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METHODOLOGY FOR FLOW AND SALINITY ESTIMATES IN THE SACRAMENTO–SAN JOAQUIN DELTA AND SUISUN MARSH

EIGHTEENTH ANNUAL PROGRESS REPORT TO THE STATE WATER RESOURCES CONTROL BOARD in accordance with Water Right Decision 1485, Order 9

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1 Introduction

This is the eighteenth annual progress report of the California Department of Water Resources' San Francisco Bay–Delta Evaluation Program (Work Authority 1463), which is carried out by the Delta Modeling Section. It documents progress in the development and enhancement of the Section's computer models and reports the latest findings of studies conducted as part of the program.

The majority of effort in the last year was devoted to further development and calibration of DSM2, the new one–dimensional river, estuary, and land model. Work also continued with artificial neural networks used to estimate carriage water. A World Wide Web home page (`http://wwwdelmod.water.ca.gov`) was established to disseminate the work of the program.

This report was compiled and edited by Ralph Finch, under the direction of Francis Chung (program manager for the Bay–Delta Evaluation Program), with production assistance from Nikki Blomquist, under the direction of Nancy Ullrey. The Land Processes Module was written by Parviz Nader; the Sensitivity Analyses and Hydro Application sections were written by Susan Lee and Parviz Nader; and the Marginal Export Cost and MDO Replacement section was written by Nicky Sandhu and Don Wilson. The remaining sections were written by Ralph Finch.

2 DSM2 Model Development

The Delta Simulation Model 2 (DSM2) is a computer model of river, estuary, and land processes that are combined in a package of three main modules: Hydrodynamics (Hydro), water quality (Qual), and particle tracking (PTM). The three modules share a common input and output system, and hydrodynamic information from Hydro is passed to Qual and PTM via a Fortran binary file which contains instantaneous and time–averaged stage and flow data. The origins of the models are fully described in the Delta Modeling Section's 1993 *Annual Progress Report*. This chapter describes changes to and tests of the models during the last year, including source code modification, sensitivity analyses, calibration efforts, and application of the model.

Source Code Changes

Many code revisions, improvements, and corrections were done to DSM2 during the past year. While only significant modifications are summarized here, almost all changes are now being tracked in ChangeLog files, available through our WWW Home Page. Source code for all three modules, as well as Intel–NT and Sparc–Solaris executable binaries, are now available on the Home Page. The source code was improved to allow error–free compilation on both the Sparc–Solaris platform using Sun's Fortran 77 compiler, and the Intel–NT platform using Microsoft Fortran Powerstation.

All source code written by the Department, or heavily modified from the original version, is copyrighted by the Department, registered with the U. S. Copyright Office, and licensed with the Gnu's Not Unix General Public License (GNU GPL). This allows other interested parties to freely copy, modify, and redistribute the code, and receive payment for doing so. The GNU GPL prevents others from restricting the distribution of the code and keeps DSM2 freely available for use by all.

Input/Output System

Changes to the Input/Output system affect all three modules. While no new significant capability was added, errors were corrected to make the current I/O system more stable and accurate. Input is split into fixed input (that which does not vary with time), and time–varying input, which is stored in Data Storage System (DSS) files. Time–varying output can be written to text and DSS files.

Graphical User Interface

The Hydrologic Engineering Center Graphical User Interface (HECGUI) project is a collaboration between the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC), the California Department of Water Resources (DWR), and the Metropolitan Water District of Southern California (MWD). HEC is providing technical expertise and programming help, DWR is providing programming help and some financial aid, and MWD is assisting with substantial financial help to hire contract programmers and engineers. The goal is to develop a state–of–the–art graphical user interface to view and manipulate physical, chemical, and biological data stored in DSS files or relational databases. A contract was written and signed by HEC and MWD in the last quarter of 1996, for work to be performed in three phases over one year. Conceptual design was performed in the first quarter of 1997, and programming work on the first phase was started in the second quarter.

