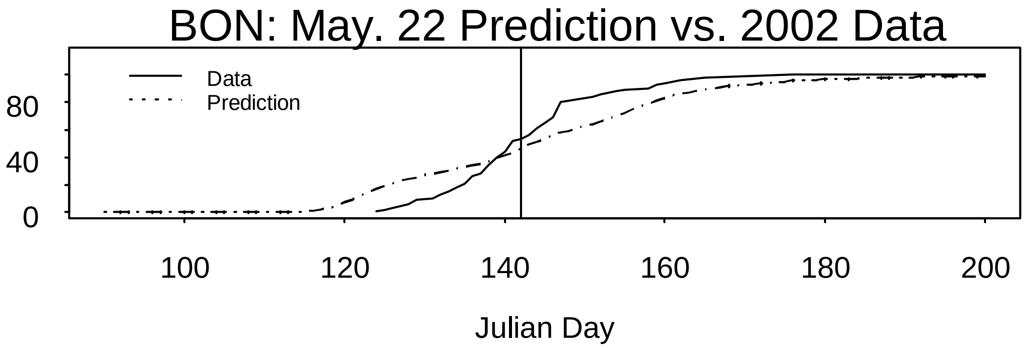


Figure C-4 CRiSP predictions for cumulative distribution of arrivals of the Composite stock at McNary Dam. Y-axis shows percent of total passage.

Composite Stock - Bonneville Dam (BON)


BON: Apr. 25 Prediction vs. 2002 Data


BON: May. 22 Prediction vs. 2002 Data

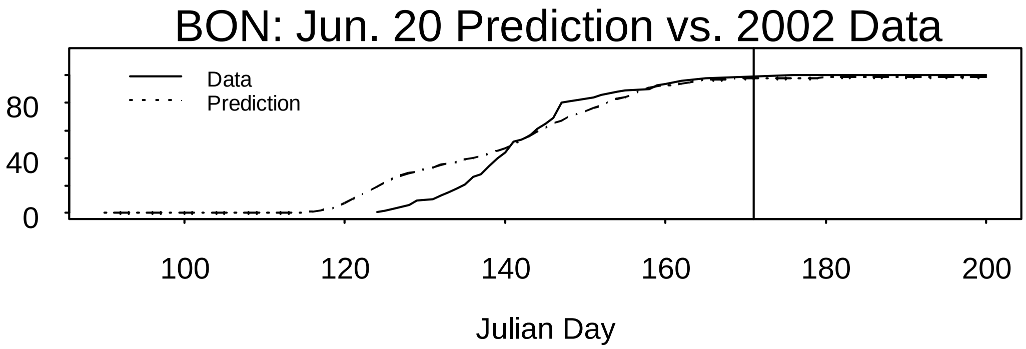
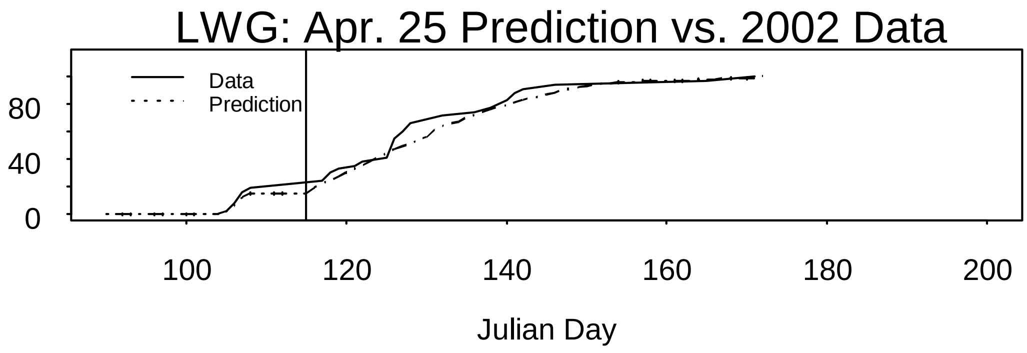
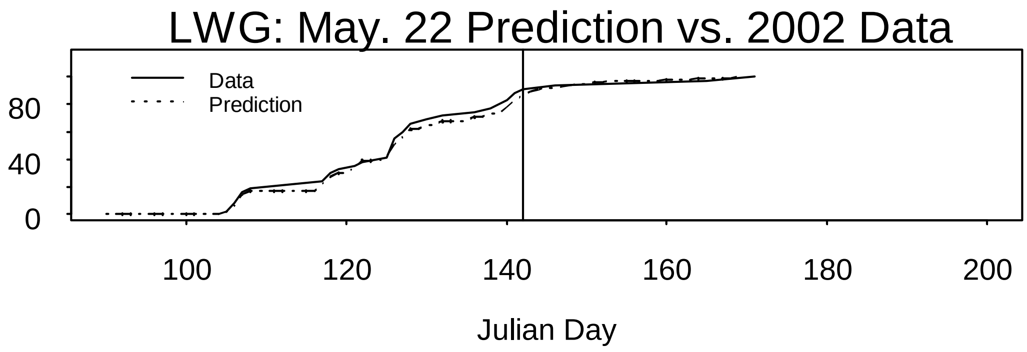

BON: Jun. 20 Prediction vs. 2002 Data

Figure C-5 CRiSP predictions for cumulative distribution of arrivals of the Composite stock at Bonneville Dam. Y-axis shows percent of total passage.

Catherine Creek – Lower Granite Dam (LWG)





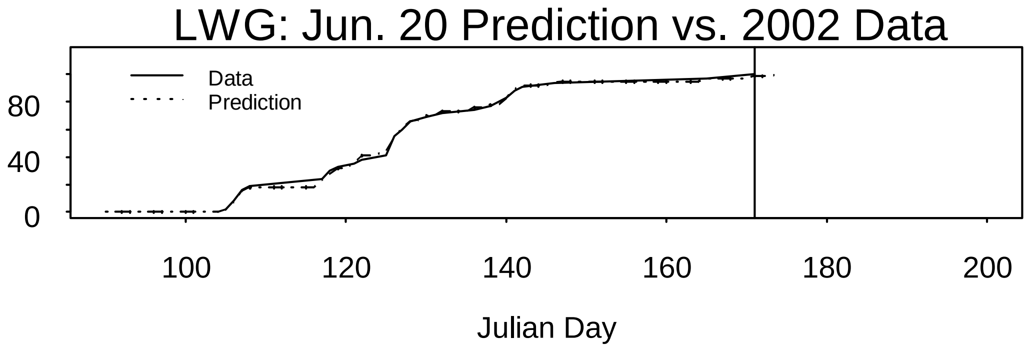
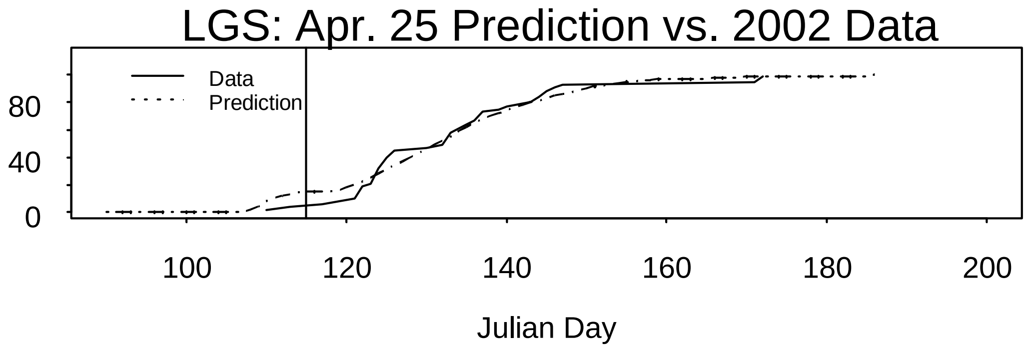
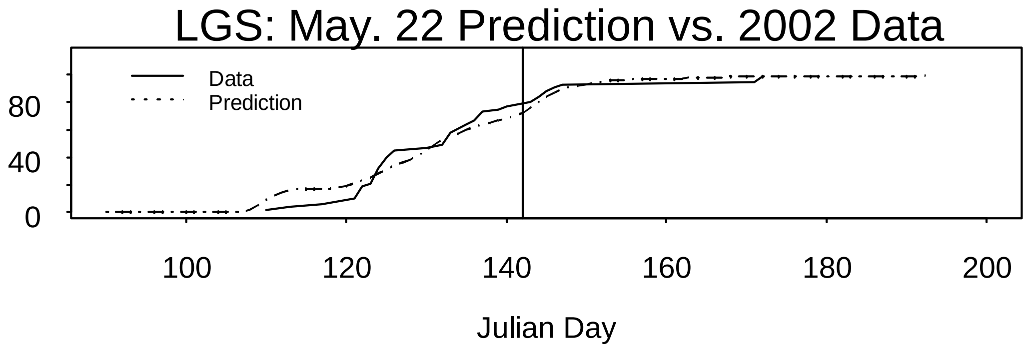


Figure C-6 RealTime predictions for the cumulative distribution of arrivals of the Catherine Creek stock at Lower Granite Dam. Y-axis shows percent of total passage.

Catherine Creek – Little Goose (LGS)





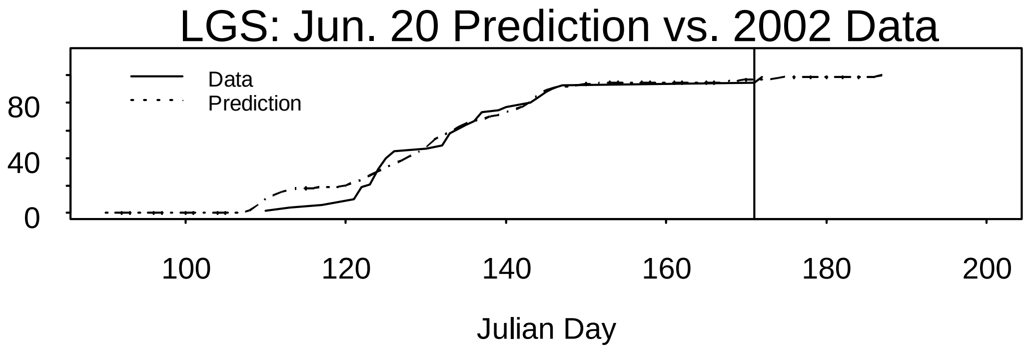
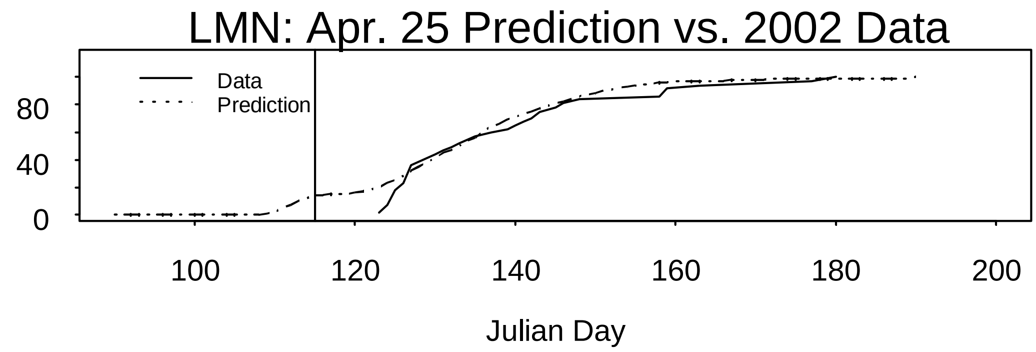
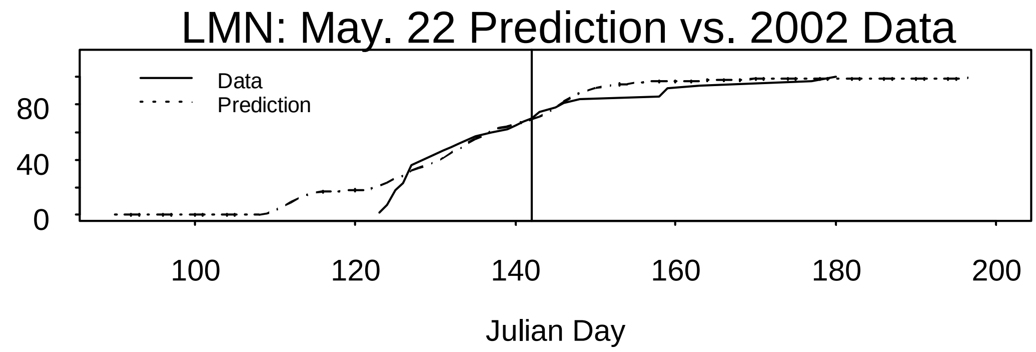


Figure C-7 CRiSP predictions for the cumulative distribution of arrivals of the Catherine Creek stock at Little Goose Dam. Y-axis shows percent of total passage.

Catherine Creek – Lower Monumental (LMN)





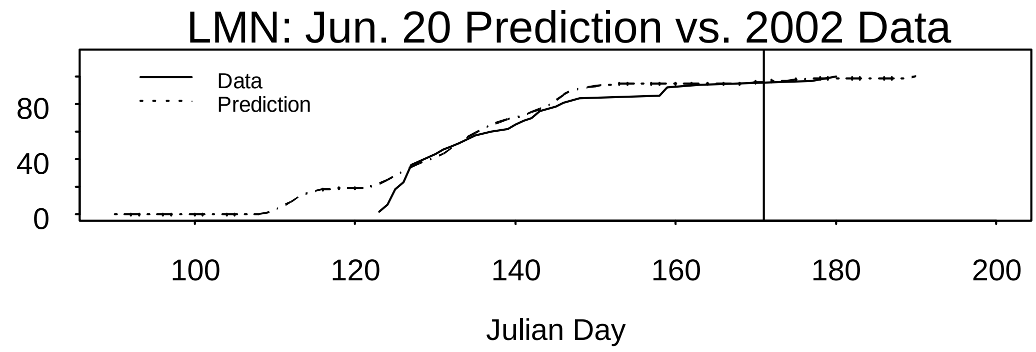


Figure C-8 CRiSP predictions for the cumulative distribution of arrivals of the Catherine Creek stock at Lower Monumental Dam. Y-axis shows percent of total passage.

Catherine Creek – McNary Dam (MCN)

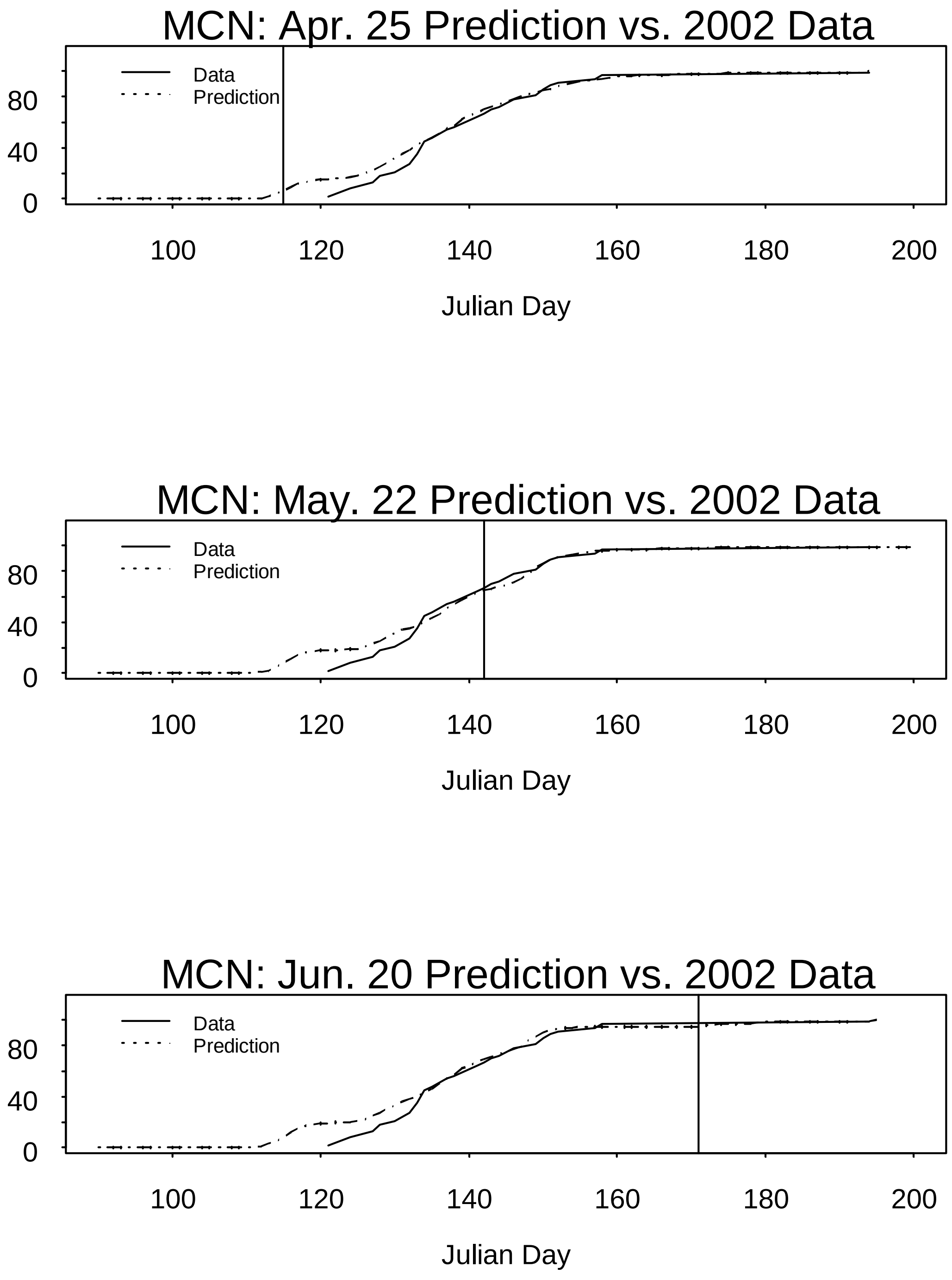
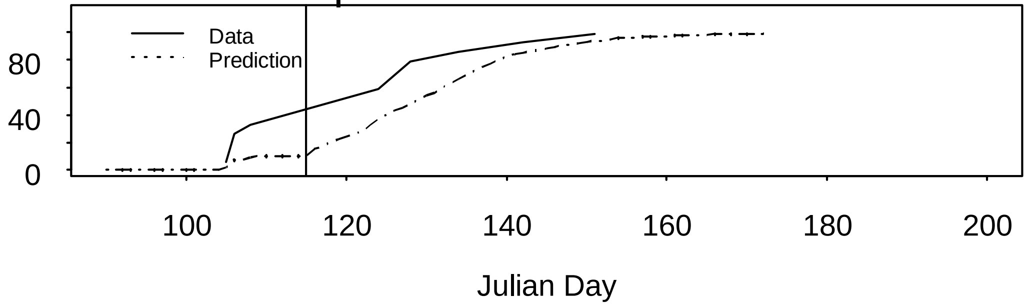


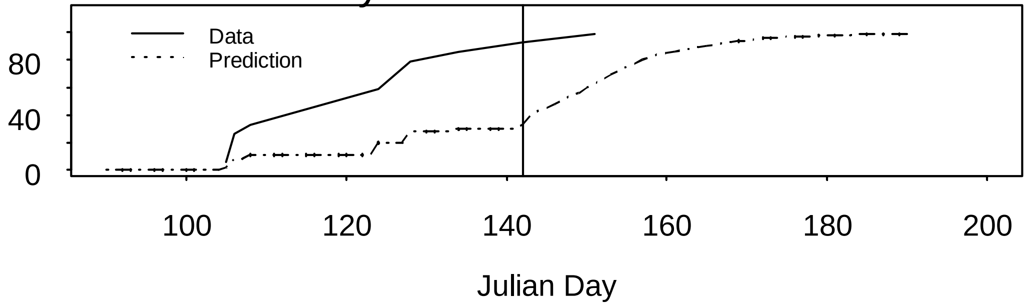
Figure C-9 CRiSP predictions for the cumulative distribution of arrivals of the Catherine Creek stock at McNary Dam. Y-axis shows percent of total passage.

Imnaha River – Lower Granite Dam (LWG)

LWG: Apr. 25 Prediction vs. 2002 Data



LWG: May. 22 Prediction vs. 2002 Data



LWG: Jun. 20 Prediction vs. 2002 Data

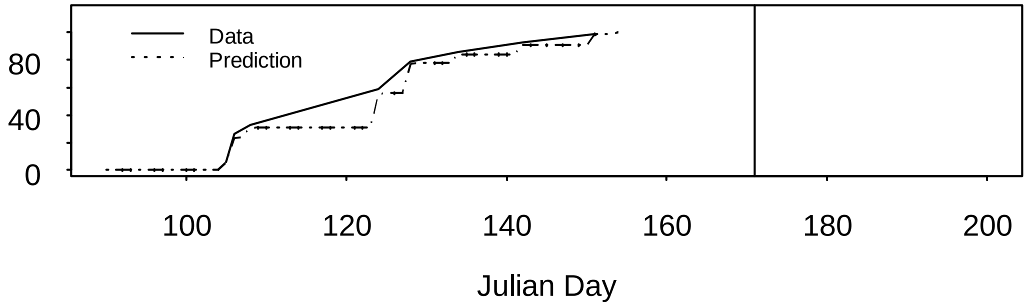
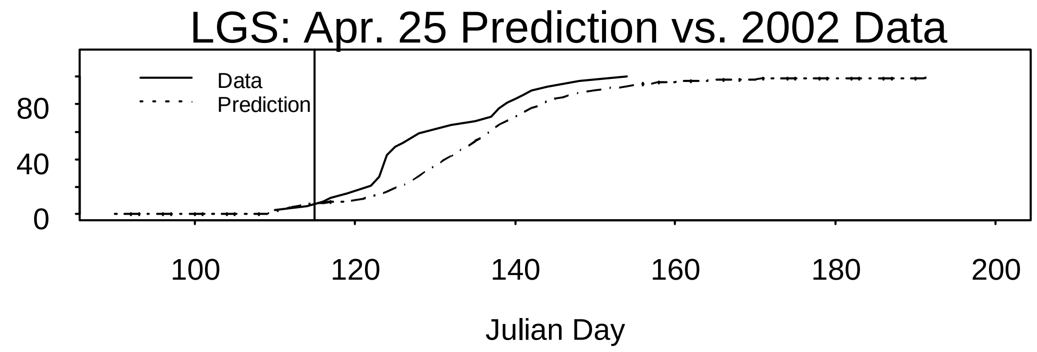
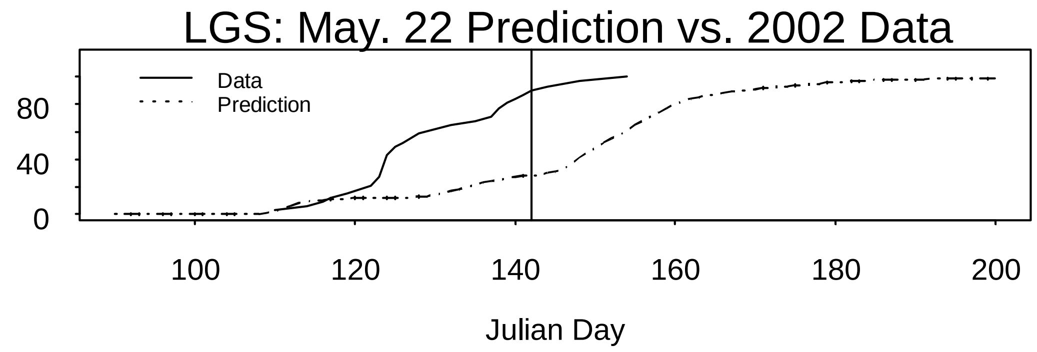


Figure C-10 RealTime predictions for the cumulative distribution of arrivals of the Imnaha River stock at Lower Granite Dam. Y-axis shows percent of total passage.

