Evaluation of the 2000 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

February 2, 2001

Executive Summary

This report is a post-season analysis of the performance of the CRiSP portion of the Real-Time/CRiSP complex. Observed 2000 data are compared to predictions made by CRiSP/Real-Time during the 2000 outmigration for arrival timing, water temperature, total dissolved gas, flow, and spill at various dams.

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 archive files that were updated approximately monthly.

Current prediction methodology may have reached an accuracy limit and therefore CRiSP's predictive powers are maximized as well. Compared to last year, a comprehensive record of all on-hand data was maintained in order to facilitate comparison of predictions before and after data modification. Input data may be modified by primary sources for a variety of reasons and we maintain records of the complete data sets as they are reported because in-season forecasts are based on whatever is available at the time.

Table of Contents

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). 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.

For 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 2000 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.

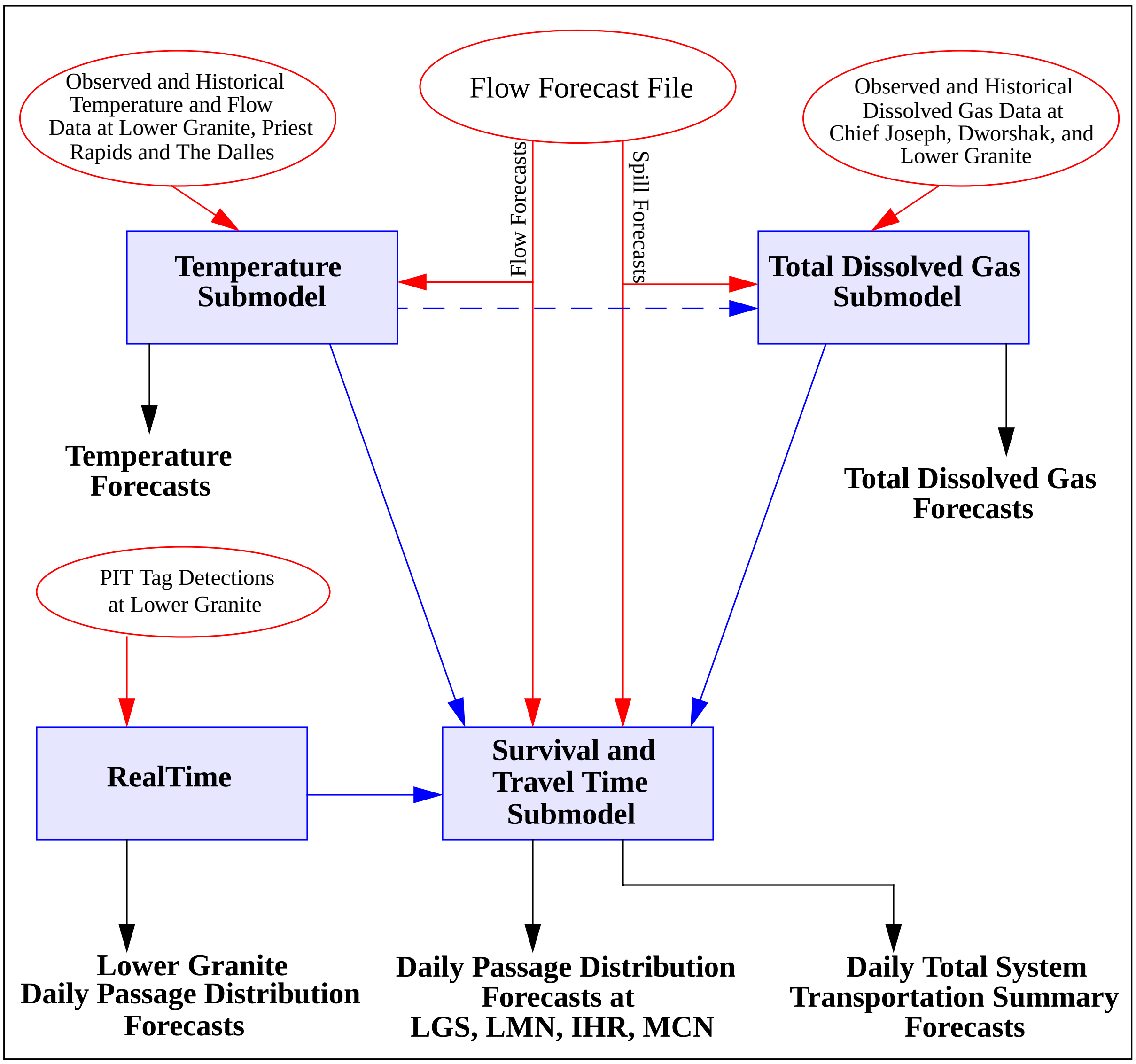


Figure 1 Simplified schematic of RealTime and CRiSP complex. Prior to migration year 2000, model generated gas was not updated with observed values for the production of daily passage distribution forecasts. PIT Tag data courtesy of Pacific States Marine Fisheries Commission. Water Quality Data courtesy 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, following guidance from NMFS.

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 processed the Army Corps forecasts and made them available to CBR staff on approximately monthly intervals. Subsequent fish arrival predictions were made based on the forecasted values for flow and spill rather than the latest available observed data. As a result, predictions of fish arrival times and river conditions vary between forecasts.

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 were based on historical temperature and flow information and the 2000 flow forecasts. The historical data includes flow and temperature profiles from Lower Granite (LWG), Priest Rapids (PRD), and The Dalles (TDA) reservoirs for the years 1976 through 2000. Historic and observed year-to-date data was obtained from the Columbia River DART database, which downloads water quality data from the Army Corps for the majority of monitoring sites in the Columbia Basin. 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.

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. TDG data are downloaded directly from the Army Corps on a near-daily basis and quality assurance is not always guaranteed. Anomalies in observed TDG data are indicators of suspicious data. These data are later corrected by the Army Corps. Corrected data is used whenever possible and may alter hindcasts. The current Army Corps water quality data can be consulted for reference. Army Corps also posts a status report for each monitor, including information on which monitors are not reporting data.

TDG forecasts in particular are sensitive to predicted flows and planned spill. For historic predictions, the accuracy of the gas predictions will depend on the quality of the historic spill data input. Data QA/QC is an ongoing process. With the correct spill data, TDG predictions are typically within 5% of the observed gas levels.

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 also be noted that the nearest downstream monitors to Bonneville Dam are 6 miles downstream, so it is expected that the gas levels at these monitors (WRNO and SKAW) will be lower than those generated at the dam.

Table 1 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	
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

Table 1 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
Lower Granite Tailwater	LGNW	Right Bank
Little Goose Tailwater	LGSW	Right Bank
Lower Monumental Tailwater	LMNW	Left Bank
Ice Harbor Tailwater	IDSW	Right Bank
McNary Tailwater	MCPW	Right Bank
John Day Tailwater	JHAW	Right Bank
The Dalles Tailwater	TDDO	Left Bank
Bonneville Tailwater	WRNO SKAW	Left Bank Right Bank

2.1.5 Archives of Model Predictions

Each time the RealTime and CRiSP models are run, results are archived for future reference. Graphs and text reports based on these same archives are available through a variety of query tools on the World Wide Web. The home page for this project and other Columbia Basin Research products can be found at http://www.cbr.washington.edu. Runs are made several times per week and the outcome recorded. Archives include daily passage distribution forecasts at each of the five 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 did not detect any seasonal behavior, so a reduced equation is used:

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

where:

r_t = the time-dependent migration rate;

t = the Julian Date;

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

β_0 and β_1 = flow-independent parameters;

α_2 = a slope parameter for the flow-independent term;

β_{FLOW} = parameter that determines the proportion of river velocity used for migration; and

$\bar{V}_t$ = the average river velocity during the average migration period, determined for each reach.

The flow-independent part of the equation starts fish at a minimal migration rate (β_{MIN}) with fish increasing their flow-independent migration rate to a maximal migration rate (β_{MAX}). 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_2 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 2000 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:

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

where:

O = the total number of observation sites,

C = the total number of cohorts,

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

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

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

$\hat{F}_{Day_{tj}}$ = 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 4 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 Lower Granite (LWG), Priest Rapids (PRD), and The Dalles (TDA) using data from 1976 to the present. We queried the Columbia River DART (Data Access in Real Time) database for current year-to-date temperature and flow data each time a prediction was made. CRiSP used the temperature profiles as representative of the Snake, Mid-Columbia and Lower Columbia temperatures, respectively, for the generation of total dissolved gas forecasts and passage distribution forecasts.

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:

$$T_i = tempmean_i + B_0 + B_1 \cdot (F_i - flowmean_i) \tag{6}$$

where:

T = temperature prediction value for day i,

tempmean = mean temperature on day i from mean temperature profile,

B_0 and B_1 = flow coefficients,

F = observed flow value, unless no value, then flow value from flow forecast file,

flowmean = mean flow on day i from mean flow profile.

Temperature was measured in Celsius and flow in kcfs. Because there is reliable historical temperature data typically only from April to September, these regressions and the flow adjustments were only done within this time interval. For the remainder of the year, the unadjusted mean temperature profiles are used.

Table 2 Values used for flow coefficients B_0 and B_1 during the 2000 migration season.

	Lower Granite	Priest Rapids	The Dalles
B_0	0.0128	-0.0135	0.0678
B_1	-0.0212	-0.0117	-0.0058

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 CBR (Anderson et al. 2000). As a part of the Gas Abatement Study at the Army Corps, WES developed gas production equations based on spill as an improvement over GASSPILL, which had previously been the predominant model for gas production.

The gas production equations are an empirical fit of spill data and monitoring 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:

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

Q_s = the total amount of spill in kcfs,

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

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

CRiSP is currently configured so that a separate spill pattern, and thus a separate gas production function, for night and for day can be set for each dam. (A spill pattern specifies which spill bays are used to discharge flow both in number and position.) Once the number of spill gates, n, for a particular pattern is set, Equation (9) is then converted into Equation (8) by the relation $q_s = Q_s/n$. This conversion formula assumes that the amount of spill is uniformly distributed among the open spill gates. The model parameters for the day and night gas production thus can be different for a given dam, reflecting a change in the position or number of gates and hence in the dynamics of gas production.

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. To locate them, navigate the web browser to “Inseason Forecasts” from http://www.cbr.washington.edu/. 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 month during the season. Forecasted flows and spills for April 3, May 22, and July 16 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. Flows in 2000 were much less than in 1999 when peaks exceeded 150,000 cfs over several days.

The highest flows occurred earlier this year than in 1999 (end of April instead of May). The flow forecasts can not anticipate spikes in flow (Figure E-1) and the corresponding spill that generally has to occur.

Spill forecasts at PRD considerably underestimated the actual spill for most of the summer. This is exactly what happened last year as well. 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 affect model results.

Flow and Spill forecasts were updated approximately every month 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.

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. By looking at yearly averages of water temperature and flow, one can see that years with higher than average flows have lower than average water temperatures, and similarly 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 month during the migration season, coinciding with the generation of a new flow forecast file.

Sample predictions versus the 2000 observed temperatures for each of 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 2000 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 136 (May 16) at The Dalles was off by an average .63 degrees for the entire season whereas the observation made one month later on Julian day 170 was off by an average .47 degrees for the entire season. The trend for the season at each of the dams is a steady improvement in the forecast compared to the data.

In general, short-term predictions (i.e. for the next week) were 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 only one or two Celsius degrees, so these inaccuracies are unlikely to have contributed significantly to any model error. Year 2000 predictions seem to be comparable to 1999 predictions for temperature.

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 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 total dissolved gas forecasts are produced for each dam by running CRiSP and generating gas production at all the dams in the basin.

Total Dissolved Gas forecasts were made each time a new flow forecast file was made available to CBR. Sample predictions versus the 2000 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 2000 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. It failed to predict the spikes in dissolved gas as a result of unanticipated spill. There are some curious results for mid-Snake River monitoring sites, but the scale that the plots are made on is drawn to maximize the differences within the plot. In fact, the LGSW gas predictions (Figure J-1) are quite stable. Predictions for PRXW[1] were not as good as last year. Others are comparable.

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 three representative dates: May 11, June 1 and July 6 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). The thick vertical bar represents the uncertainty of the forecast for that day based on historical conditions. Complete plots showing the current forecast with historic conditions are available on our web site at http://www.cbr.washington.edu/. Navigate to “Inseason Forecasts” to view passage plots.

1. Observed data for Priest Rapids Dam forebay and tailrace are made available by Grant County PUD. There were periods during the 2000 migration season when the observed data was not updated and made available on a daily basis.

Table 3 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	30	25	10	13	13	13
Imnaha River	63	51	26	31	31	31
Minam River	74	84	43	54	54	54
S. Fork Salmon River	39	34	20	21	3	22
Composite	206	194	99	119	n/a	120

a. The RealTime/CRiSP complex uses a subset of all available PIT-tagged fish for the stocks of interest. For the 2000 migration season, we used: wild, spring/summer chinook released between 5/31/1999 and 11/01/1999 which were tagged by PIT-tag coordinators PMS (of ODFW) and SA (of NMFS). The selection criteria for the PIT-tagged fish used by RealTime/CRiSP changes each season and is 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 apparent from the low numbers at John Day and subsequent observations at Bonneville. 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.

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. At Lower Granite, the prediction accuracy (as measured by MAD) steadily improved.

By looking at the difference between the observed and predicted data points before the forecasting line, one can see that some of the outlying temperatures were in fact later corrected by the Army Corps and Grant County PUD. Any differences between the predictions and the observed data before the forecasting line reflect the changes in the data after it was collected when quality control was applied to the data (e.g. Figure G-2 upper panel).

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 degrees 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 late season predictions made in late March was not very good due to the unanticipated spikes in flow and spill. Early season forecasts are notoriously poor (see Appendix F for comparison of late-March predictions in 1998, 1999, and 2000 to observed data), although some are clearly more realistic than others (compare 1999 predictions at Ice Harbor and Priest Rapids).

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.

The apparent lack of any prediction of spill for Priest Rapids throughout the season is similar for other Columbia dams above the confluence with the Snake. Very low or no spill is reported in the flow archives for these dams this year.

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. The larger values at the beginning of the season are a result of the unanticipated spikes in the system-wide flow and corresponding spill especially in the Snake River system. Notice the very low levels after that point (approximately Julian 150). The final MAD values are at or below two for each of the dams.

4.1.4 Passage Timing Predictions

The MAD results for RealTime and the downstream predictions are presented in Table 4 for the end of the season. The RealTime MAD is calculated from RealTime output files at the end of the season. The reported 2000 “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 4 Mean absolute deviations (MAD) in smolt run timing predictions at the four observation sites for the end of 2000. MAD at Lower Granite is from archived RealTime data files and the other three are from archived CRiSP run results.

Stock	MAD at LWG	Downstream MAD		
		LGS	LMN	MCN
Catherine Creek	0.41	8.6	11.0	5.74
Imnaha River	0.32	7.13	7.78	2.76
Minam River	0.20	10.16	8.48	5.13
S. Fork Salmon River	2.16	8.67	12.14	7.73
Composite	9.81	11.6	9.02	2.41

In principle, the composite stock is easier to predict than individual stocks, as the composite stock represents a substantially larger number of fish. 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.

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

1) CRiSP releases fish at Lower Granite Dam and the migration parameters for these fish are such that they do not begin to swim at their fastest speed until some time later in their migration. If the fish were released (in the model) in their natal streams they would likely be migrating at or close to their top speed as they pass Lower Granite Dam and maintain this speed as they move downstream from there. The fact that the fish move slowly at first is an artifact of the general fitting procedure used to calibrate travel times between actual release points and downstream locations. The actively migrating fish have migration parameters that were calibrated to their historical travel time between LWG and downstream dams. These parameters give fish the best possible “running start” given that they have actually been migrating for days or weeks prior to arrival at Lower Granite. This partially explains the success of predicting passage at MCN compared to other dams upstream. 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.

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. RealTime does not necessarily use all of the PIT tag detections for a stock but uses particular ones (tagged during a particular time period, by a particular group of researchers). This makes their sample size smaller and therefore more sensitive to individual fish arrivals.

3) RealTime is a statistical procedure, and one should expect 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.

5) The data used to make the predictions is different from the data that is finally compiled at the end of the year and used in this report for comparison to the model predictions. The DART database is updated regularly with additions and corrections for missing or corrected data. Updates and corrections to PIT Tag records are received on a regular basis from the PTAGIS database maintained by the Pacific States Marine Fisheries Commission. This is highly significant given that the arrivals and detections at Lower Granite dam are the foundation for the input to the CRiSP model. This analysis queries the database for observation data and compares that to the predictions made during the season. The final observation data is not the same data that was used to make the predictions and new predictions of the true distribution of fish at LWG is made each day even if new fish have not arrived simply because near the end of the season, the confidence that it is truly the end of the season is increased.

6) Some data is missing and is never updated because some data records are still 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.

7) 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.

8) 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 2000, these files were updated monthly which means that as much as 30 days out from a forecast, we are using predictions instead of observed data. Some of the sudden jumps and changes in the MAD profiles can be attributed to this problem. Table 5 shows the number of flow/spill archive files used during each year since 1996.

Table 5 Counts of flow\spill archive files available for use in predicting smolt passage from 1996 through 2000.

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

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. Distinct sigmoidal arrival distributions at dams below Lower Granite Dam may be a result of high levels of spill at those projects: fish that were detected at Lower Granite could have been swept over the spillways of lower dams, and would not have been detected. The sudden flattening of cumulative arrival distributions means that fish are not being detected and either died or were spilled. Cramer (1996) found an association between high levels of dissolved gas and increased smolt mortality during the 1996 outmigration.

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.

With accurate reporting of PIT-tagged fish arrivals, inputs to the CRiSP model can be made more accurate; however, it cannot make up for other inaccuracies in its inputs.

This year, we kept track of the input data files used to make predictions for each model run and confirmed that only additions of new data were used to update files even though periodic updates have changed historical passage numbers in the past as data has been corrected.

We are minimizing errors in the transfer of information between RealTime and CRiSP. Since the processes are automated but separately developed, small details that may have an impact will be investigated. For example, RealTime may only use a subset of PIT-tagged fish within a stock and they then output the subset counts to us for use as the dam passage observations even though the total numbers of a stock may be greater.

Another example is the use of flow data. RealTime makes a daily query of DART for daily flows and spills at Lower Granite dam and this is used in the expansion factors. CRiSP uses a flow forecast file provided by the Army Corps which was updated every month. The important difference between RealTime and CRiSP's data needs is that CRiSP needs forecasts of flow and spill in order to move the fish downstream.

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. In the absence of more timely flow/spill files, we will at least consider updating the observations from other sources. Even if the predictions then become unreasonable, we will still be better able to predict smolt passage.

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.

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

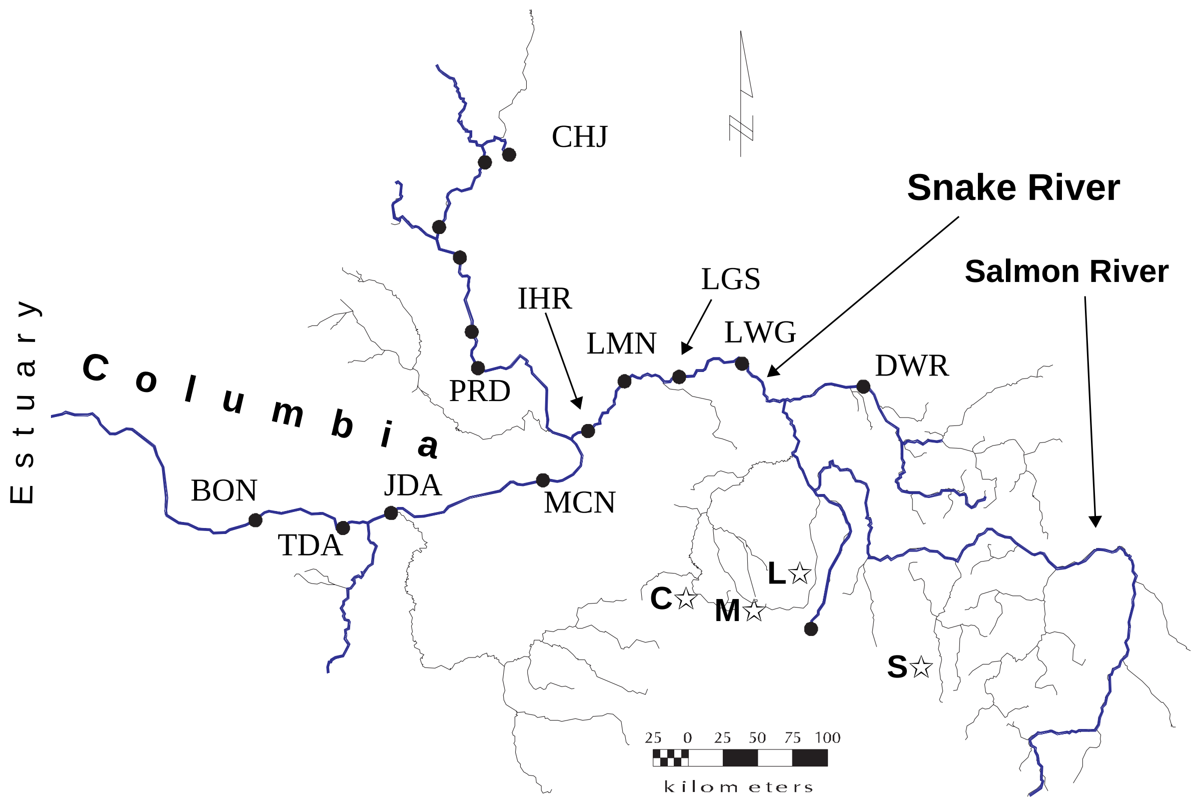


Figure A-1 Map of CRiSP locations

"●" 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
Bonneville	0.38	1741	13249
Bonneville II	0.44		
The Dalles	0.46	1741	13249
John Day	0.64	1741	13249
McNary	0.95	1741	13249
Ice Harbor	0.71	547	14094
Lower Monumental	0.61	547	14094
Little Goose	0.82	547	14094
Lower Granite	0.78	547	14094

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 2000 values in Table B-4.

Table B-3 Reservoir Specific Parameters used for CRiSP runs

Reservoir	Predator Density
Estuary	1950
Jones Beach	1950
Columbia Gorge	1950
Bonneville Tailrace	1950

Table B-3 Reservoir Specific Parameters used for CRiSP runs

Reservoir	Predator Density
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

Year Jackknifed	parameter estimates (std. error)						σ^2	resid. ss
	β_{MIN}	β_{MAX}	β_{FLOW}	a_2	$T_{sea}s$	α_2		
				Catherine Creek Spring Chinook				
93	-7.8845	4.1743	1.7192	0.1268	45.9573	0.2686	43.16	1637.588
94	-7.5073	4.1700	1.5851	0.1269	45.9269	0.4016	44.84	1208.892
95	-7.2789	4.1887	1.5517	0.1275	45.7119	0.2923	43.77	1828.954
96	-7.5572	4.1554	1.7417	0.1268	45.9521	0.2674	46.61	1725.678
97	-7.3770	4.1514	1.6705	0.1268	45.9699	0.2686	46.14	1782.010
98	-6.9801	4.1764	1.5901	0.1269	45.9193	0.3579	43.17	1244.617
99	-7.2608	4.1517	1.5343	0.1269	45.9296	0.2922	42.01	1488.339
00	-7.6871	4.1615	1.6261	0.1268	45.9639	0.2974	45.68	1812.014
				Imnaha Spring Chinook				
93	-3.69381	11.23345	0.84772	0.32787	96.51307	0.47442	34.04	1871.353

Year Jackknifed	parameter estimates (std. error)						σ^2	resid. ss
	β_{MIN}	β_{MAX}	β_{FLOW}	a_2	$T_{sea}s$	α_2		
94	-3.6897	11.2433	0.8393	0.3385	96.2445	0.4720	29.99	1640.938
95	-3.6593	12.7899	2.2803	0.0039	116.1085	0.0513	32.42	2150.944
96	-3.6592	12.7899	2.2803	0.0039	116.1079	0.0513	31.76	2403.732
97	-3.5009	12.7845	0.7617	0.3215	99.4979	0.5472	31.01	2391.488
98	-3.2906	3.0318	1.2898	0.3994	67.5704	0.0580	33.44	1778.788
99	-5.5366	12.1223	0.8610	0.5234	82.8257	0.5137	33.95	2424.699
00	-4.8890	6.0181	1.0823	0.3328	68.7233	0.3707	32.34	2483.666
Minam River Spring Chinook								
93	-5.0767	7.5084	1.0752	0.1570	60.0012	0.3739	44.15	1885.403
94	-5.3381	7.7544	1.1655	0.1999	47.0010	0.2650	38.81	1430.110
95	-6.1050	7.0384	1.2552	0.1899	80.5944	0.2766	41.68	1364.678
96	-4.8004	7.5577	1.0929	0.2001	66.0942	0.3319	43.58	1709.678
97	-4.6673	7.7670	1.1467	0.2056	70.1999	0.2259	42.39	1907.677
98	-3.3370	7.0241	1.0523	0.2000	59.9964	0.2435	40.28	1601.715
99	-4.0193	7.9045	0.9501	0.2000	70.0274	0.3644	41.99	1699.990
00	-4.7073	5.7499	1.0707	0.1204	69.6332	0.4389	41.90	1923.161
Salmon River South Fork Spring Chinook								
93	0.3900	11.0333	0.6645	0.2465	104.3574	0.2037	60.27	7123.838
94	0.2061	18.2831	0.5729	0.2651	105.6191	0.2240	48.10	4129.434
95	-0.3669	12.7229	0.6767	0.2656	102.8795	0.2101	65.62	6848.031
96	0.2409	13.1313	0.6071	0.2538	103.8657	0.2066	62.08	7953.437
97	0.2147	10.3728	0.6913	0.2566	104.8487	0.2089	60.52	7626.049
98	0.2676	15.3387	0.5162	0.2411	96.7796	0.2176	65.70	6727.001
99	0.0028	7.3067	0.6736	0.2528	102.7425	0.2060	69.03	7438.996
00	-0.06387	11.84526	0.70418	0.17251	103.0559	0.22771	62.08	8089.525

Appendix C Arrival Time Distribution plots

The following figures present the CRiSP/RealTime predictions on May 11, June 1 and July 6. 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 and McNary). The predicted distribution at Lower Granite Dam is generated by the RealTime program, and the predicted distributions at Little Goose, Lower Monumental and McNary 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.

Composite Stock - Lower Granite Dam (LWG)

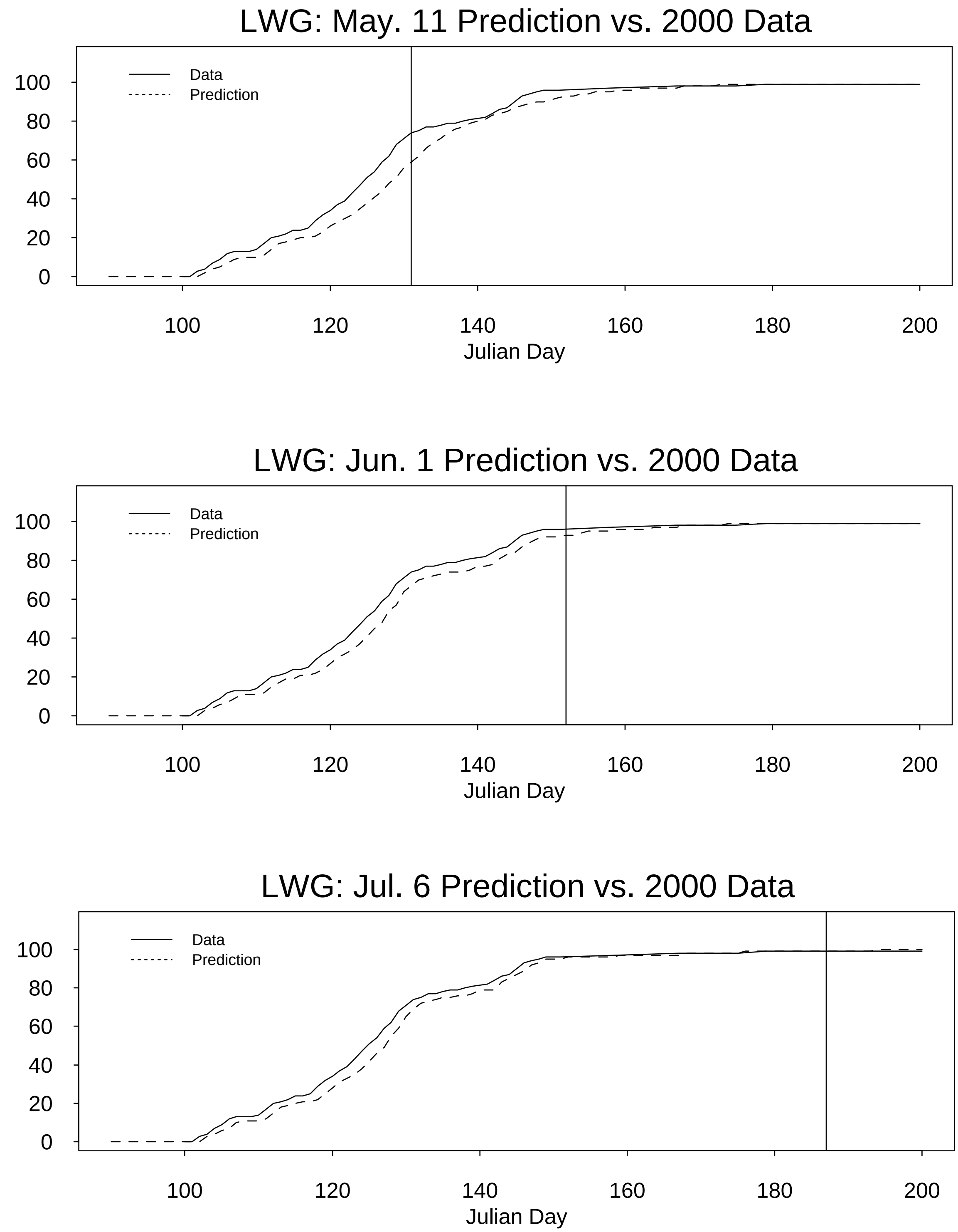


Figure C-1 RealTime predictions for cumulative distribution of arrivals of the Composite stock at Lower Granite Dam. Y-axis shows percent of total passage.