Intermediate products should be available throughout development, with the final product due at the end of 1997. The final product will be capable of examining a variety of measured and computed data—including stage, flow, precipitation, water quality concentrations, and biological parameters—using different plot types: time-series, scatter, contour, profile, and animations. Furthermore, it will be able to modify data to correct errors and set data quality flags. The majority of the GUI will be written in Java, a fairly new programming language specifically designed to be portable between different hardware and operating systems, and to be secure on the Web. This means that users should be able to view data from remote databases, as well as local databases, allowing easy collaboration between users.

Hydrodynamics Module (Hydro)

Apart from correcting errors and making minor improvements to the Hydro module, a significant change was made to the method for handling irregular cross sections in Hydro. The original method of dealing with irregular cross sections required each cross section in a channel to have the same number of layers, and interpolated in two directions during runtime. The new method allows any number of cross sections, with any number of layers; interpolates along the channel before runtime; checks for possible sources of error before the run; and uses output from the Bathymetry Data Display (BDD) program as its input. With the new system in place, the user will typically draw cross sections using the BDD and save the raw data to a file. A pre–processor converts the raw BDD data to another format readable by DSM2. DSM2 reads the irregular cross section data and assigns cross sections to channels. Rectangular cross sections are used in channels with insufficient irregular cross section data. Before the hydrodynamic time loop is started, intermediate ("virtual") cross sections are generated at computational points along the channel in Hydro by interpolating horizontally between actual cross sections. Then, during the run, the virtual cross sections are interpolated vertically using the calculated stage at each computational point.

Another change to Hydro and Qual allows head–difference flows, and pumping, between reservoirs. This change was needed to study CALFED alternatives.

Hydro source code was made publicly available via the Internet during May 1996.

Water Quality Module (Qual)

The significant advancements to Qual in the past year were the connection of the non–conservative constituent routines to the I/O system, and the addition of the capability to model multiple conservative constituents from different sources. At this time, Qual can simulate conservative constituents from different sources in a single run, and the following non–conservative constituents: water temperature, dissolved oxygen, organic nitrogen, ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, phosphate phosphorus, organic phosphorus, algae, and biochemical oxygen demand.

Qual source code was made publicly available via the Internet during November 1996.

Particle Tracking Module (PTM)

The Particle Tracking Module was completely rewritten last year in C++ for use in DSM2. The original PTM code was written in Fortran 77 for use in DSM1, the Fisher-based Delta simulation model. During the attempt to convert that code to DSM2, we realized a significant revision would be needed to connect to DSM2, improve clarity, and to remove errors. At that time, we decided to try object-oriented techniques in programming, which meant using a new computer language. Little new functionality is available beyond the first Fortran version, but because of the object-oriented approach, it should be much easier to add new functionality, such as reading water quality output from Qual and adding particle behavior based on flows or water quality.

After we rewrote the PTM in C++, a new object-oriented language named Java became popular and appears destined to become perhaps the most widely used object-oriented language. Java offers several advantages over C++. For example, there are no pointers, so learning the language is easier and memory errors are less common. Java offers built-in array bounds checking, which also helps to reduce memory-related errors. A Java program will run without change on many different computer platforms. It is Web-aware, which means it can easily be used across the Internet. Because of these advantages, the PTM may be rewritten in Java soon.

PTM source code was made publicly available via the Internet during December 1996.

Land Processes Module (DICU)

- Agricultural Return Flows

In 1995, a project was initiated to improve the Delta Island Consumptive Use (DICU) model and to develop a new model to estimate drainage water quality from Delta islands. This project was contracted out to Professor Kenneth K. Tanji from UC Davis. Details of this modeling activity are available in a report prepared by Professor Tanji and his student. The main focus of this study was to improve the physical representation of the interaction between the water bodies and the agricultural lands. The following is a brief summary of the assumptions and mathematical development of the proposed model.

Each island is divided into a three-compartment, water-flow pathway: root (soil) zone, shallow groundwater, and open drain. Seepage enters directly into shallow groundwater where it is partitioned into rising groundwater into the root zone, into open drains, and into storage in the shallow groundwater. Irrigation water is classified as surface and sub-surface. For surface irrigation, the root zone drainage and surface runoff act as inputs into the groundwater and the open drain, respectively. Subsurface irrigation water is routed directly into the root zone, and any excess water flows to the surface and is routed into open drains. Precipitation and leaching irrigation flow into the root zone, and any excess water from the root zone enters into the groundwater. Runoff from precipitation and leaching irrigation is routed directly into open drains.