Imnaha River – Little Goose Dam (LGS)





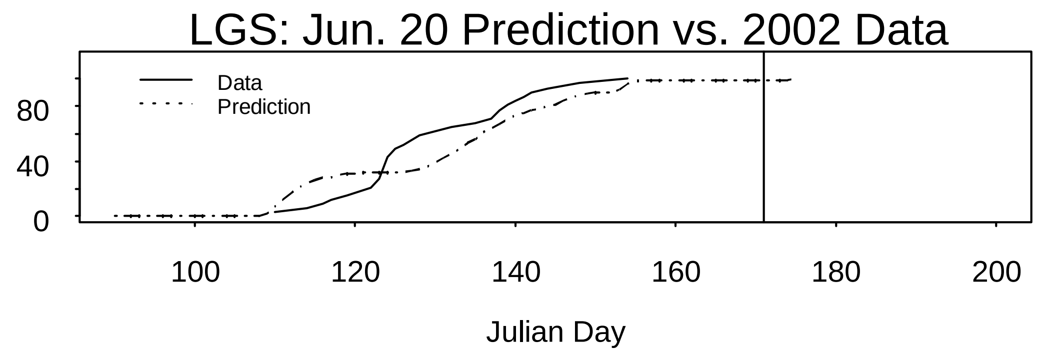
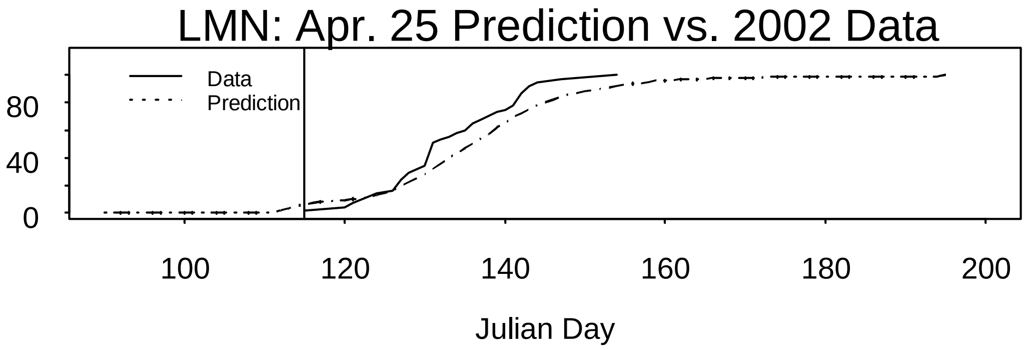
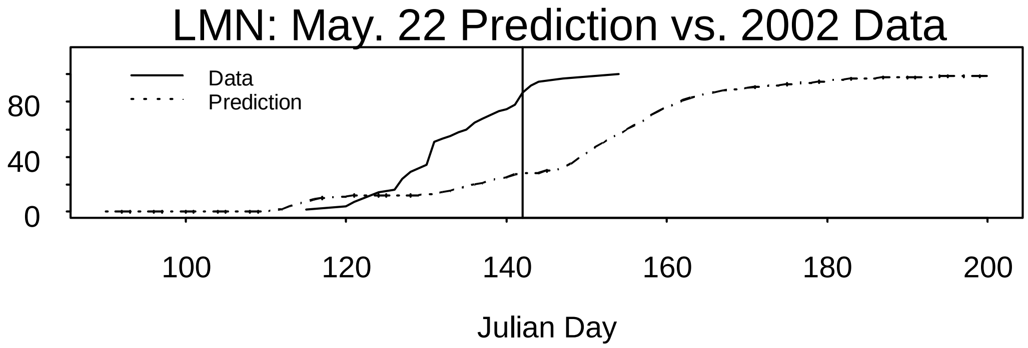


Figure C-11 CRiSP predictions for the cumulative distribution of arrivals of the Imnaha River stock at Little Goose Dam. Y-axis shows percent of total passage.

Imnaha River – Lower Monumental Dam (LMN)





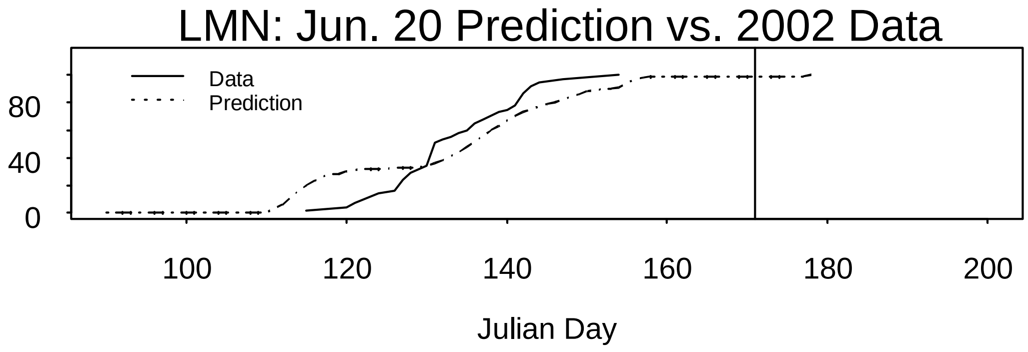
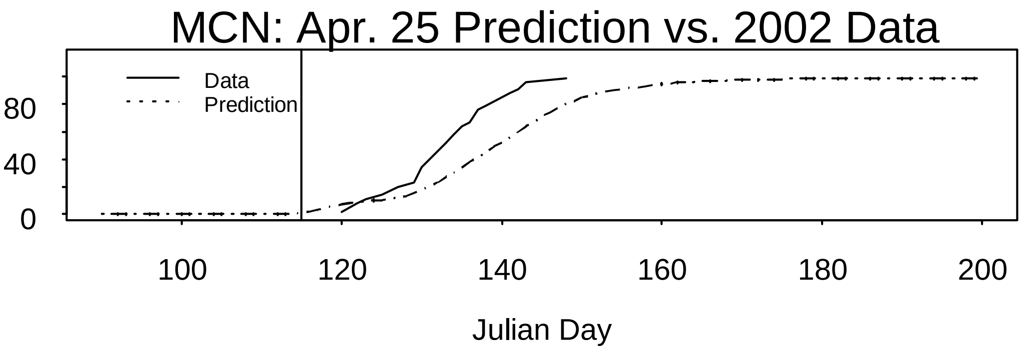
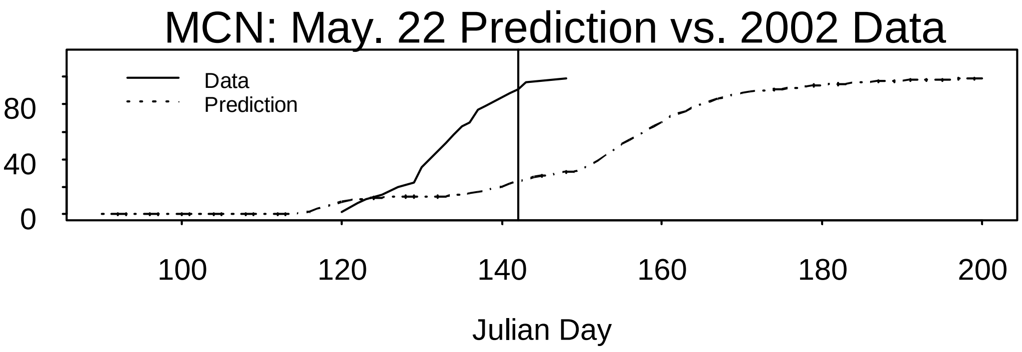


Figure C-12 CRiSP predictions for the cumulative distribution of arrivals of the Imnaha River stock at Lower Monumental Dam. Y-axis shows percent of total passage.

Imnaha River – McNary Dam (MCN)





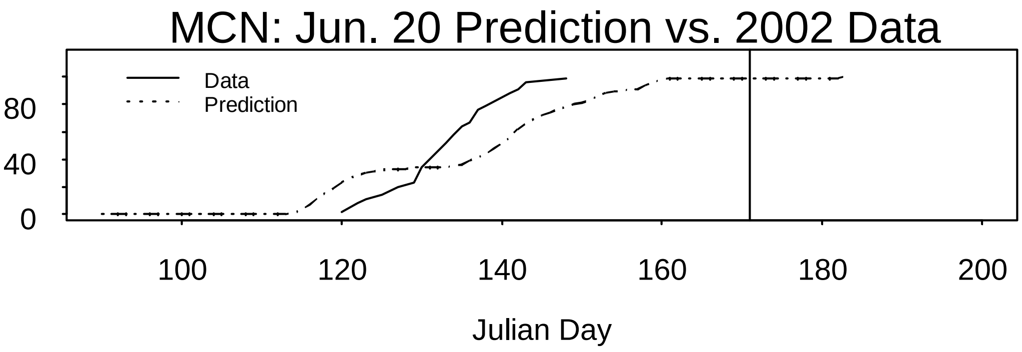


Figure C-13 CRiSP predictions for the cumulative distribution of arrivals of the Imnaha River stock at McNary Dam. Y-axis shows percent of total passage.

Minam River – Lower Granite Dam (LWG)

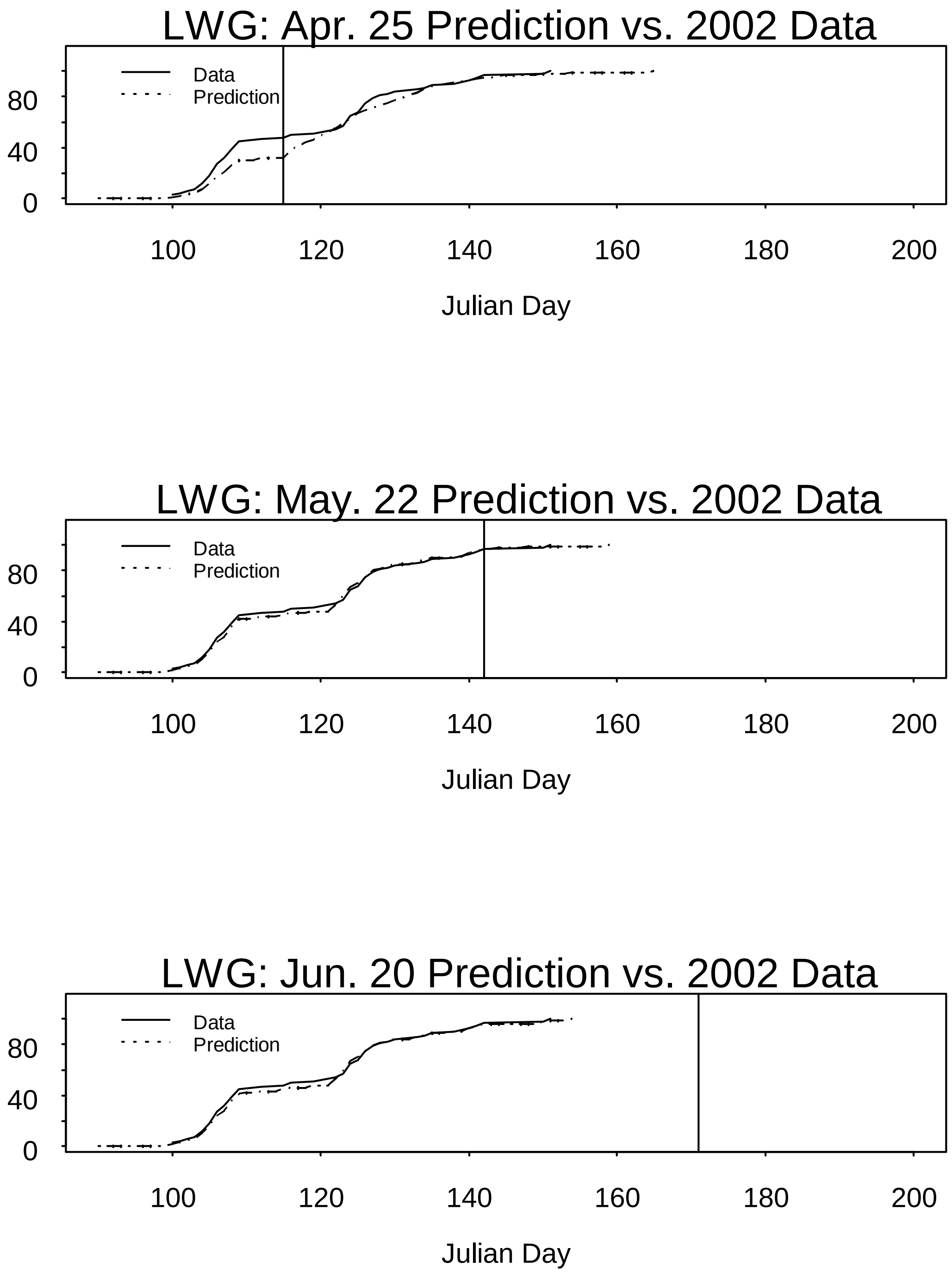
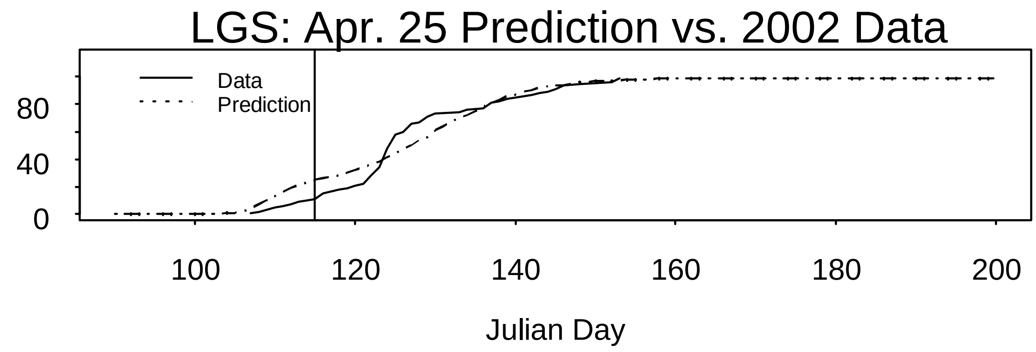
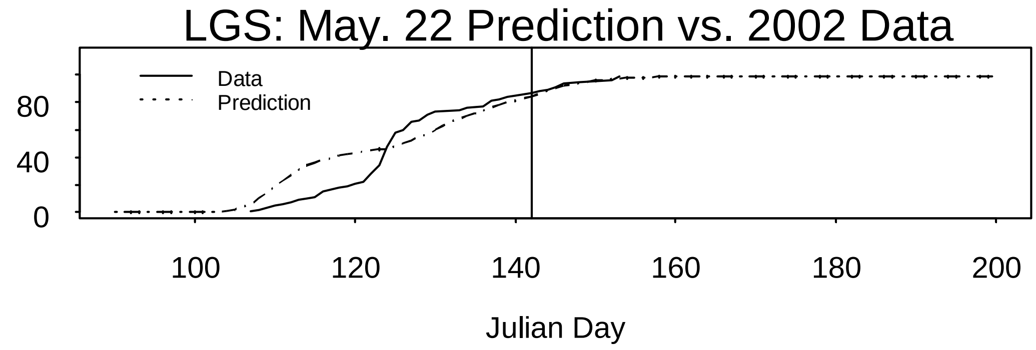


Figure C-14 Realtime predictions for the cumulative distribution of arrivals of the Minam River stock at Lower Granite Dam. Y-axis shows percent of total passage.

Minam River – Little Goose Dam (LGS)





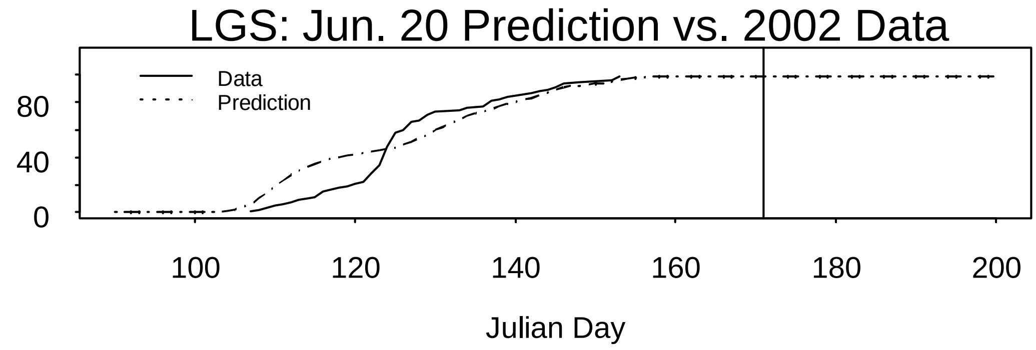


Figure C-15 CRiSP predictions for the cumulative distribution of arrivals of the Minam River stock at Little Goose Dam. Y-axis shows percent of total passage.

Minam River – Lower Monumental Dam (LMN)

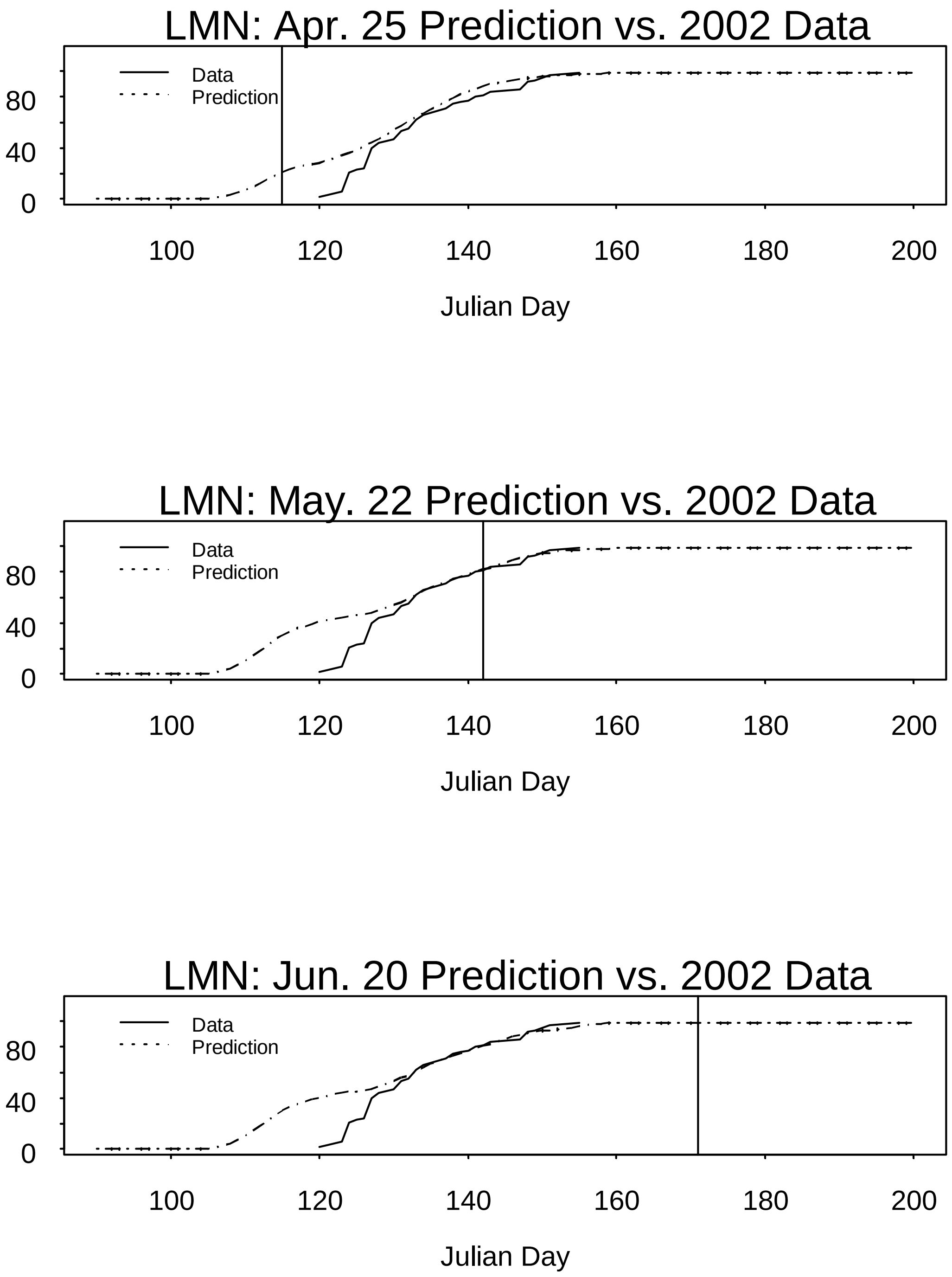


Figure C-16 CRiSP predictions for the cumulative distribution of arrivals of the Minam River stock at Lower Monumental Dam. Y-axis shows percent of total passage.