Composite Stock - Little Goose Dam (LGS)

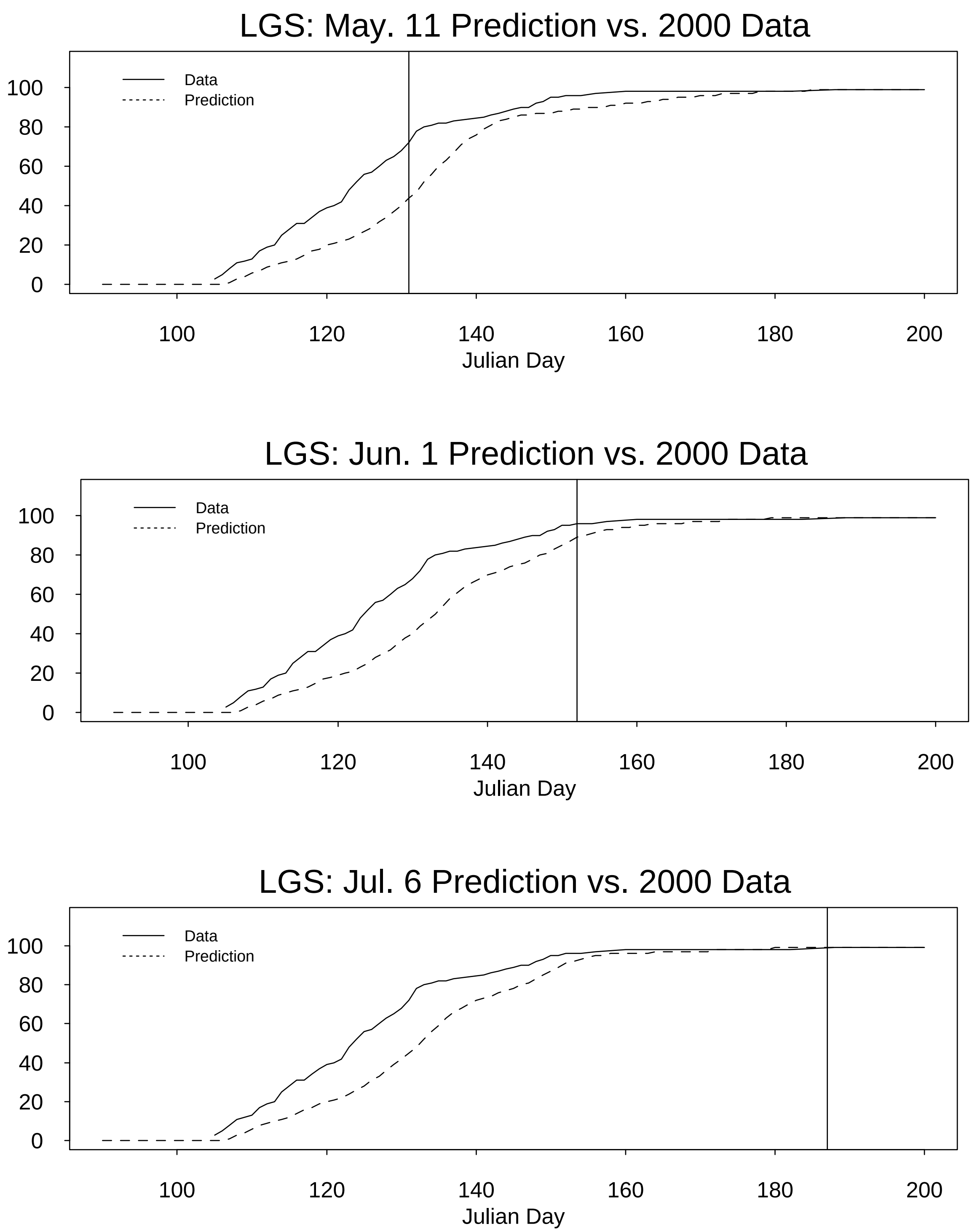
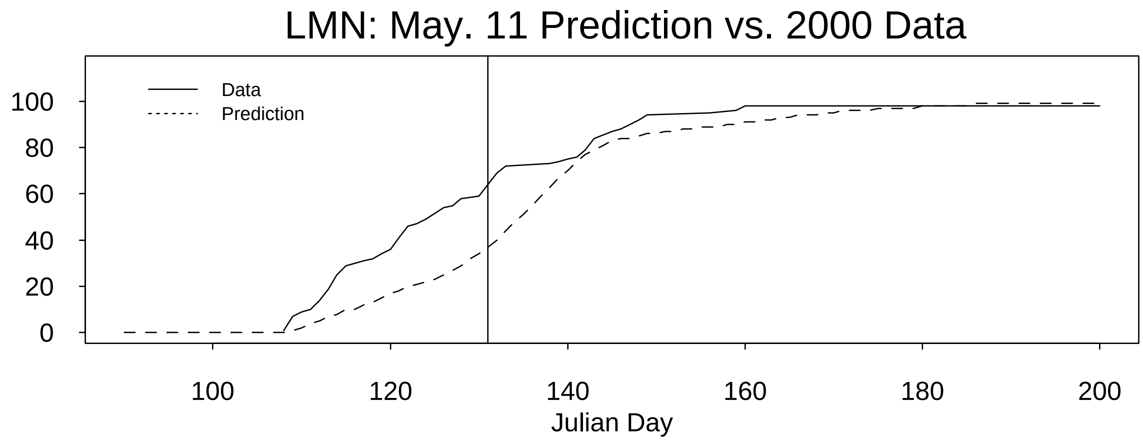
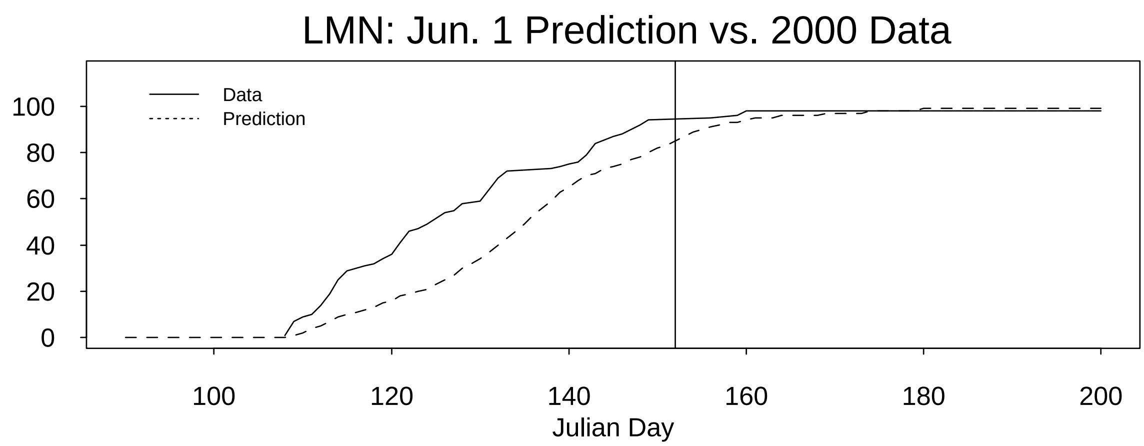


Figure C-2 CRiSP predictions for cumulative distribution of arrivals of the Composite stock at Little Goose Dam. Y-axis shows percent of total passage.

Composite Stock - Lower Monumental Dam (LMN)





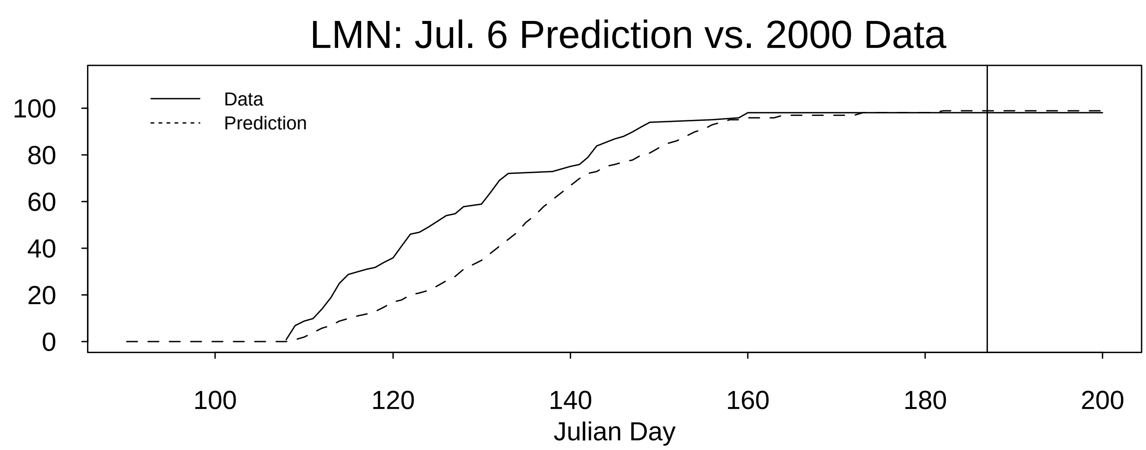
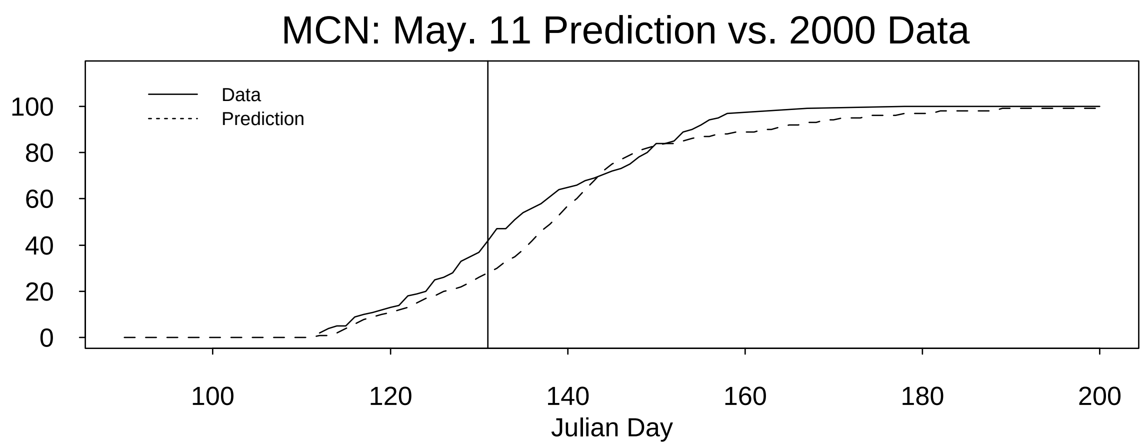
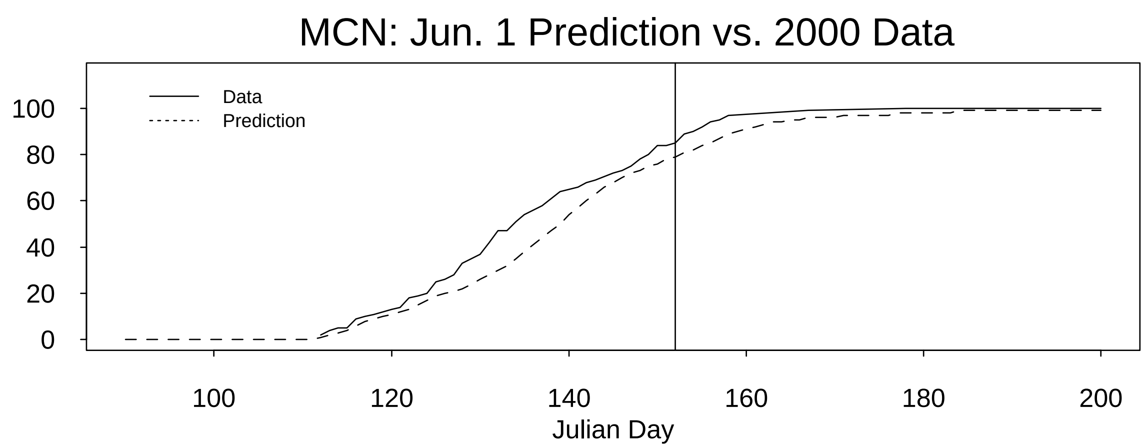


Figure C-3 CRiSP predictions for cumulative distribution of arrivals of the Composite stock at Lower Monumental Dam.Y-axis shows percent of total passage.

Composite Stock - McNary Dam (MCN)





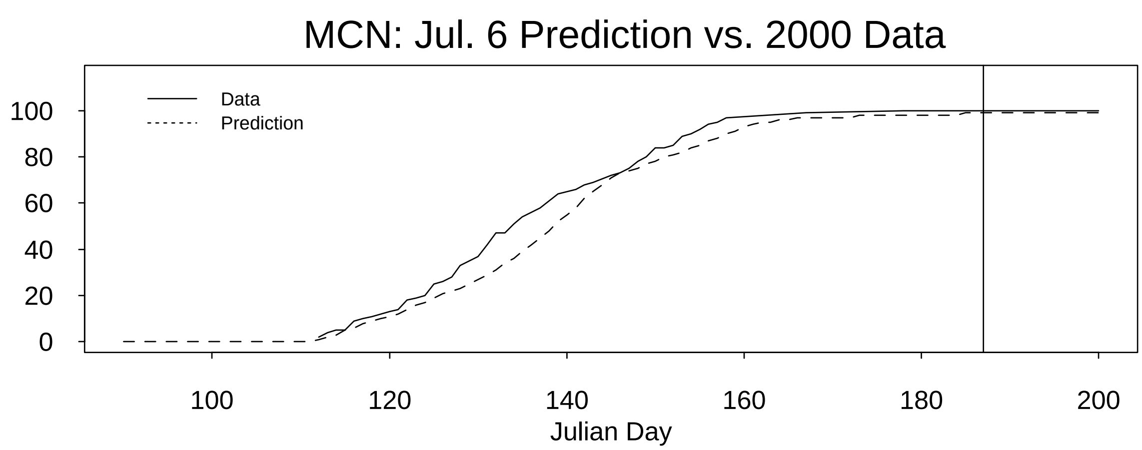


Figure C-4 CRiSP predictions for cumulative distribution of arrivals of the Composite stock at McNary Dam. Y-axis shows percent of total passage.

Composite Stock - Bonneville Dam (BON)

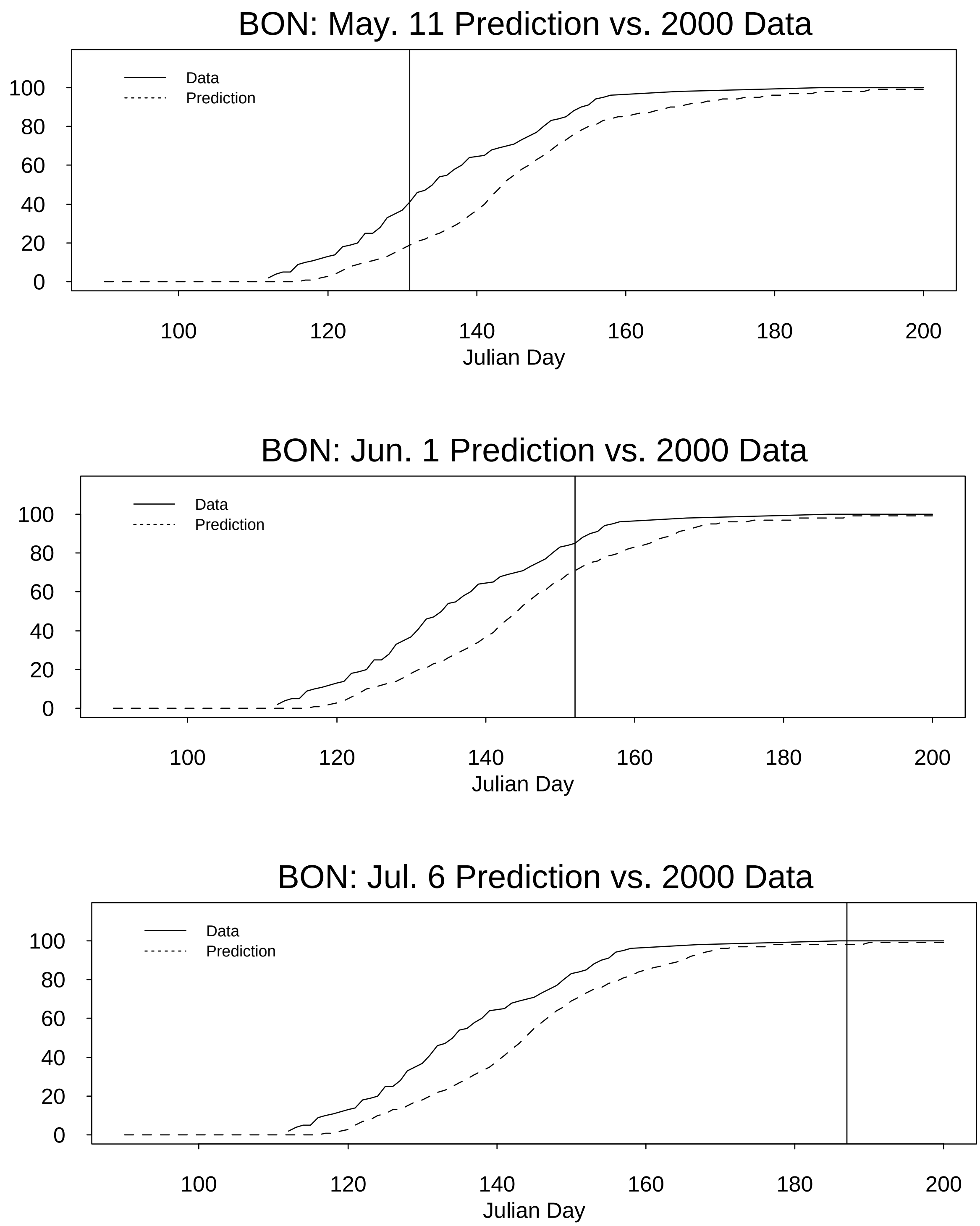


Figure C-5 CRiSP predictions for cumulative distribution of arrivals of the Composite stock at Bonneville Dam. Y-axis shows percent of total passage.

Catherine Creek – Lower Granite Dam (LWG)

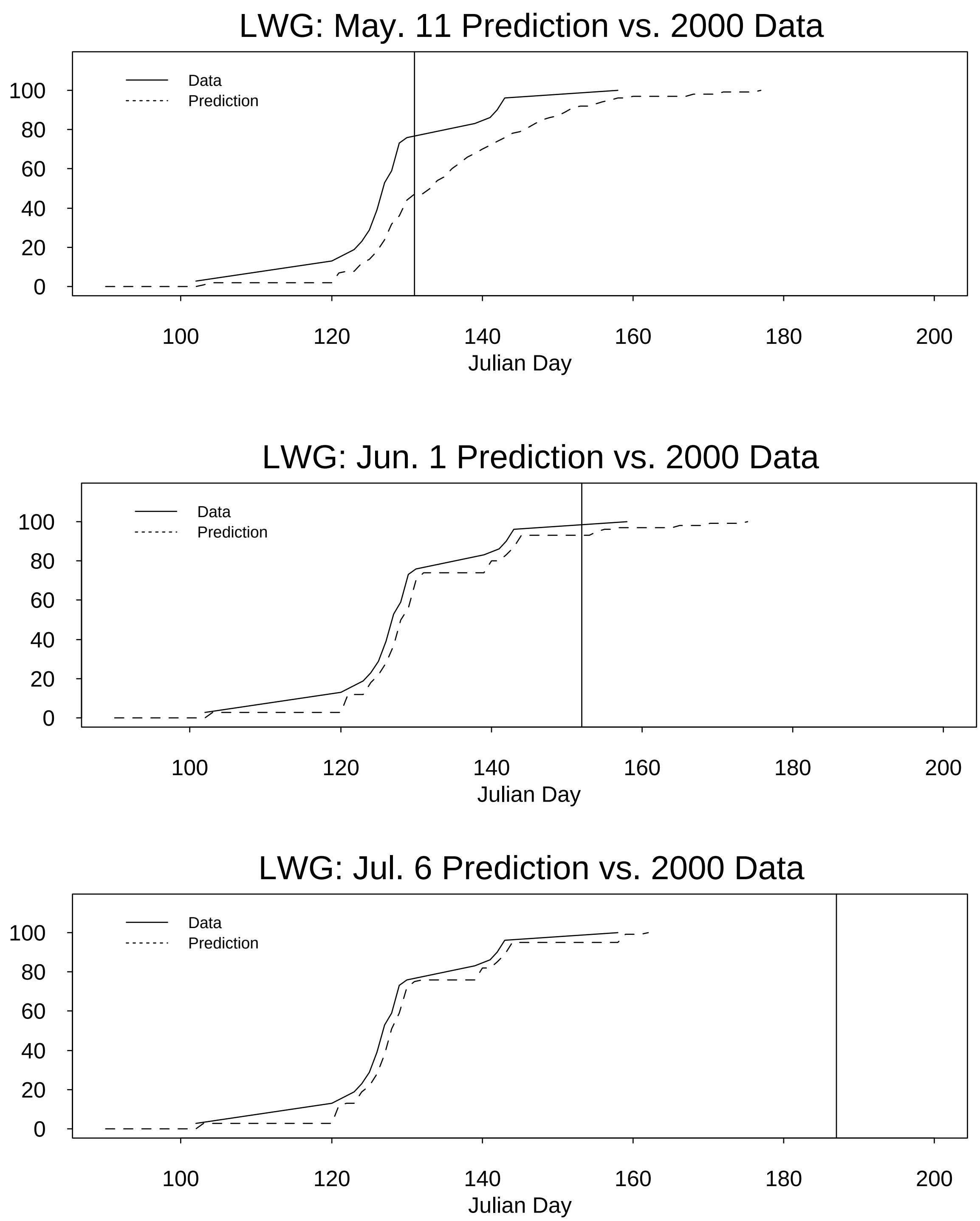
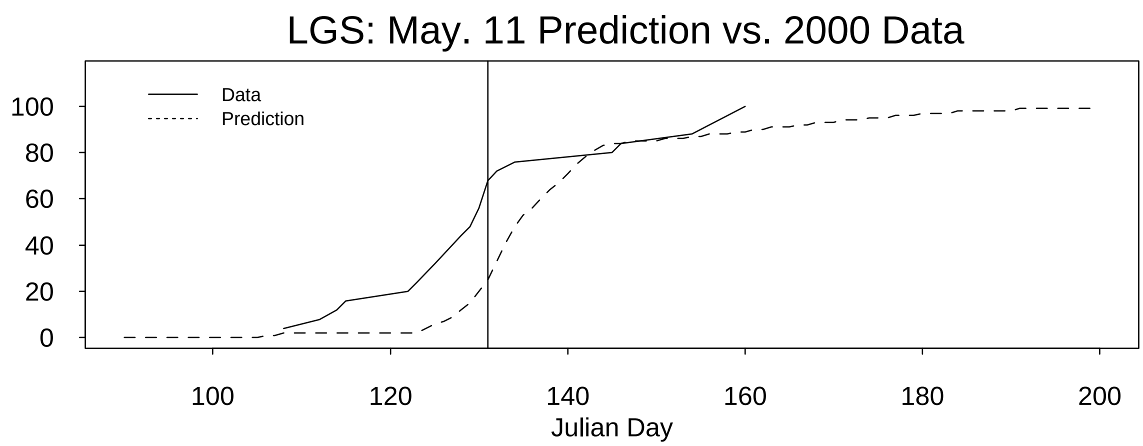
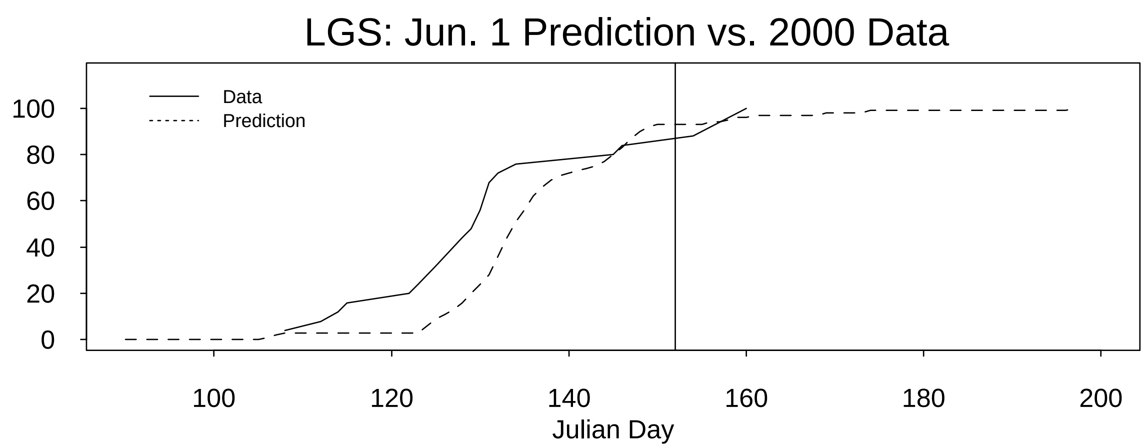


Figure C-6 RealTime predictions for the cumulative distribution of arrivals of the Catherine Creek stock at Lower Granite Dam. Y-axis shows percent of total passage.

Catherine Creek – Little Goose (LGS)





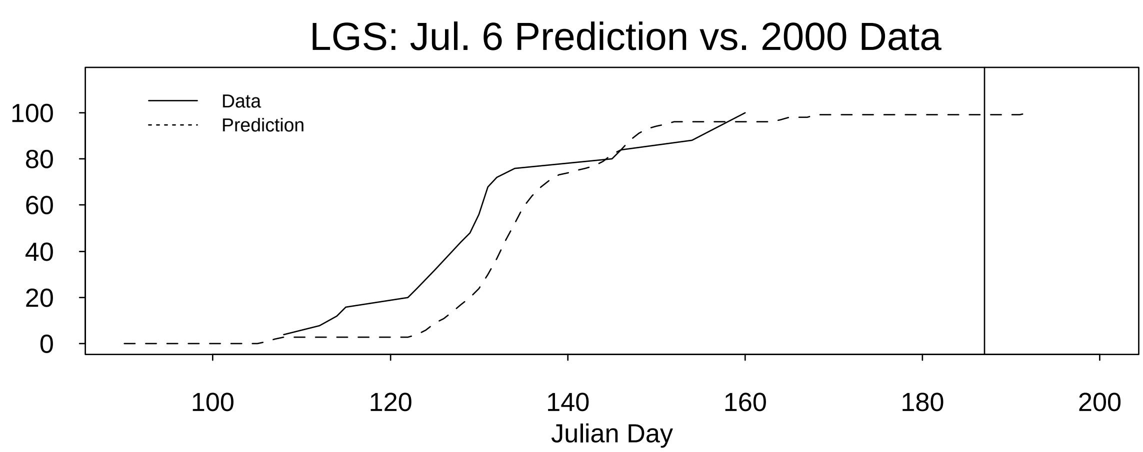
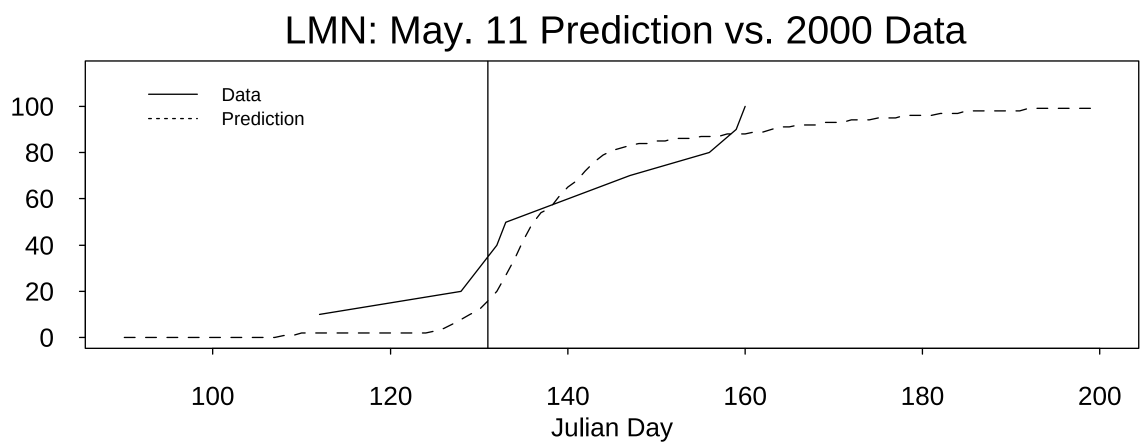
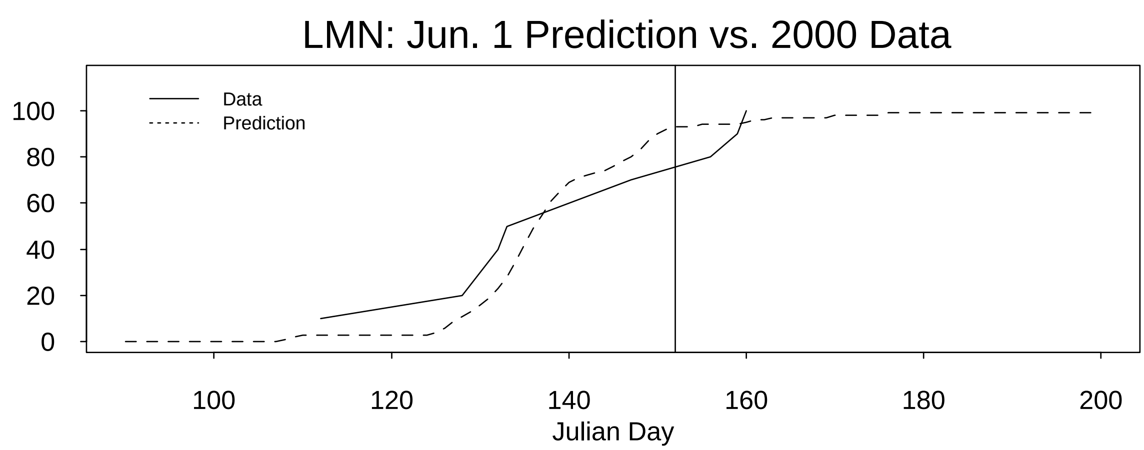


Figure C-7 CRiSP predictions for the cumulative distribution of arrivals of the Catherine Creek stock at Little Goose Dam. Y-axis shows percent of total passage.