For the salt–balance, the root zone is divided into four quartiles to account for the fact that roots of crops extract different amounts of water at different depths. Based on the various data available, it is assumed that about 40% of evapotranspiration (ET) is extracted from the top quartile, 30% from the second, 20% from the third, and 10% from the fourth quartile. During the simulation, the salt concentration for each quartile is calculated and updated. It is further assumed that each quartile has an independent interaction with the root zone. A parameter is introduced by the name Leaching Fraction (LF). Leaching Fraction has the opposite relationship to the Efficiency Factor used in the DICU Model. Thus, if in a given time period, 90% of the water in a given quartile is absorbed by the root (LF=0.1), its assigned salinity is increased by tenfold. This is done to model the build–up of salt in the soil layers. Based on the description offered in the report, the drainage salinity seems to be very sensitive to the value assigned to LF. This is probably an area which needs some modifications.

Applied water either enters from the top (surface irrigation) or from the bottom (subsurface irrigation) of the root zone. For surface irrigation, salt concentration of the water increases as the water travels from one quartile to next, leaving the highest salt concentration in the bottom. For subsurface irrigation, water enters from the bottom quartile and works its way up. In this case, the salt concentration has the opposite pattern with the highest concentration at the top.

The time step proposed for the model is one month (the same as DICU). During the simulation, the salt concentration of water and soil in each quartile is computed, taking into account all of the processes described above. The model was delivered to DWR in the form of a spreadsheet. The results of the model were compared to field data obtained during a study about corn's salt tolerance on Terminous Island in 1981. There are some instances where the model shows fairly good agreement with the field data, and some where the results differed greatly. One reason for the discrepancy may be that the model seems to be highly sensitive to assumptions for LF.

- Dissolved Organic Carbon (DOC) Production Model

An initial attempt was made to develop a model to simulate the DOC production in Delta soils. There is only limited data available from a current USGS–DWR study. These data were collected during flooded conditions. More comprehensive data are needed to fully test and calibrate the model. The proposed model is based on a first–order rate equation. The magnitude of the rate coefficient was estimated to be about 1.16 mg/l per month. Professor Tanji explains that decomposition of organic matter in soil is dependent upon temperature, but it is not included in the mathematical formulation for this initial development. The best match with the data was found when the rate coefficient was set to 0.5, which was different from the laboratory–estimated value. Professor Tanji explains that more data for DOC concentrations within the soil profile are necessary to extend this model beyond winter leaching conditions.

DSM2 Calibration and Verification

Hydro

Calibration of DSM2 began with the Hydro module. First we identified the times when various Ultrasonic Velocity Meter (UVM) flow measurement devices were operational, and when the various barriers and gates in the Delta were operating (Tables 2–1a, b, and c). Then, based on that information, we developed four different periods to run Hydro: May 1988, December 1992–January 1993, May–July 1994, and October 1994. These periods allow us to calibrate and verify the flows and stages during a variety of flow conditions and gate positions.

There are three main areas of importance in the Delta that have UVM flow meters installed: the North Delta around Steamboat/Sutter Sloughs, the Cross Channel, and Georgiana Slough; Three Mile Slough and Jersey Point; and central Delta flow through Old and Middle Rivers. Data from a fourth area, the San Joaquin River near Stockton, was not available when calibration began. Also, further flow comparisons around the Delta can be made from May 1988 tidal cycle measurements.

When sufficient data are available (i.e. several days of continuous UVM measurements), we believe it is important to show residual flow comparisons, as well as instantaneous flow comparisons. Residual flows can be computed by taking a moving average of about one tide cycle or multiple of tide cycles, which are about 25 hours in length. Residual flows are important to show long–term flow affects on salinity, which are not evident in instantaneous flow plots.

Stages can be important to show how tidal energy, as evidenced by stage amplitude, is carried from the downstream boundary landward through the Delta. Absolute comparison of stage measurements between observed and computed data is probably less important because of uncertainties in the historical datum used when collecting stage measurements.

Results for flow comparisons are shown in Figures 2–1 to 2–27, and stage amplitude comparisons in 2–28 to 2–30.