Minam River – McNary Dam (MCN)

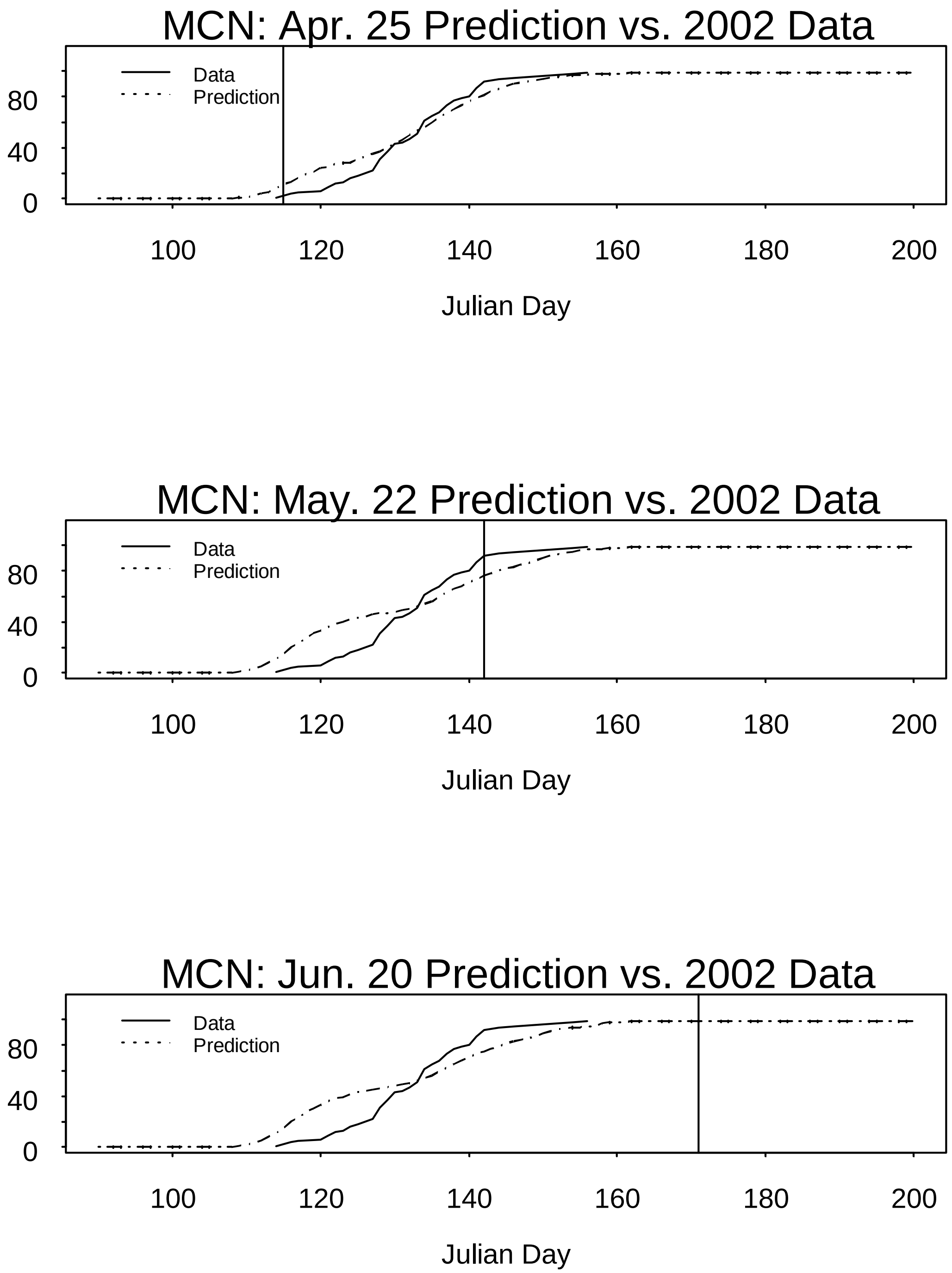


Figure C-17 CRiSP predictions for the cumulative distribution of arrivals of the Minam River stock at McNary Dam. Y-axis shows percent of total passage.

South Fork Salmon River –Lower Granite Dam (LWG)

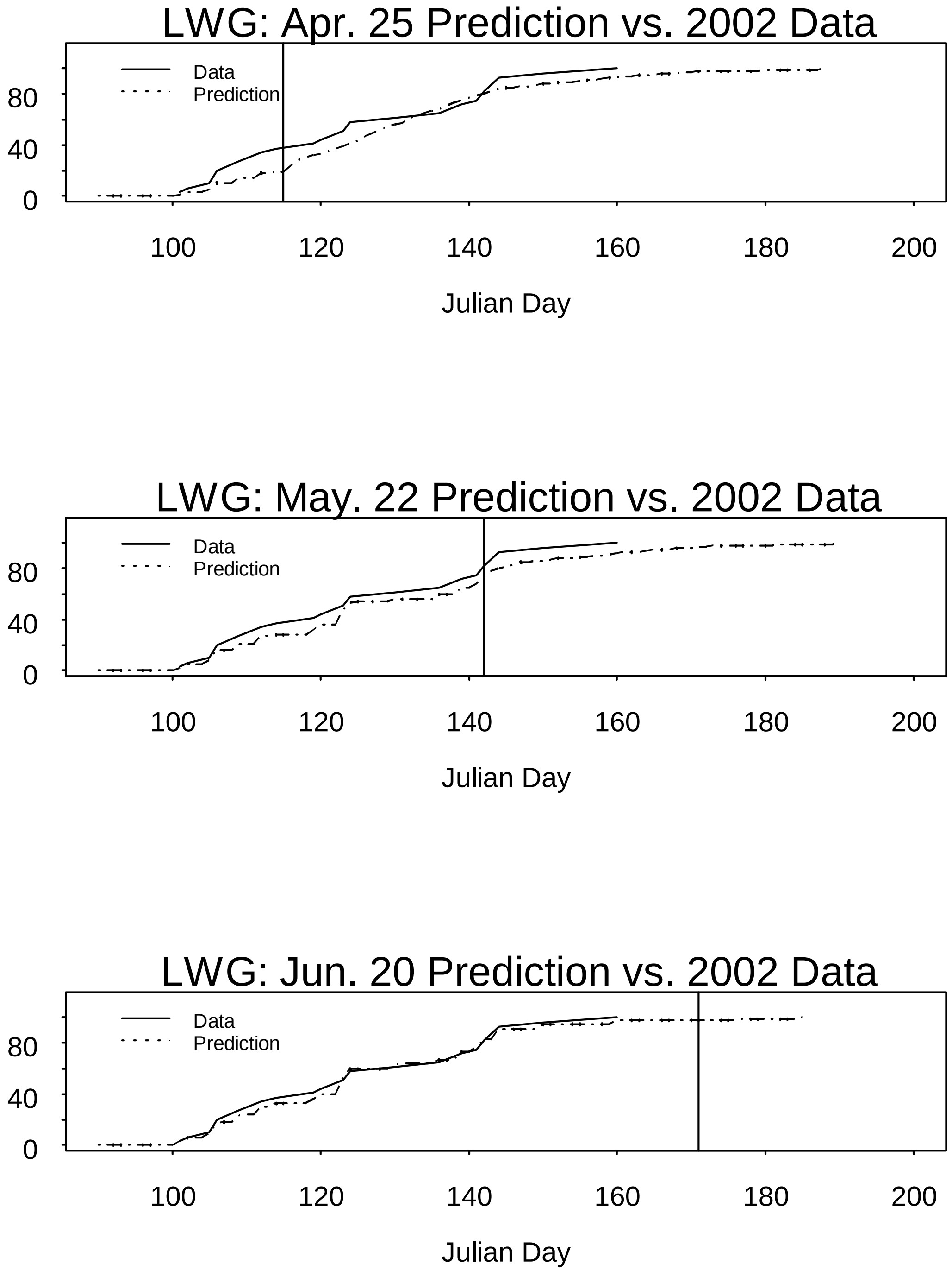
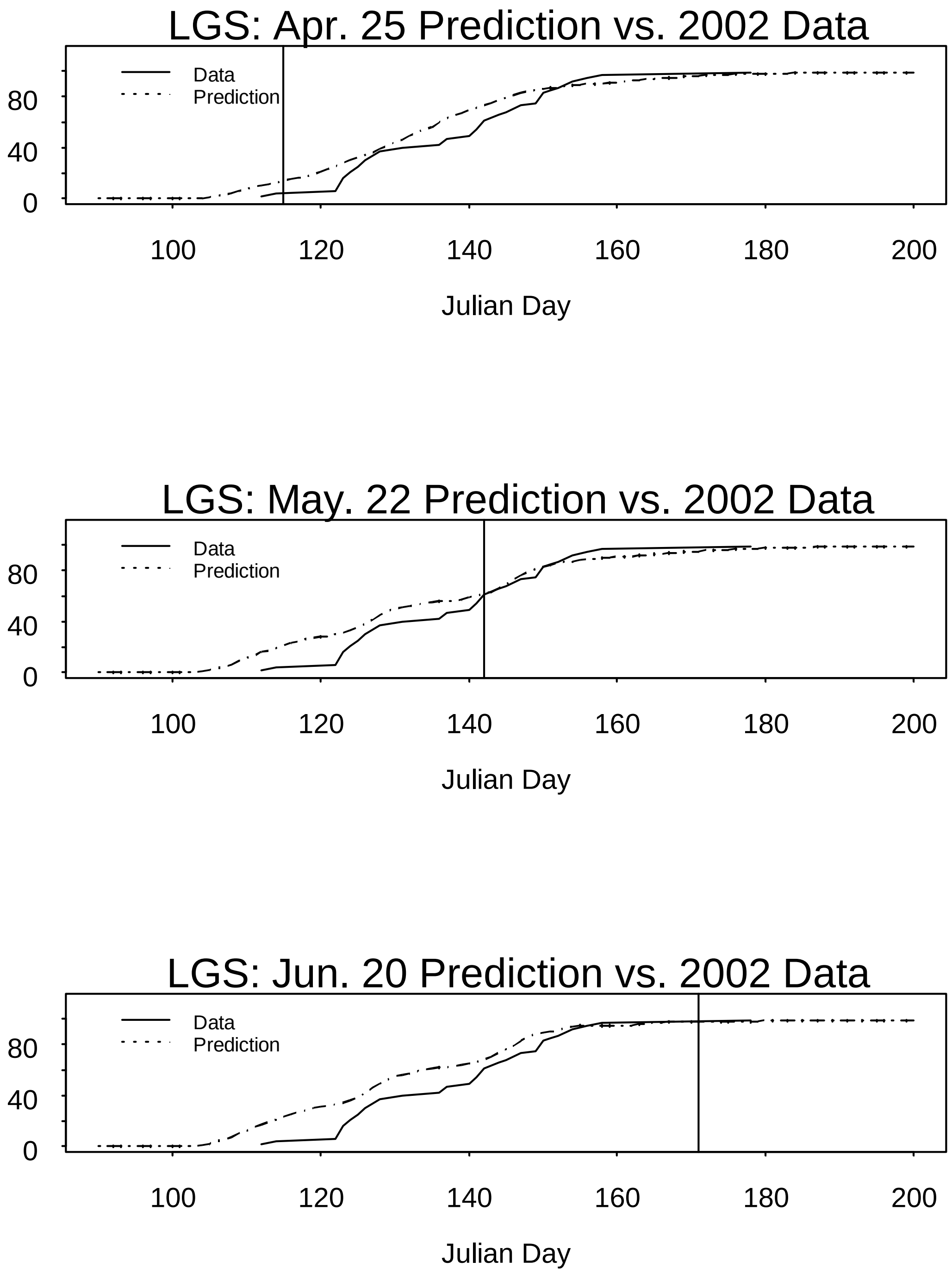


Figure C-18 RealTime predictions for the cumulative distribution of arrivals of the S. Fork Salmon stock at Lower Granite Dam. Y-axis shows percent of total passage.

South Fork Salmon River – Little Goose Dam (LGS)

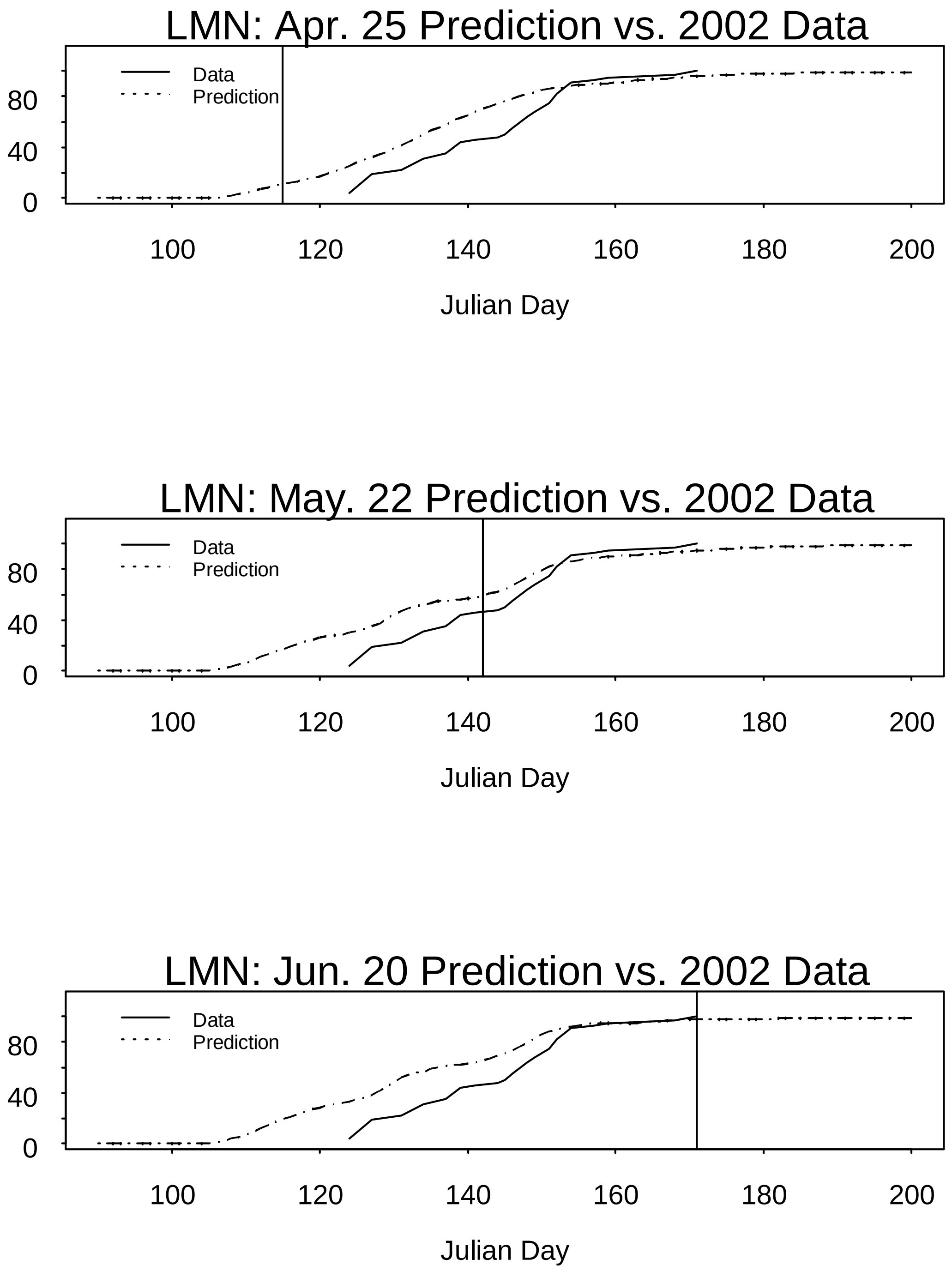

LGS: Apr. 25 Prediction vs. 2002 Data

LGS: May. 22 Prediction vs. 2002 Data

LGS: Jun. 20 Prediction vs. 2002 Data

Figure C-19 CRiSP predictions for the cumulative distribution of arrivals of the S. Fork Salmon River stock at Little Goose Dam. Y-axis shows percent of total passage.

South Fork Salmon River – Lower Monumental Dam (LMN)


LMN: Apr. 25 Prediction vs. 2002 Data

LMN: May. 22 Prediction vs. 2002 Data

LMN: Jun. 20 Prediction vs. 2002 Data

Figure C-20 CRiSP predictions for the cumulative distribution of arrivals of the S. Fork Salmon stock at Lower Monumental. Y-axis shows percent of total passage.

South Fork Salmon River – McNary Dam (MCN)

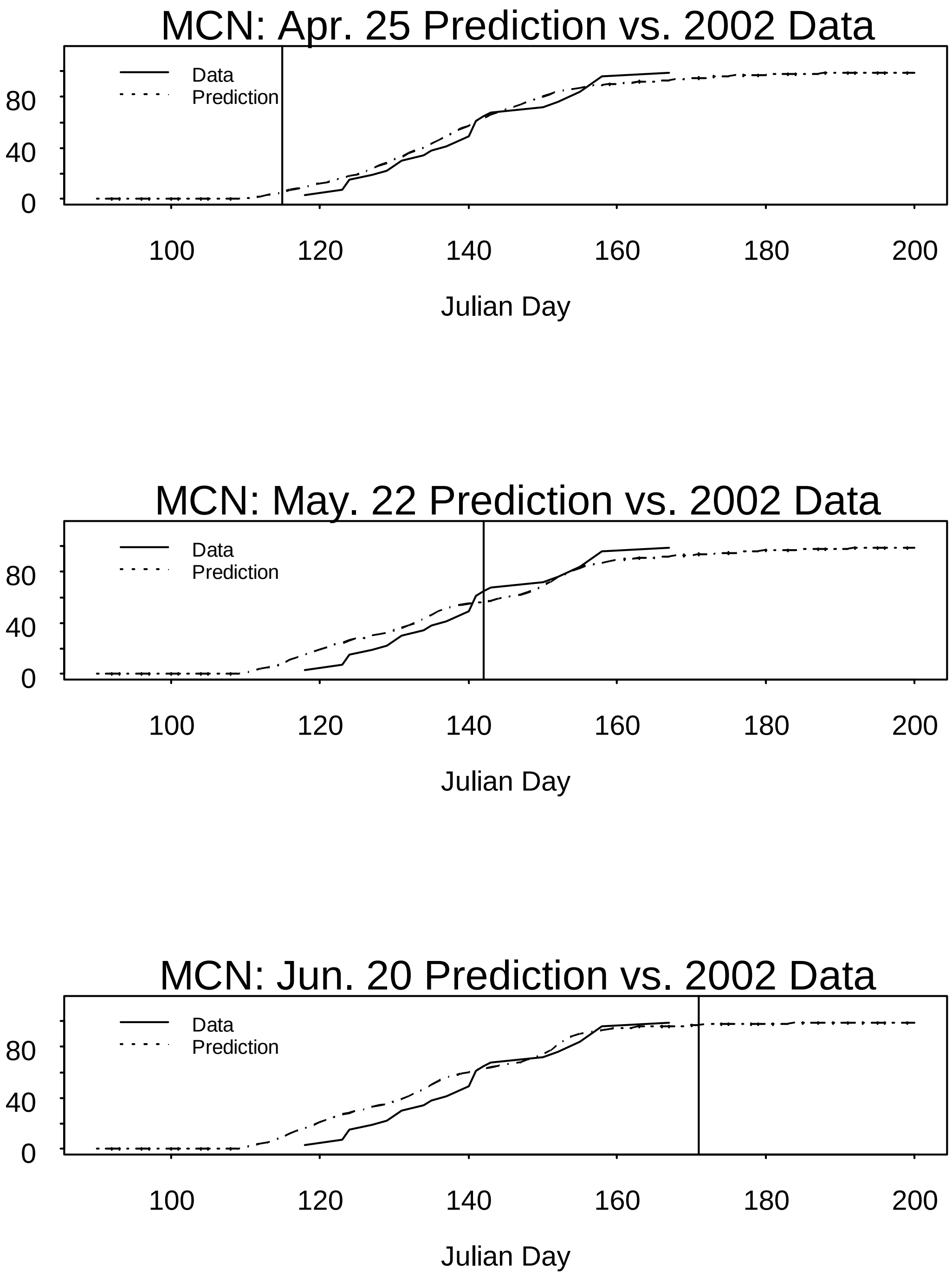
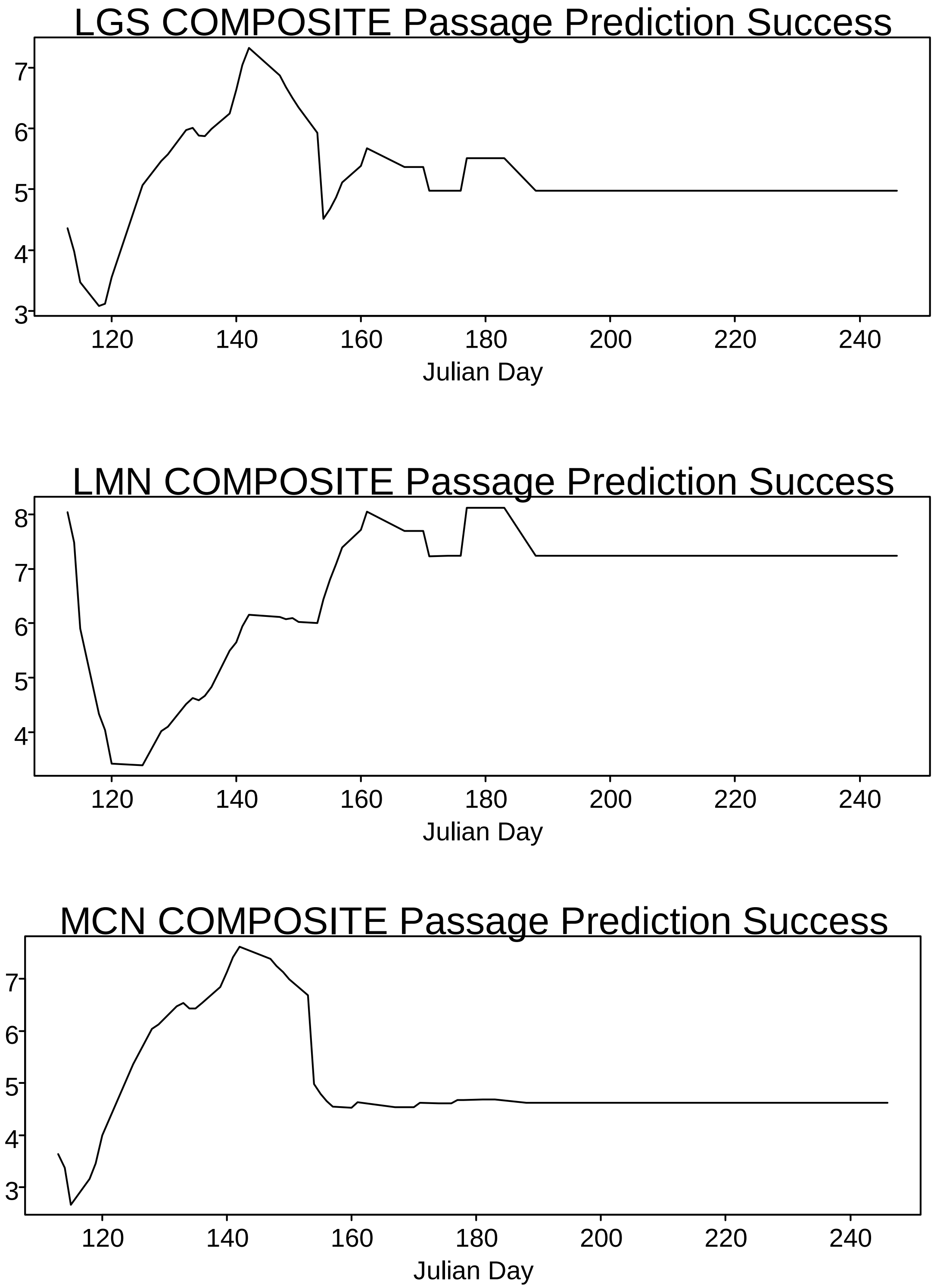


Figure C-21 CRiSP predictions for the cumulative distribution of arrivals of the S. Fork Salmon River stock at McNary Dam. Y-axis shows percent of total passage.