Catherine Creek – Lower Monumental (LMN)





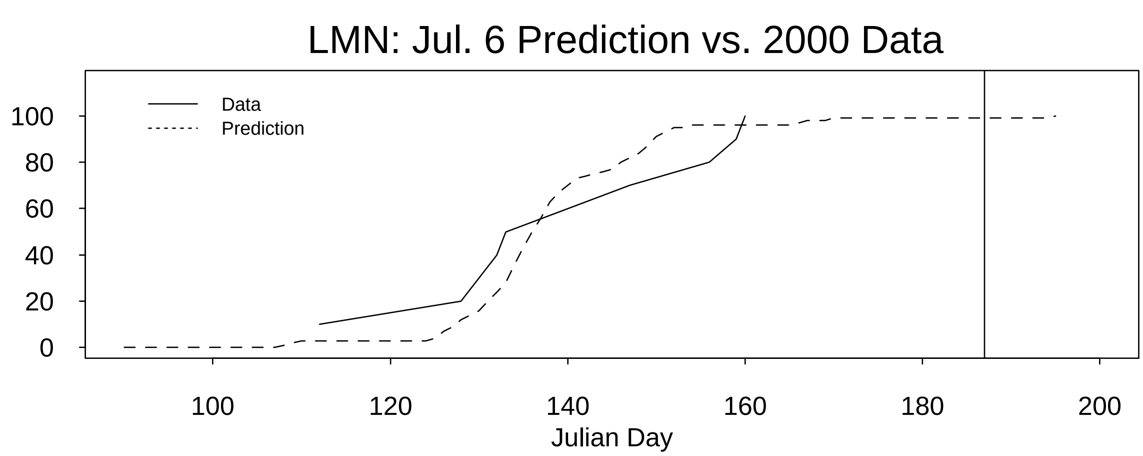


Figure C-8 CRiSP predictions for the cumulative distribution of arrivals of the Catherine Creek stock at Lower Monumental Dam. Y-axis shows percent of total passage.

Catherine Creek – McNary Dam (MCN)

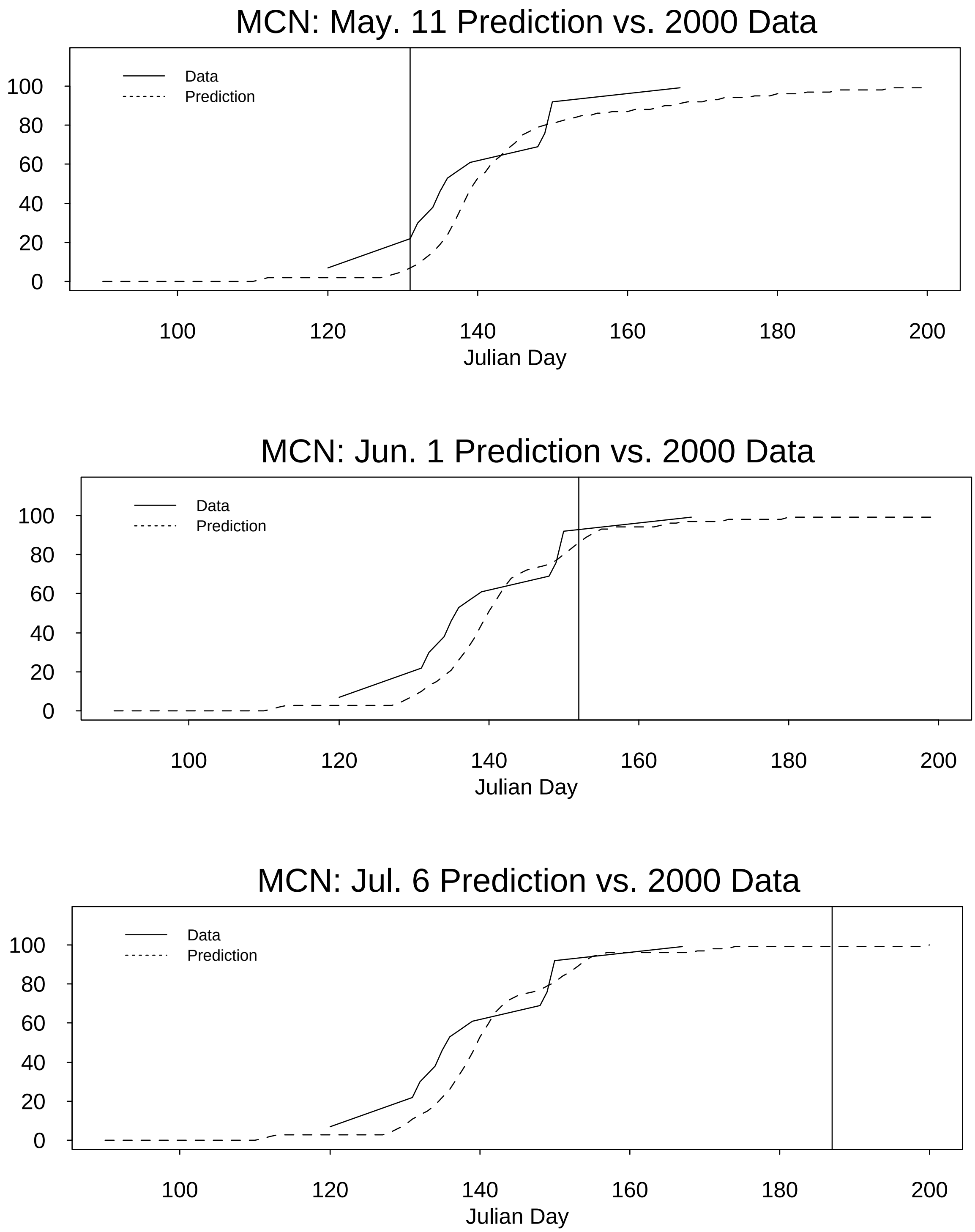


Figure C-9 CRiSP predictions for the cumulative distribution of arrivals of the Catherine Creek stock at McNary Dam. Y-axis shows percent of total passage.

Imnaha River – Lower Granite Dam (LWG)

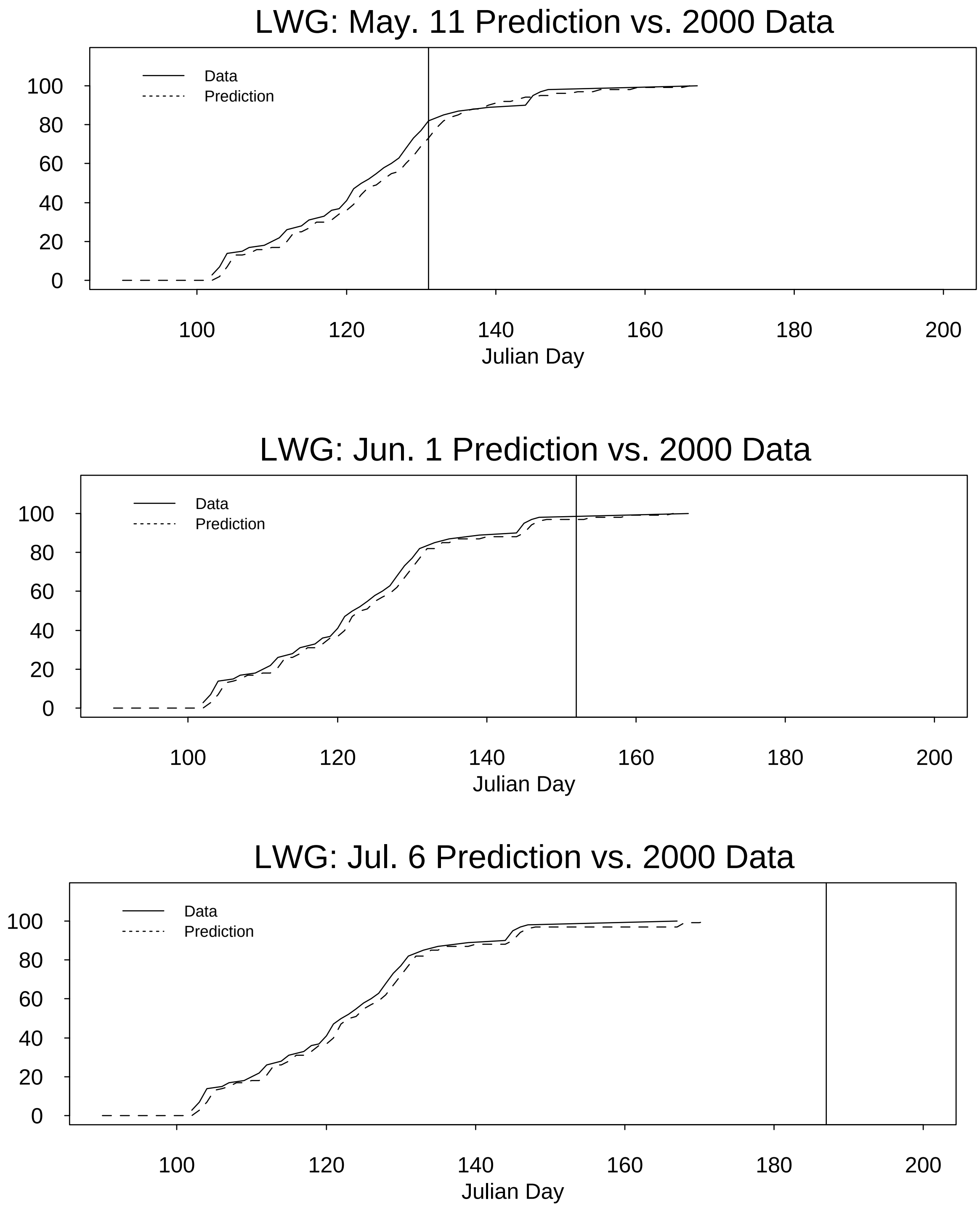
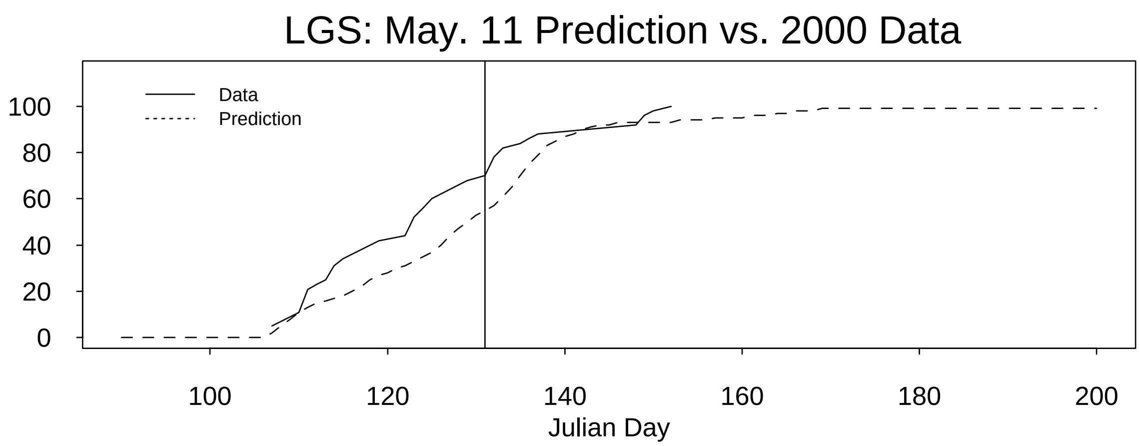
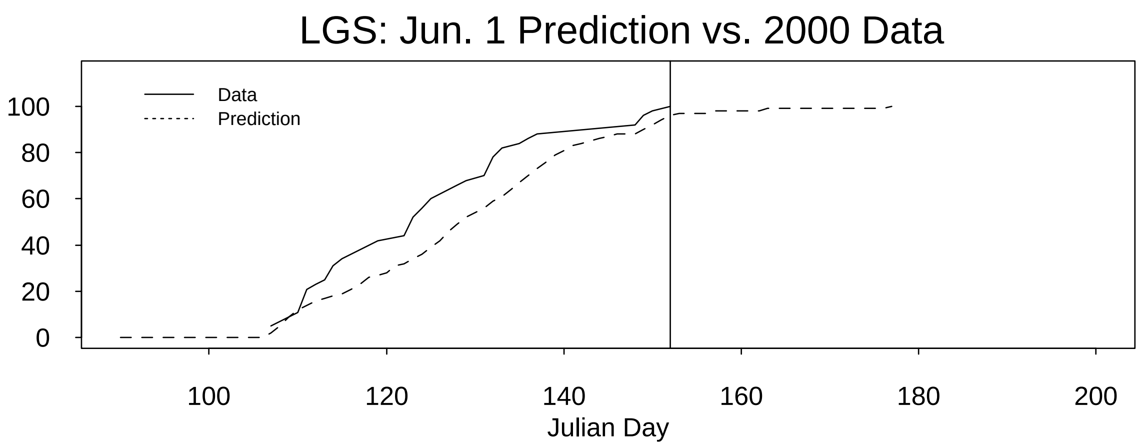


Figure C-10 RealTime predictions for the cumulative distribution of arrivals of the Imnaha River stock at Lower Granite Dam. Y-axis shows percent of total passage.

Imnaha River – Little Goose Dam (LGS)





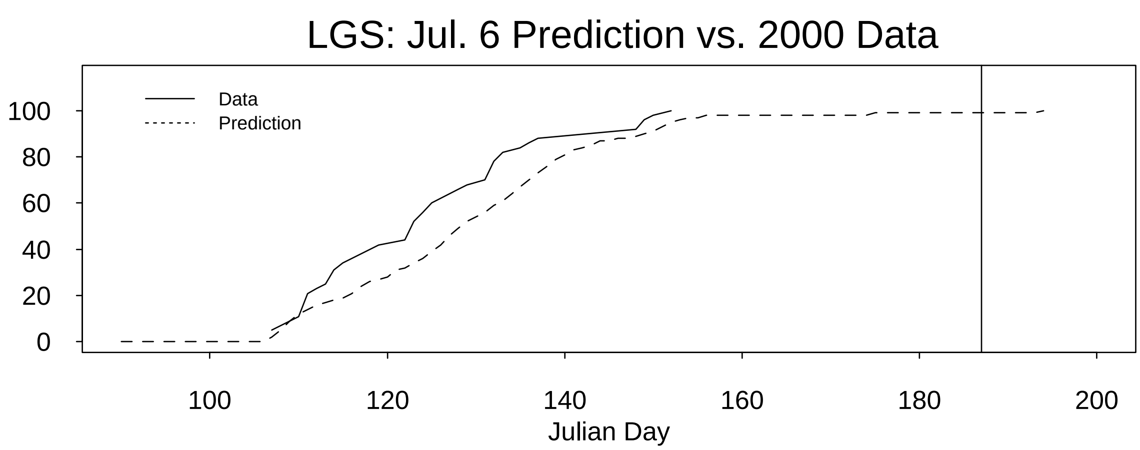


Figure C-11 CRiSP predictions for the cumulative distribution of arrivals of the Imnaha River stock at Little Goose Dam. Y-axis shows percent of total passage.

Imnaha River – Lower Monumental Dam (LMN)

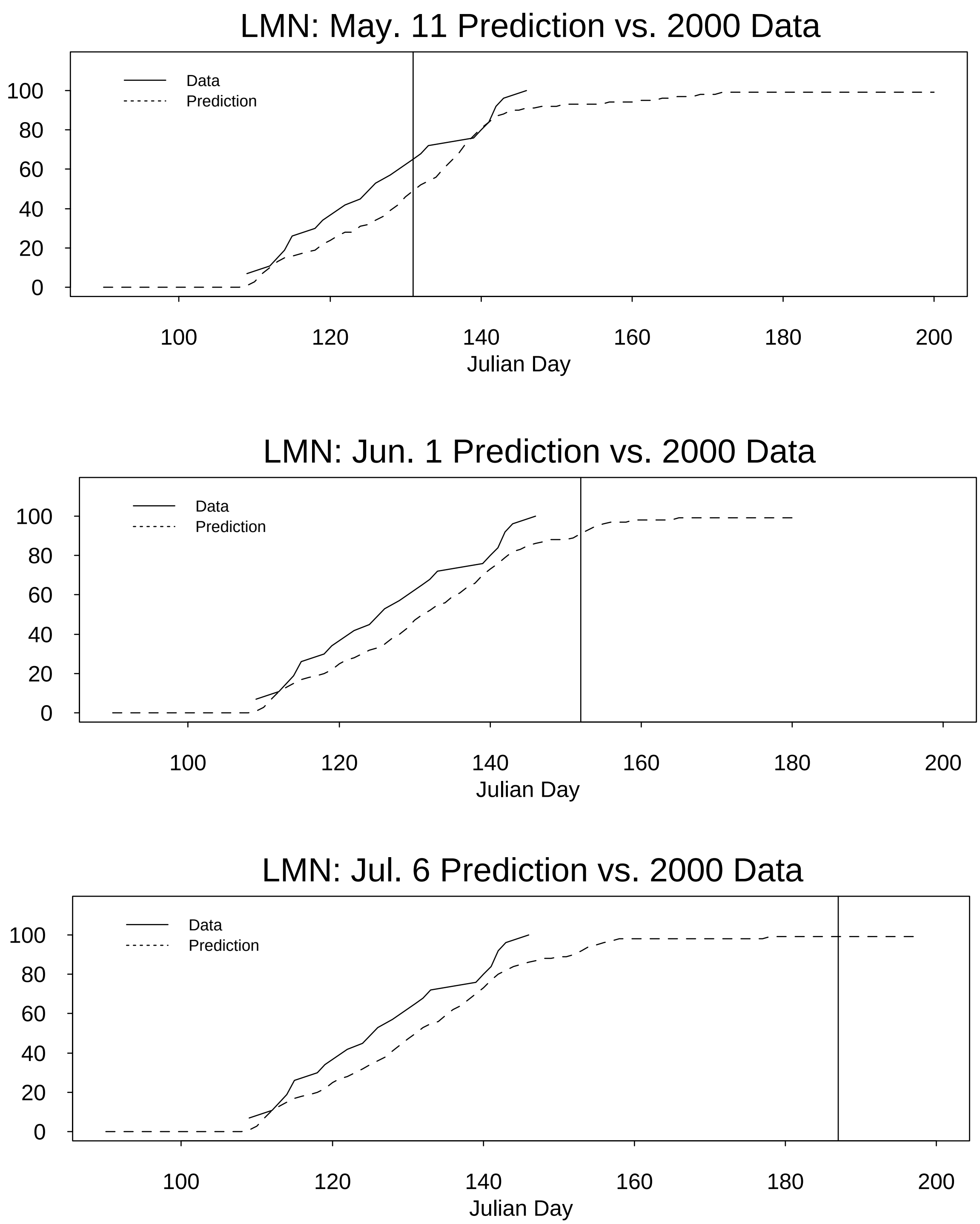
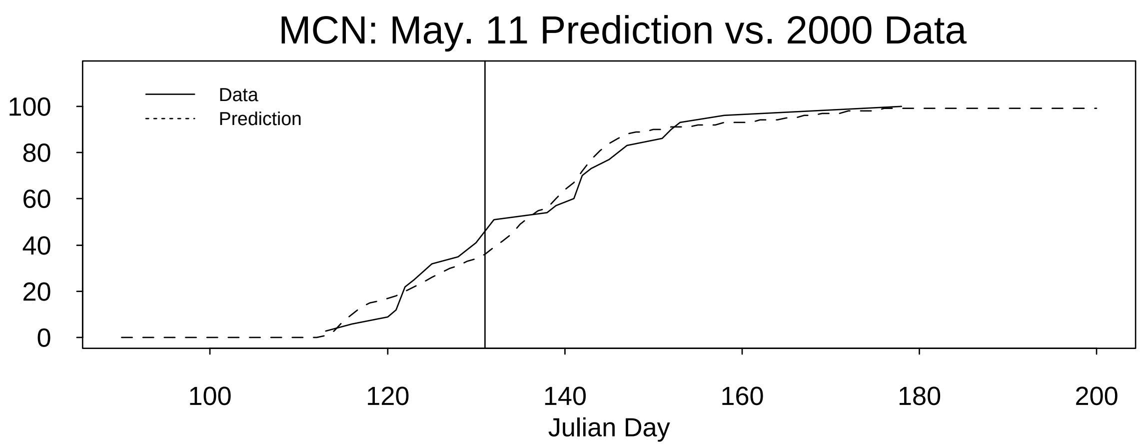
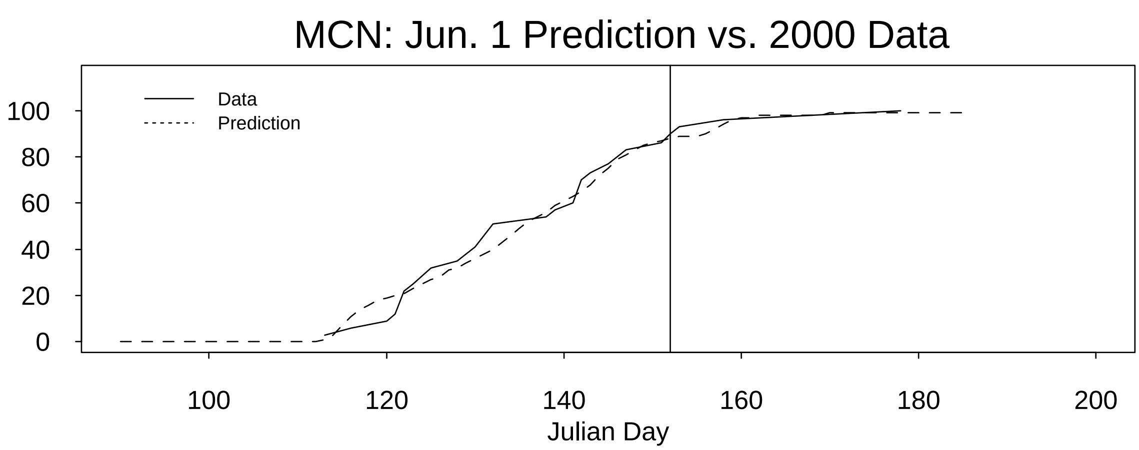


Figure C-12 CRiSP predictions for the cumulative distribution of arrivals of the Imnaha River stock at Lower Monumental Dam. Y-axis shows percent of total passage.

Imnaha River – McNary Dam (MCN)





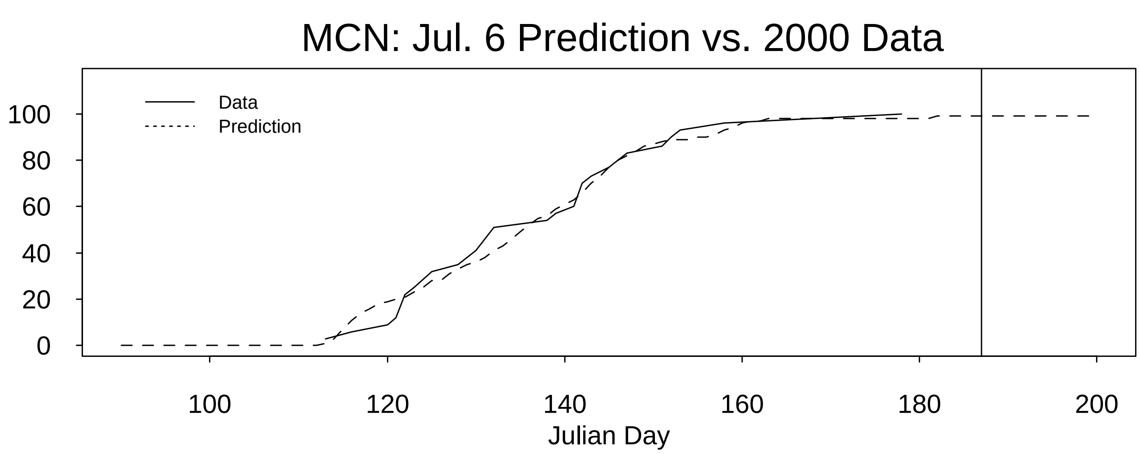
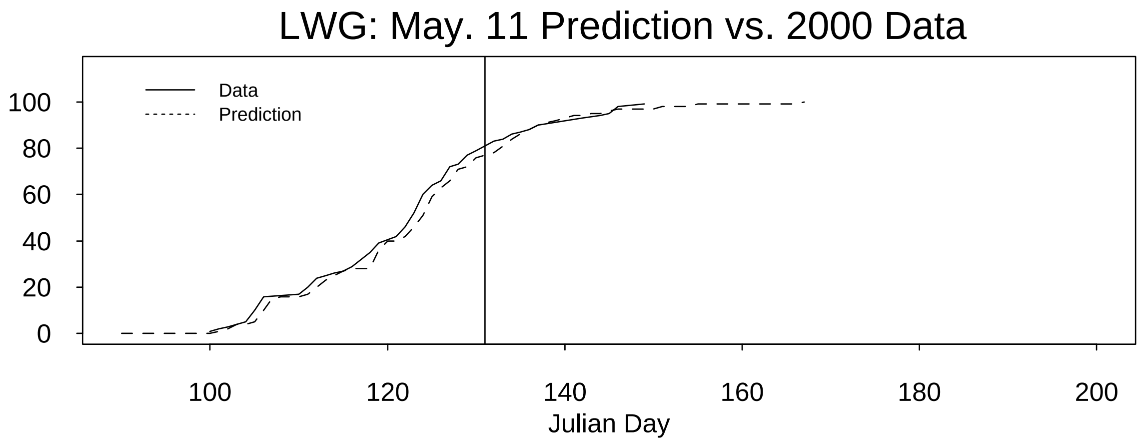
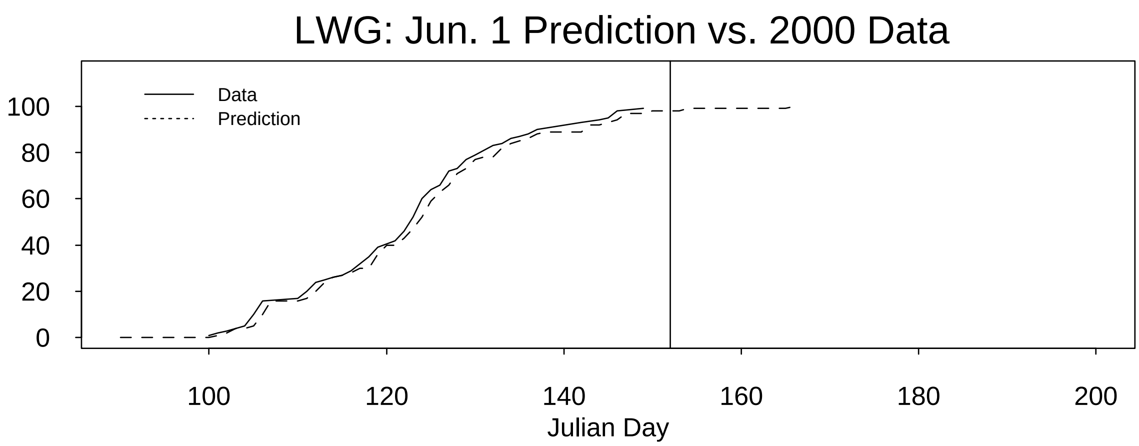


Figure C-13 CRiSP predictions for the cumulative distribution of arrivals of the Imnaha River stock at McNary Dam. Y-axis shows percent of total passage.