Qual

After this first stage of calibrating Hydro based only on flow data, we started using Qual. A fairly short (6 month) run was set up using real tides from Hydro, as well as a 23 year period, using the 19–year mean stage and monthly averaged hydrologies. The real tide run period, January through July of 1992, was chosen to see how the model reacted to an initial low flow/high salinity condition, followed by high flows, then decreasing flows and increasing salinities. The multiple year run tests the model over a wide variety of hydrologic conditions in a mode similar to that used for planning studies.

It was evident during this second phase of calibration that the use of Qual provides very important feedback to Hydro. Ideally, before calibrating Qual, Hydro would be fully calibrated using only flow and stage data, and the only adjustments made to Qual would be in the dispersion coefficients. In practice, information from Qual must be used to change parameters in Hydro because of the lack of complete flow data.

A fundamental problem was noticed in DSM2 that also exists in the Section's current Delta model, DSM1. When Manning's n values are such that stage amplitude at Martinez, the downstream boundary, is carried upstream in a manner similar to observed amplitude, far too much salt is moved into the Suisun Bay area. This results in approximately correct salt concentrations in the lower Sacramento River, and too high concentrations in the San Joaquin River and central Delta. On the other hand, when amplitudes are dampened with higher Manning's n values in the Western Delta, then the Suisun Bay, lower San Joaquin, and central Delta salinities are correct, but lower Sacramento salinities are far too low.

We conducted several experiments with different parameters to find a controlling factor to correct this problem. We tried changing the volume in rectangular and irregular channels, adjusting the flow coefficients into and out of reservoirs, and changing the datum of the downstream forced stage at Martinez. None of these tests had a significant effect in correcting the problem noted above.

Therefore, in this first major phase of calibration of DSM2, we decided to split the difference in error between the Suisun Bay and lower Sacramento. Manning's n was increased slightly in channels in the Suisun Bay and dispersion set to zero. In the lower Sacramento River, Manning's n values were decreased and dispersion increased in an attempt to move salt upstream. In the San Joaquin River, only dispersion was adjusted. This results in too high salinities in the Suisun Bay/Western Delta, too low salinities in the lower Sacramento, and about correct salinities in the San Joaquin River and central Delta.

Comparison plots between DSM2 and observed data are in figures 2–31 to 2–36 for real tide runs, and figures 2–37 to 2–42 for 20 year runs with a 19–year mean tide and monthly hydrologies. Neither the Andrus Island levee break of 1972 nor the 1976–1977 drought are fully modeled, and thus will show a significant discrepancy from observed data.

Summary of Calibration and Verification

Important findings during the calibration and verification process were:

- **Channel bathymetry (cross section geometry) at some locations can significantly impact flow and salinity results**. For instance, simply changing one cross section in Three Mile Slough can change net tidal flow by 2,000 cfs. However, at other locations (such as the Suisun Bay region), channel geometry changes had little effect. Figure 2–43 shows the averaged cross sections chosen for Three Mile Slough, and Figure 2–44 shows the change in the cross section at the Sacramento River end. Two runs were done with the two different sets of cross sections. While instantaneous flows seem to differ very little in the slough and in the San Joaquin River at Jersey Point (Figure 2–45), the change in residual flow is more significant (Figure 2–46). This is also evident in the salinity at Jersey Point, though little change is noted at nearby stations (Figure 2–47).

- **The model shows significant sensitivity to Manning's *n*.** This may indicate that a more sophisticated Manning's *n* calculation should be used in the computations.

At this time, DSM2 may have reached the limits of the accuracy of the input data. While further calibration could be done, it might result in the model producing "correct" answers for the wrong reasons.

Based on these observations, we recommend the following:

- **Resurvey the Delta channel bathymetry**, starting with the more important channels with the oldest or most doubtful data, such as Three Mile Slough and the Sacramento River.
- **Investigate a more sophisticated approach to Manning's *n***, for instance, perhaps it should vary as a function of depth.
- **The baroclinic term** (density of water as a function of salt concentration) should be turned on in Hydro and studies performed to see whether this would alleviate some of the difficulties in achieving the proper stage amplitude and salinity.
- **Errors in time-series measurements** should be investigated to see how representative a point measurement is of salinity in the entire channel cross section.