Appendix D 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 Lower Granite Dam are used as input to CRiSP1 which then predicts the arrival of fish at downstream locations. In the figures that follow, *MAD* computations for each modeled day of arrivals at Lower Granite Dam, Lower Monumental Dam and McNary Dam are displayed. Patterns of prediction success at an upstream location are propagated downstream.



LGS COMPOSITE Passage Prediction Success

LMN COMPOSITE Passage Prediction Success

MCN COMPOSITE Passage Prediction Success

Figure D-1 Seasonal variation in passage prediction success for the Composite stock at Little Goose, Lower Monumental and McNary Dams. Y axis is the *MAD* value.

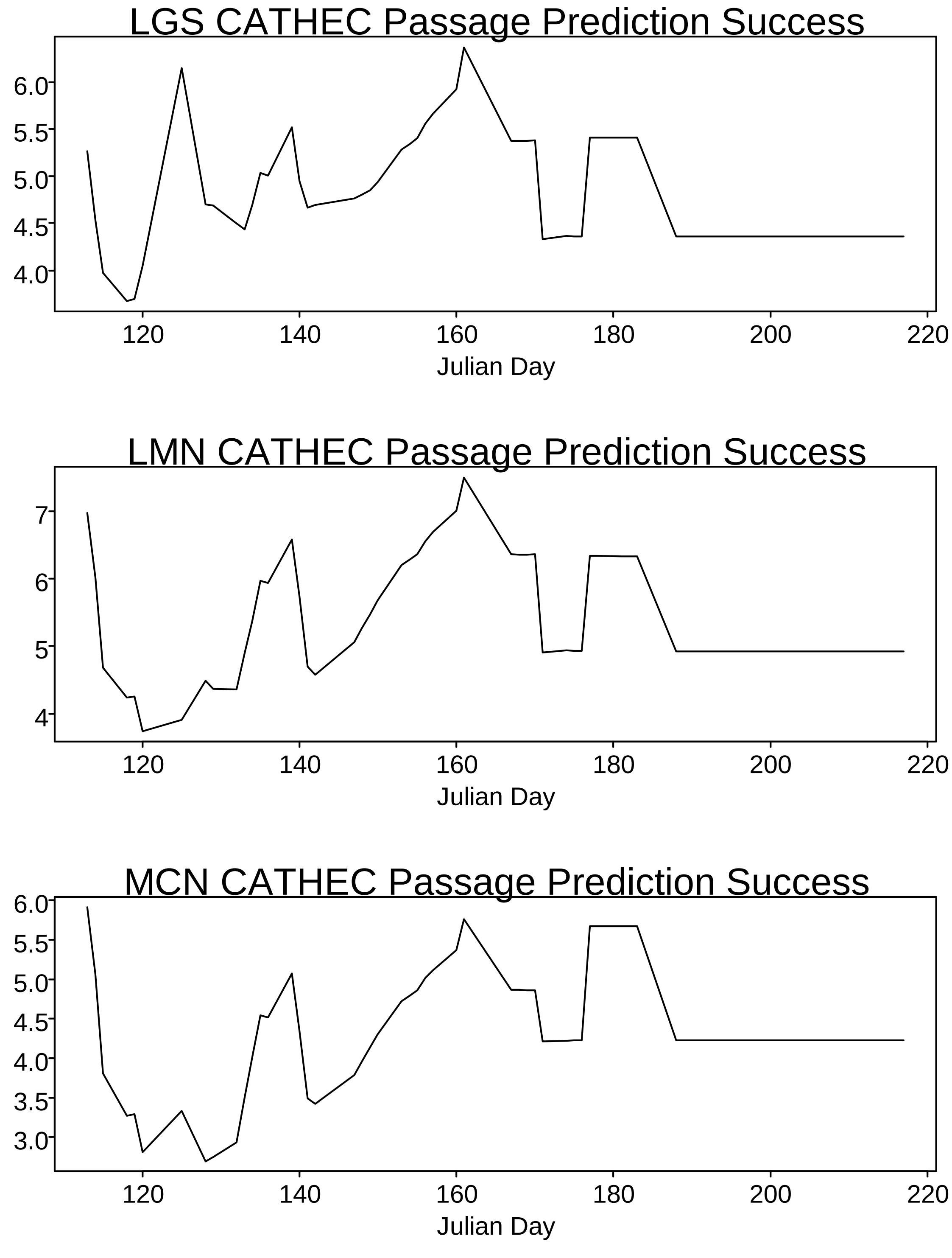


Figure D-2 Seasonal variation in passage prediction success for Catherine Creek stocks at Little Goose, Lower Monumental and McNary Dams. Y axis is the *MAD* value.

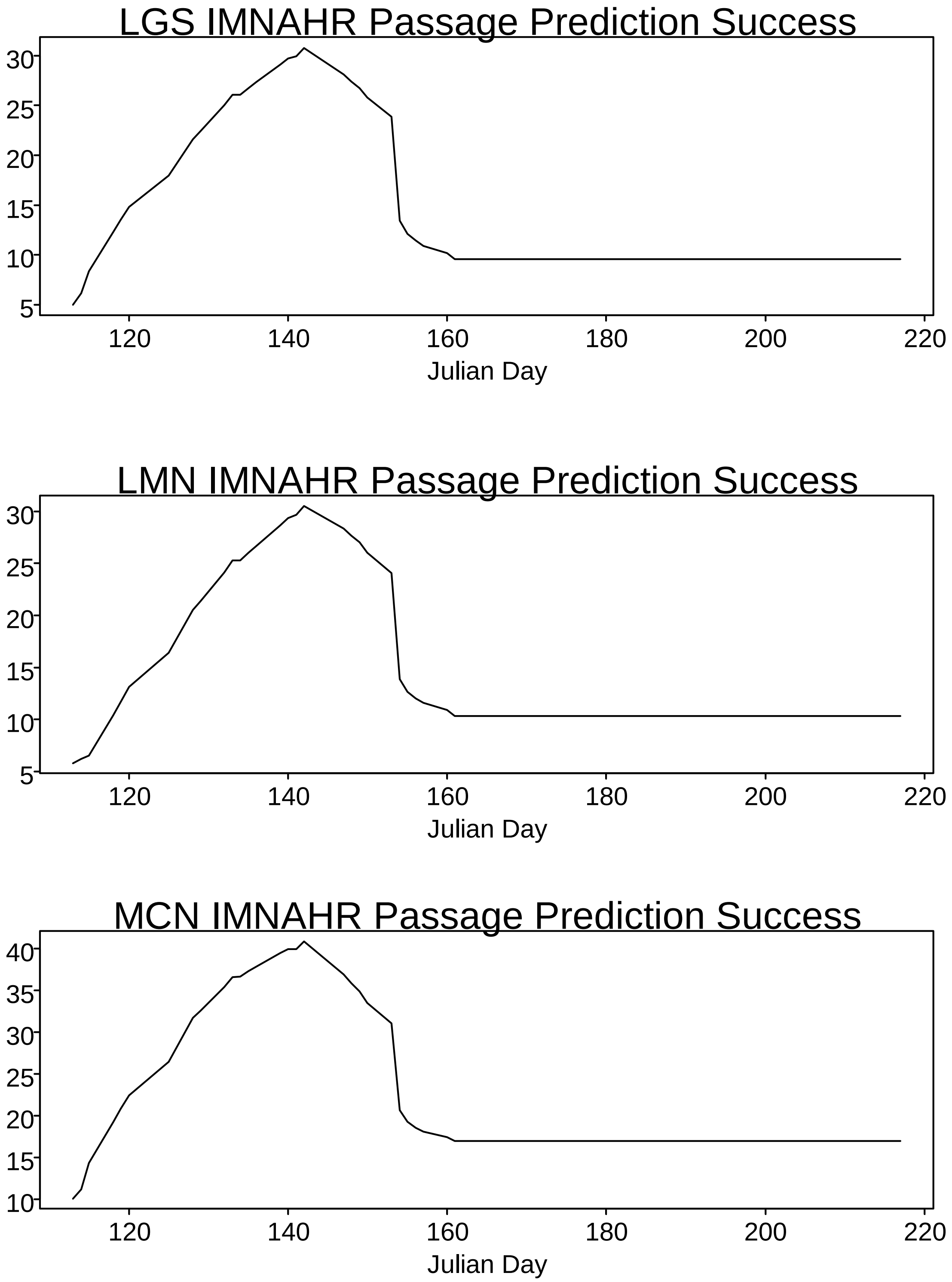


Figure D-3 Seasonal variation in passage prediction success for Imnaha River stocks at Little Goose, Lower Monumental and McNary Dams. Y axis is the *MAD* value.

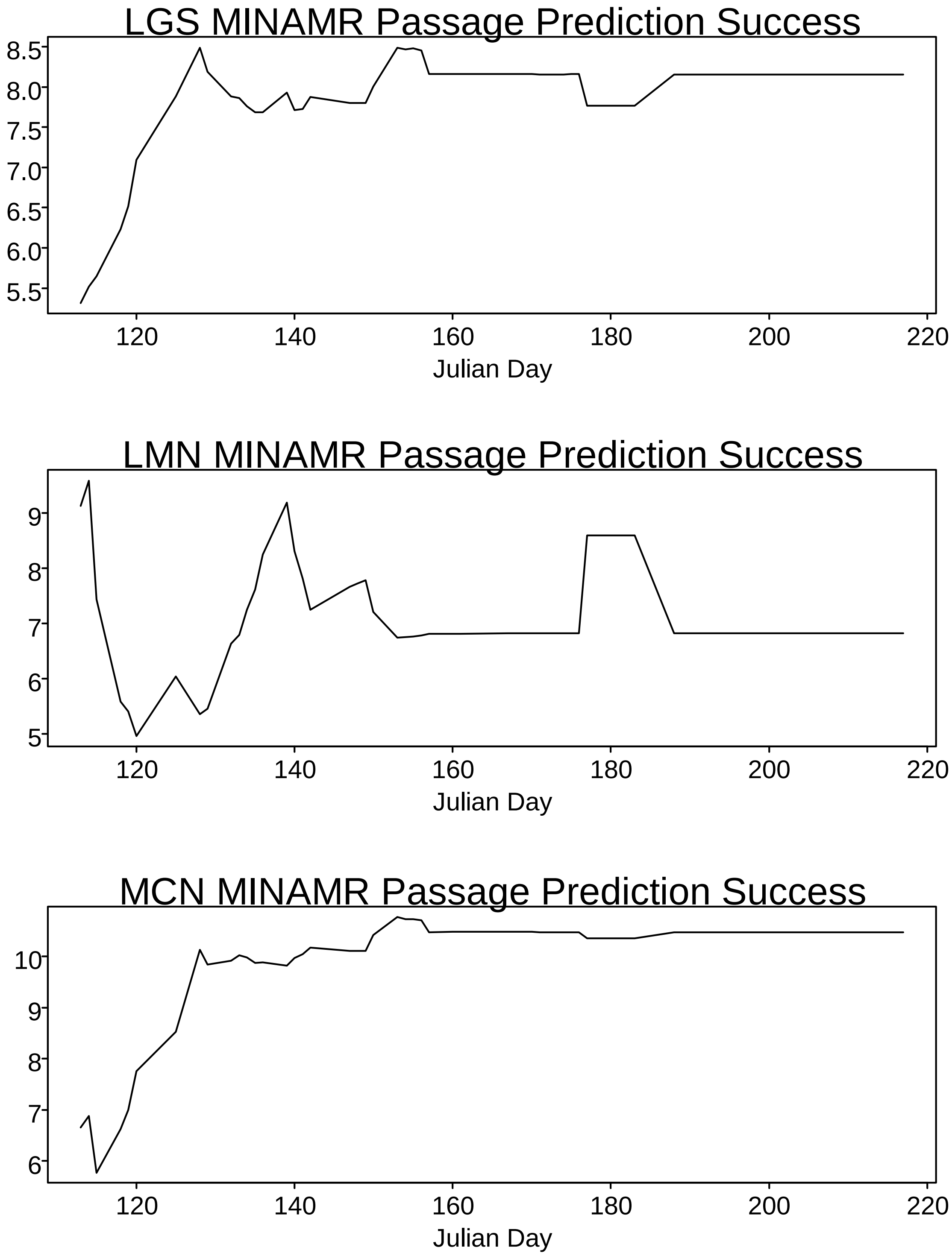


Figure D-4 Seasonal variation in passage prediction success for Minam River stocks at Little Goose, Lower Monumental and McNary Dams. Y axis is the *MAD* value.

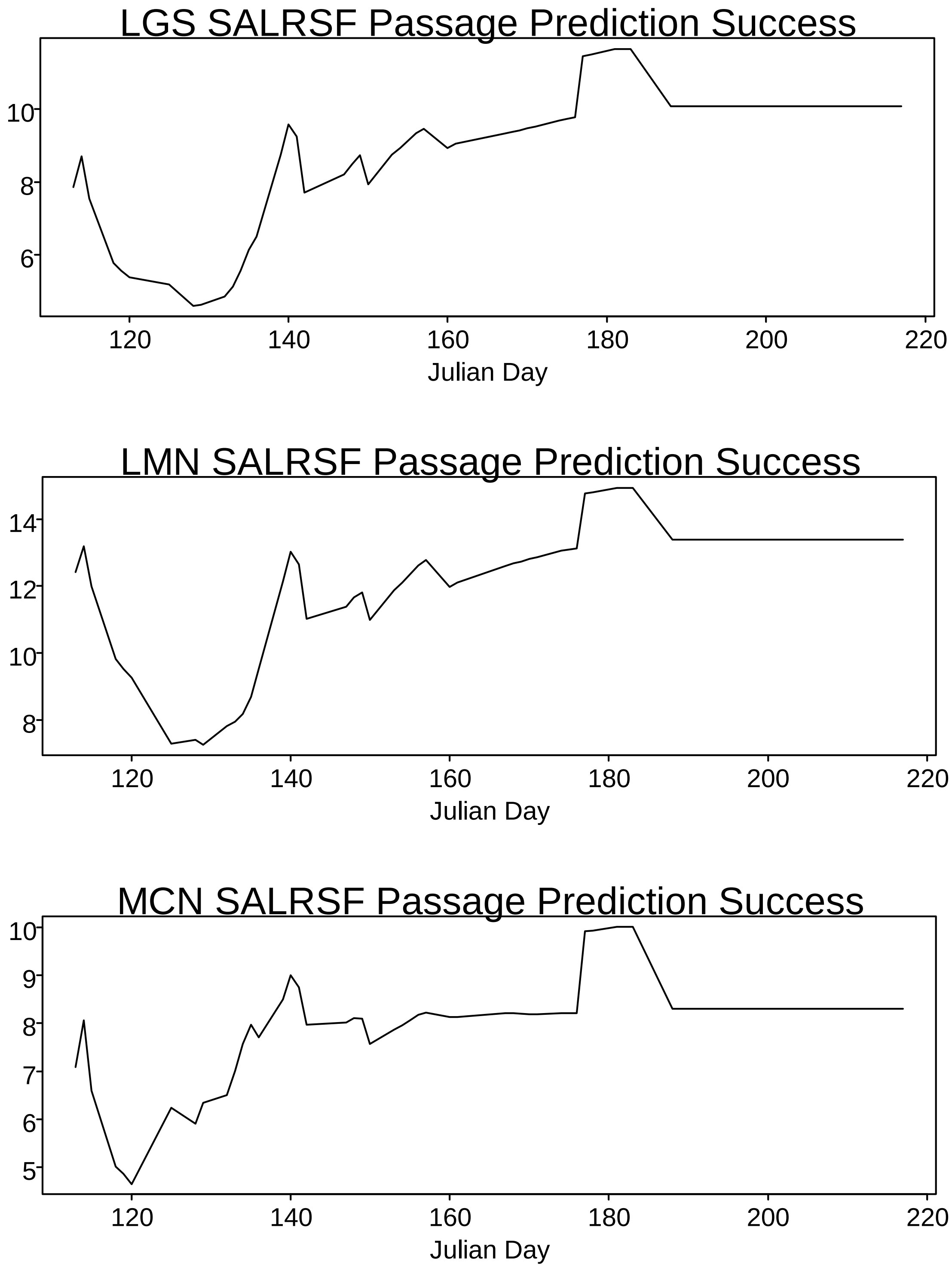


Figure D-5 Seasonal variation in passage prediction success for South Fork Salmon River stocks at Little Goose, Lower Monumental and McNary Dams. Y axis is the *MAD* value.

Appendix E 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 spill 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 5 for the target percent values used by CRiSP as forecasted values for the Mid-Columbia dams. These values are different than what appears in the plots (Figure E-4).

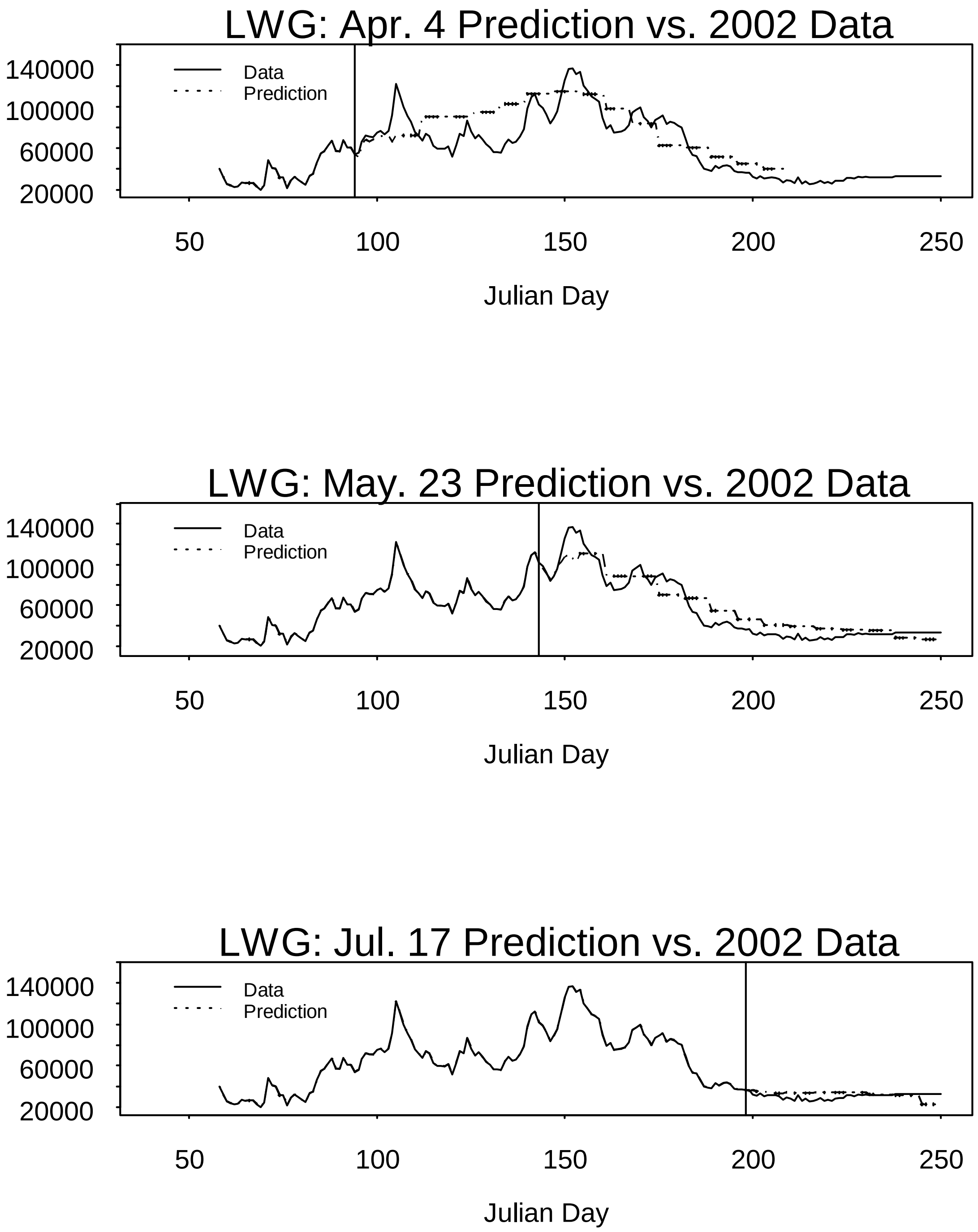


Figure E-1 Flow predictions and observations for Lower Granite Dam. Y axis shows CFS.