Minam River – Lower Granite Dam (LWG)





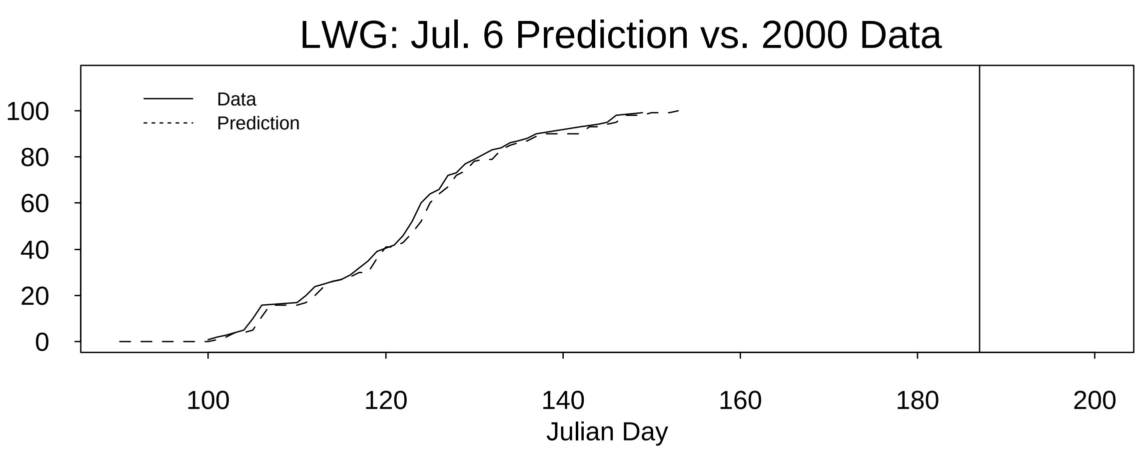
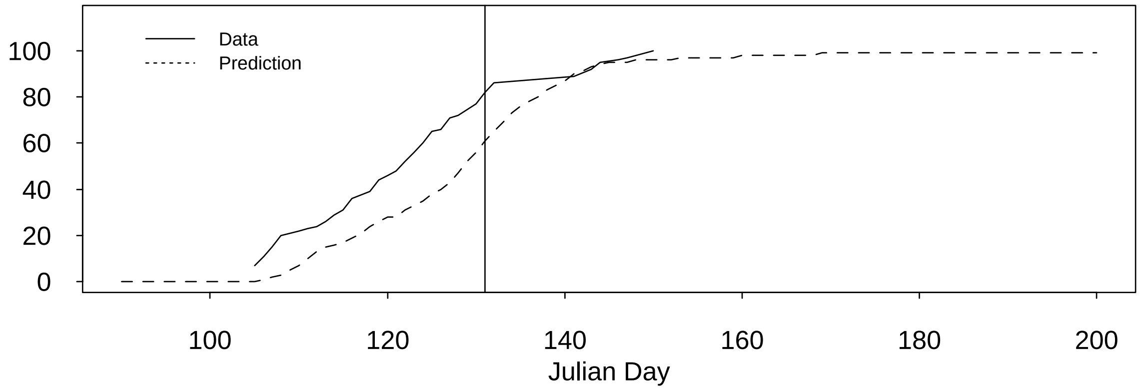


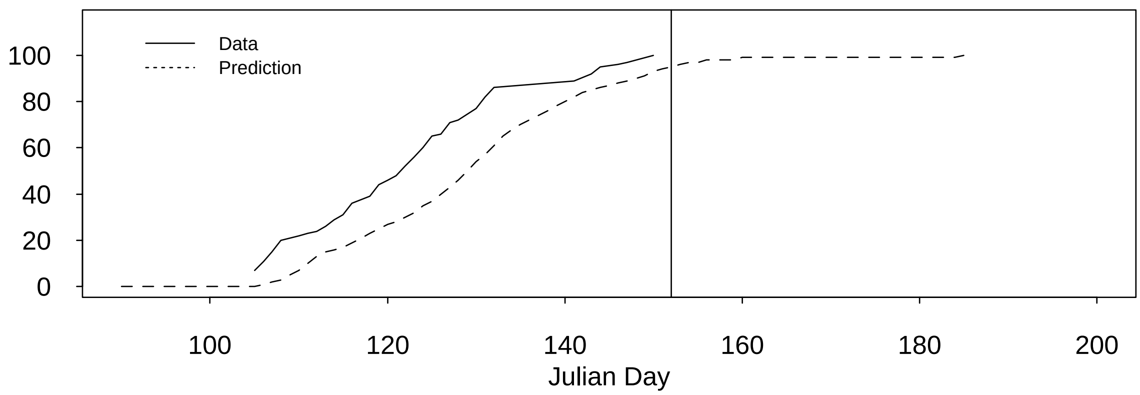
Figure C-14 Realtime predictions for the cumulative distribution of arrivals of the Minam River stock at Lower Granite Dam. Y-axis shows percent of total pas-

Minam River – Little Goose Dam (LGS)

LGS: May. 11 Prediction vs. 2000 Data



LGS: Jun. 1 Prediction vs. 2000 Data



LGS: Jul. 6 Prediction vs. 2000 Data

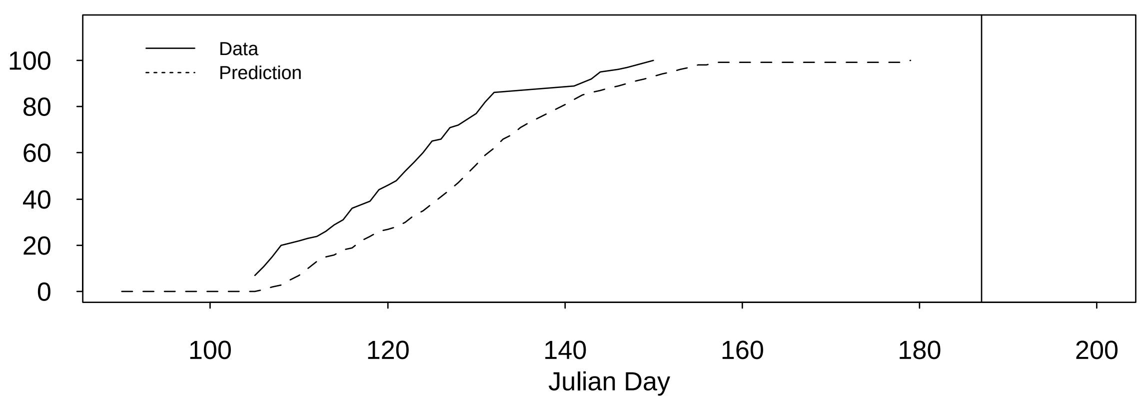
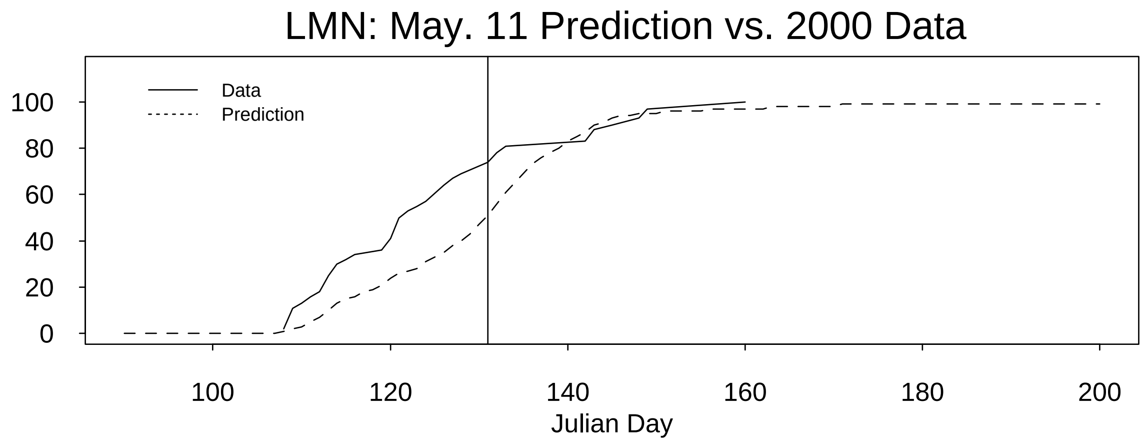
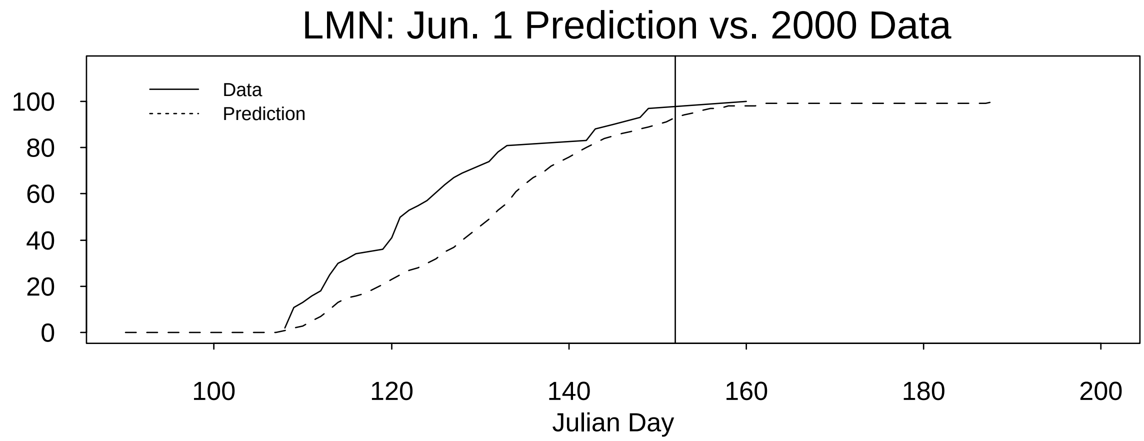


Figure C-15 CRiSP predictions for the cumulative distribution of arrivals of the Minam River stock at Little Goose Dam. Y-axis shows percent of total passage.

Minam River – Lower Monumental Dam (LMN)





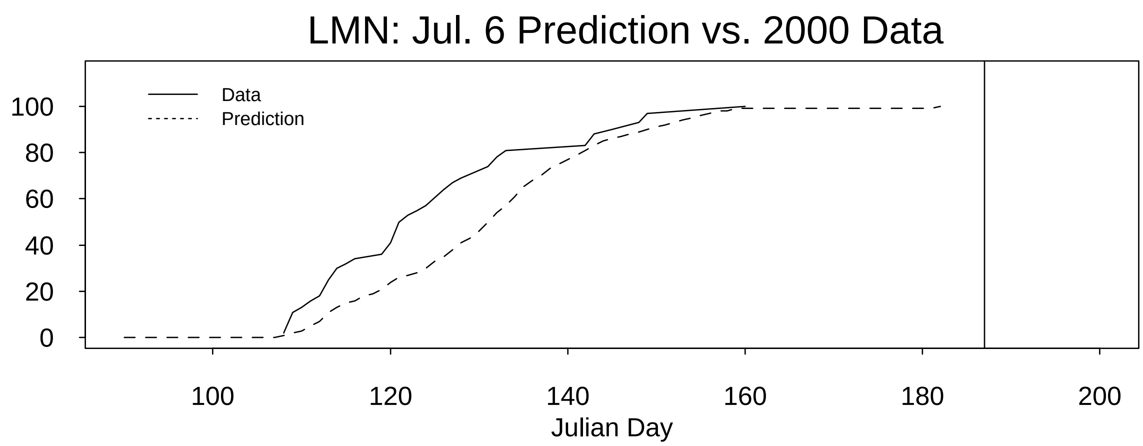


Figure C-16 CRiSP predictions for the cumulative distribution of arrivals of the Minam River stock at Lower Monumental Dam. Y-axis shows percent of total passage.

Minam River – McNary Dam (MCN)

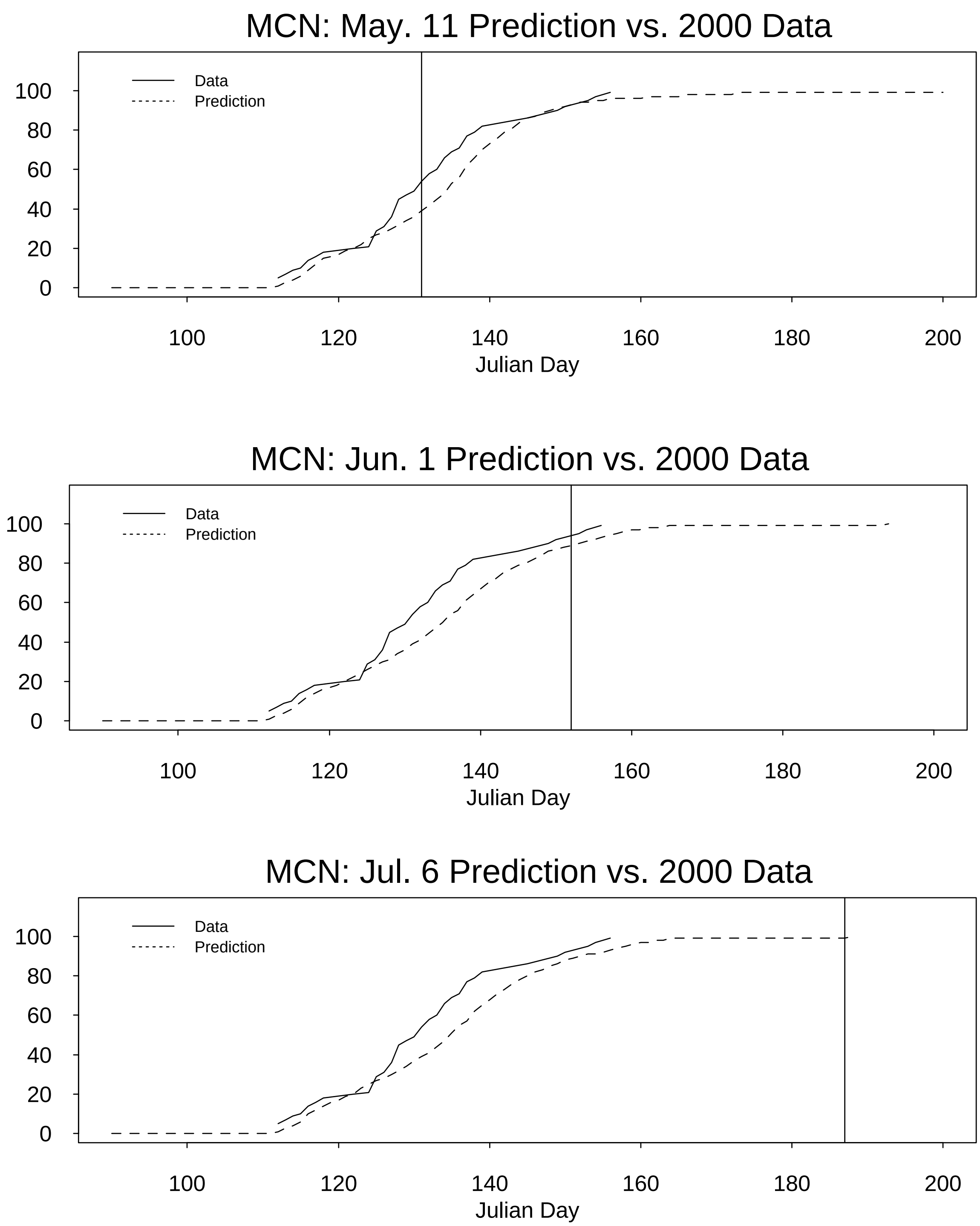


Figure C-17 CRiSP predictions for the cumulative distribution of arrivals of the Minam River stock at McNary Dam. Y-axis shows percent of total passage.

South Fork Salmon River –Lower Granite Dam (LWG)

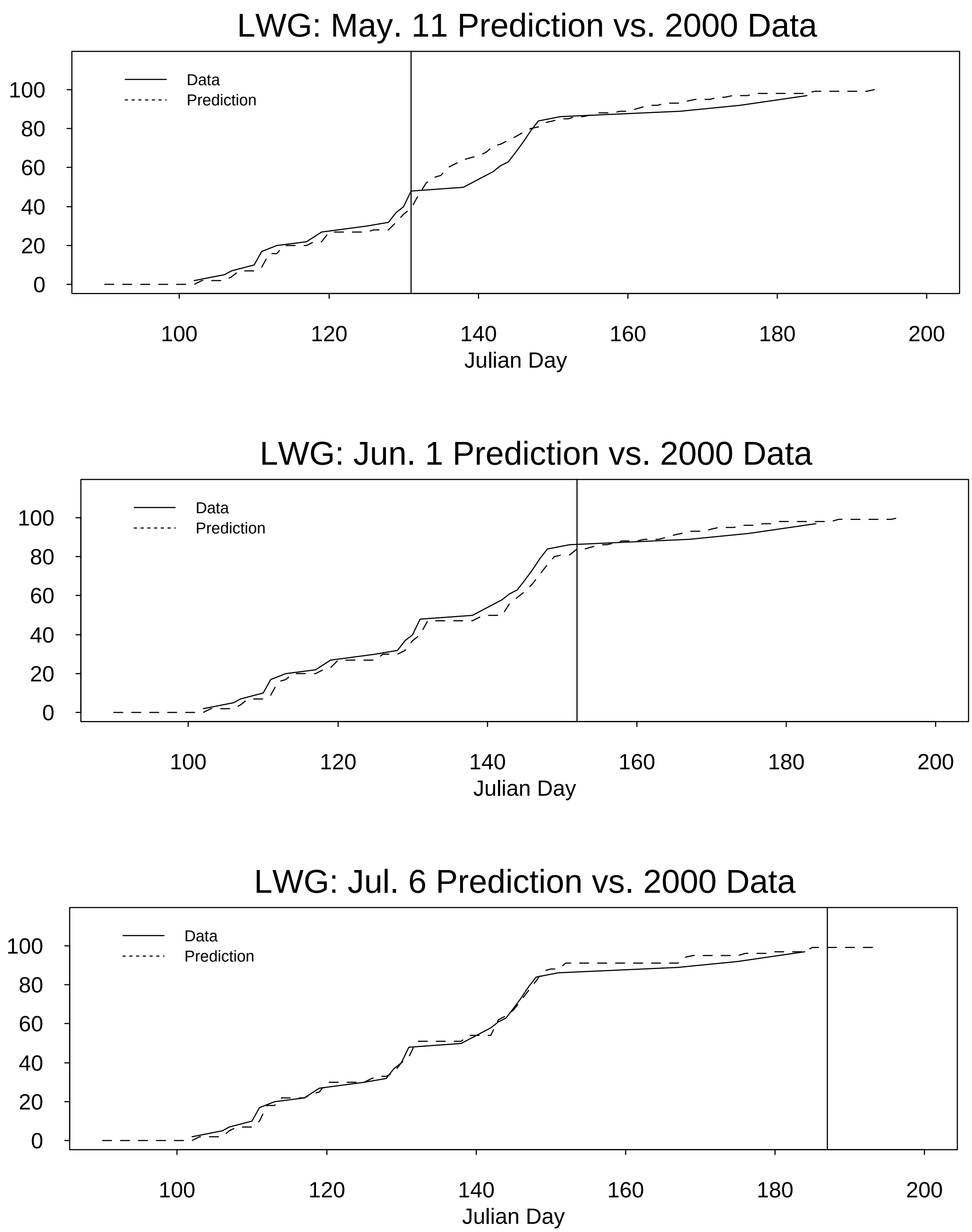
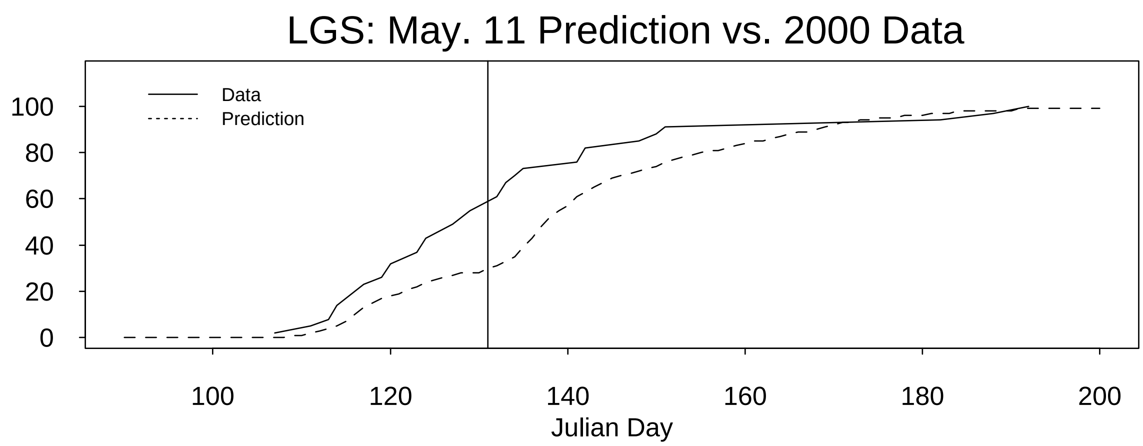
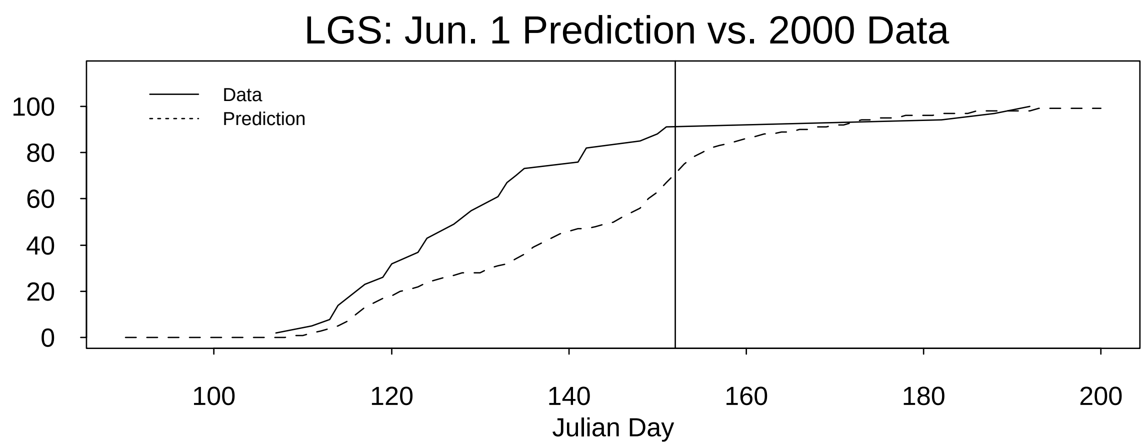


Figure C-18 RealTime predictions for the cumulative distribution of arrivals of the S. Fork Salmon stock at Lower Granite Dam. Y-axis shows percent of total passage.

South Fork Salmon River – Little Goose Dam (LGS)





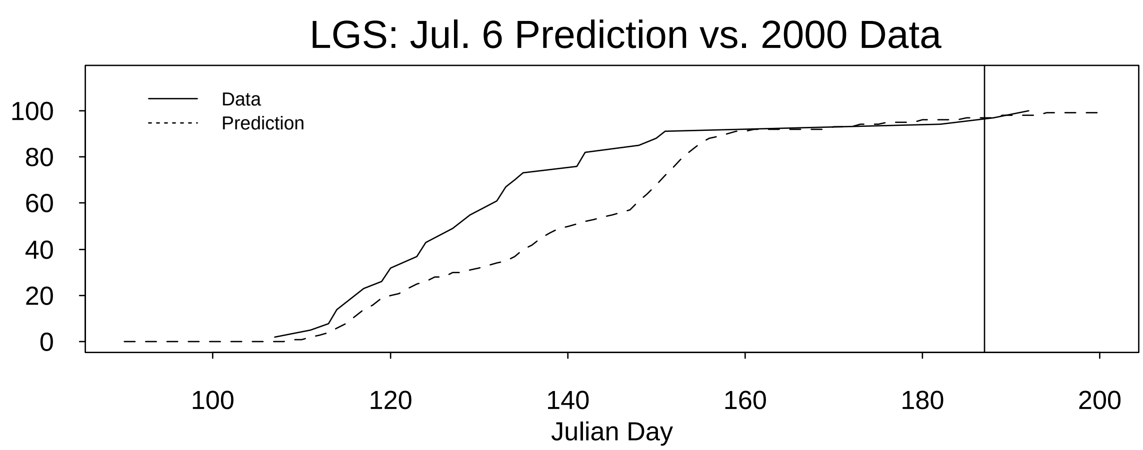
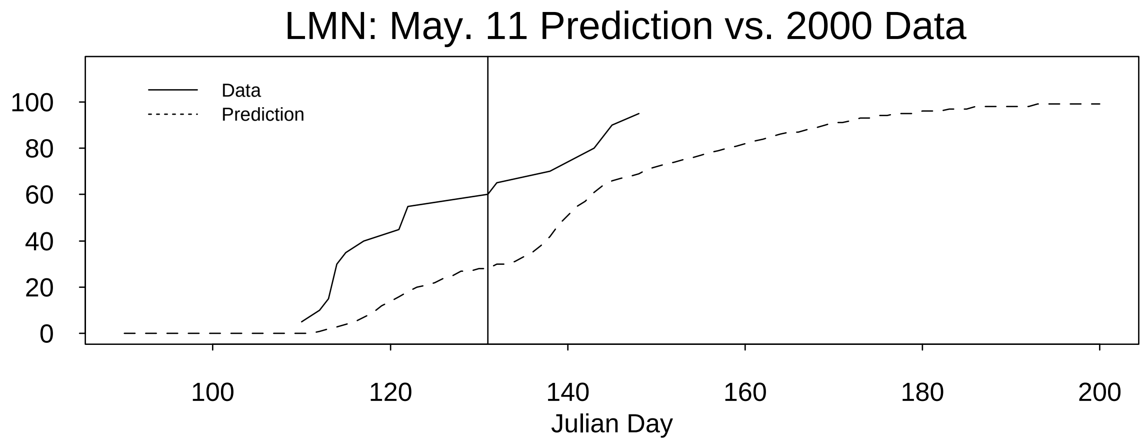
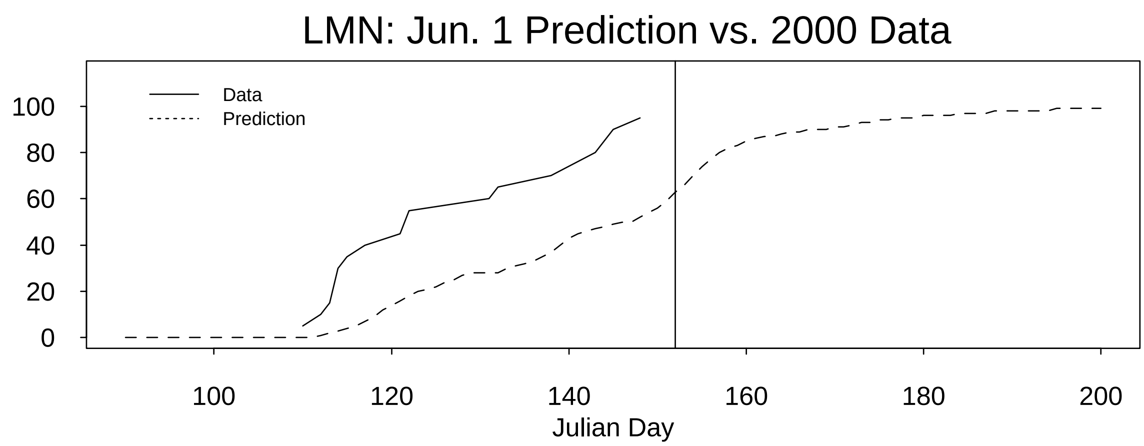


Figure C-19 CRiSP predictions for the cumulative distribution of arrivals of the S. Fork Salmon River stock at Little Goose Dam. Y-axis shows percent of total passage.