After the above tasks are completed, it would be appropriate to conduct a second calibration, which would incorporate accurate geometry, and possibly more accurate treatment of channel roughness and water density, as described above. This should result in a model that probably is near the capabilities of a one-dimensional formulation.

Sensitivity Analyses

We tested the model to check the sensitivity of DSM2 (both Hydro and Qual) to changes in some of the basic input parameters. The goal of this testing was to determine what values (or range of values) should be assigned to each parameter and to ensure that the model response is fairly stable with respect to changes in those parameters. In addition, some further tests were done to ensure the validity of the model results.

Hydro

The following is a list of input parameters which was used in the testing. All of these parameters are part of a group called SCALARS, which can be easily modified by the user.

- DELTAX

DELTAX (Δx) is the distance between two successive computational points within a channel. Each channel has at least three computational points, one at each end and one at mid-channel, but some channels may have more than three, depending on their length. The momentum and continuity equations are discretized at the computational points using a finite-difference scheme. A small value for DELTAX will lead to a more accurate discretization (in most cases) but it comes at a cost of longer run time. The object of this testing was to find an optimum value. In Hydro, the user can specify one value for DELTAX, but the actual DELTAX used by the model may be different in each channel because of the requirement that all the computational points be separated by an equal distance. For example, if the user selects a DELTAX of 5,000 feet, and a particular channel is 11,000 feet long, then a DELTAX of 5,500 feet will be assigned to this channel. Therefore, the actual value of DELTAX can vary from one channel to another.

The model was tested using three values of DELTAX equal to the channel length, 5,000 feet, and 2,500 feet.

Flow and stage were compared at various locations in the Delta. The model response was very similar for all the runs. There was only a small difference in results between the first and second tests (DELTAX of channel length and 5,000 feet) and practically no difference in the results of the second and third tests (DELTAX of 5,000 feet and 2,500 feet). Test 2 took about 11 percent higher CPU time than test 1, but test 3 took about 92 percent higher CPU time than test 1. Based on accuracy and speed, the conclusion was to use DELTAX of 5,000 feet.

- Time step

The time step was tested at 3, 5, and 10 minutes, with all the other input parameters set at standard values. The run length was set to 25 hours. There were very small differences observed during the first 4 hours, but after that the results did not vary much. Because of the need to output a tidefile every 15 or 60 minutes, and also because of the possibility that the model might be used in cases where more transient situations may be encountered, it was decided to use a time step of 5 minutes.

- MAXITER

MAXITER is the maximum number of iterations allowed per time step. Two tests were conducted using a maximum of 10 and 15 iterations. All other input parameters were standard values. The run length was 25 hours. Results did not vary by much and the amount of CPU time was about the same. This suggests that MAXITER of both 10 and 15 provide good results, but a MAXITER of 15 may give the user slightly more accurate results.

- THETA

THETA is the time-weighting parameter used in the discretization of momentum and continuity. At first glance it seems that a value of THETA equal to 0.5 (trapezoidal rule) may be the most accurate. However, as Lew Delong (author of the original FourPoint model) points out, a value of 0.5 may lead to instability. Lew Delong has suggested a value of 0.6 for THETA. However, it is believed that a value of THETA greater than 0.5 may dampen the response in a four-point finite-difference scheme. Three tests were conducted, with THETA values set to 0.55, 0.6, and 0.75. The run length was set to 25 hours. During the first few hours, there were some small differences observed, but after that there was no difference. Based on this experiment, it is suggested that a value of 0.6 be used for THETA. Because there is little difference between results for

THETA of 0.55 and 0.75, it may be safe to state that dampening the response may not be a problem.

- TOLERANCEQ/TOLERANCEZ

TOLERANCEQ and TOLERANCEZ specify the closure criteria for discharge and water–surface elevation, respectively. In other words, they are the maximum errors allowed between two successive iterations to satisfy convergence. Three tests were conducted with the following combinations:

	Run A	**Run B**	**Run C**
TOLERANCEQ	0.2	0.3	0.5
TOLERANCEZ	0.001	0.005	0.01

All other input parameters were standard values. The run length was 25 hours. The results did not show any noticeable differences among the three tolerance combinations, and there was only a little difference between the CPU time. TOLERANCEQ of 0.2 and TOLERANCEZ of 0.001 remained the standard.