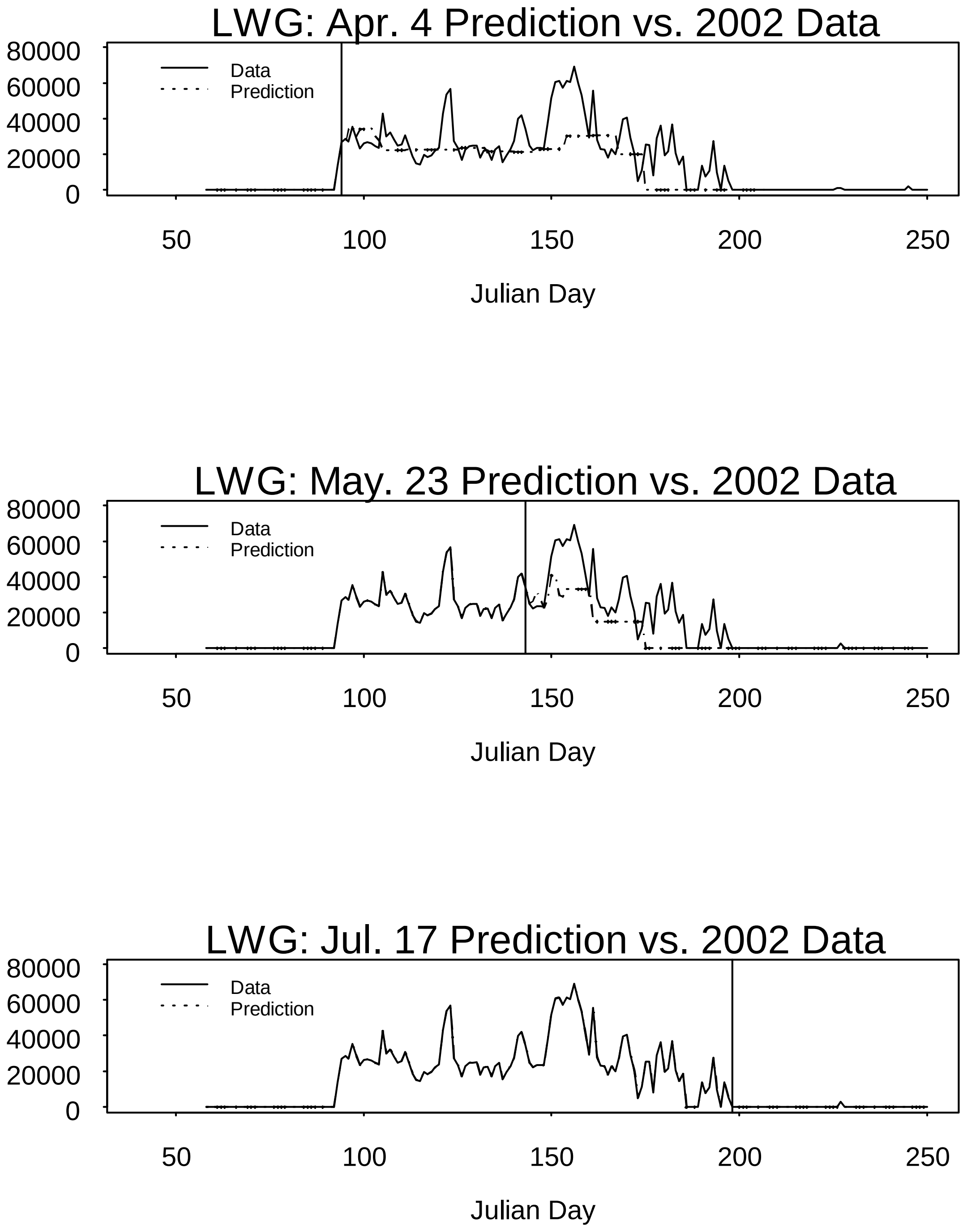
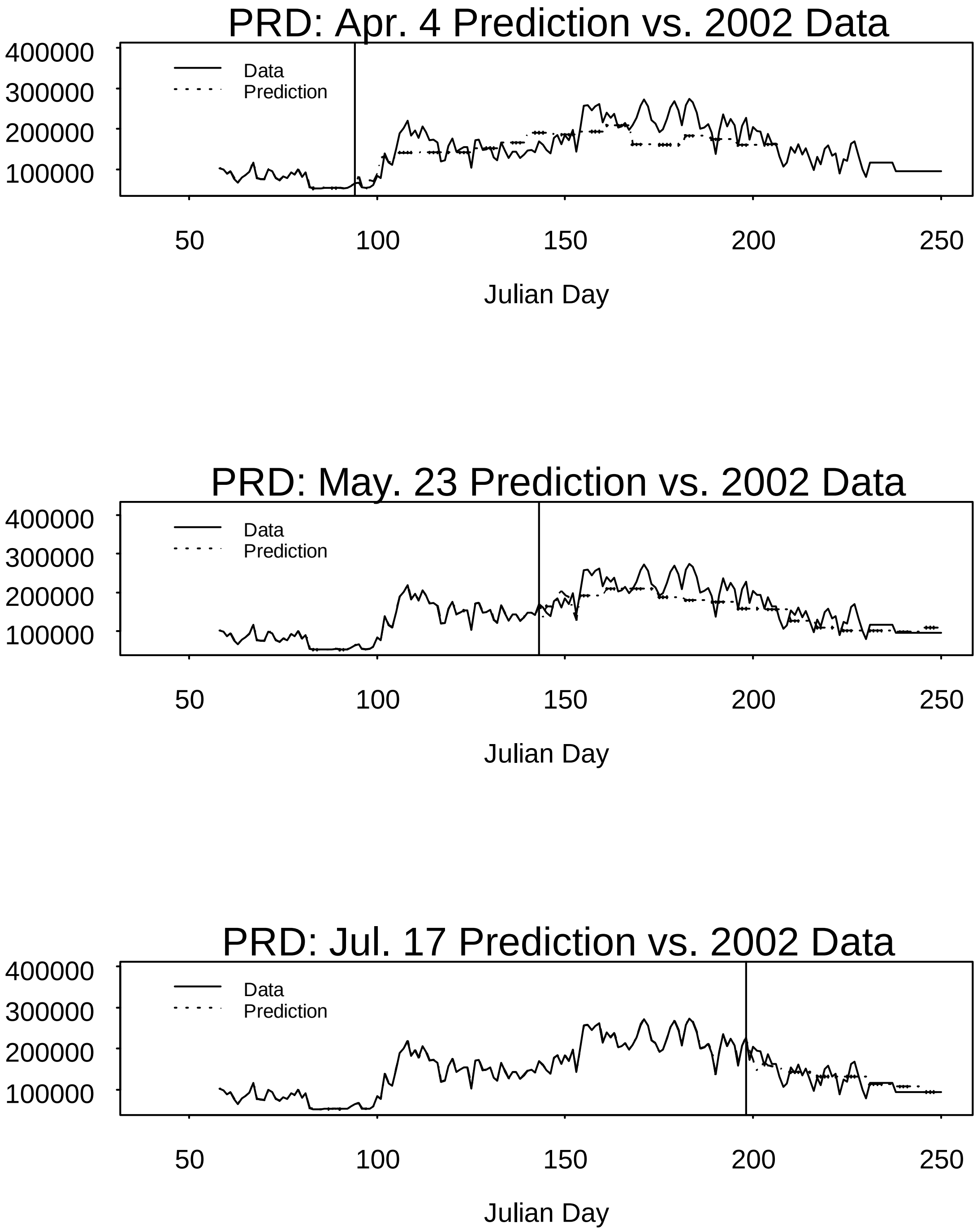


Figure E-2 Spill predictions and observations for Lower Granite Dam. Y axis shows CFS.

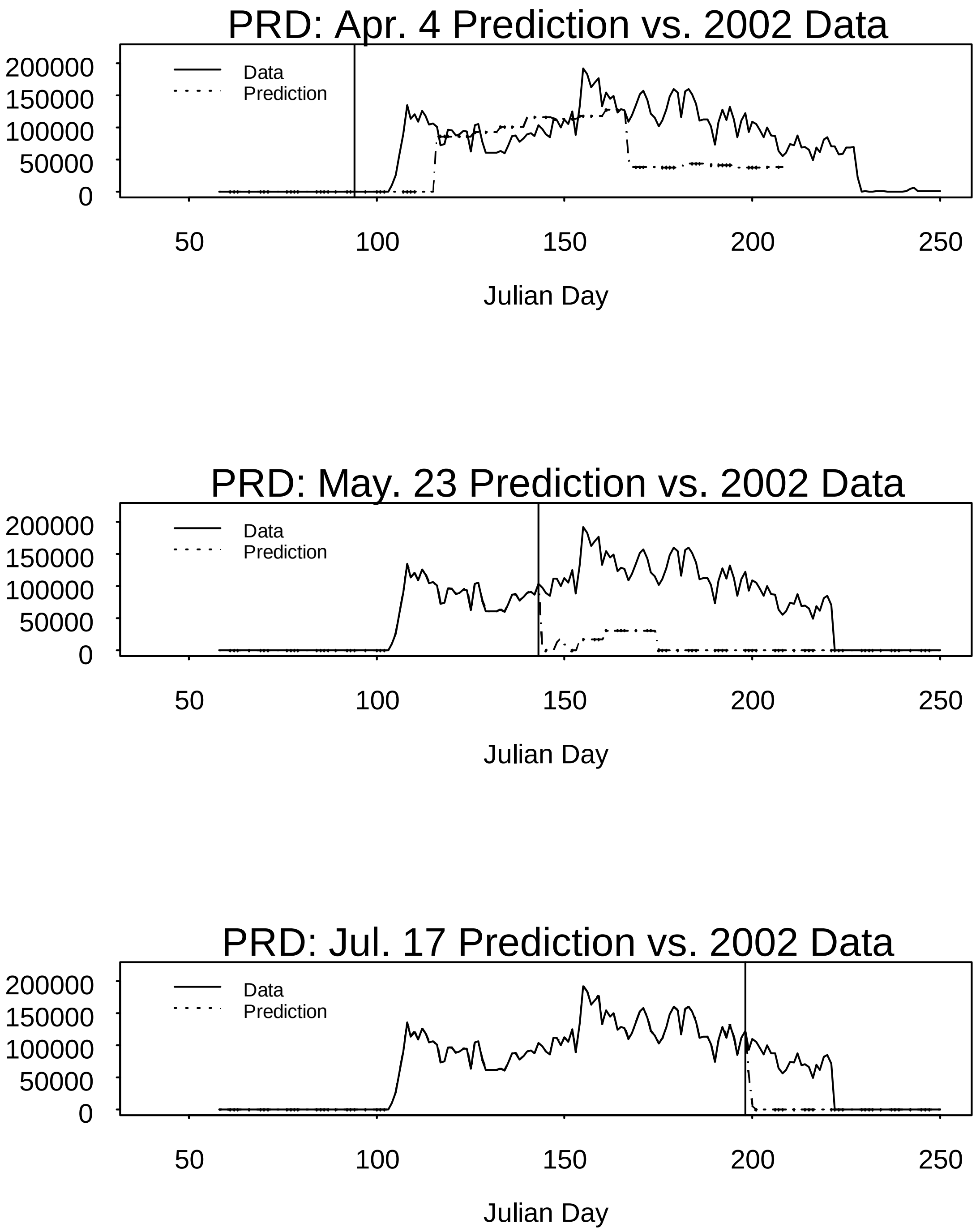


PRD: Apr. 4 Prediction vs. 2002 Data

PRD: May. 23 Prediction vs. 2002 Data

PRD: Jul. 17 Prediction vs. 2002 Data

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



PRD: Apr. 4 Prediction vs. 2002 Data

PRD: May. 23 Prediction vs. 2002 Data

PRD: Jul. 17 Prediction vs. 2002 Data

Figure E-4 Spill predictions based on forcasts and observations for PRD, however, mid-Columbia PUDs used fixed spill percentage targets during the season. Y axis shows CFS.

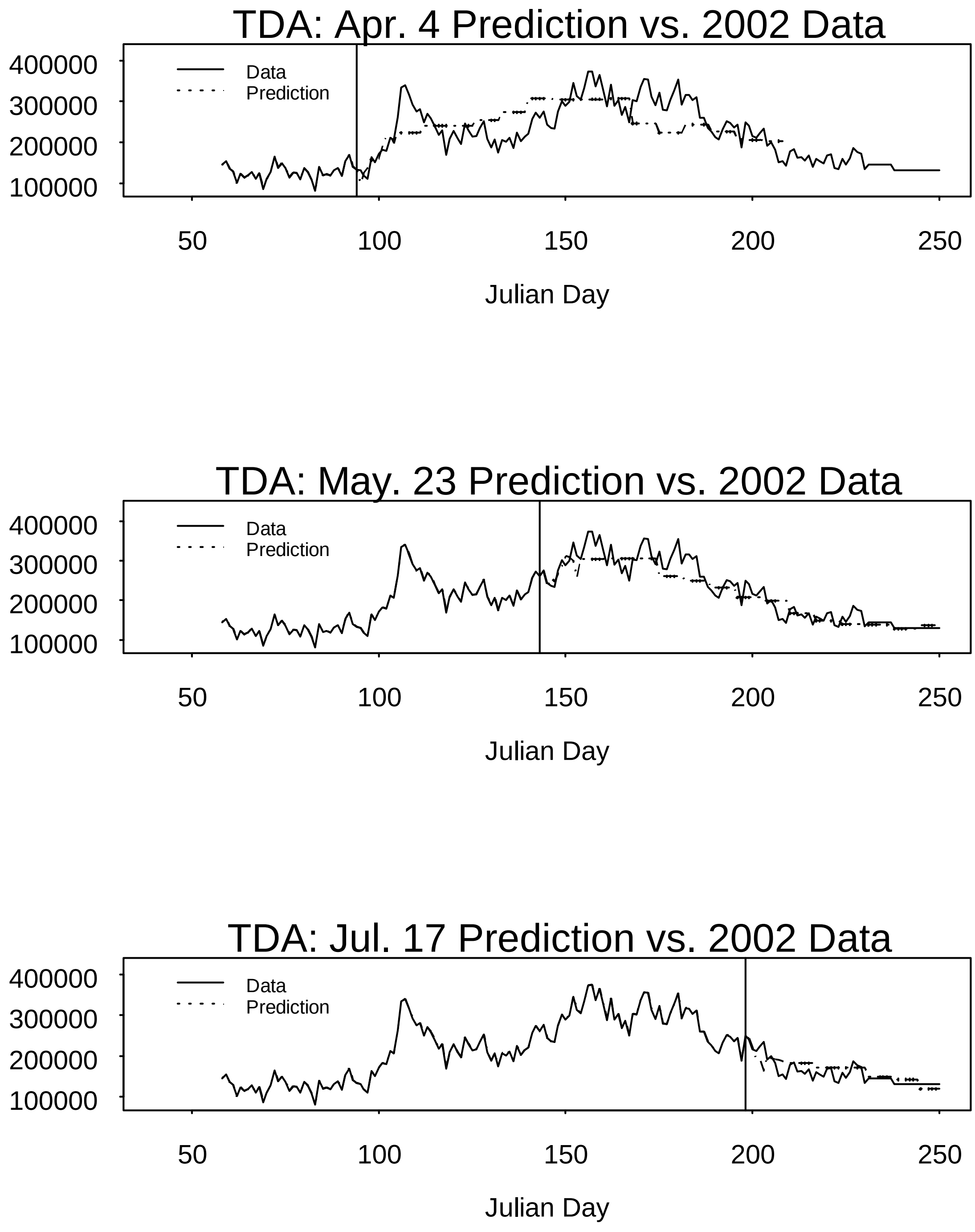


Figure E-5 Flow predictions and observations for The Dalles Dam. Y axis shows CFS.

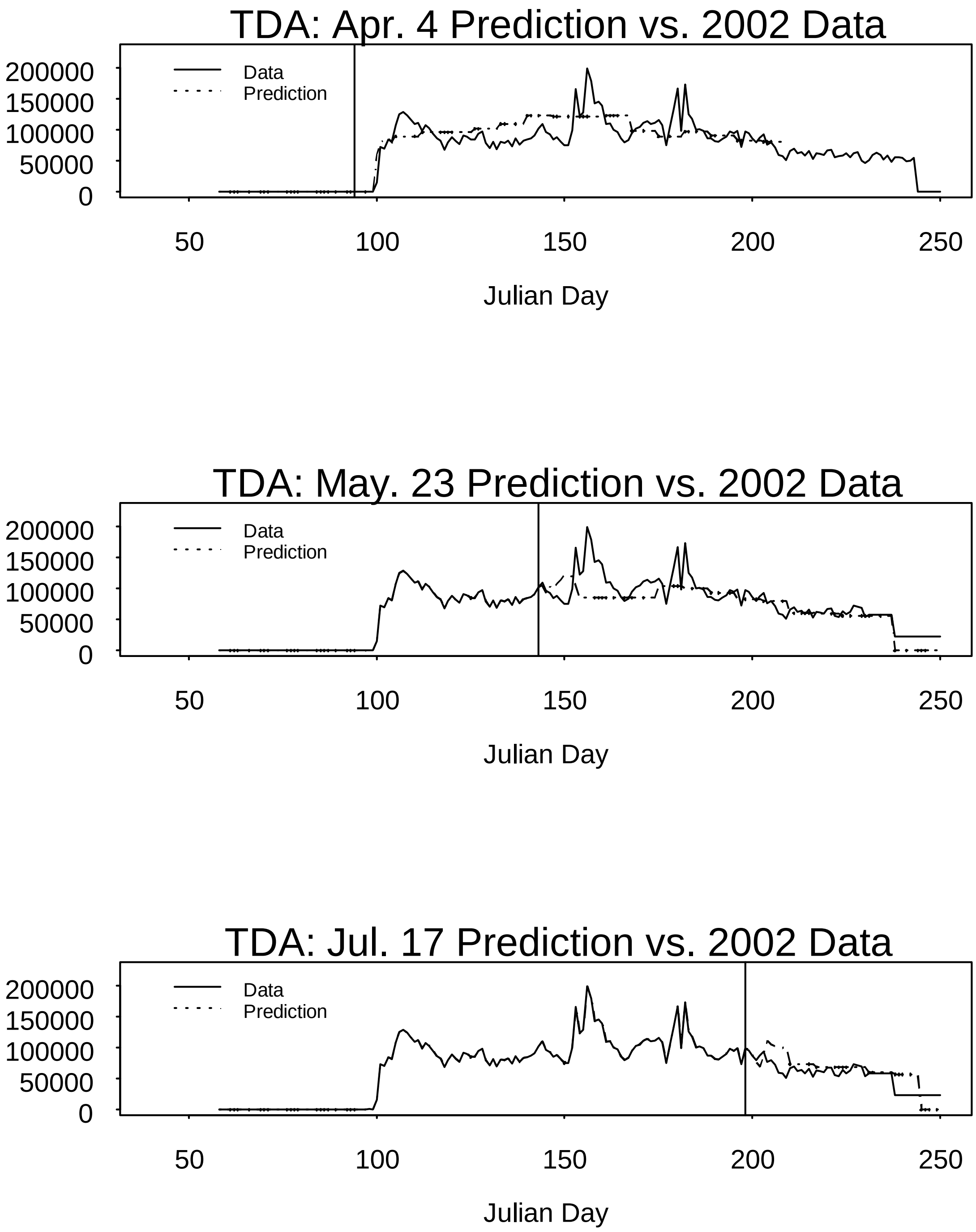


Figure E-6 Spill predictions and observations for The Dalles Dam. Y axis shows CFS.