South Fork Salmon River – Lower Monumental Dam (LMN)





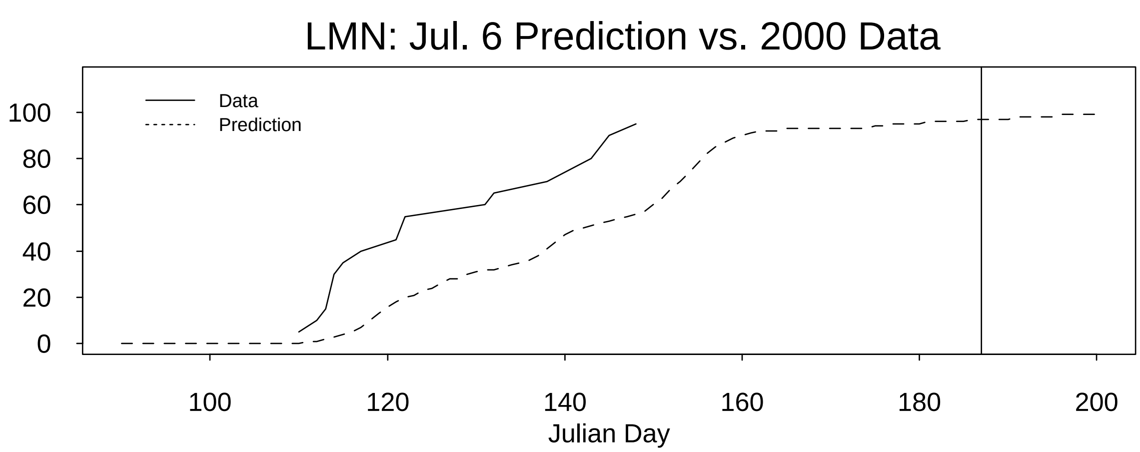


Figure C-20 CRiSP predictions for the cumulative distribution of arrivals of the S. Fork Salmon stock at Lower Monumental. Y-axis shows percent of total passage.

South Fork Salmon River – McNary Dam (MCN)

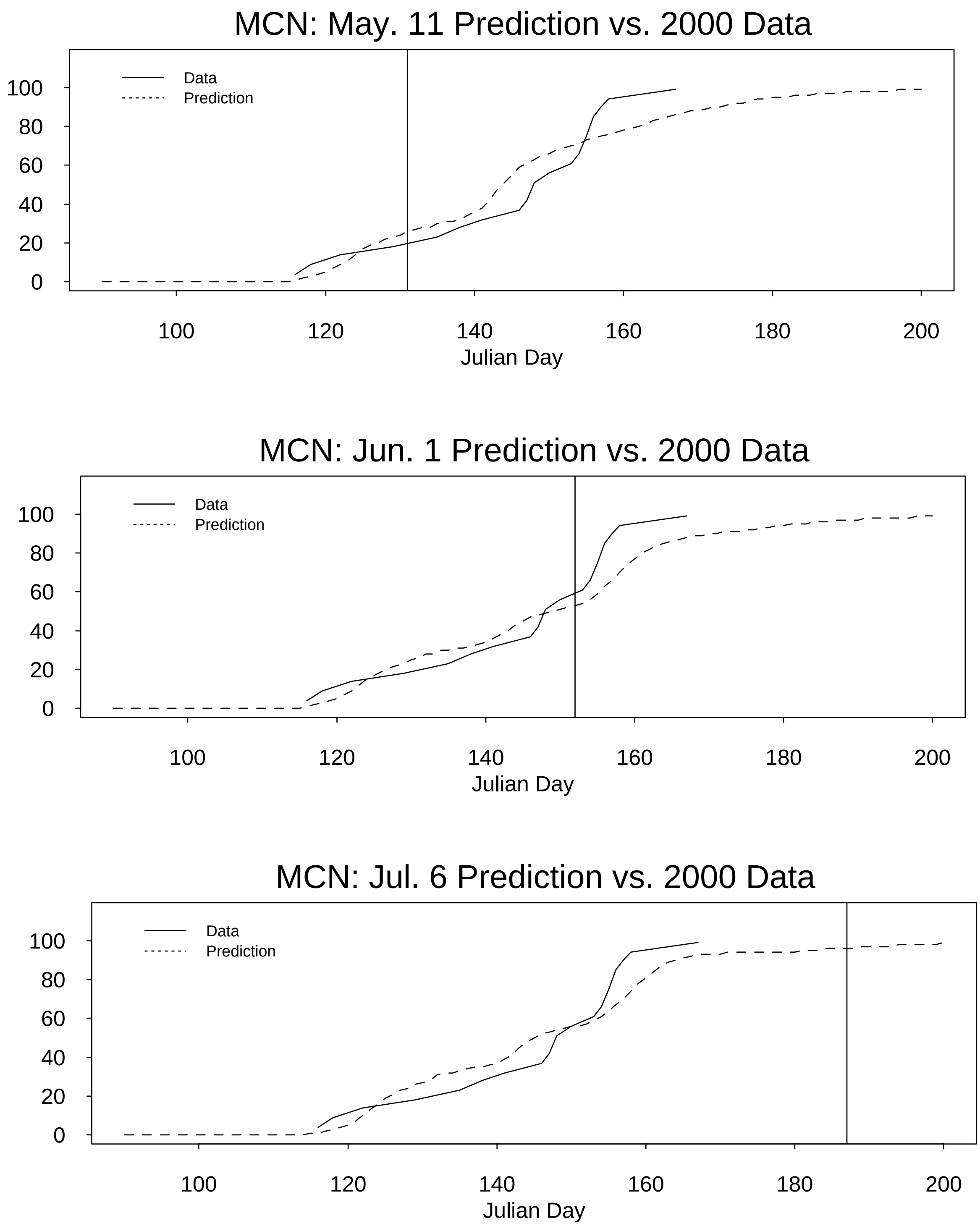


Figure C-21 CRiSP predictions for the cumulative distribution of arrivals of the S. Fork Salmon River stock at McNary Dam. Y-axis shows percent of total passage.

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.

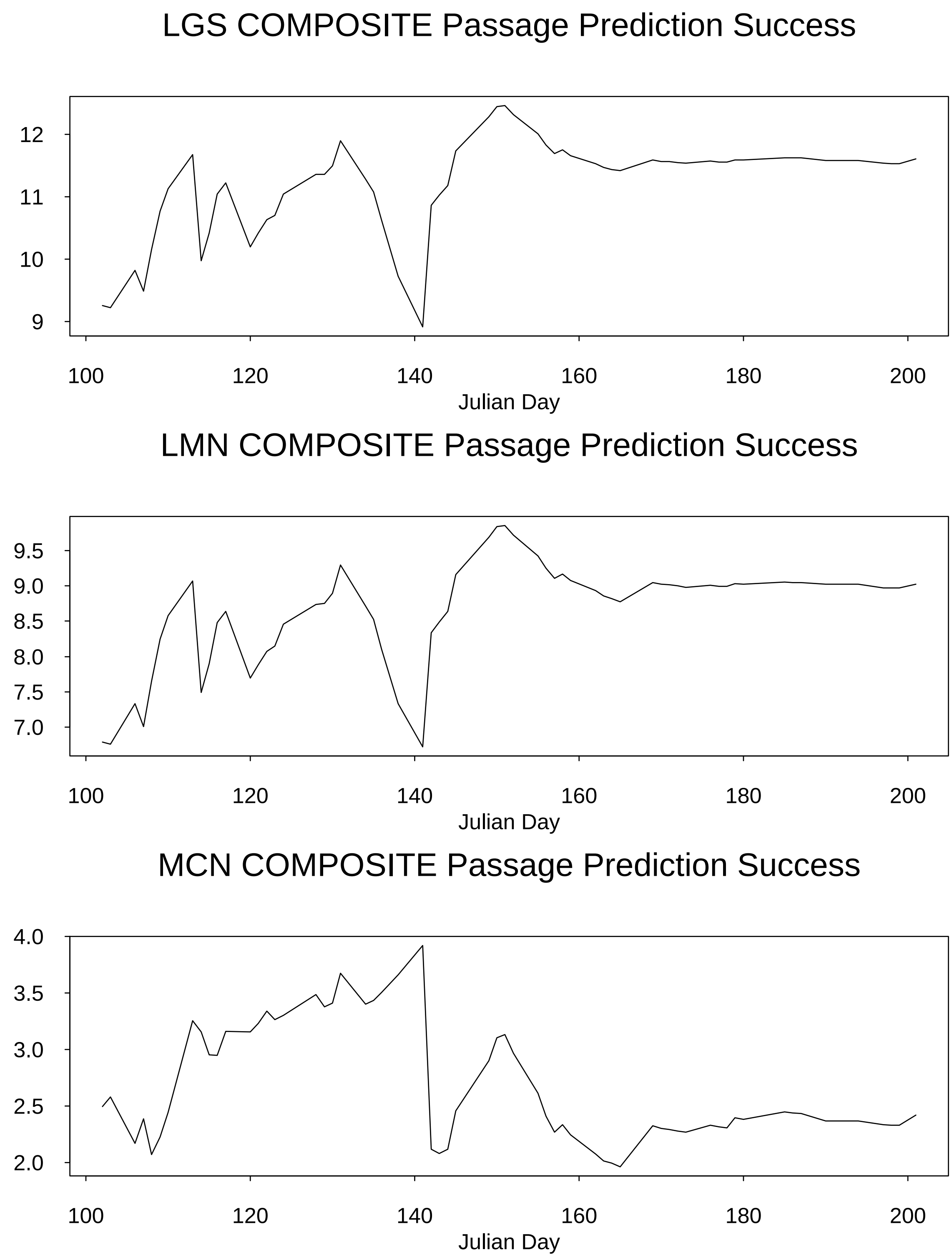


Figure D-1 Seasonal variation in passage prediction success for the Composite stock at Little Goose, Lower Monumental and McNary Dams Y axis is the *MAD* value.

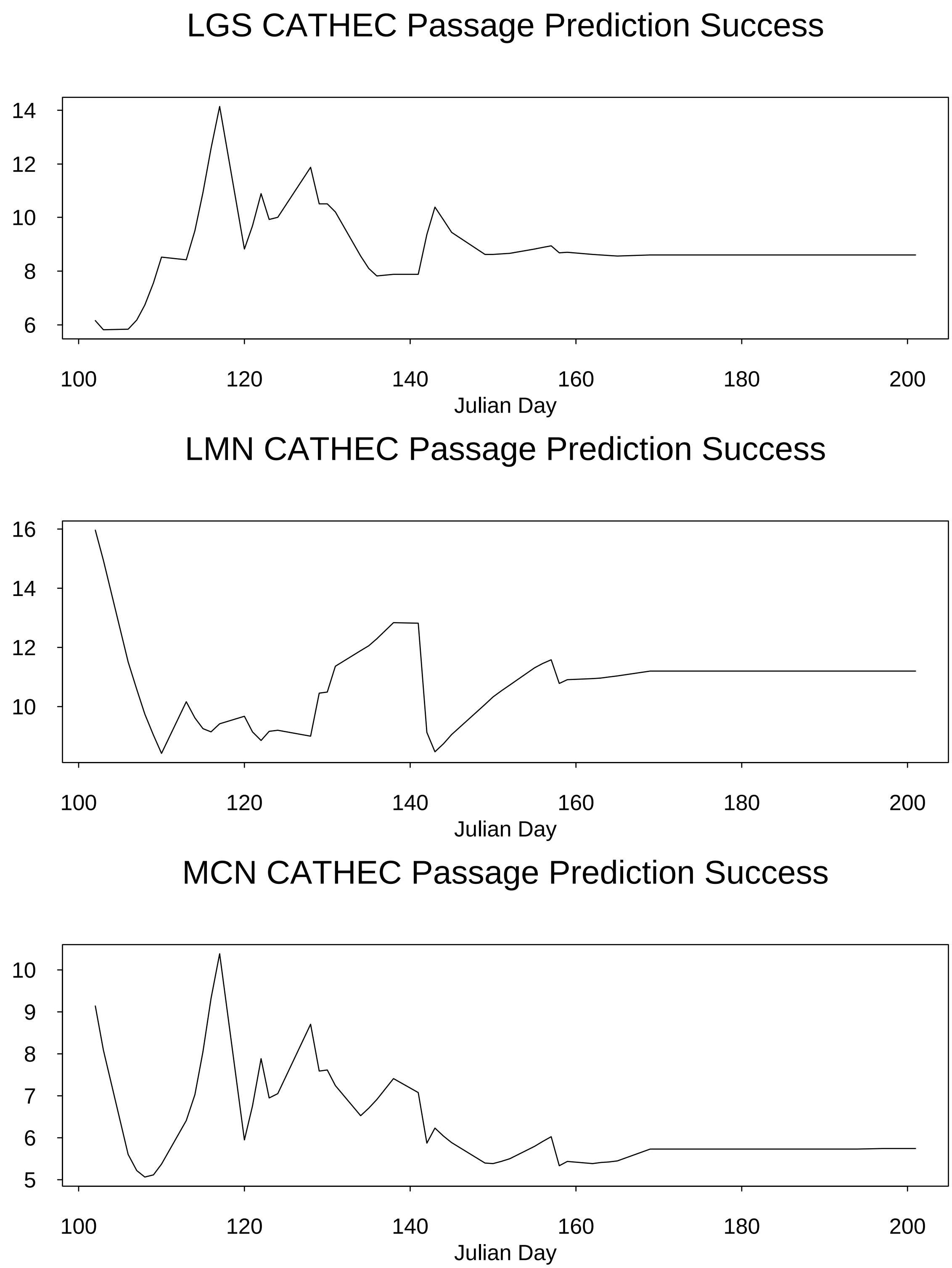


Figure D-2 Seasonal variation in passage prediction success for Catherine Creek stocks at Little Goose, Lower Monumental and McNary Dams. Y axis is the *MAD* value.

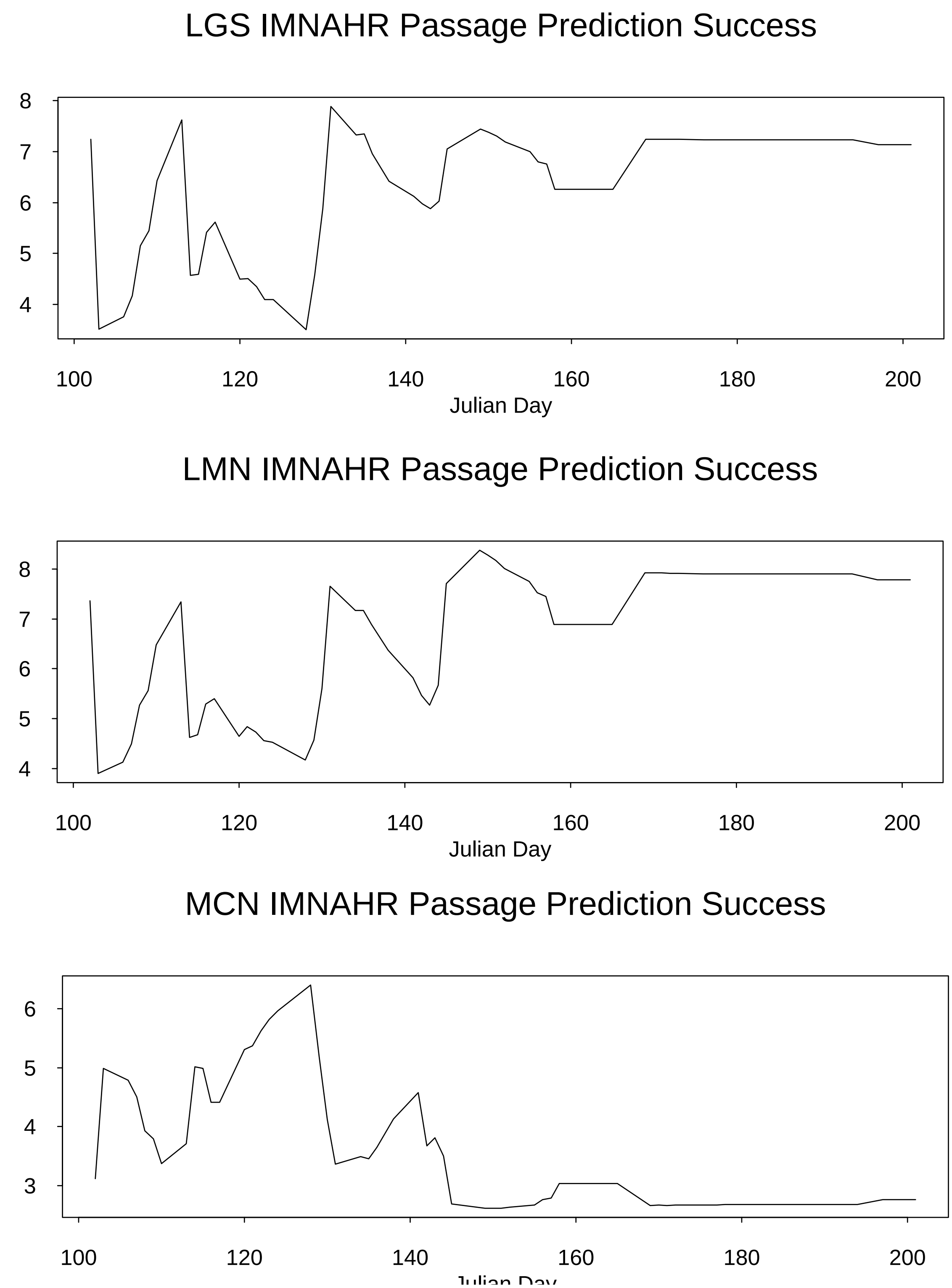


Figure D-3 Seasonal variation in passage prediction success for Imnaha River stocks at Little Goose, Lower Monumental and McNary Dams. Y axis is the *MAD* value.

.

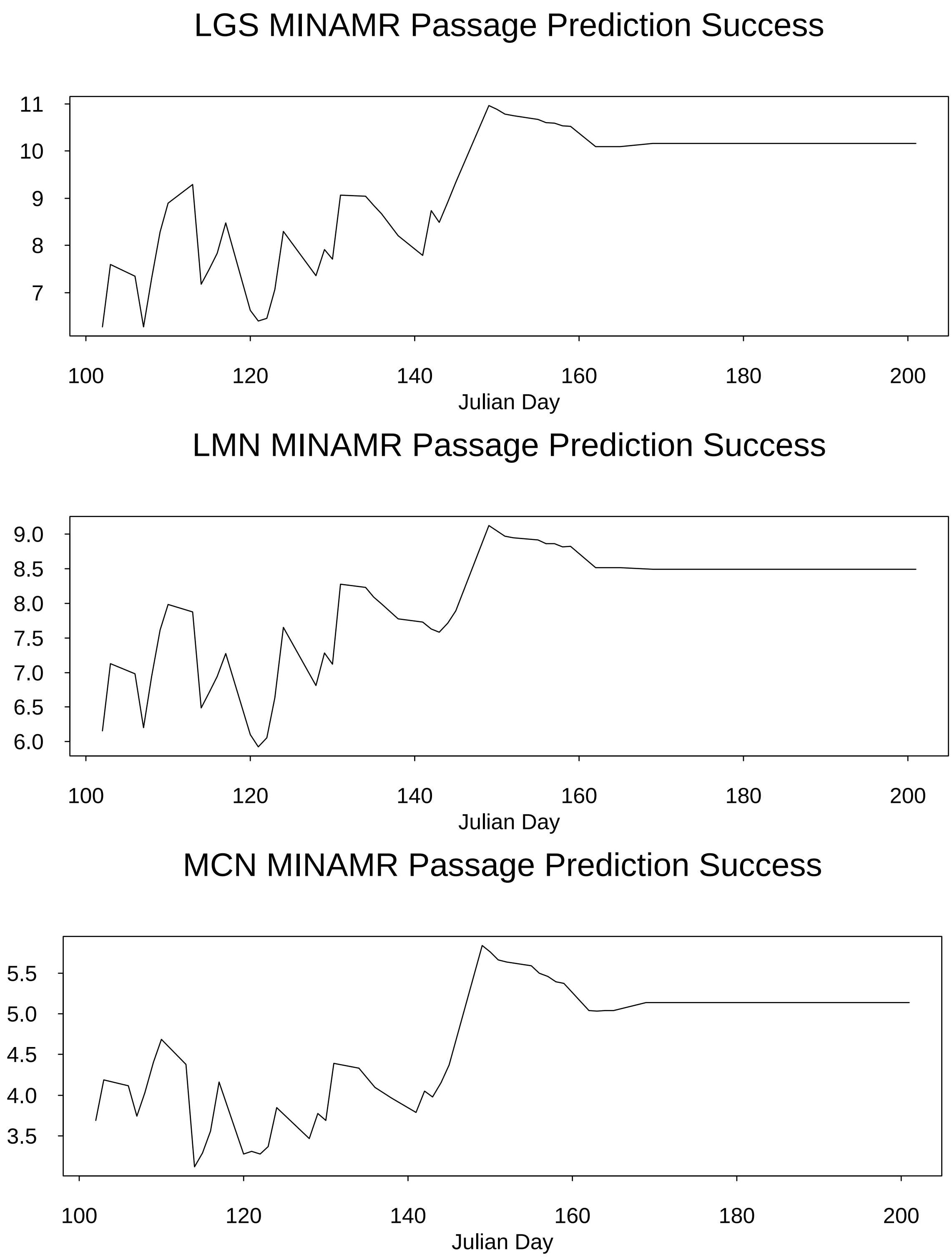


Figure D-4 Seasonal variation in passage prediction success for Minam River stocks at Little Goose, Lower Monumental and McNary Dams. Y axis is the *MAD* value.

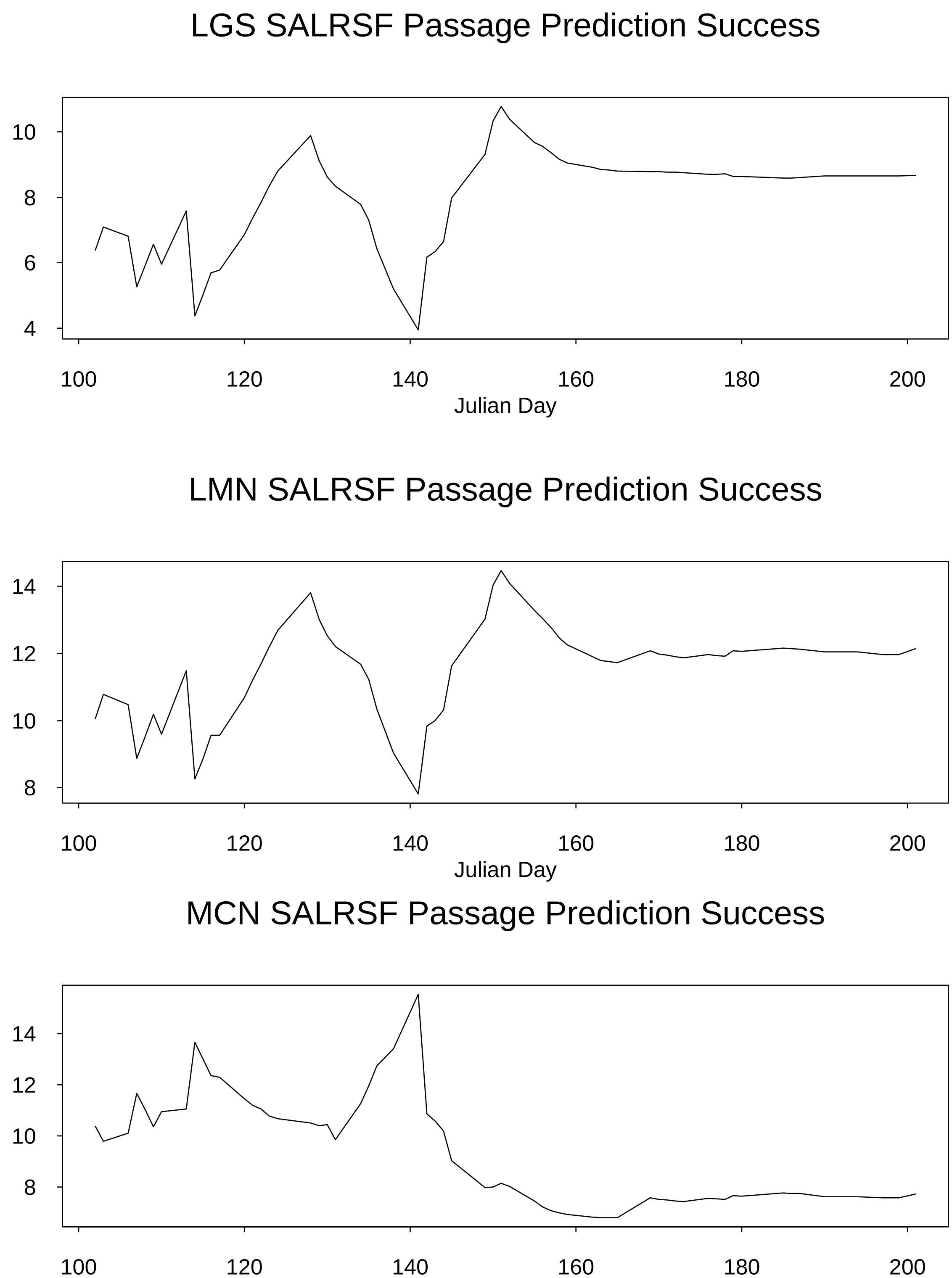
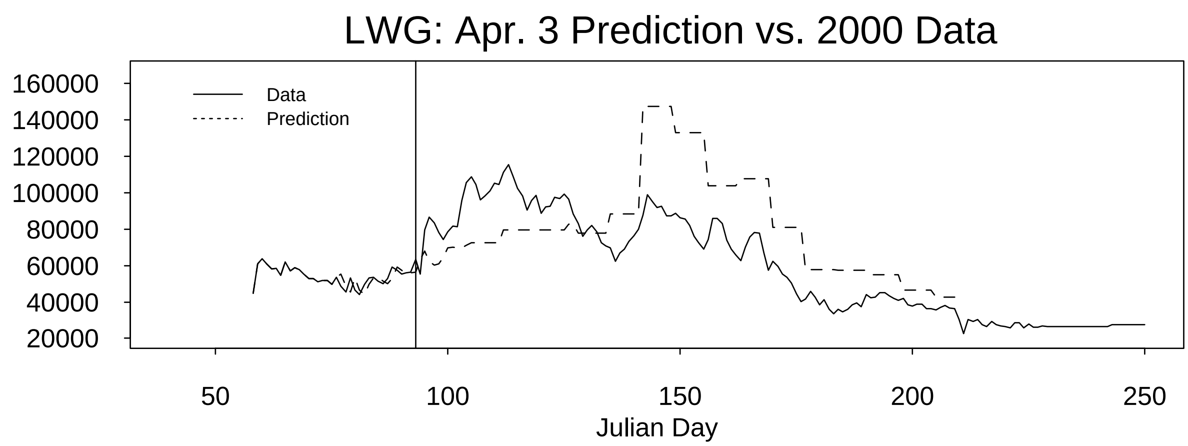
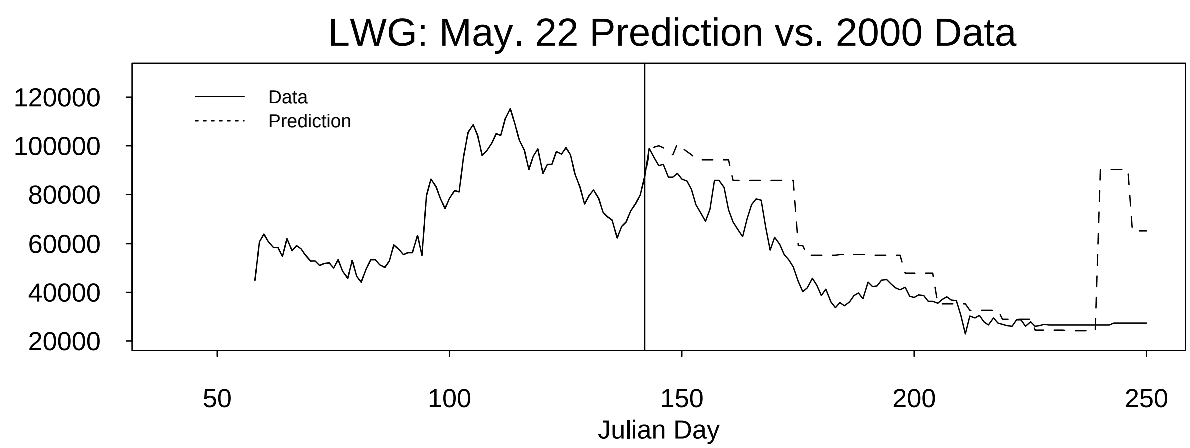


Figure D-5 Seasonal variation in passage prediction success for South Fork Salmon River stocks at Little Goose, Lower Monumental and McNary Dams. Y axis is the *MAD* value.

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.