- LUINC

Hydro has to solve a set of simultaneous equations for every time–step and every iteration. But this is a time–consuming operation. LUINC controls how often the right–hand side of the matrix is updated. Every time this matrix is updated, the model has to perform a process called forward elimination, which is very CPU intensive. So in theory, a value of LUINC of 1 gives the highest accuracy but also the highest CPU time. Two tests were conducted with values of LUINC set at 1 and 4. All other input parameters were standard values. The run length was 25 hours. No differences in the flow and stage at selected channels were observed between two LUINC values. A LUINC of 4 remained the standard.

- Pulse Flows

The effect of a one hour pulse of flow from the Sacramento and San Joaquin rivers was examined. The flow was suddenly raised to a high value and, after one hour, the flow was set to zero. The tide at Benicia was set to a constant stage. All inflows into and diversions from the Delta were set to zero. The results showed that the flows gradually damped out to zero and, after some fluctuations, the stage stayed constant at the tide level at Benicia.

- Numerical Precision

Currently, most of the variables used in Hydro are single precision numbers. Because of the high number of simultaneous equations involved, numerical precision could become a potential problem, which may require the use of double precision variables. However, that solution is very undesirable, because it will double the memory requirement and may increase the CPU time accordingly.

Two tests were conducted of the single precision variables. In the both tests, all the parameters were set to standard levels. In the first test, channels numbered in a standard manner so as to reduce array sizes. In the second test, the channels were renumbered randomly, thus changing the order in which the computations were taking place. In theory, if numerical precision is a problem, then the results would be somewhat different if the order of the computations is changed. The tests showed only a very small difference. The maximum difference observed was about 0.04%, thus suggesting that the use of double precision variables is not justified.

Qual

Three sensitivity tests were applied to Qual: time step, Hydro tide output interval in relation to Qual time step, and maximum number of parcels within a channel.

- Time step

The time step was tested at 5, 10, 15, and 30 minutes with the tide output interval set at 30 minutes. All other input parameters were set at standard values. The run length was 8 days. The results showed that the difference between the first three runs (5, 10, and 15 minutes) is fairly small (about 1 percent), but the results for the 30 minute time step showed a noticeably bigger difference. Based on the above results, a Qual time step of 15 minutes is recommended.

- Hydro Tide Output Interval

The Qual time step was fixed at 15 minutes, while the tide output interval was set to 15, 30, and 60 minutes. The tide output interval controls how often hydrodynamic results are stored in the binary tide file. DSM1 is currently using 1 hour tide intervals. All other input parameters were set at standard values with a run length of 8 days. The results showed small differences, but no trends were observed. It is assumed that a tidefile interval of 15 minutes is more accurate, but that accuracy comes at a cost of much bigger files. For example, the sizes of the binary tidefiles for an 8 day run were 11.7 MB and 2.9 MB for tidefile intervals of 15 minutes and 60 minutes, respectively. For a short duration model run (two to three weeks), it may be satisfactory to use a 15 minute tide interval, but for longer periods, a higher number is suggested. For a model run exceeding a few months, the use of a 60 minute tide interval is recommended.

- Maximum Number of Parcels in a Channel

Qual is based on a Lagrangian coordinate system. Each channel is divided into a series of parcels. During each time step, parcels are added and removed at each end of a channel. The model has the capability to set a maximum number of parcels within a channel. Four tests were conducted with the maximum number of parcels set at 10, 16, 22, and 30. All other input parameters were set at standard values. The run length was 8 days. The results for runs with a maximum number of parcels of 16 and 22 were within 2 percent of the run with a maximum number of parcels of 30, but the run based on maximum number of parcels equal to 10 showed a bigger difference. Since the CPU time between 16 and 22 parcels varied by less than 5 percent, the maximum channel parcel of 22 remained standard.