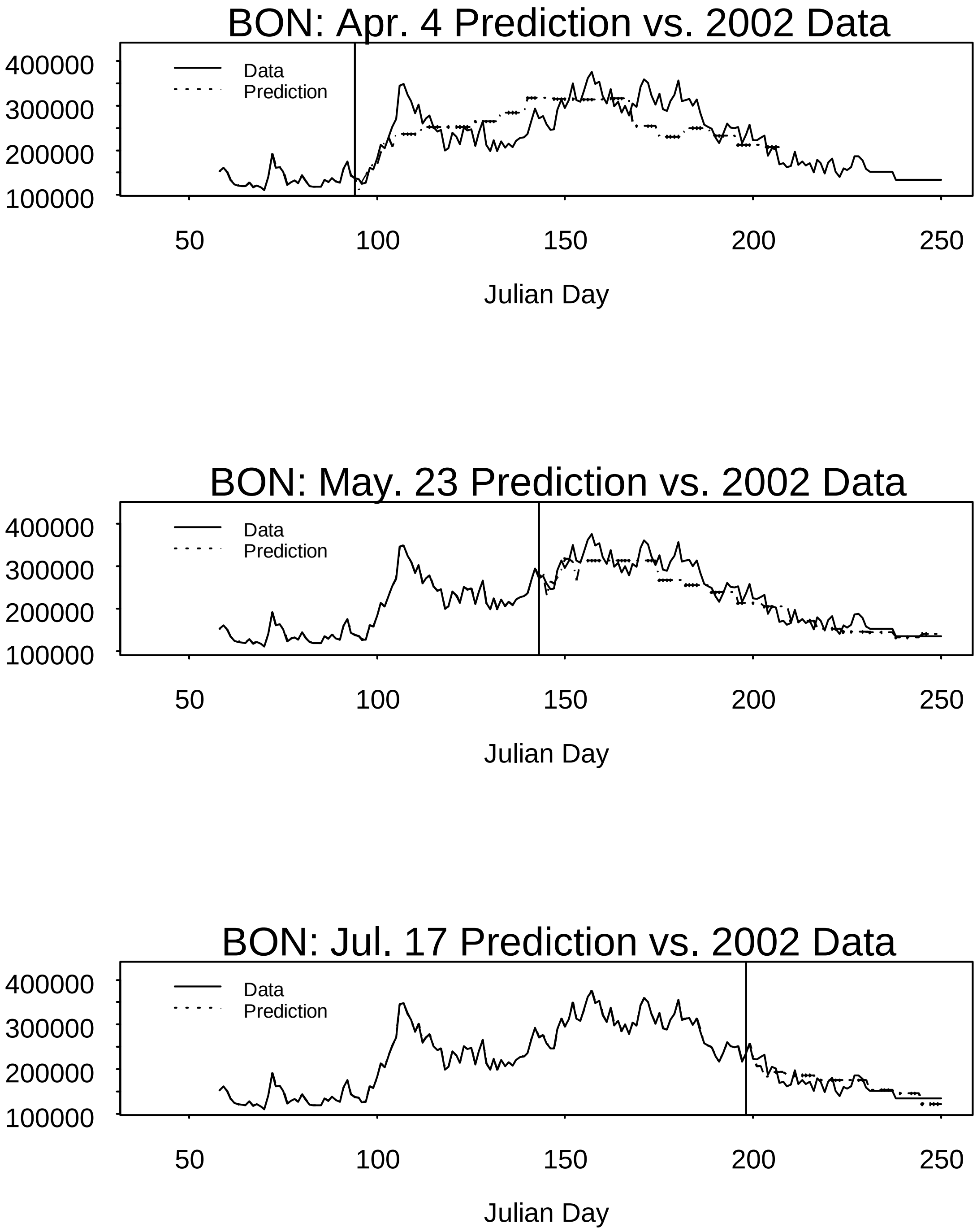


Figure E-7 Flow predictions and observations for Bonneville Dam.Y axis shows CFS.

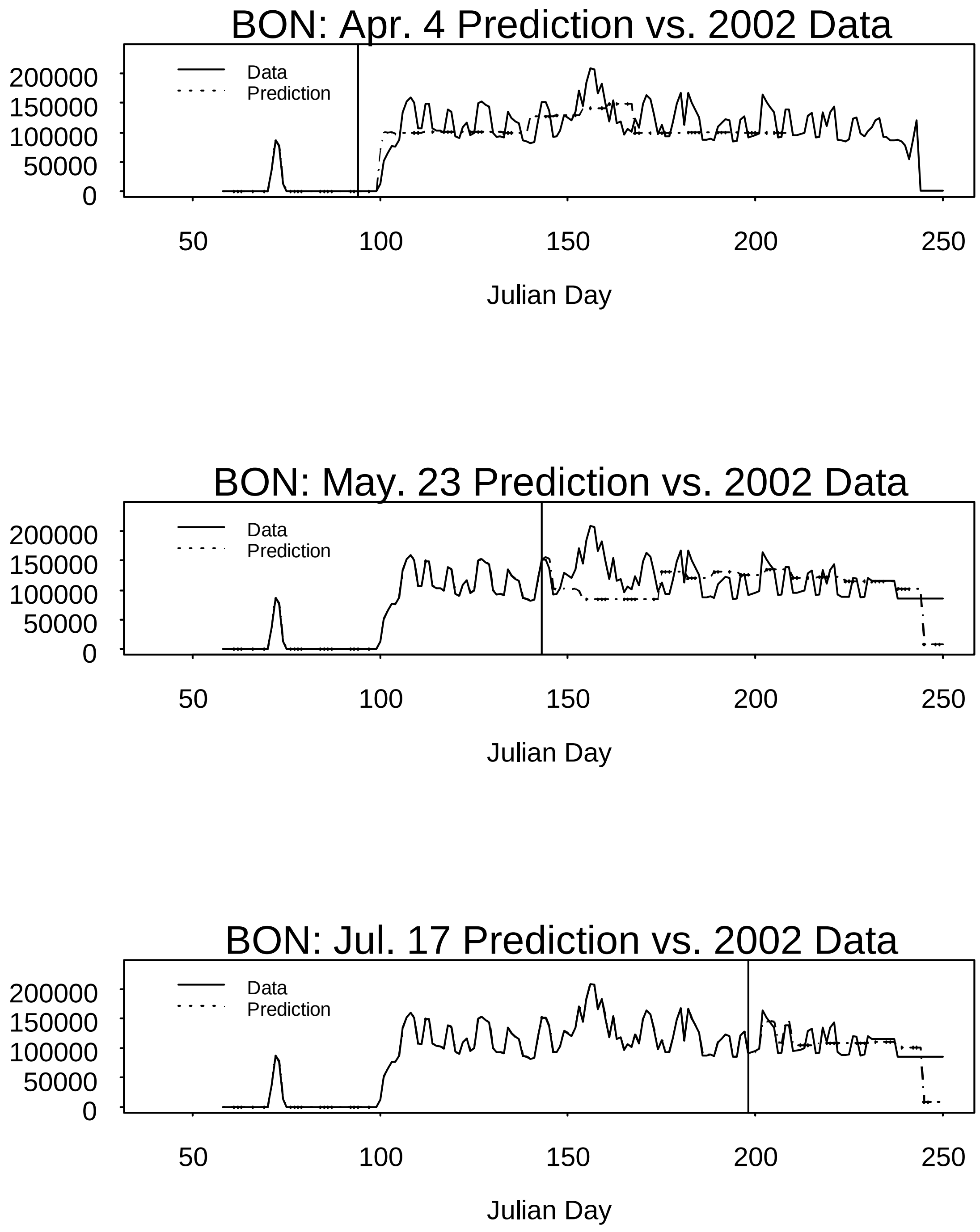


Figure E-8 Spill predictions and observations for Bonneville Dam.Y axis shows CFS.

Appendix F Spill Forecast History Plots

Spill predictions during the early season are difficult to make. Shown here are late March/ early April predictions compared to data for Priest Rapids and Ice Harbor. For the last three years, there has been at least one spike in the spill volumes (mostly due to large flows in the system).

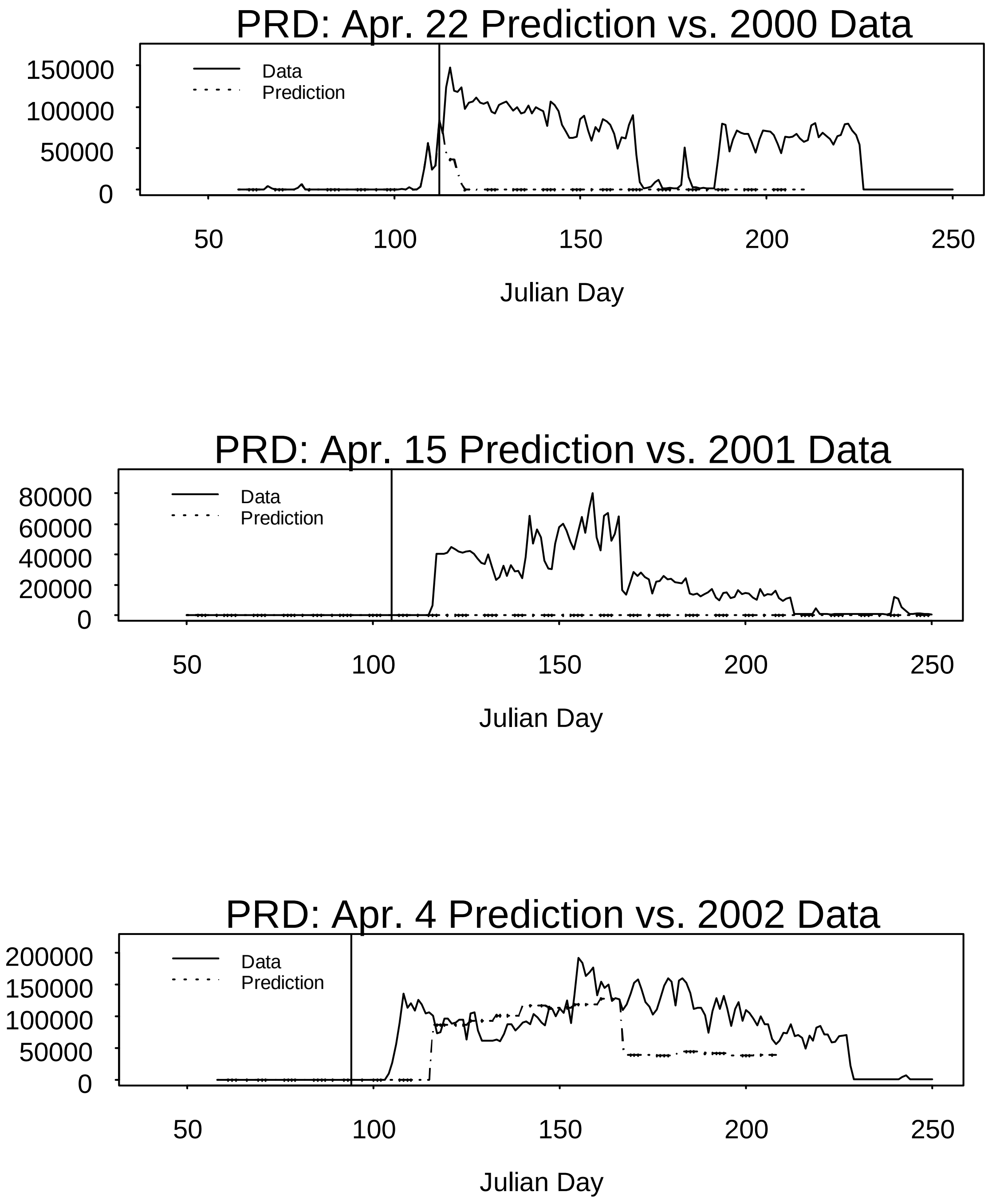


Figure F-1 Early season spill predictions for the last three years compared to data at Priest Rapids Dam.

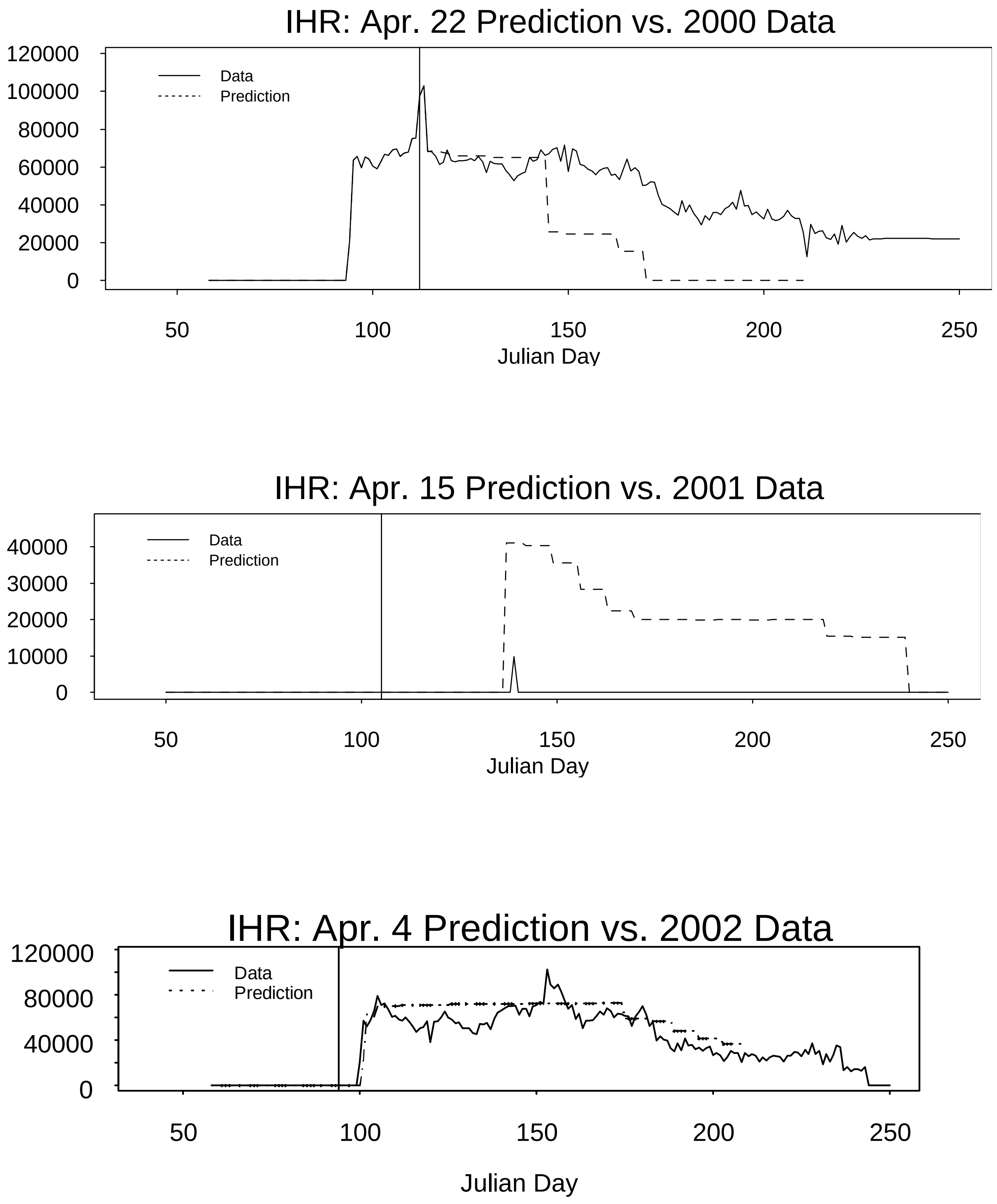
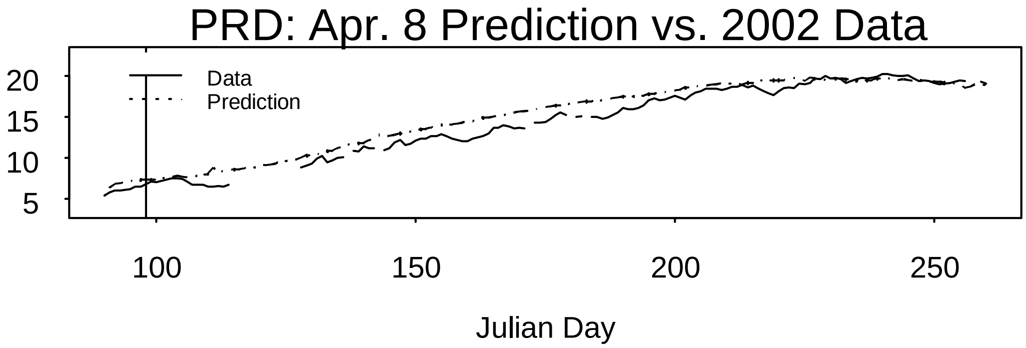
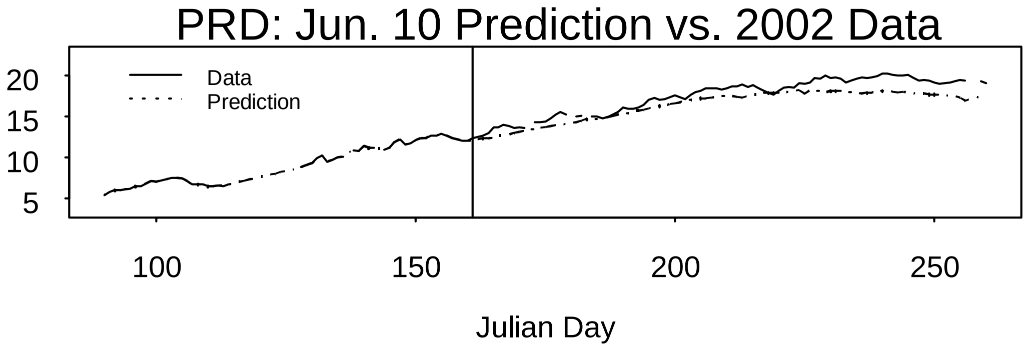


Figure F-2 Early season spill predictions for the last three years compared to data at Ice Harbor dam.

Appendix G Temperature Forecast Plots


PRD: Apr. 8 Prediction vs. 2002 Data


PRD: Jun. 10 Prediction vs. 2002 Data

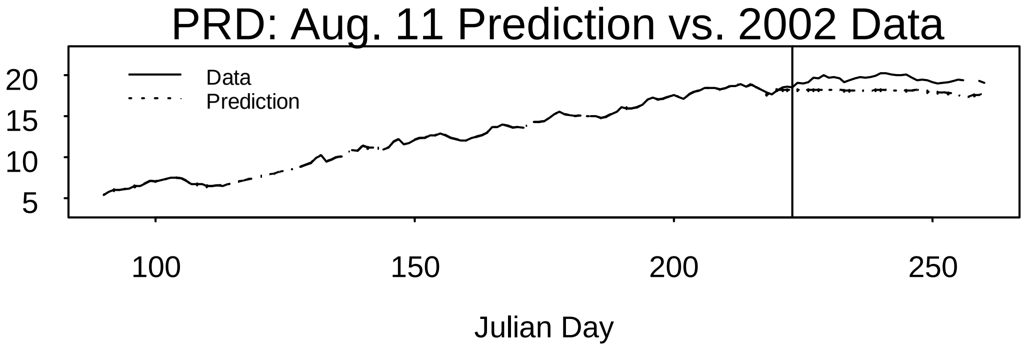

PRD: Aug. 11 Prediction vs. 2002 Data

Figure G-2 Temperature predictions and observations for Priest Rapids Dam. Y axis is °C.

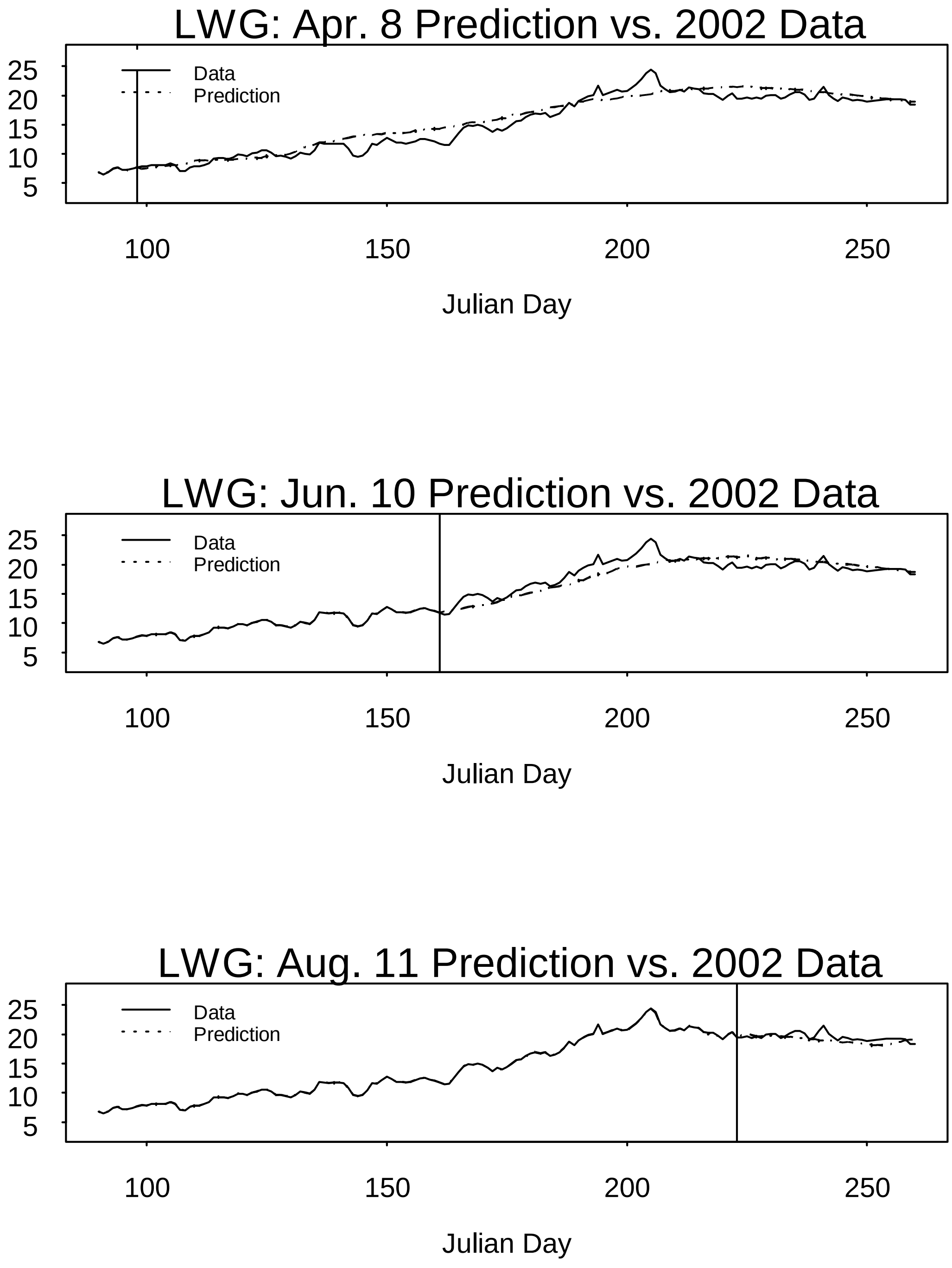


Figure G-1 Temperature predictions and observations for Lower Granite Dam. Y axis is °C.