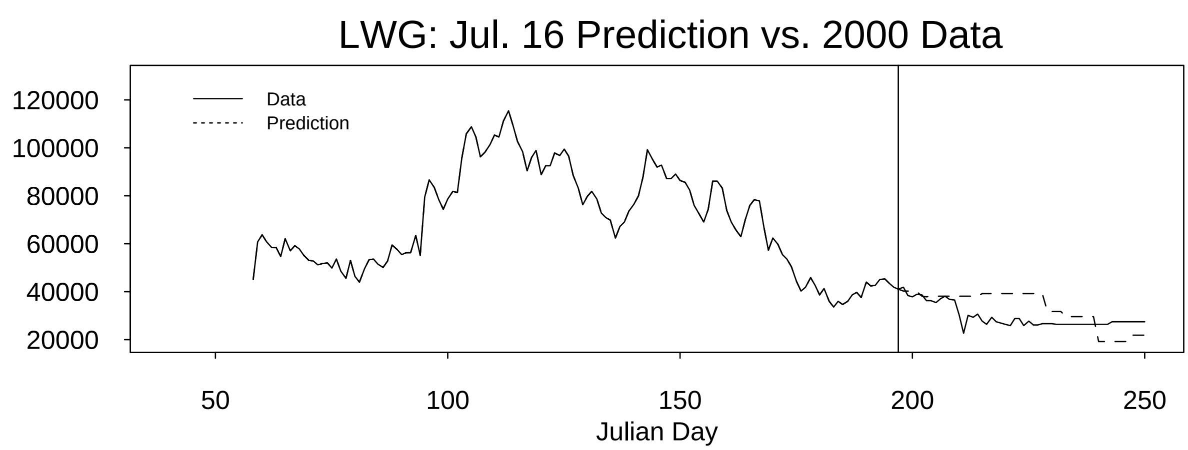


Figure E-1 Flow predictions and observations for Lower Granite Dam. Y axis shows CFS.

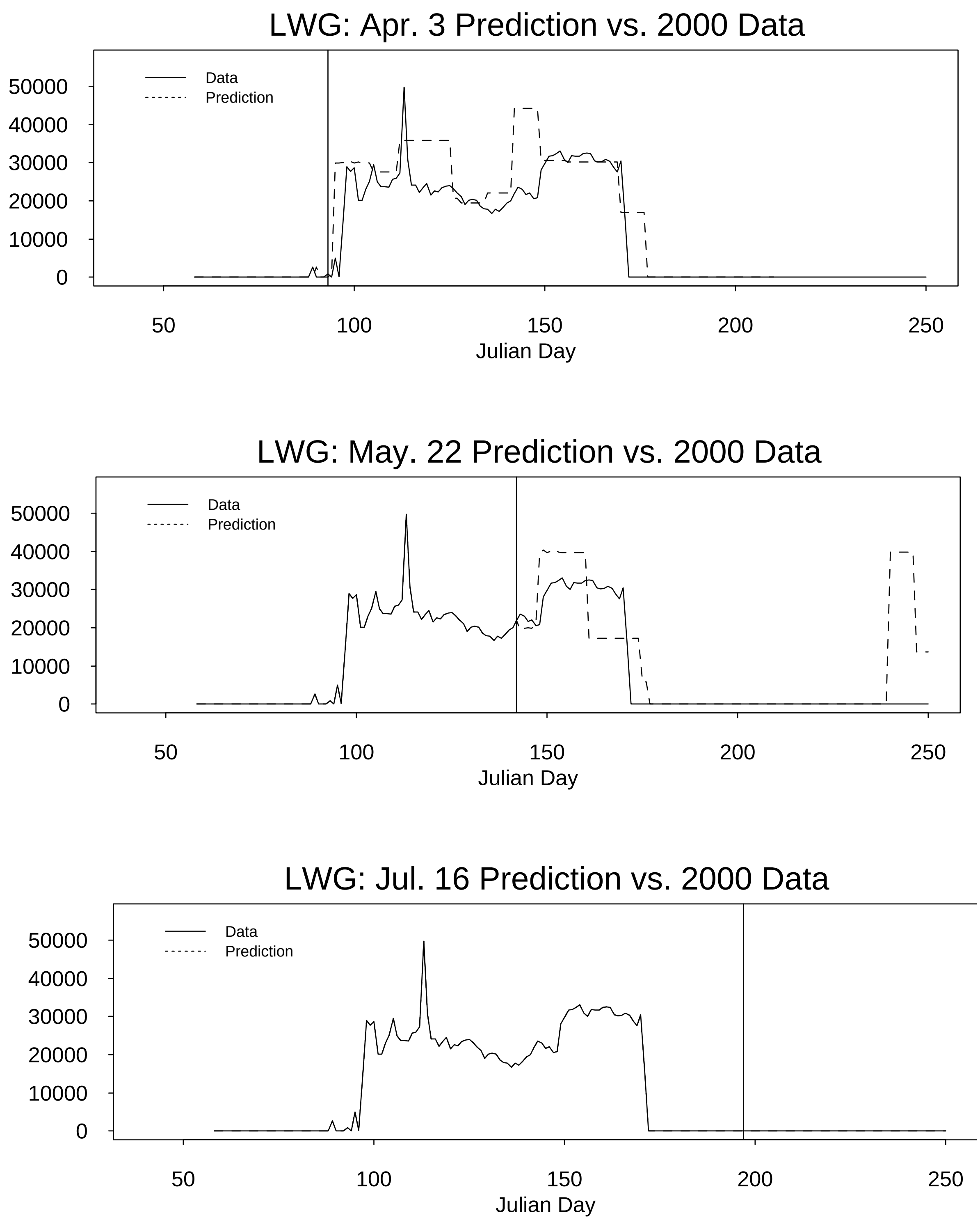
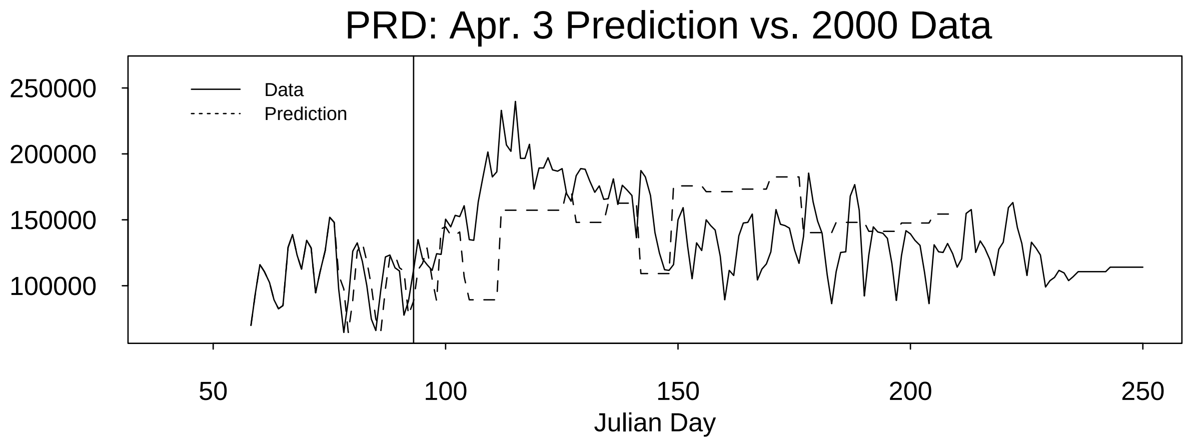
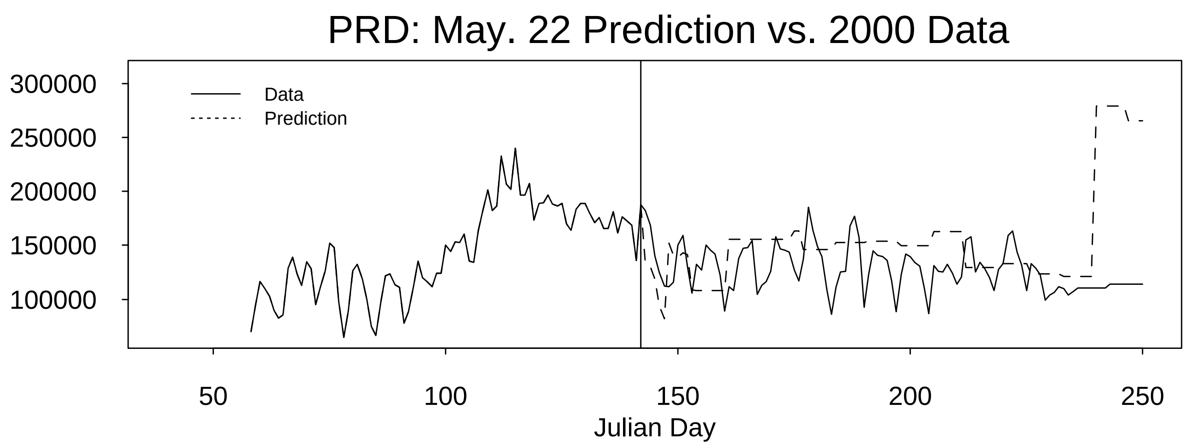


Figure E-2 Spill predictions and observations for Lower Granite Dam. Y axis shows CFS.





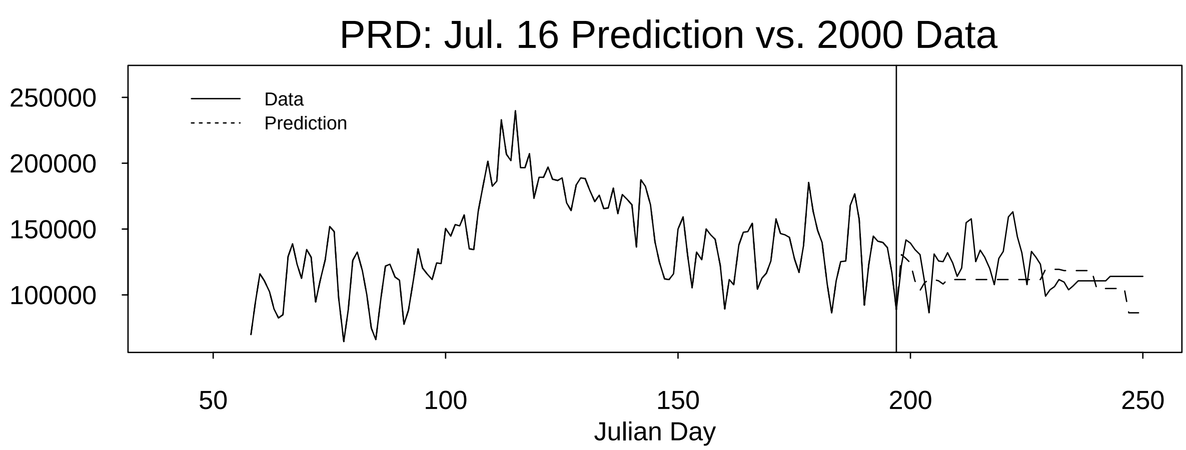
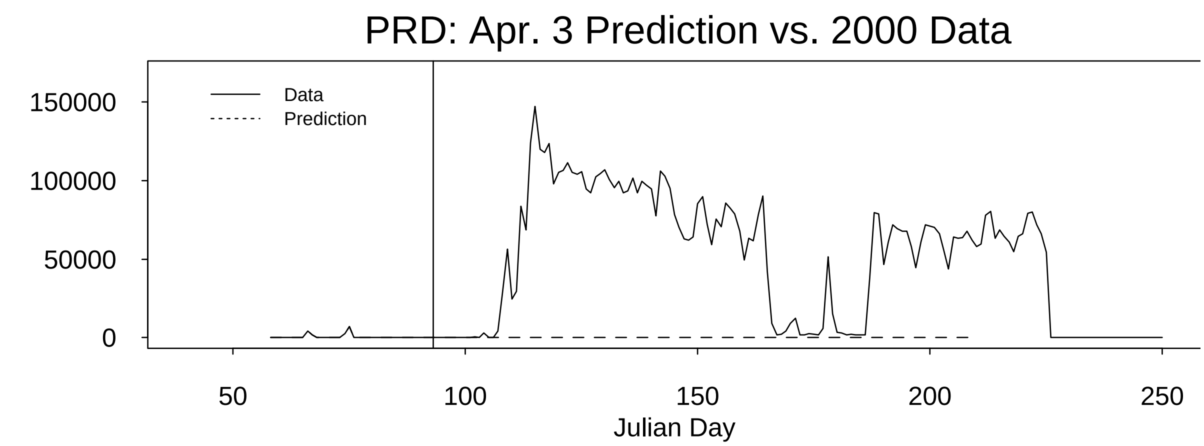
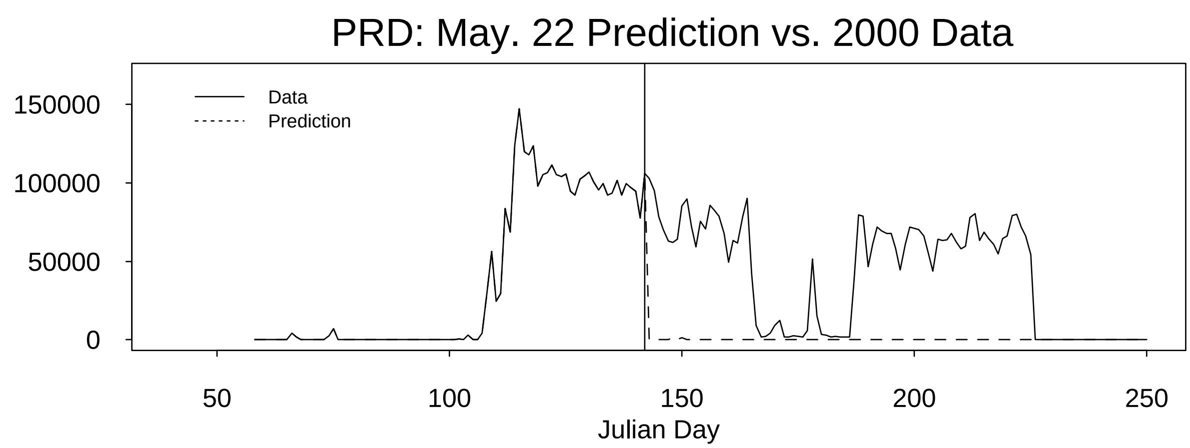


Figure E-3 Flow predictions and observations for Priest Rapids Dam.Y axis shows CFS.





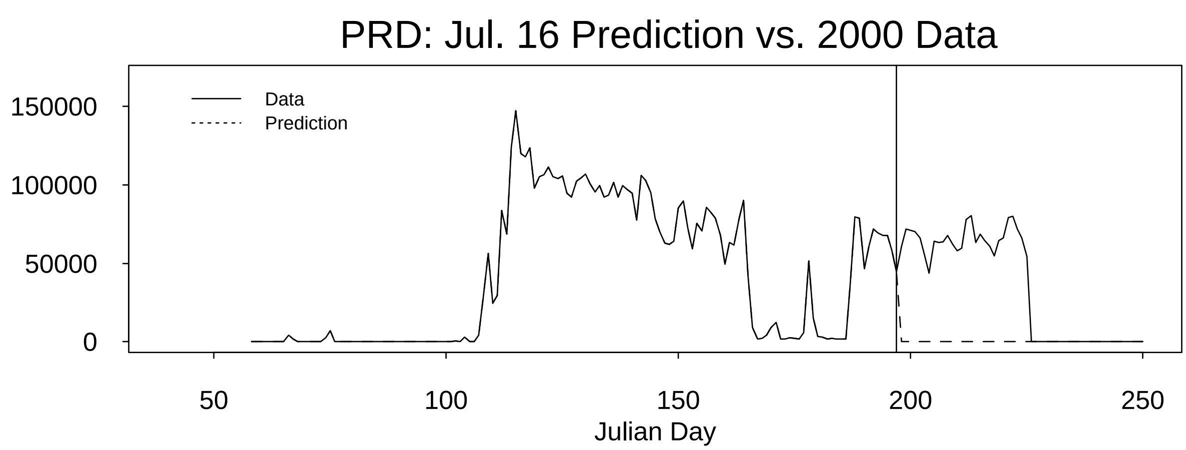


Figure E-4 Spill predictions and observations for Priest Rapids Dam. Y axis shows CFS.

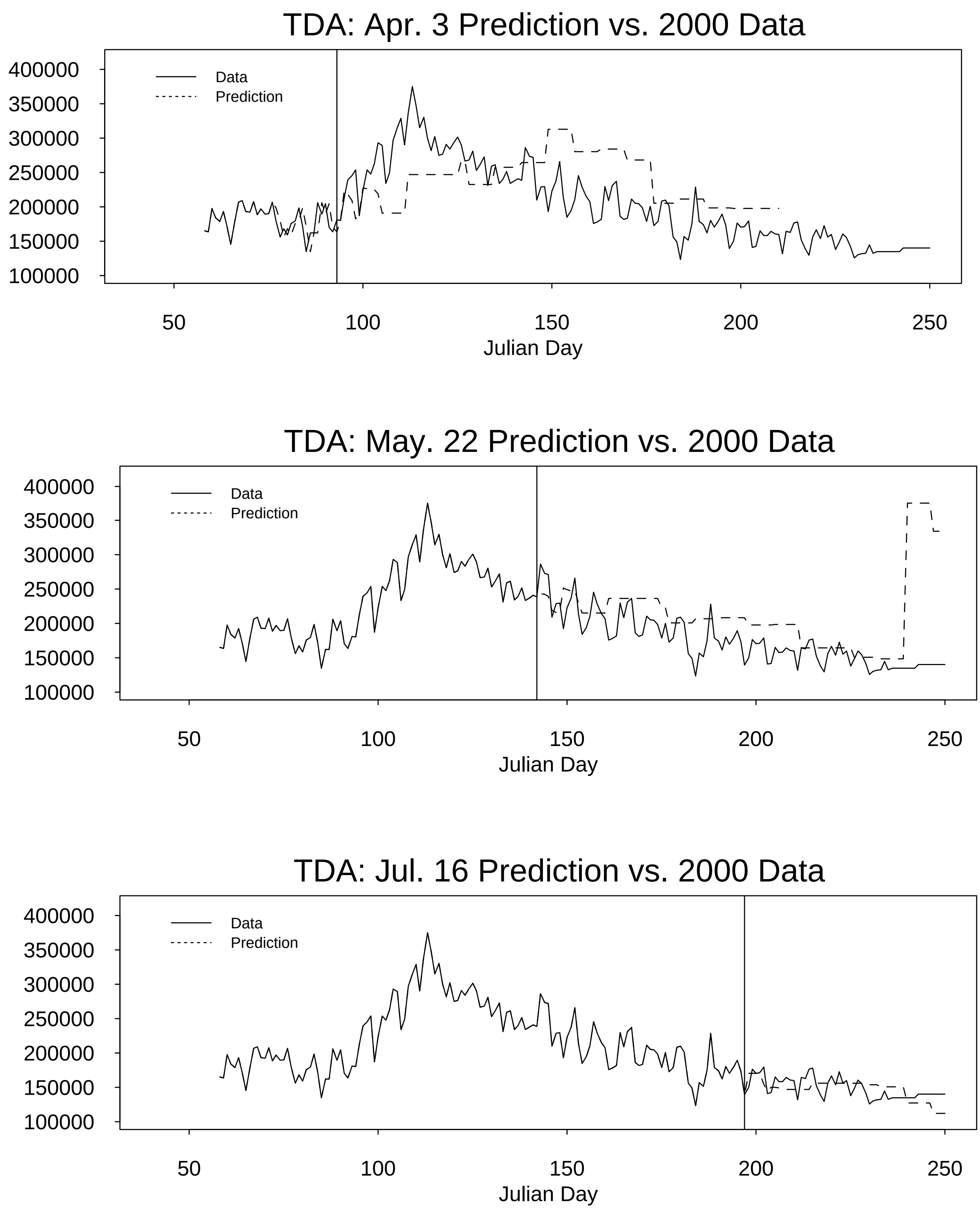


Figure E-5 Flow predictions and observations for The Dalles Dam. Y axis shows CFS.

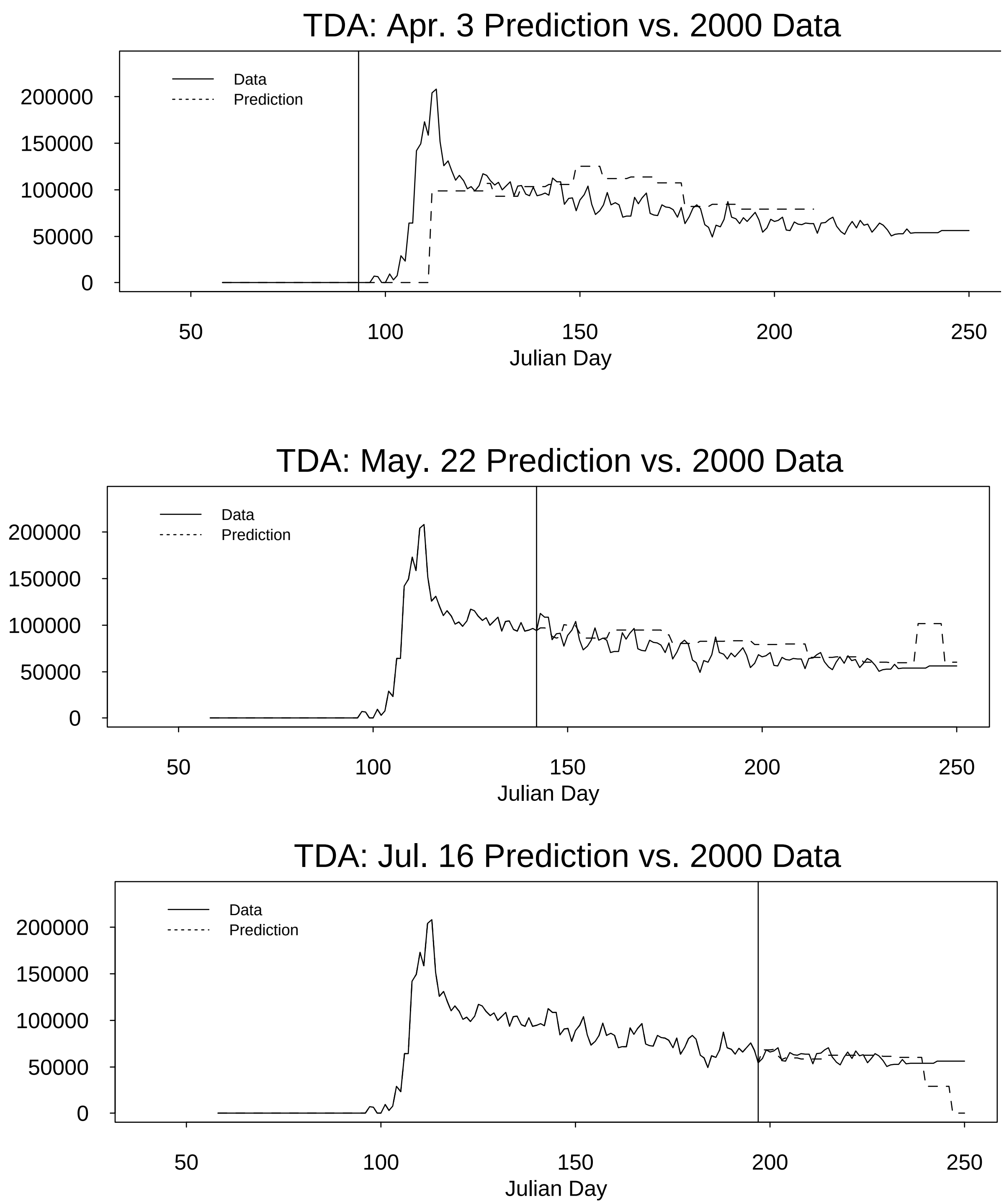
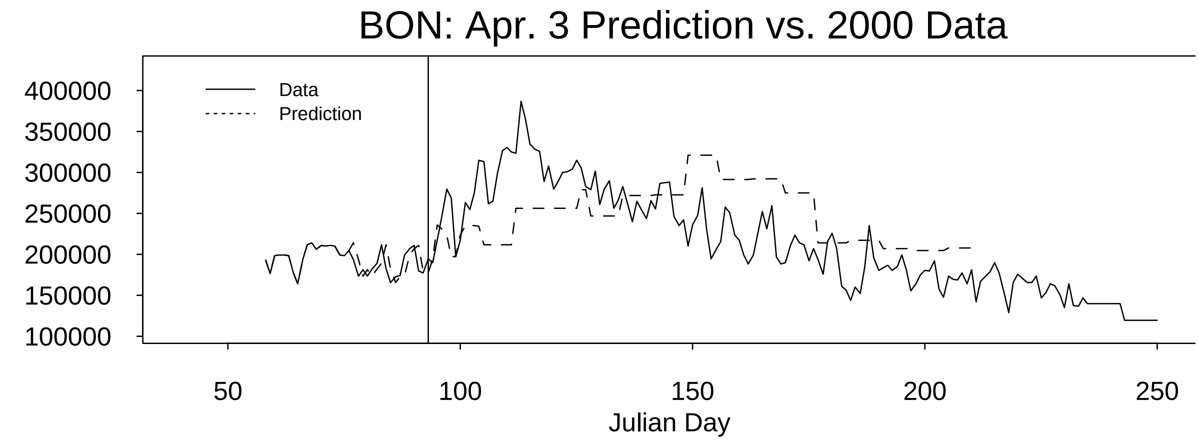
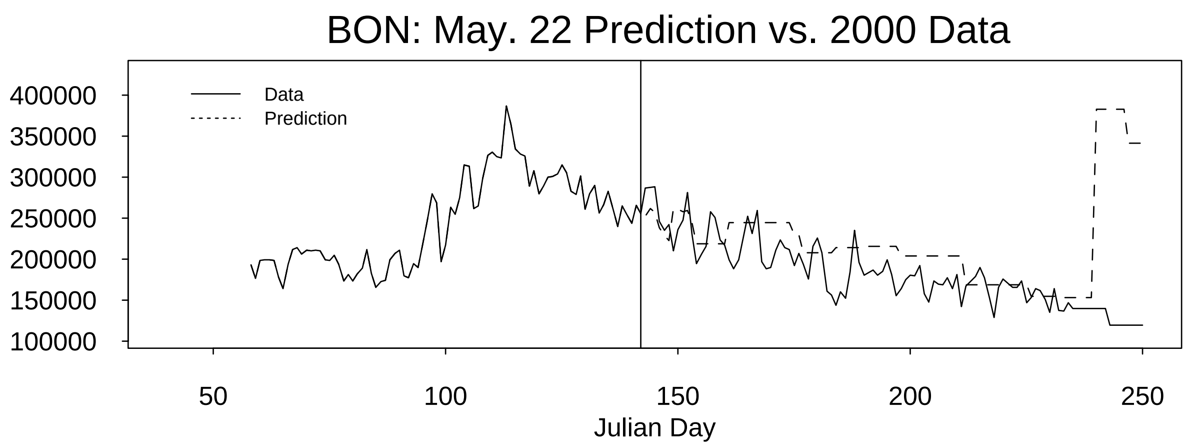


Figure E-6 Spill predictions and observations for The Dalles Dam.Y axis shows CFS.





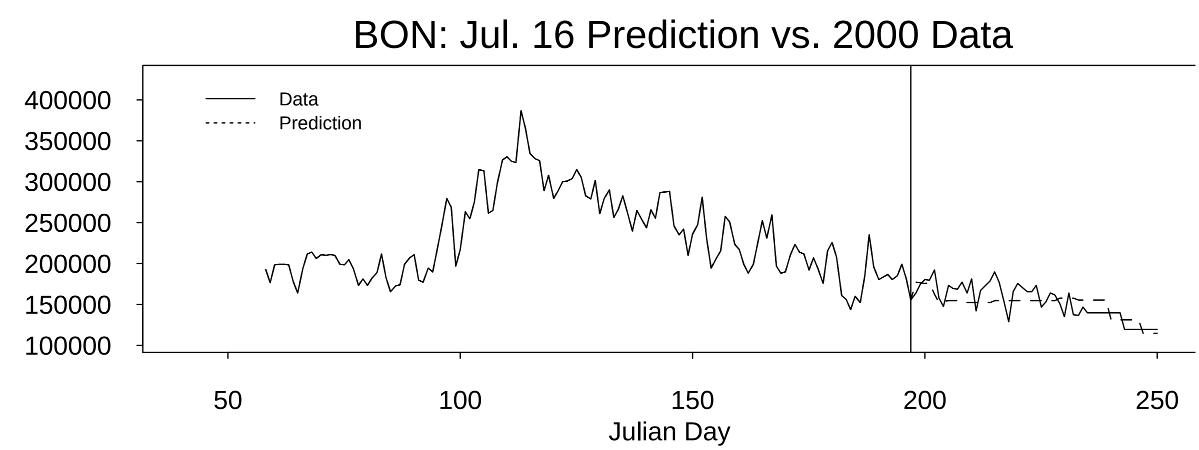


Figure E-7 Flow predictions and observations for Bonneville Dam.Y axis shows CFS.