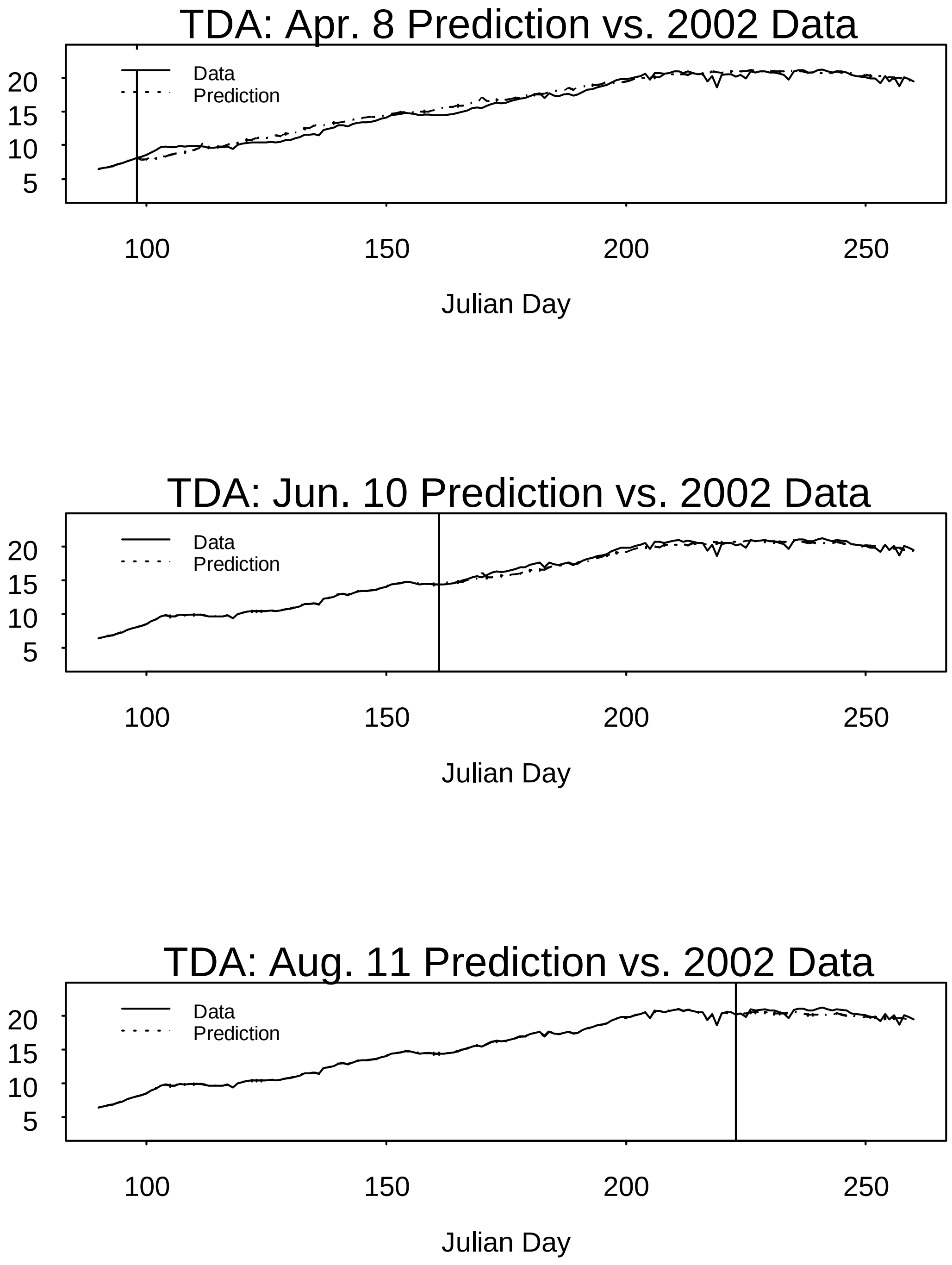


Figure G-3 Temperature predictions and observations for The Dalles Dam. Y axis is °C.

Appendix H 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 10.)

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.

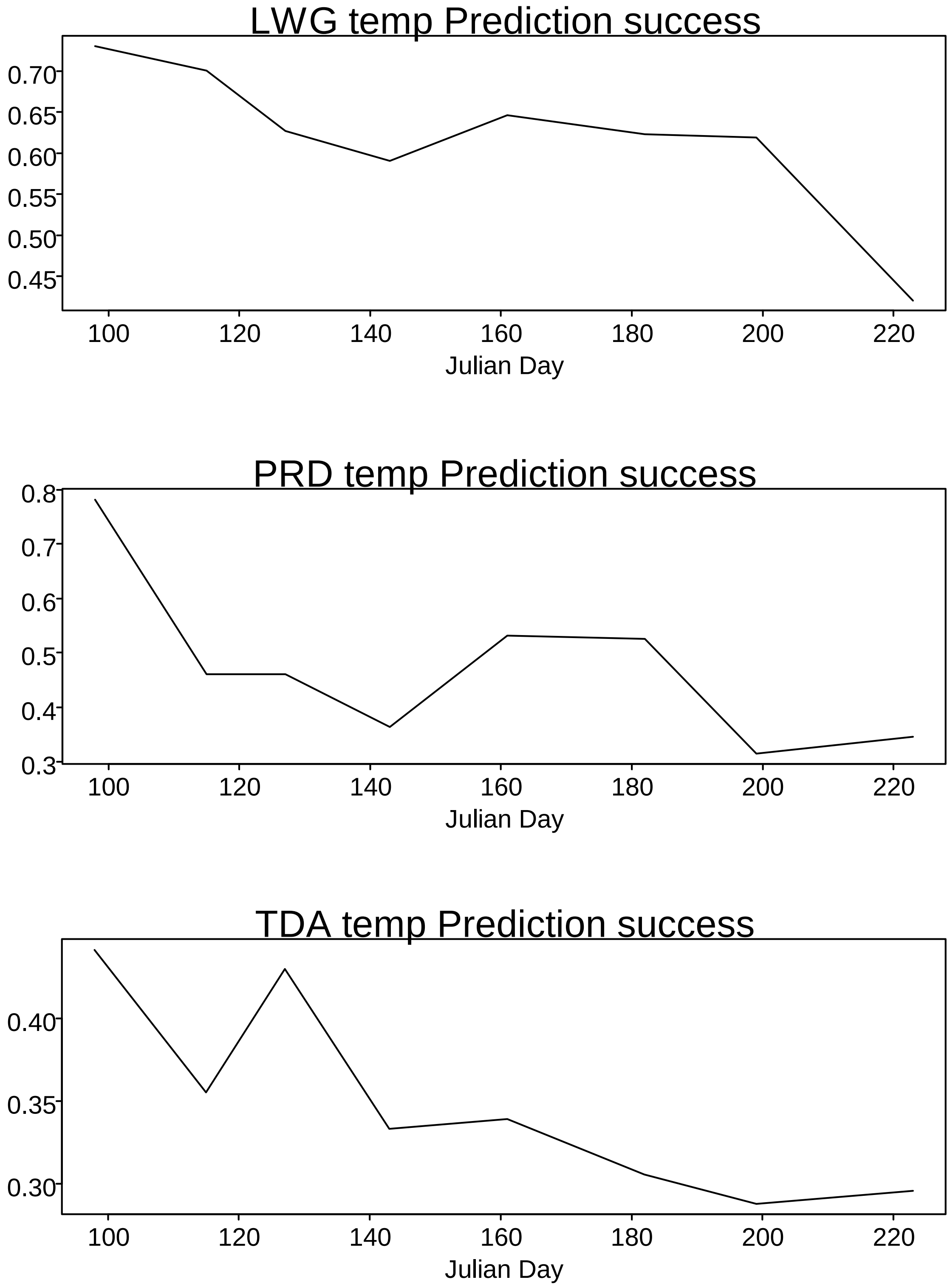


Figure H-1 Seasonal variation in temperature prediction success at three locations as measured by MAD (Y-axis).

Appendix I 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.

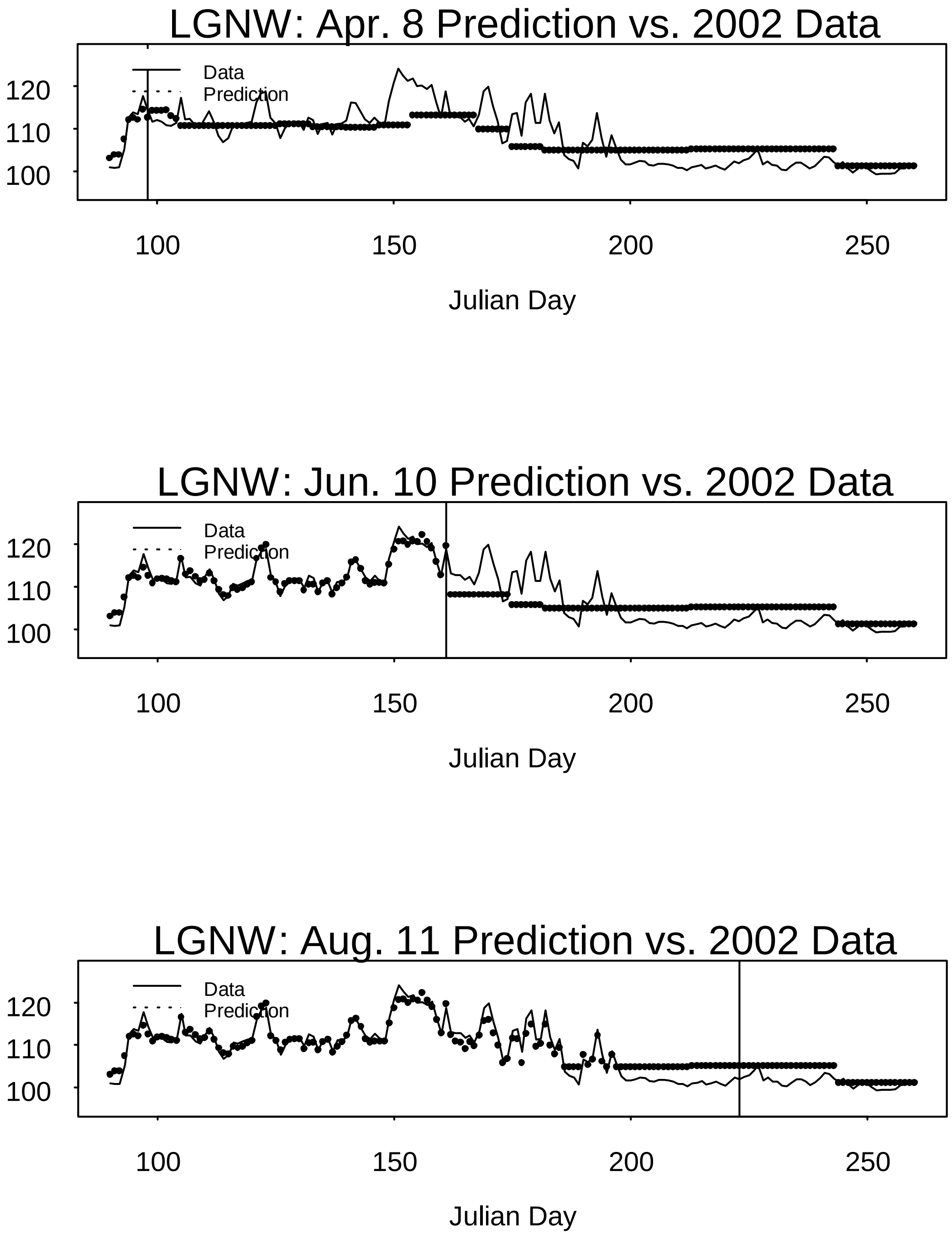


Figure I-1 Total Dissolved Gas predictions and observations for Lower Granite Dam as measured at LGNW. Y axis is the percent saturation.

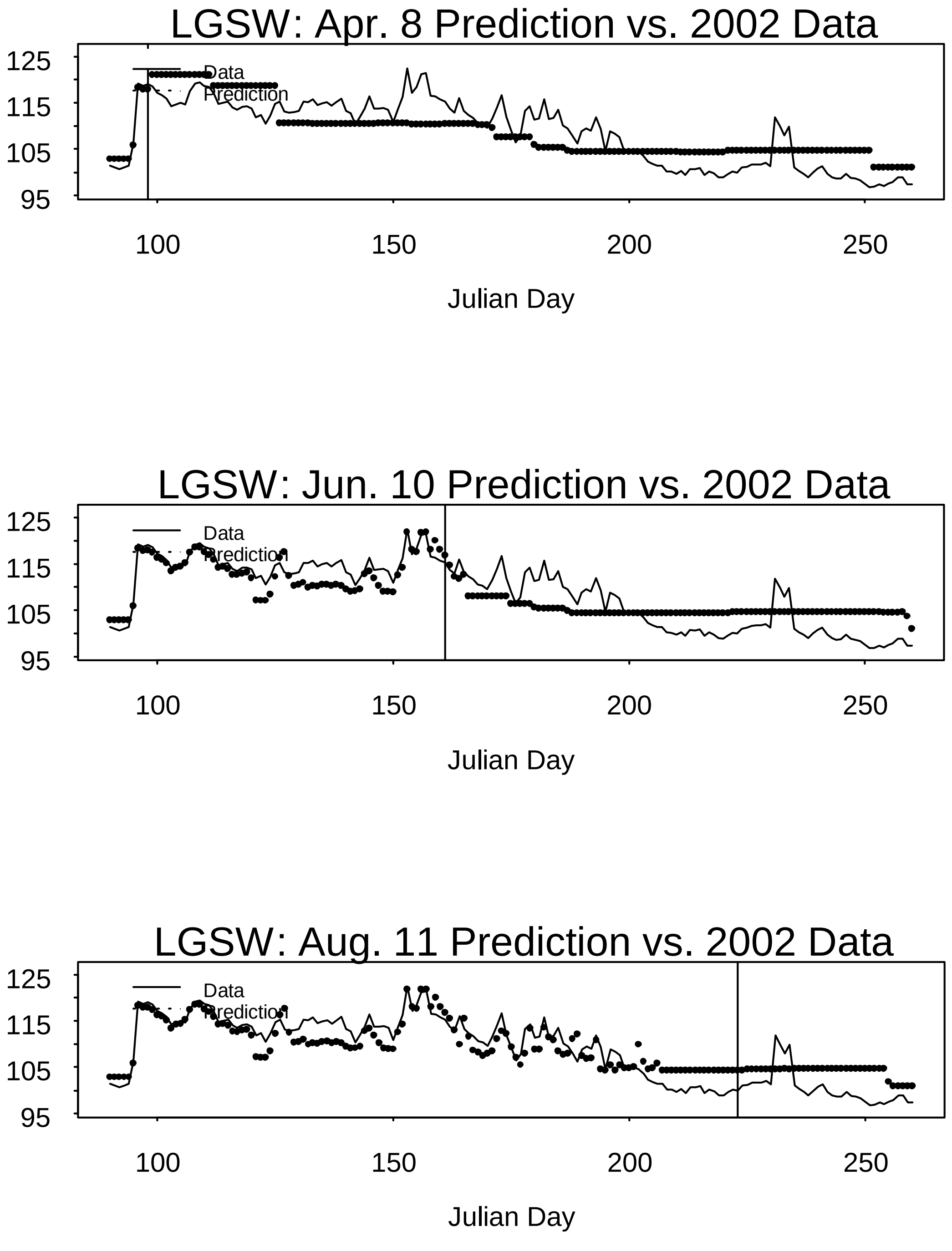


Figure I-2 Total Dissolved Gas predictions and observations for Little Goose Dam as measured at LGSW. Y axis is the percent saturation.

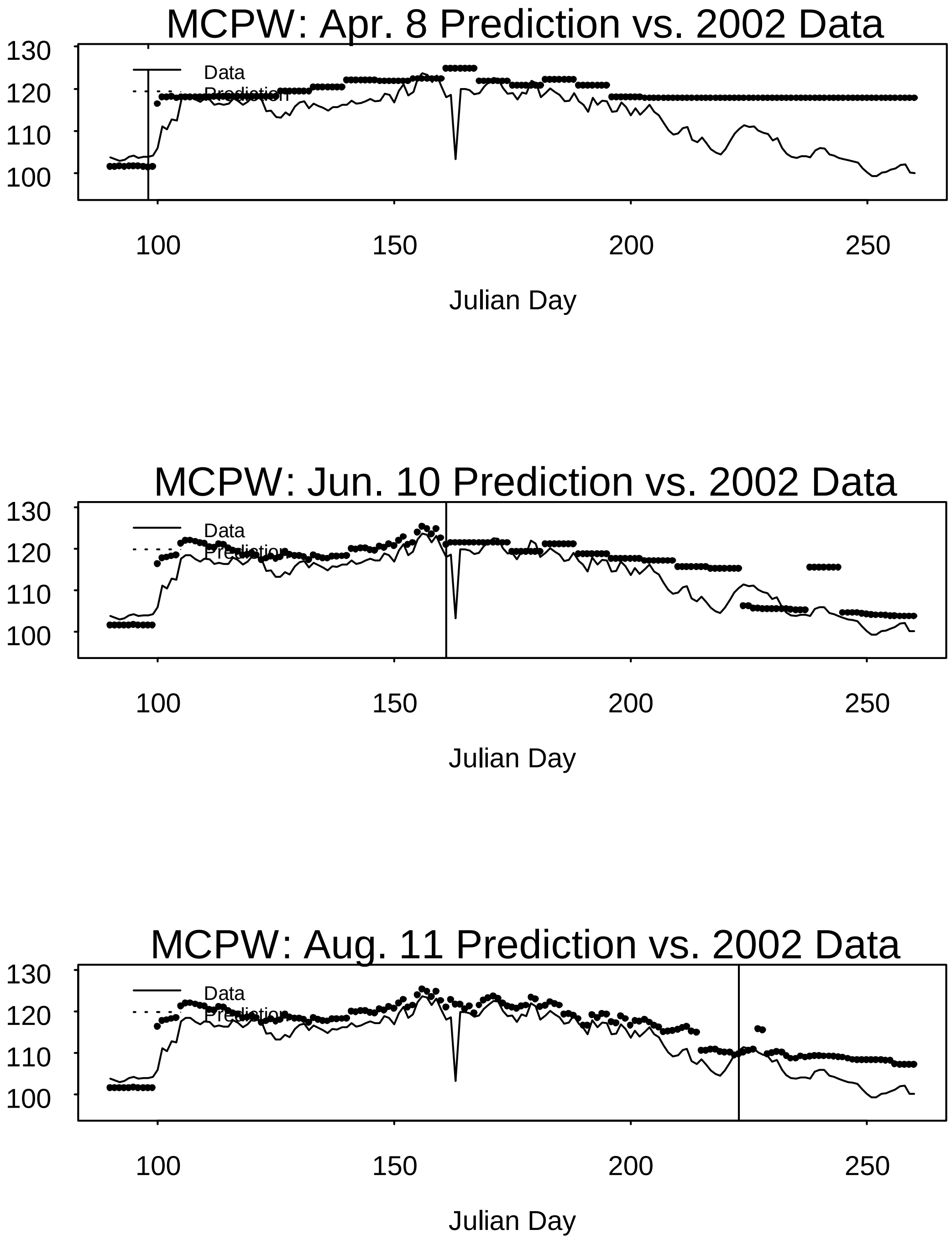


Figure I-3 Total Dissolved Gas predictions and observations for McNary Dam as measured at MCPW. Y axis is the percent saturation.

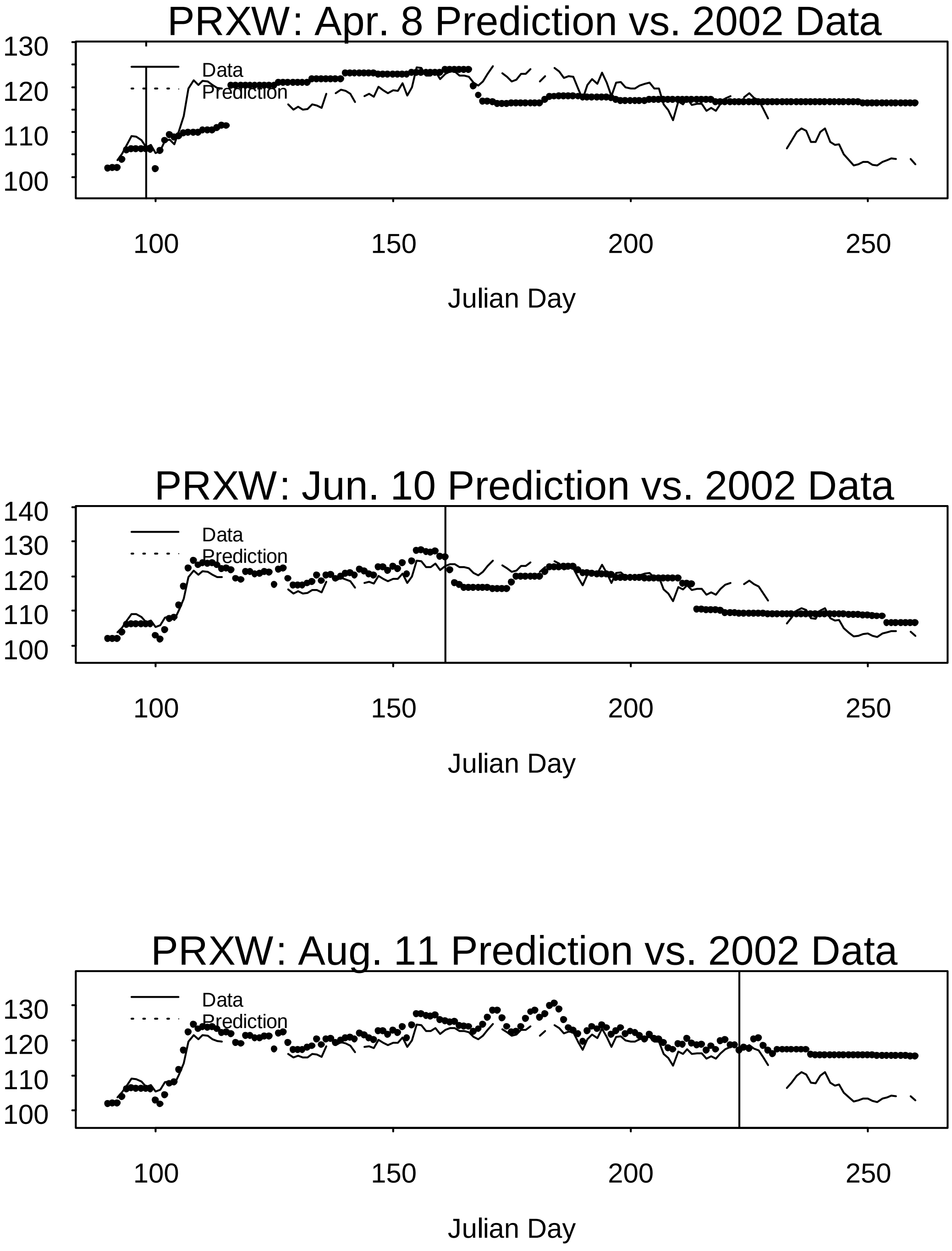
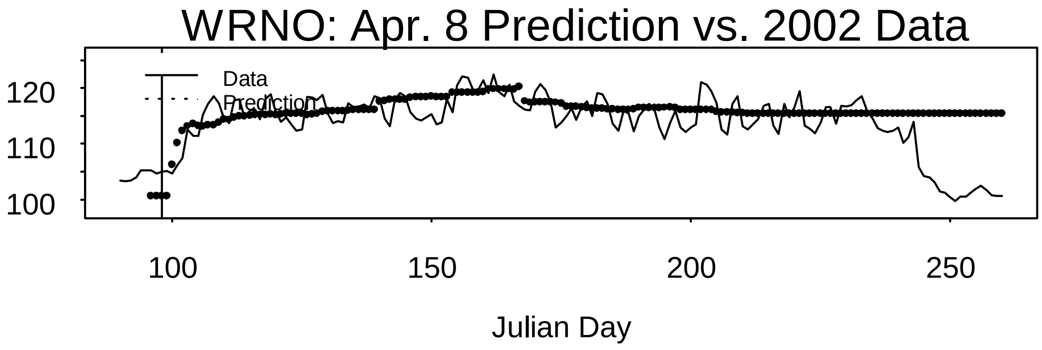
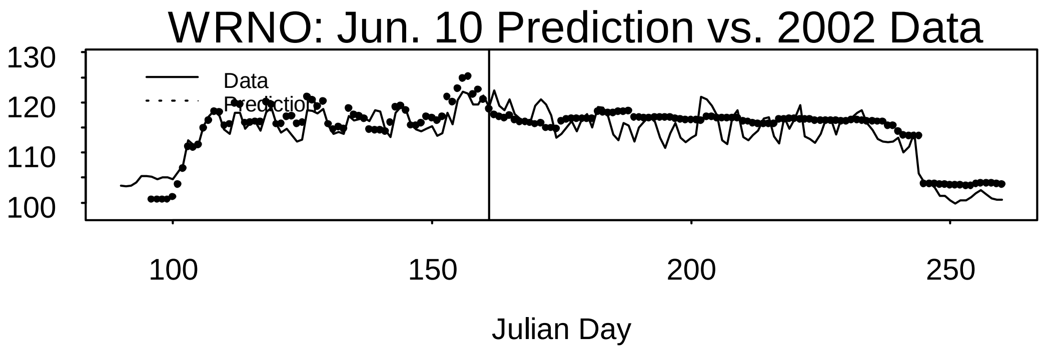


Figure I-4 Total Dissolved Gas predictions and observations for Priest Rapids Dam as measured at PRXW. Y axis is the percent saturation.





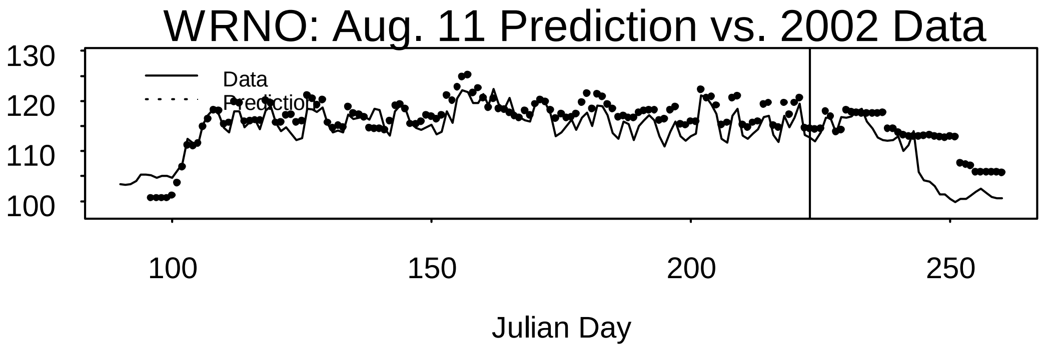


Figure I-5 Total Dissolved Gas predictions and observations for Bonneville Dam as measured at the WRNO site. Y axis is the percent saturation.

Appendix J 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.

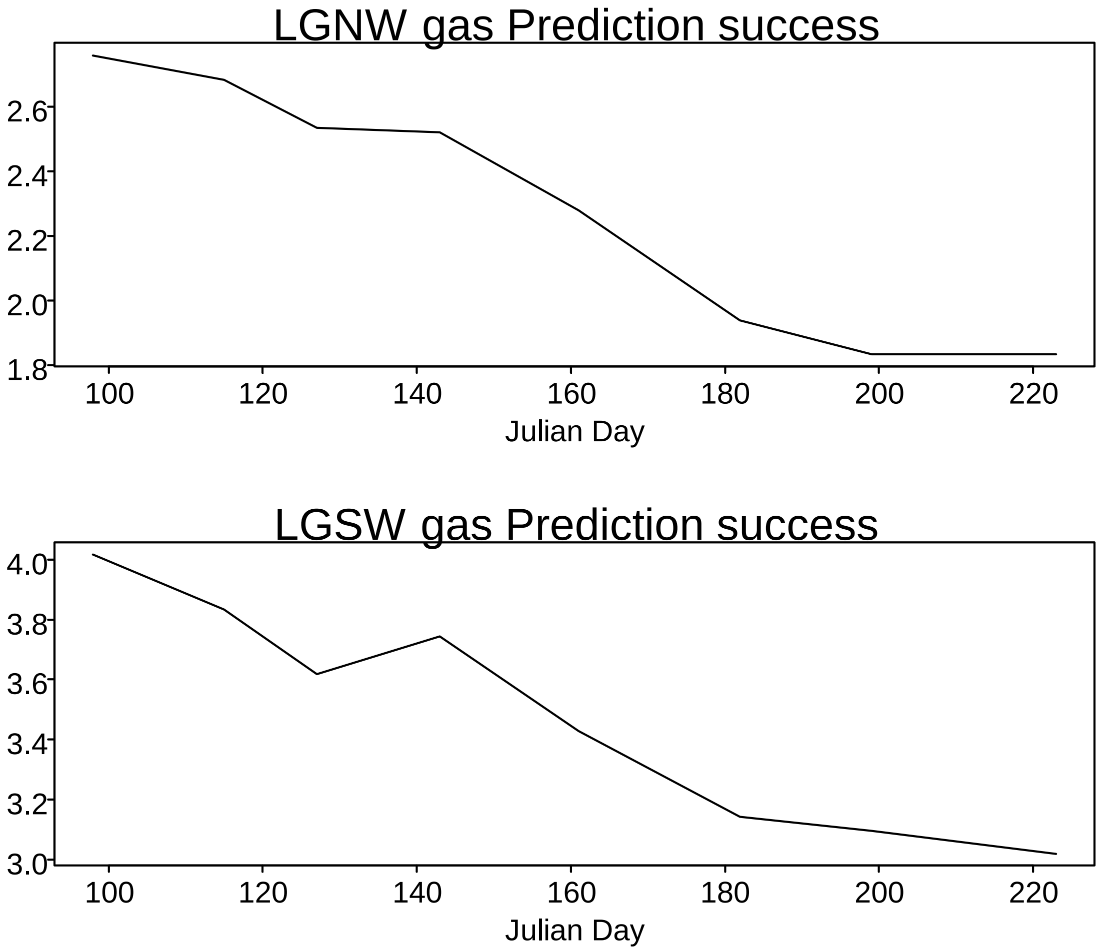


Figure J-1 Season variation in Total Dissolved Gas prediction at two monitoring sites below Lower Granite Dam and Little Goose Dam (top to bottom respectively).

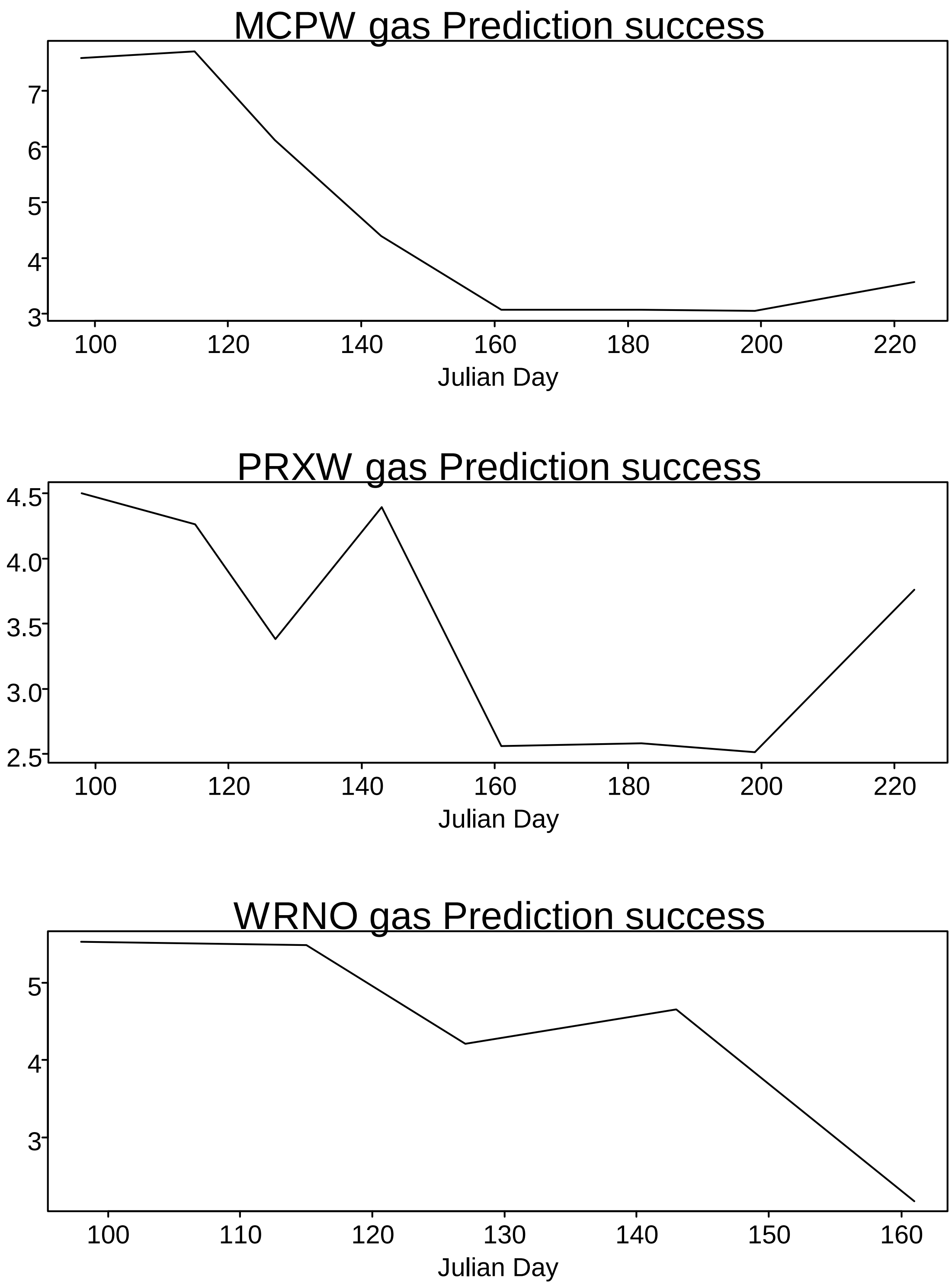
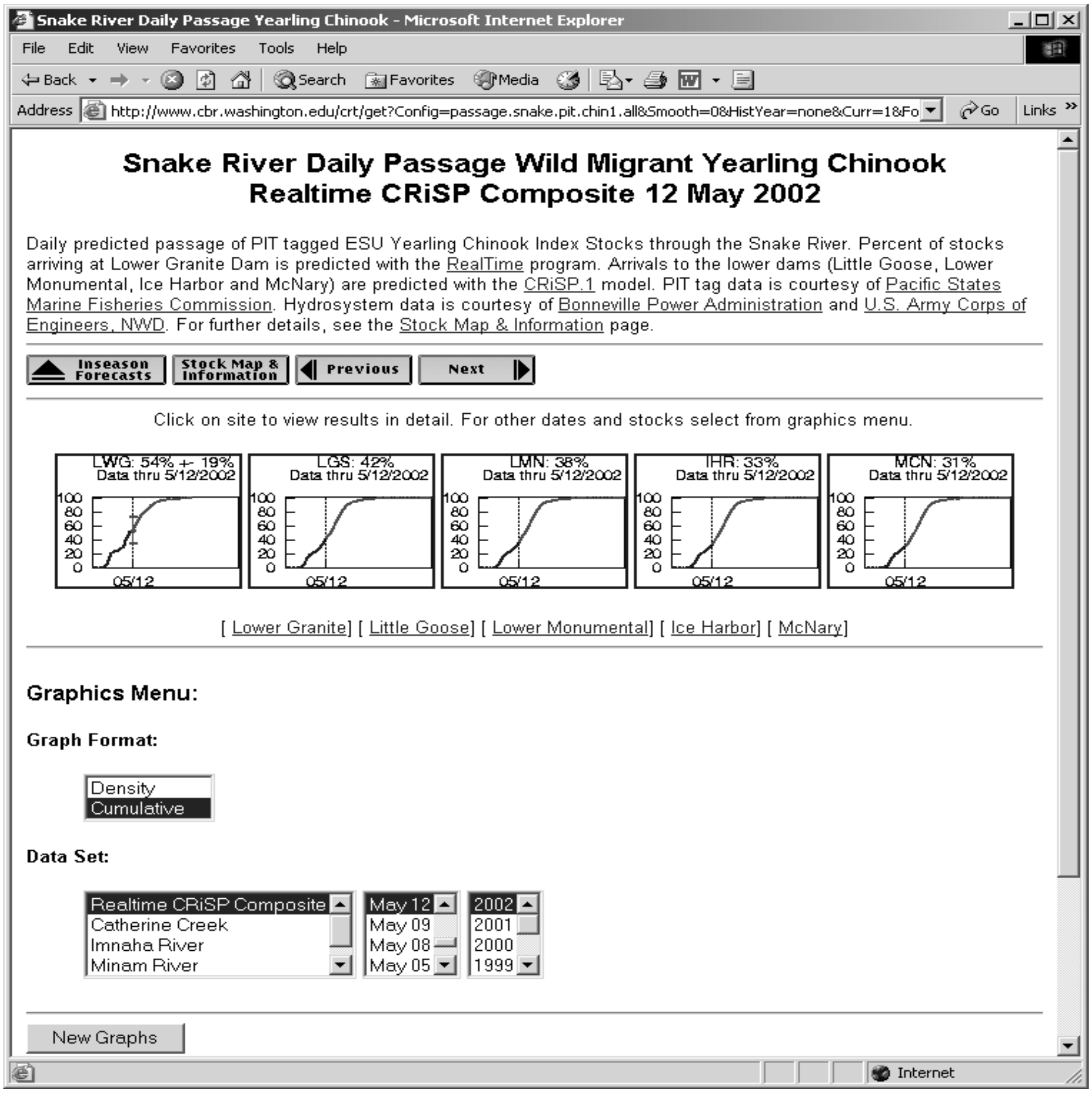


Figure J-2 Season variation in Total Dissolved Gas prediction at three monitoring sites below McNary, Priest Rapids Dam and Bonneville Dam (top to bottom respectively).

Appendix K Example Graphics from WWW Pages



Snake River Daily Passage Wild Migrant Yearling Chinook
Realtime CRiSP Composite 12 May 2002

Daily predicted passage of PIT tagged ESU Yearling Chinook Index Stocks through the Snake River. Percent of stocks arriving at Lower Granite Dam is predicted with the RealTime program. Arrivals to the lower dams (Little Goose, Lower Monumental, Ice Harbor and McNary) are predicted with the CRiSP.1 model. PIT tag data is courtesy of Pacific States Marine Fisheries Commission. Hydrosystem data is courtesy of Bonneville Power Administration and U.S. Army Corps of Engineers, NWD. For further details, see the Stock Map & Information page.

Click on site to view results in detail. For other dates and stocks select from graphics menu.

[Lower Granite] [Little Goose] [Lower Monumental] [Ice Harbor] [McNary]

Graphics Menu:

Graph Format:

Density
Cumulative

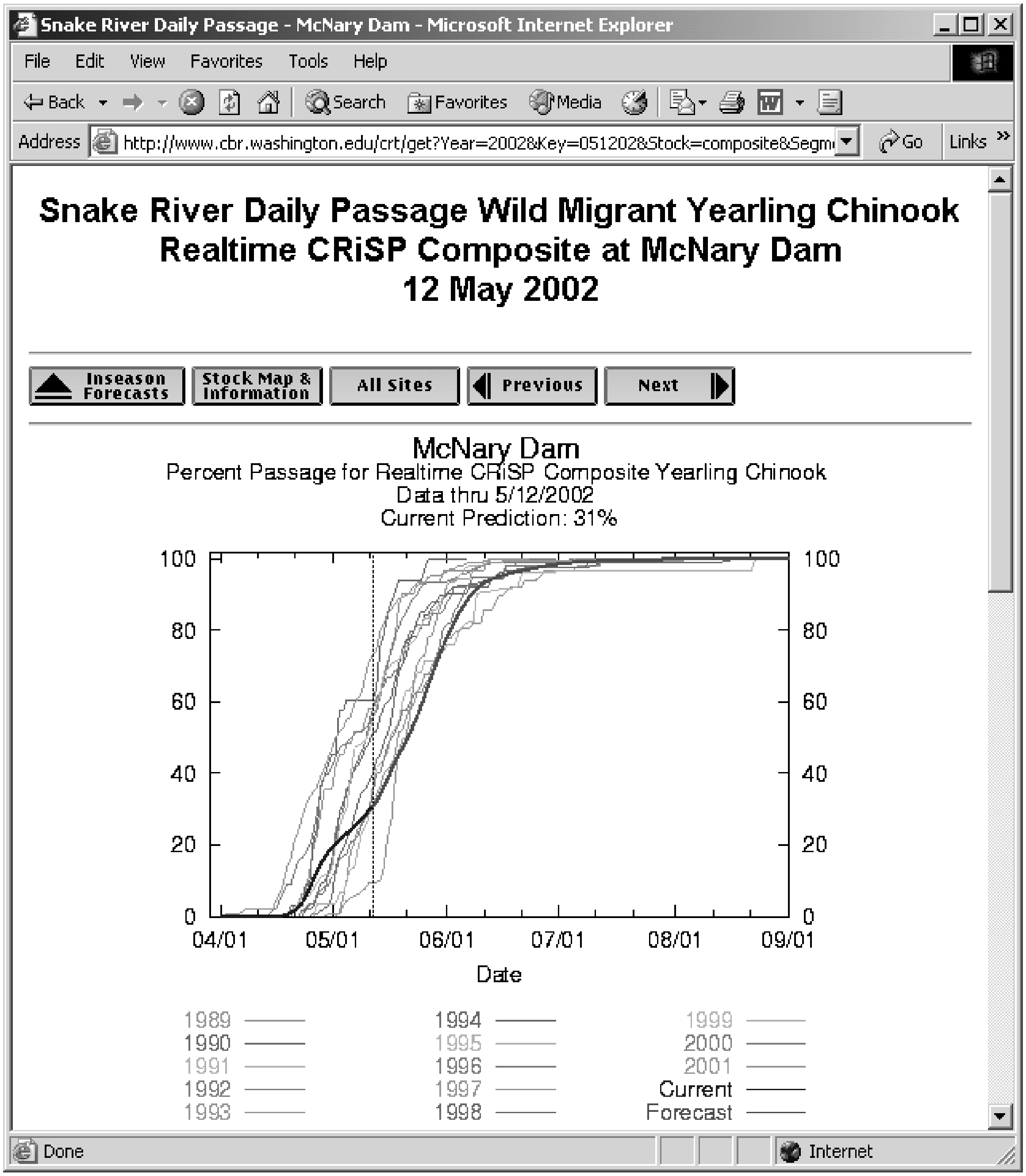
Data Set:

Realtime CRiSP Composite
Catherine Creek
Imnaha River
Minam River

May 12
May 09
May 08
May 05

2002
2001
2000
1999

Figure K-1 Screen shot from WWW page, showing the five thumbnail graphs of cumulative percent arrival, with confidence intervals where available, at each of the Snake projects and McNary Dam, for the composite yearling chinook stock. This estimate was made on the 12th of May. Clicking on a thumbnail produces a large version of the graph for that dam alone (Figure K-2)).



Snake River Daily Passage Wild Migrant Yearling Chinook
Realtime CRiSP Composite at McNary Dam
12 May 2002

McNary Dam
Percent Passage for Realtime CRiSP Composite Yearling Chinook
Data thru 5/12/2002
Current Prediction: 31%

Figure K-2 Screen shot from WWW page, showing the graph for a single dam. This graph shows cumulative arrival at McNary Dam, estimated on May 12. The vertical line shows the day of the prediction; the “forecast” is to the right of that line, and “current” to the left of it. Available years of data are overlaid on the plot. The same plot can be generated for a variety of individual stocks, with or without historical data, and can also be smoothed.