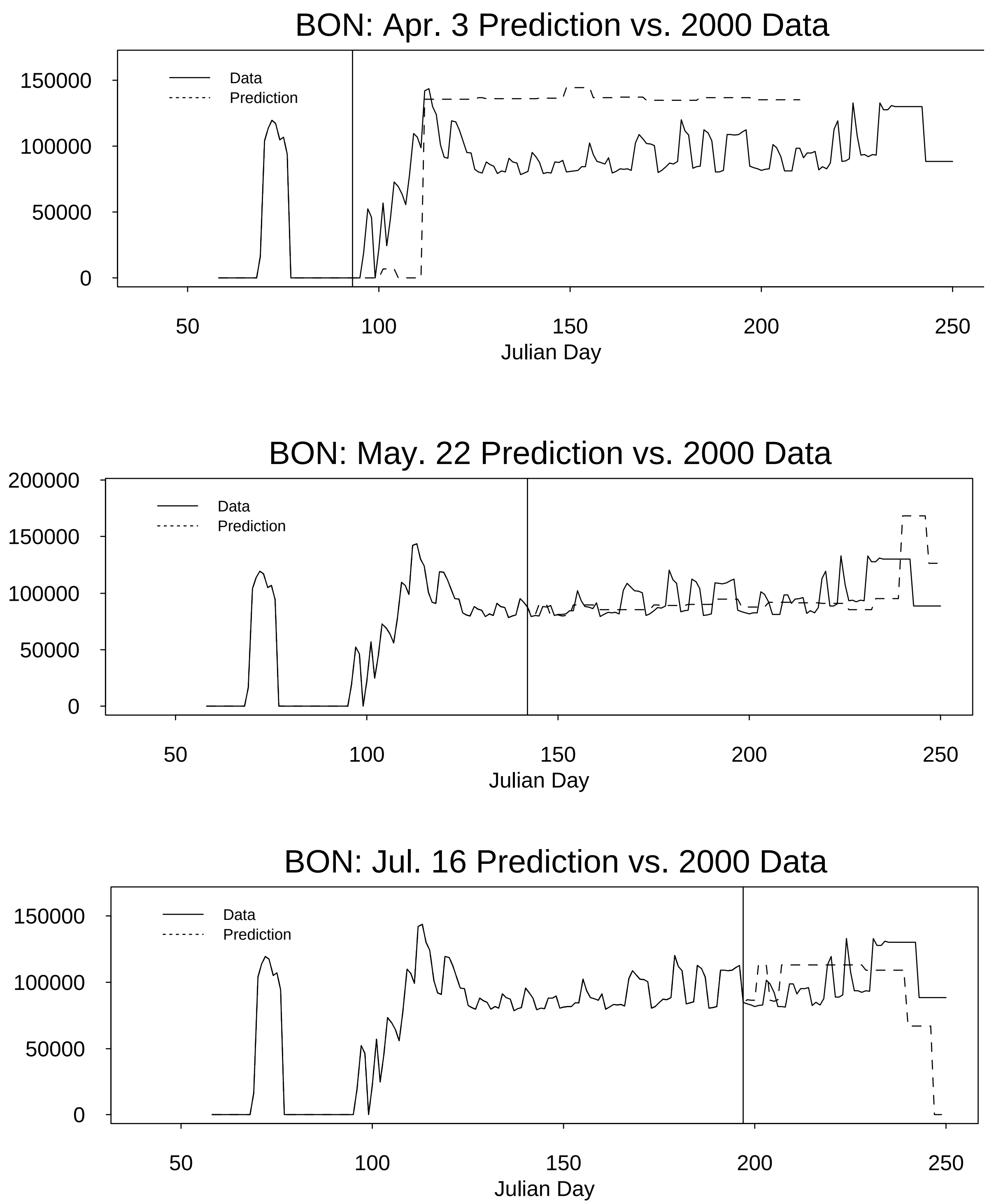


Figure E-8 Spill predictions and observations for Bonneville Dam.Y axis shows CFS.

Appendix F Spill Forecast History Plots

Spill predictions during the early season are difficult to make. Shown here are late March 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).

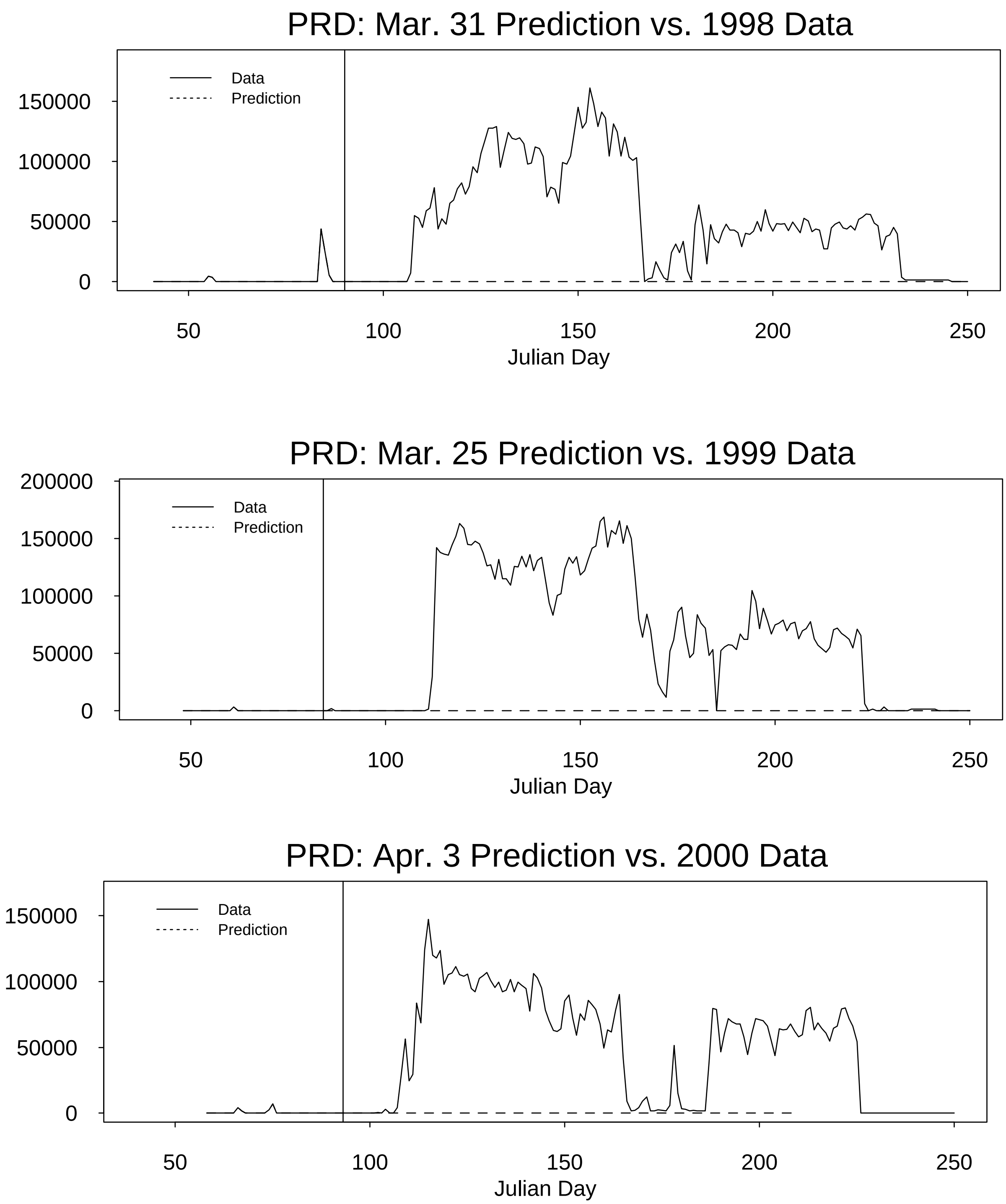
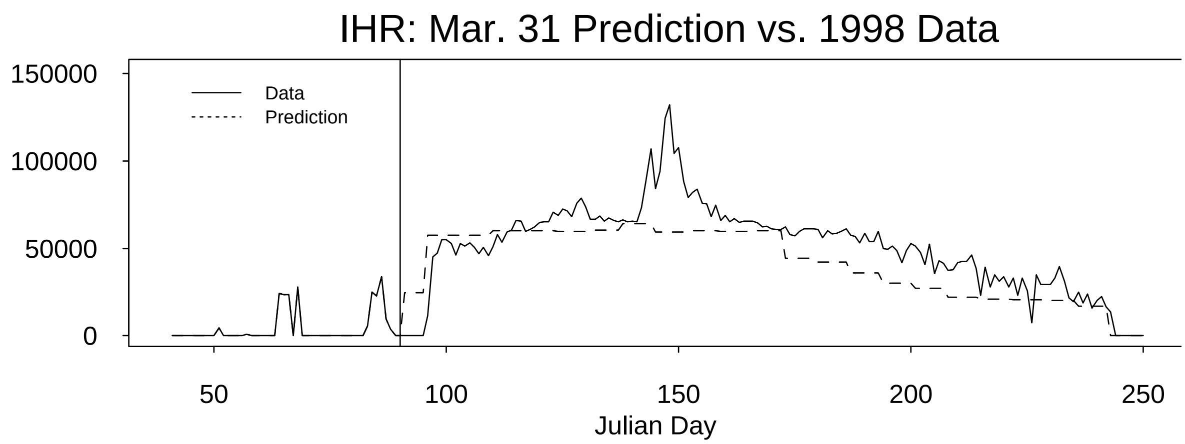
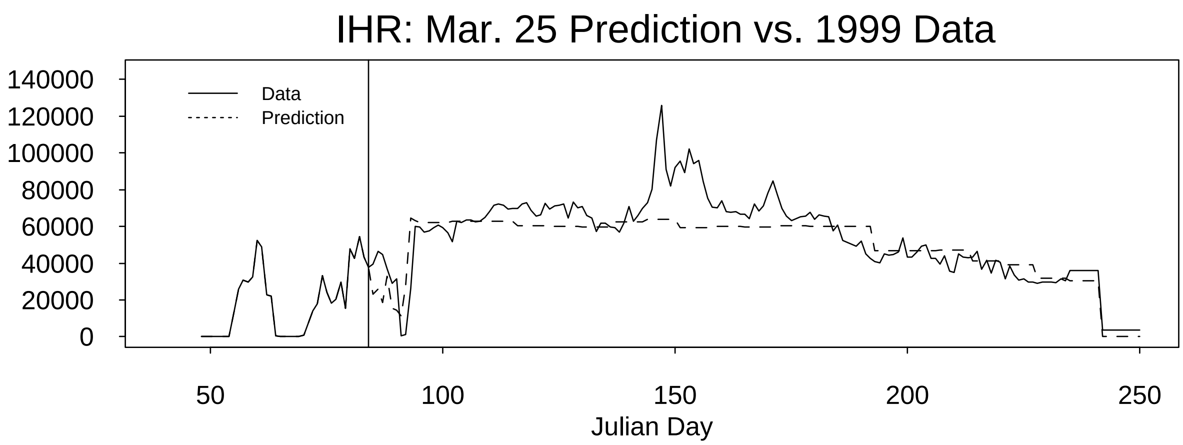


Figure F-1 Early season spill predictions for the last three years compared to data at Priest Rapids Dam.





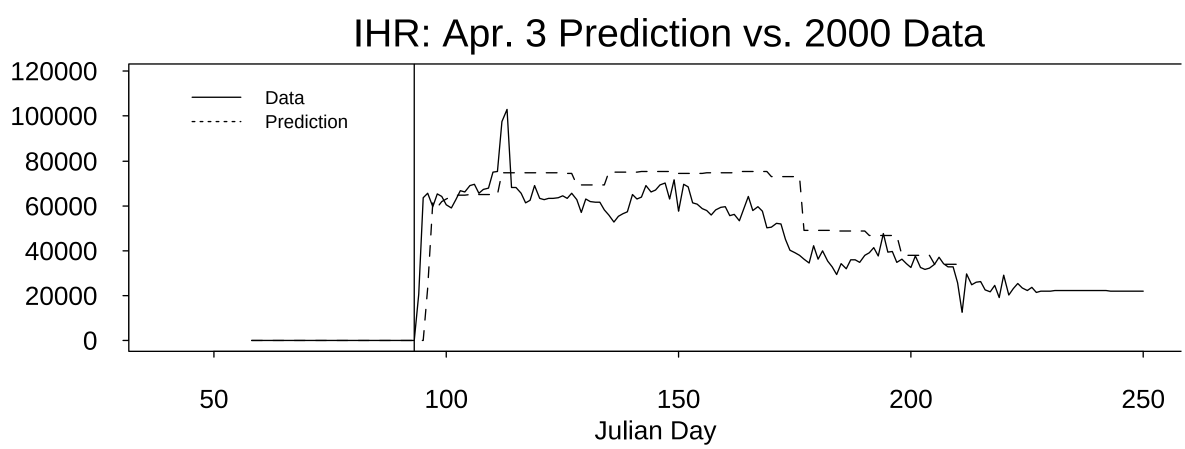


Figure F-2 Early season spill predictions for the last three years compared to data at Ice Harbor dam.

Appendix G Temperature Forecast Plots

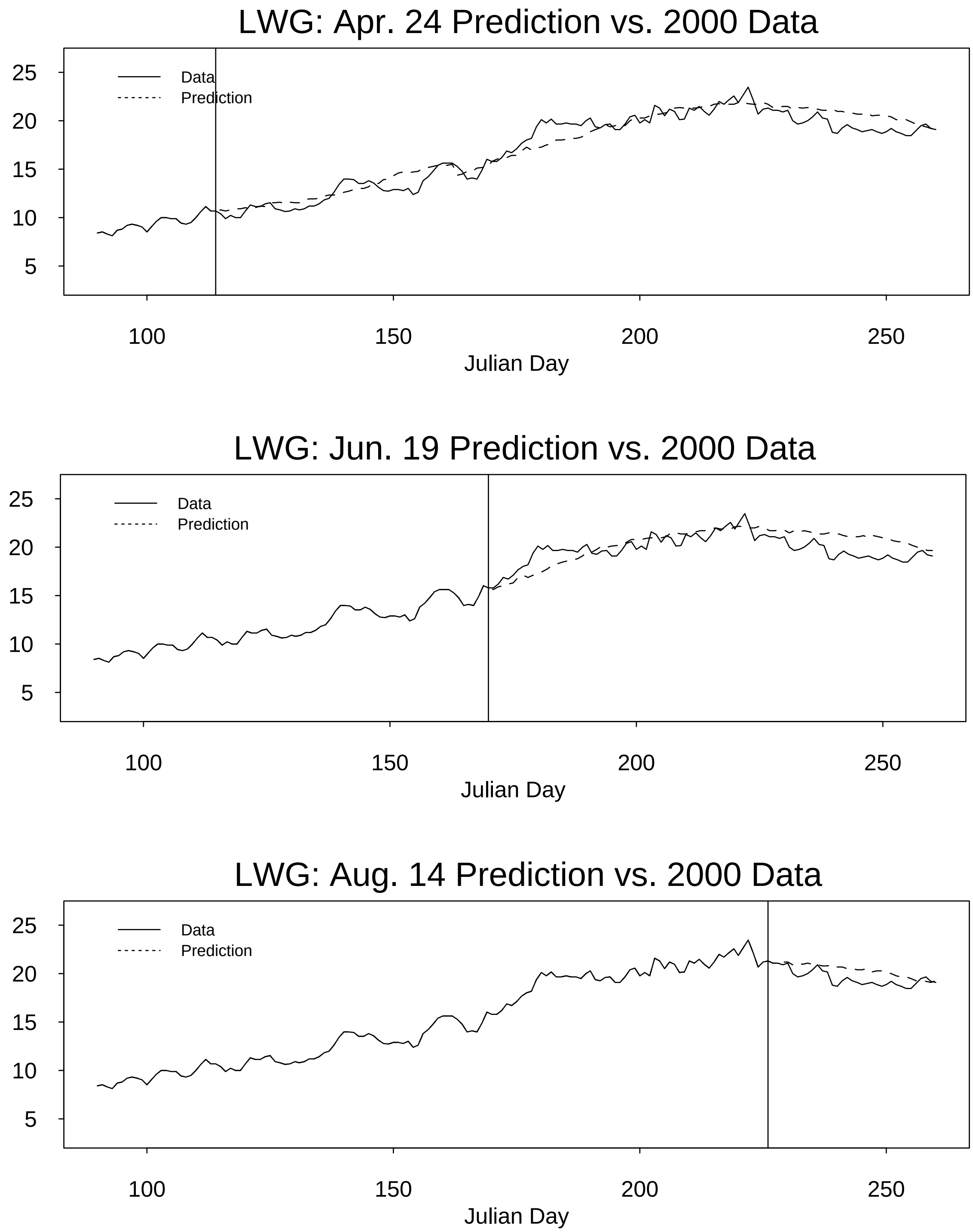


Figure G-1 Temperature predictions and observations for Lower Granite Dam. Y axis is ˚C.

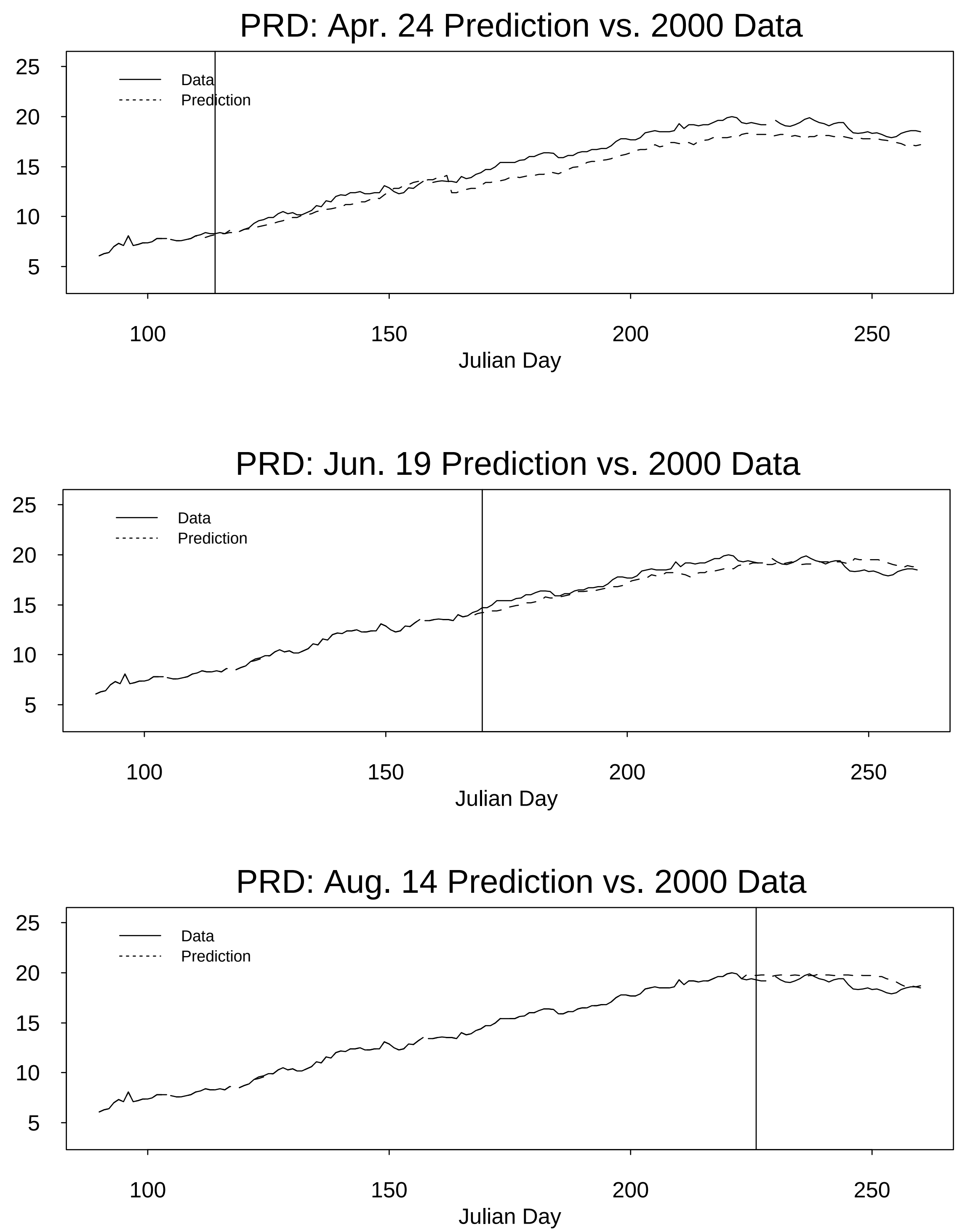
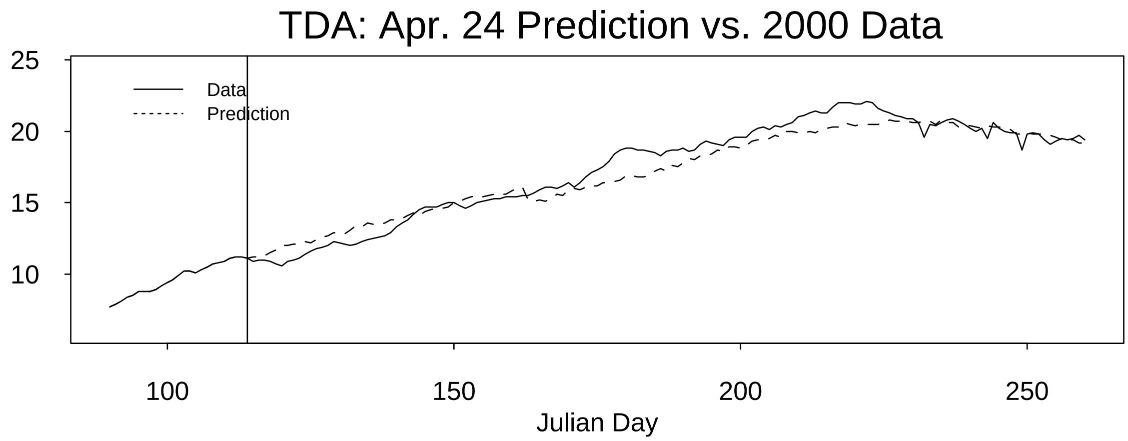
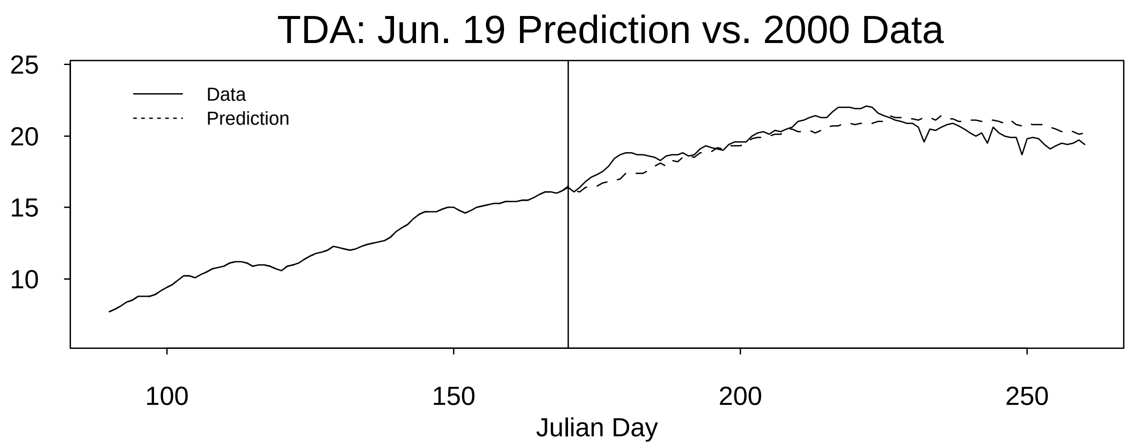


Figure G-2 Temperature predictions and observations for Priest Rapids Dam. Y axis is ˚C.





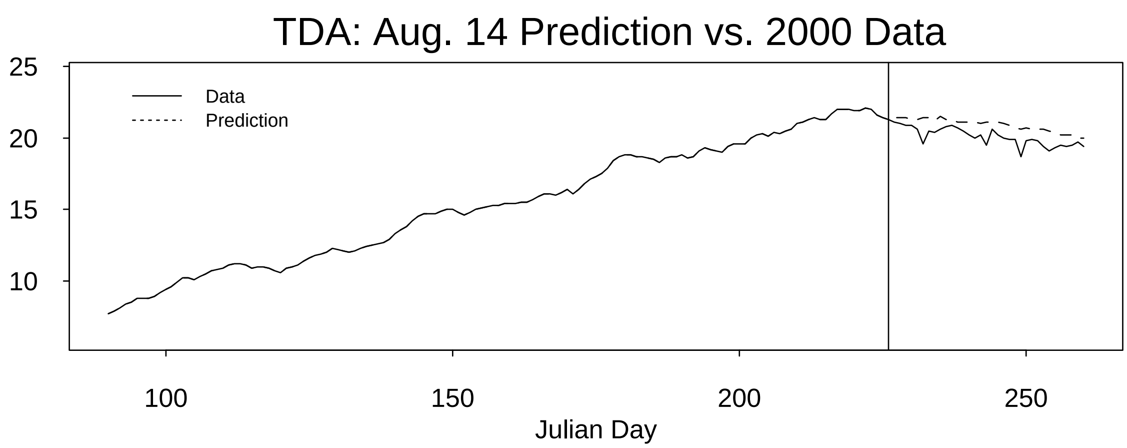


Figure G-3 Temperature predictions and observations for The Dalles Dam. Y axis is ˚C.

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 9).

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.

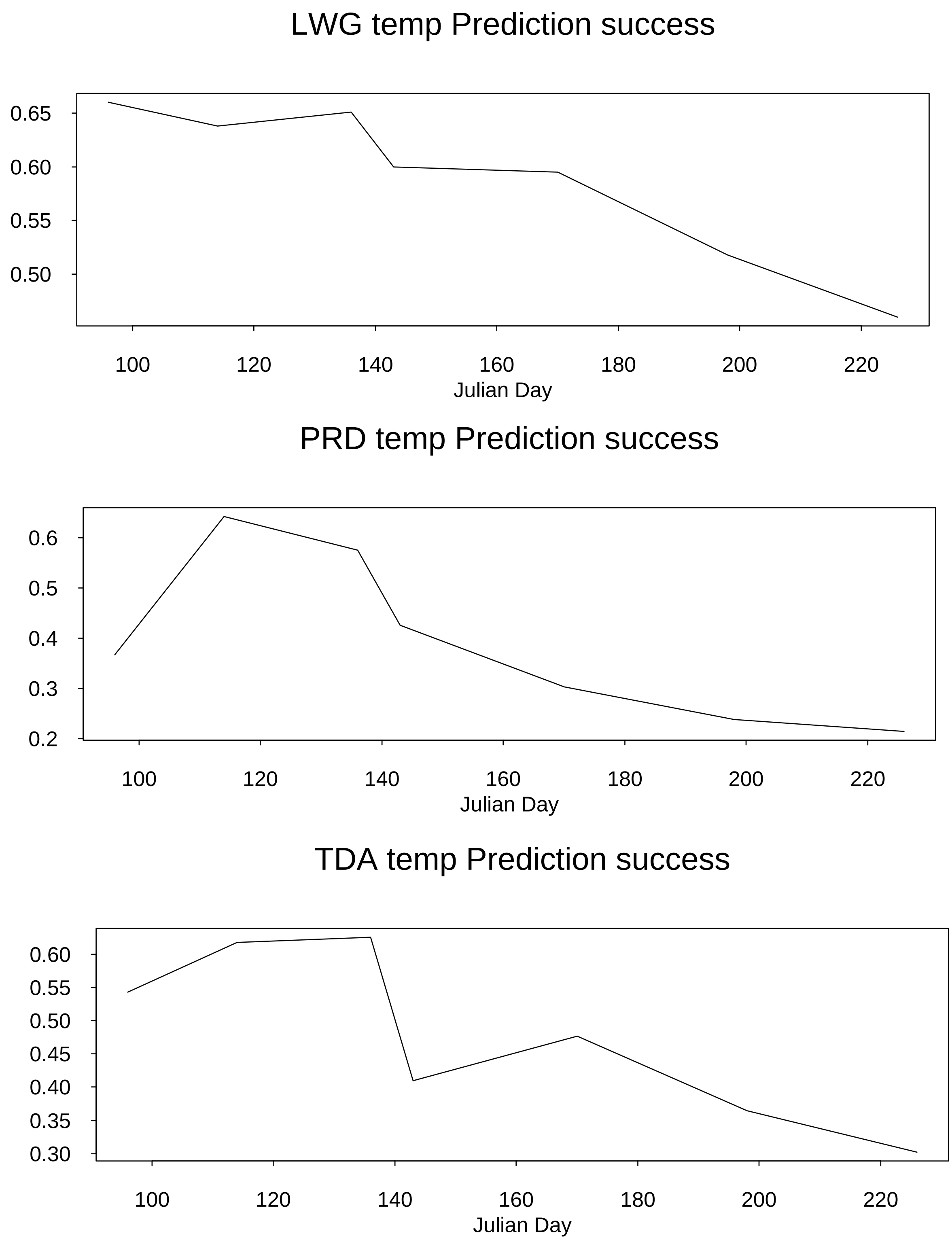


Figure H-1 Seasonal variation in temperature prediction success at three locations as measured by MAD (Y-axis).

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.

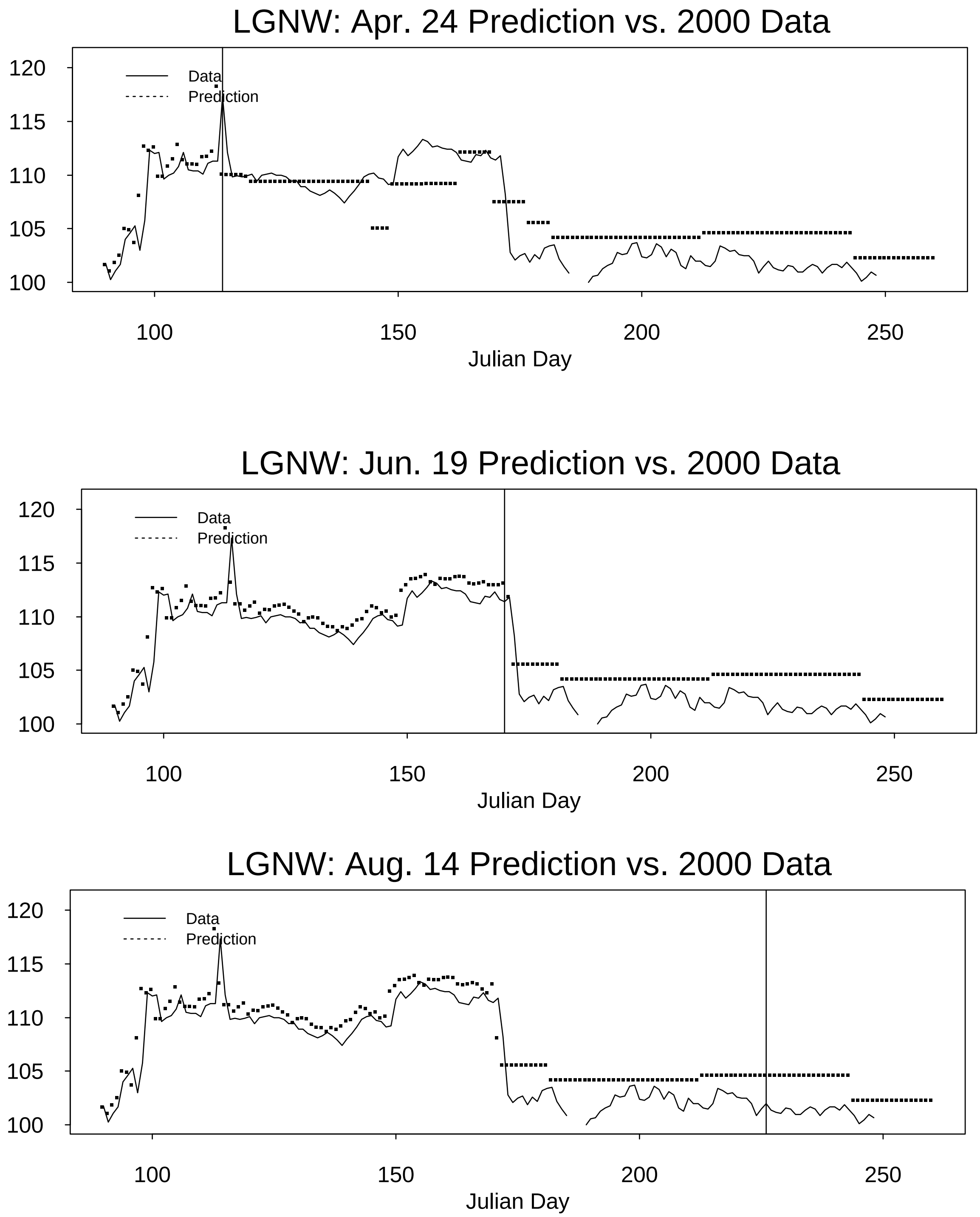


Figure I-1 Total Dissolved Gas predictions and observations for Lower Granite Dam as measured at LGNW. Y axis is the percent saturation.

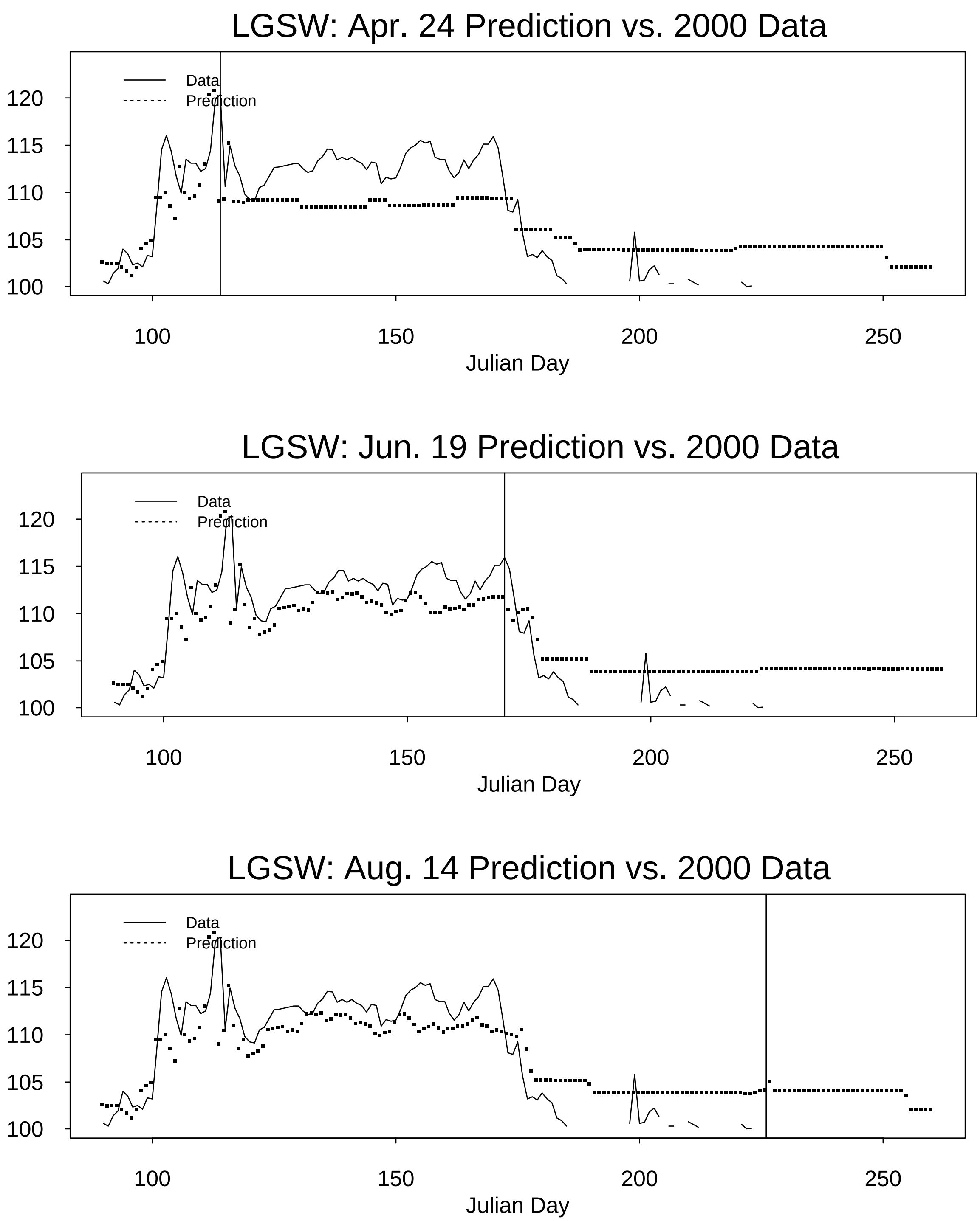


Figure I-2 Total Dissolved Gas predictions and observations for Little Goose Dam as measured at LGSW. Y axis is the percent saturation.

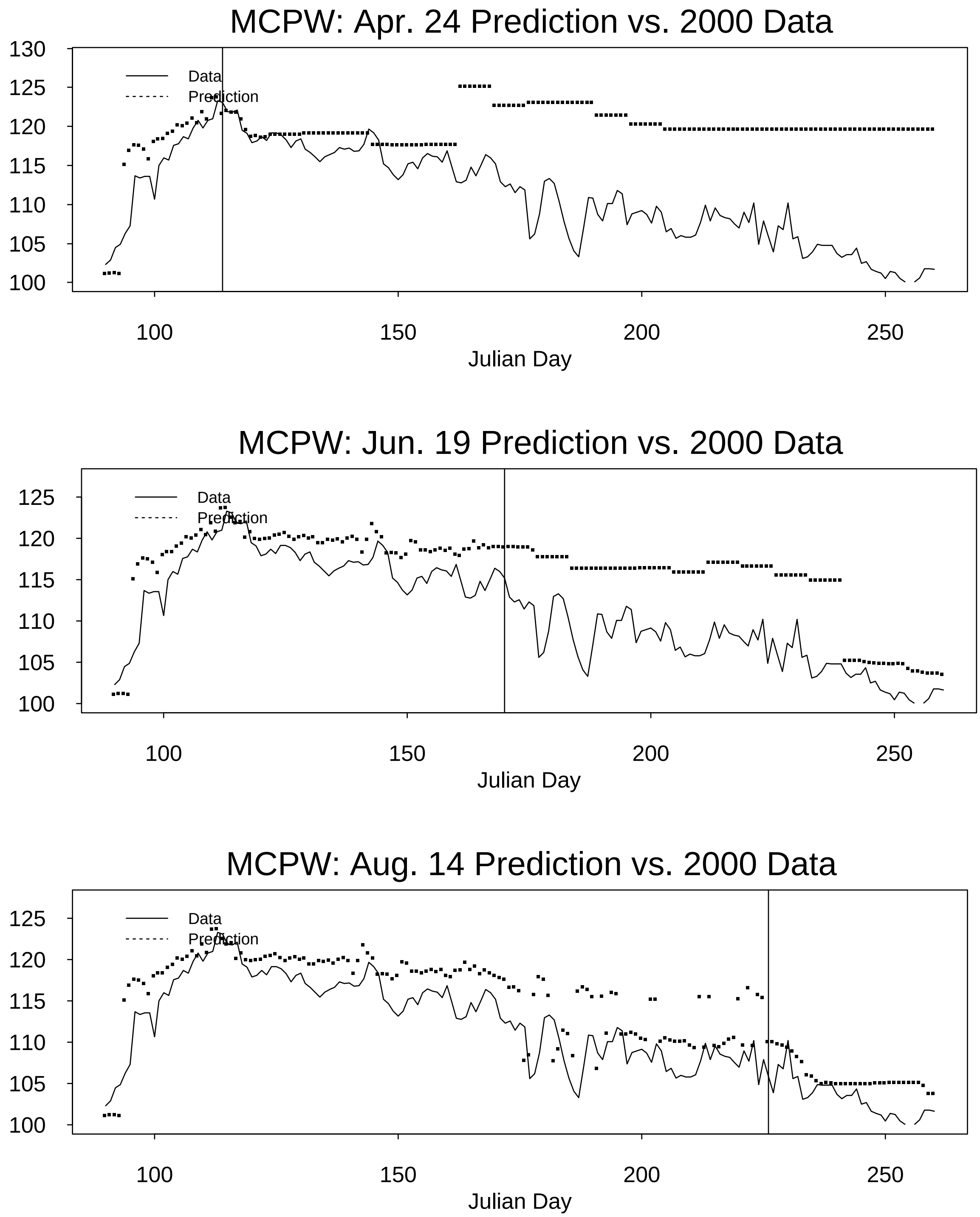
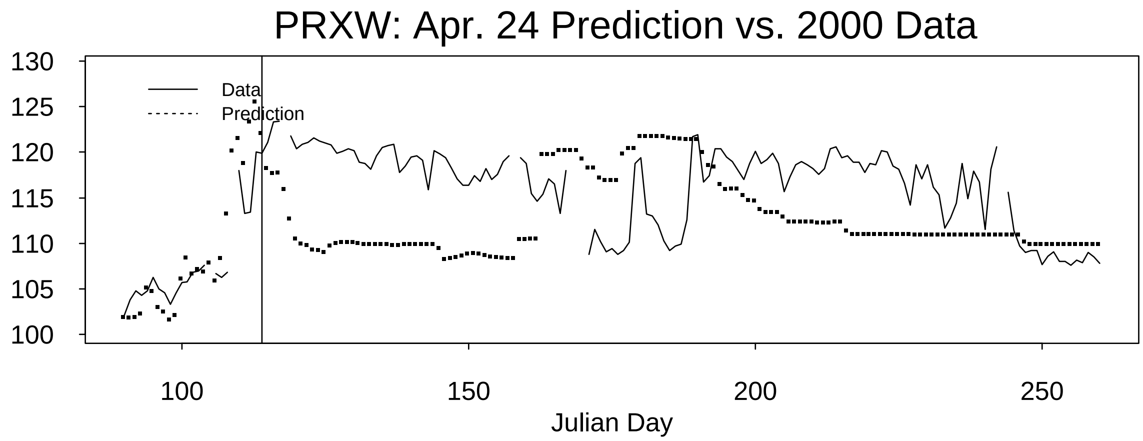
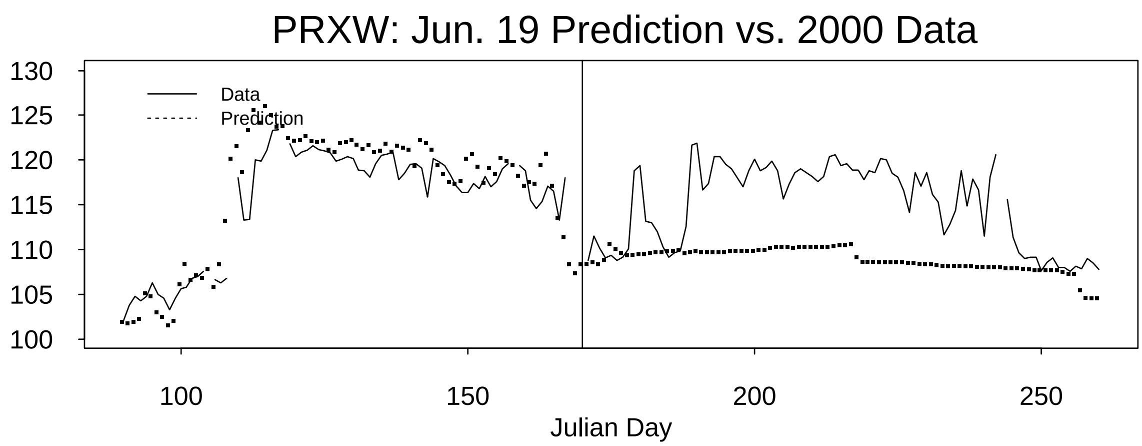


Figure I-3 Total Dissolved Gas predictions and observations for McNary Dam as measured at MCPW. Y axis is the percent saturation.





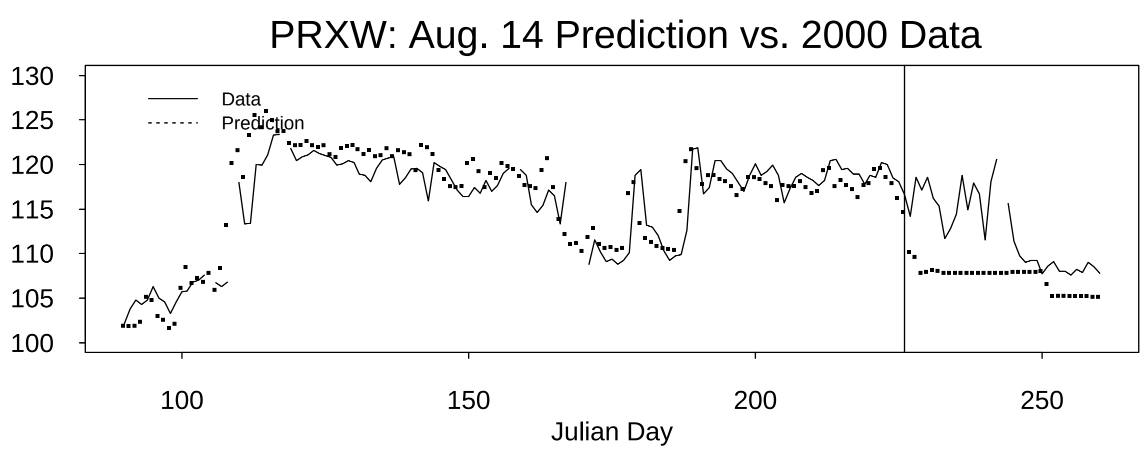
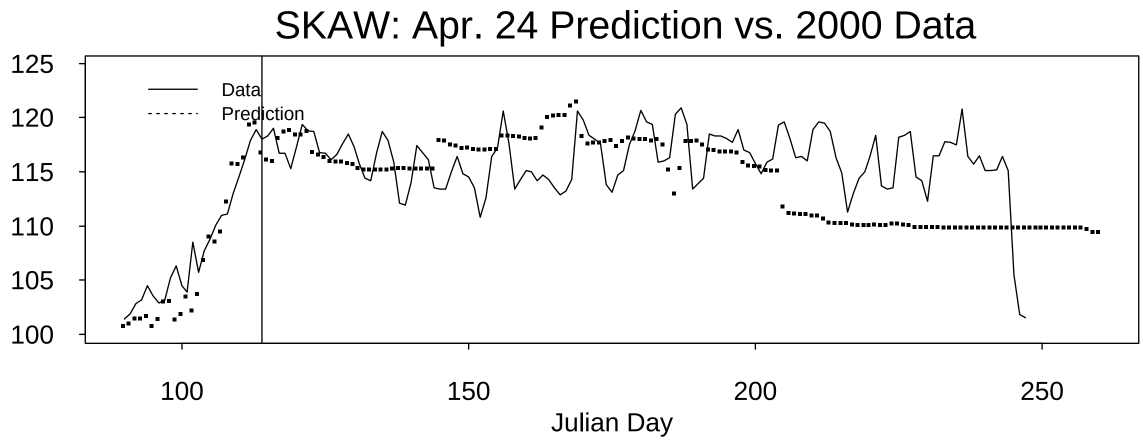
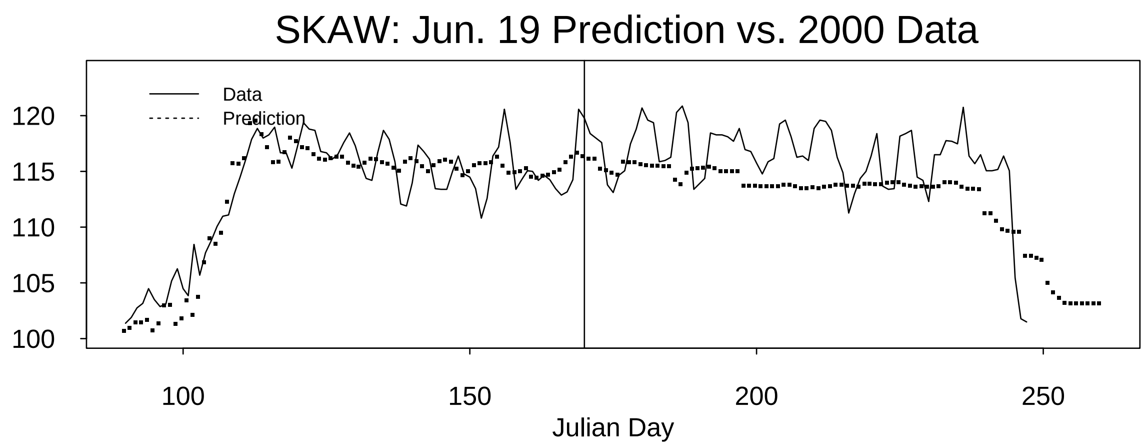


Figure I-4 Total Dissolved Gas predictions and observations for Priest Rapids Dam as measured at PRXW. Y axis is the percent saturation.





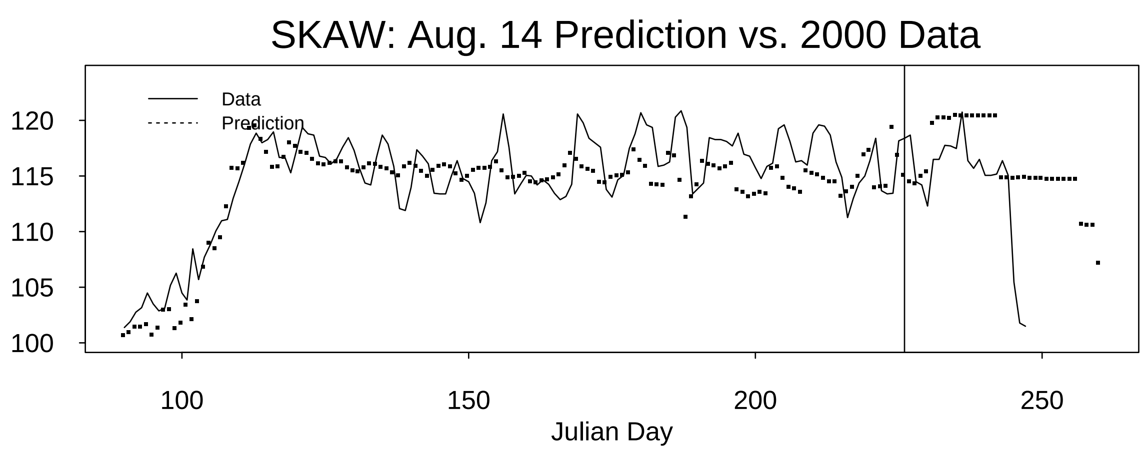


Figure I-5 Total Dissolved Gas predictions and observations for Bonneville Dam as measured at the SKAW site. Y axis is the percent saturation.

Appendix J Seasonal Variation in TDG Forecasts

Prediction success for Total Dissolved Gas throughout the season is show 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.

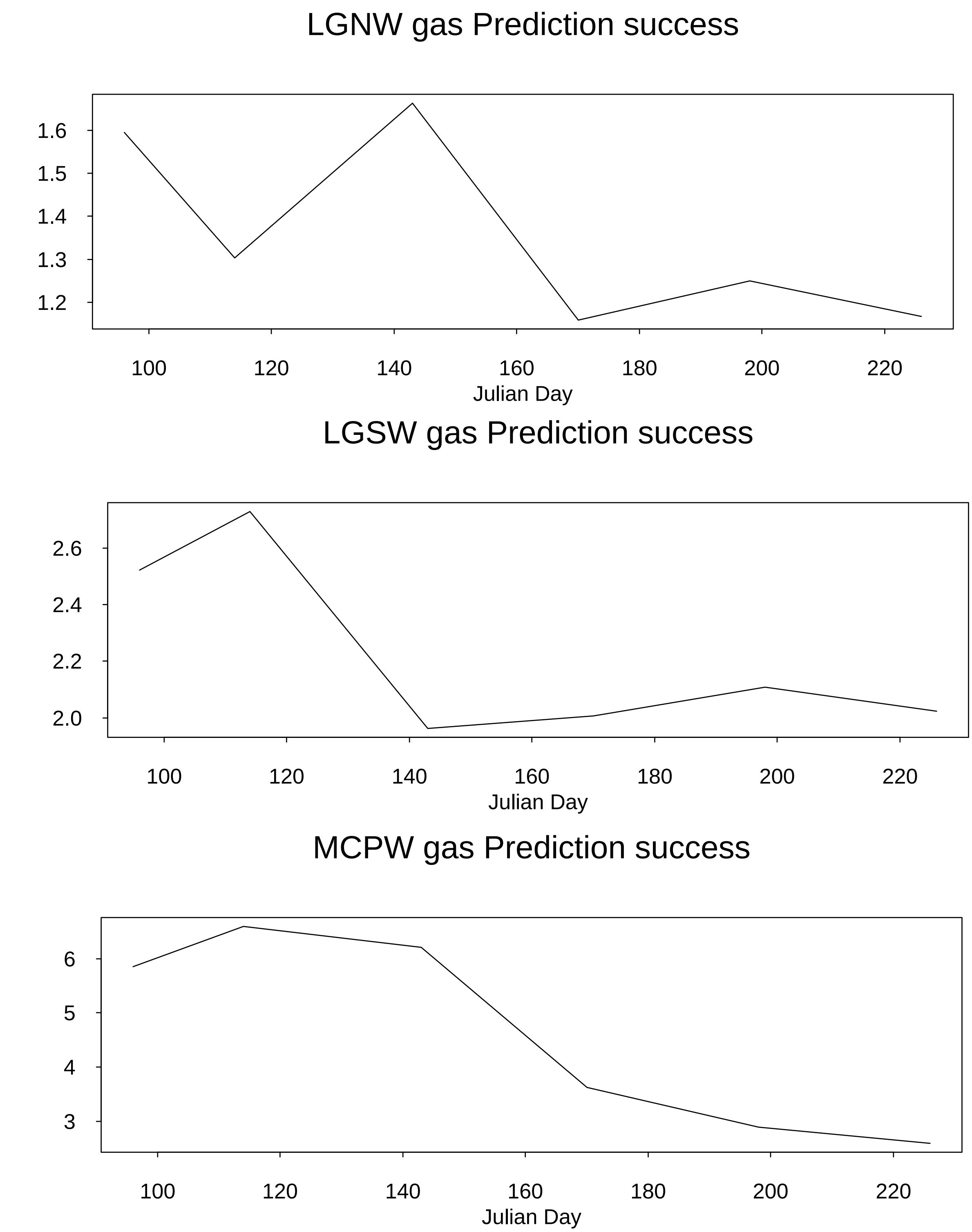
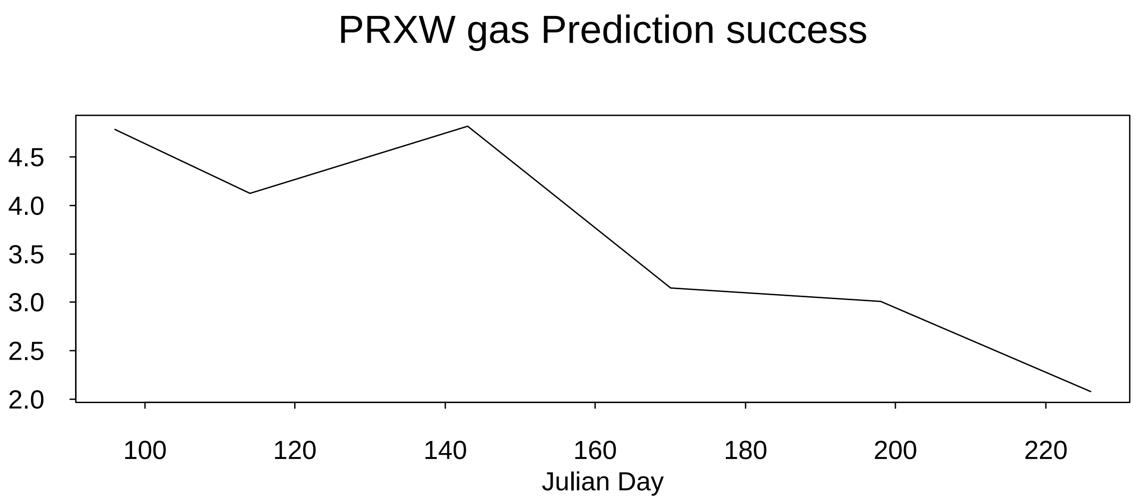


Figure J-1 Season variation in Total Dissolved Gas prediction at three monitoring sites below Lower Granite Dam, Little Goose Dam and McNary (top to bottom respectively).



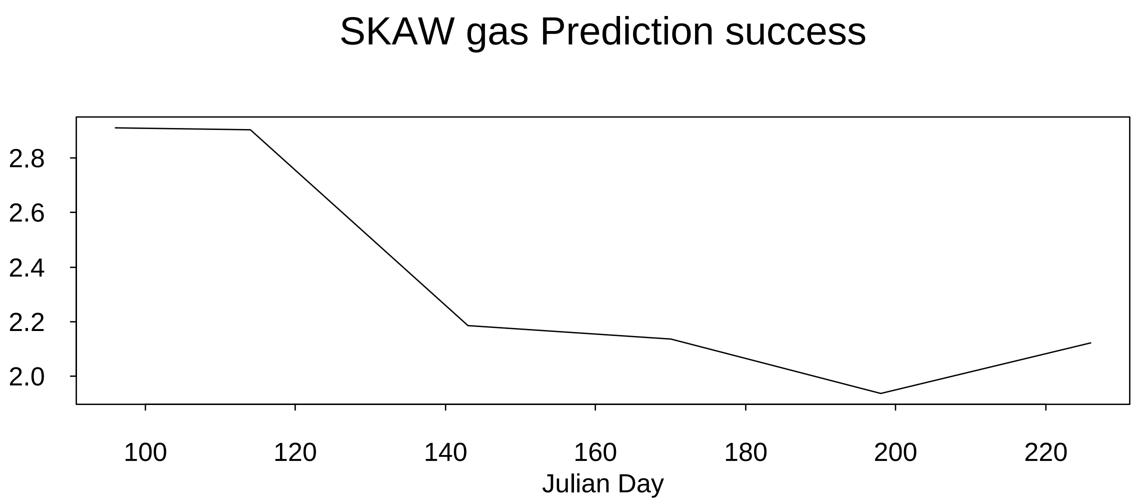


Figure J-2 Season variation in Total Dissolved Gas prediction at two monitoring sites below Priest Rapids Dam and Bonneville Dam (top to bottom respectively).