Hydro Application

In March, 1997, six preliminary Delta alternatives, as described in CALFED Bay-Delta Program Draft Delta Conveyance and Storage Component dated January 30, 1997, were analyzed using DWR's Delta Simulation Model (DSM1). The results of this study were later published and presented in CALFED's Storage and Conveyance Workshop on March 20, 1997.

In April 1997, the Delta Modeling Section repeated the simulation of five of the six alternatives using Hydro (the Chain of Lakes alternative was not simulated). The time period for the simulation was April–May 1989. Both DSM1 and Hydro used daily varying flow input, and daily varying tide at the downstream boundary (Martinez). The descriptions of the five alternatives are summarized in Table 2–2.

Table 2–2. Summary of Five CALFED Alternatives

Alternative	Description
Base	Existing Delta conditions.
Interim South Delta Plan (ISDP)	Base plus flow control and fish control structures, and enlargement of a portion of Old River.
North Delta Plan (NDP)	ISDP plus additional Cross Channel Gates; widened Cross Channel; and enlargement of portions of Snodgrass Slough, Dead Horse Cut, and North and South forks of Mokelumne River.
North Delta Plan with Hood Diversion (NDPH)	NDP plus 5,000 cfs diversion at Hood, enlargement of Snodgrass Slough extended upstream, and Cross Channel width reverts back to existing condition.
California Urban Water Agencies (CUWA)	ISDP plus Clifton Court intake on Italian Slough; enlargement of sections of Italian Slough; Tyler Island conveyance; and open water areas in the interior and east Delta.

Channel Geometry

All of the alternatives, except for the base case, involved enlarging certain channels in the Delta, by widening and/or dredging a specified amount. The changes in geometry for DSM1 were fairly straightforward, since DSM1 is based on rectangular cross sections. However, Hydro is capable of simulating irregular cross sections and non–prismatic channels. The base case geometry has been developed using a database of hundreds of thousands of data points to capture the conditions in the field. To make the dredgings more realistic, a procedure similar to the one used by ISPD in Old River was followed. The following basic guidelines were used in the dredging:

- Only the middle two–thirds of the channel can be dredged.
- A maximum slope of 3:1 was to be maintained at all the areas which were to be dredged or widened.

The geometry for the CUWA alternative has been developed by Metropolitan Water District based on the DSM1 Suisun Marsh version. To maintain consistency between the alternatives for the DSM2 model run, the additional channels and nodes in the

Suisun Marsh area and differences in Manning's coefficient due to MWD's input data were ignored. Furthermore, it was assumed that Tyler Island is basically flat, so that rectangular cross sections could be used for making the island into a through-Delta conveyance.

Discussion of Results

Figures 2–48 through 2–55 show DSM1 generated flows. Figures 2–56 through 2–63 show the corresponding Hydro results. Each figure shows the maximum seaward, maximum landward, and daily residual flows for all five alternatives at the given location. Almost all of the plots indicate that Hydro's results are very consistent with those of DSM1, including the variations of daily flow patterns for all the alternatives.

In general, Hydro's results indicate the same trends as those of DSM1, with the CUWA alternative causing the highest incremental changes at most locations (compared to base condition). This is not surprising because the CUWA alternative requires the biggest changes in geometry. Table 2–3 provides a summary of the flow results at each location. The numbers in parentheses are the channel numbers used in DSM1 and Hydro.

Table 2–3. Comparison of Hydro Results to DSM1 at Eight Delta Locations

Location	Results
QWEST	About the same daily flow range and incremental response for all the alternatives.
Chipps Island (437)	Same daily flow range and incremental change for all alternatives.
Lower Old River at SJR (124)	Higher flows, but about the same incremental response for all the alternatives, except for CUWA, which indicates an opposite incremental change. See discussion below.
Lower Middle River at SJR (161)	About the same daily flow range, and same incremental response for all the alternatives.
Columbia Cut (160)	Lower seaward and higher landward flow; lower incremental difference for all the alternatives, except for CUWA, which showed a slightly higher incremental difference.
Turner Cut (172)	Slightly higher seaward and landward flow, about the same residual and incremental response for all the alternatives, except CUWA, which showed an opposite incremental response. See discussion below.
Old River at Santa Fe RR (96)	Same daily flow range, and about the same incremental response for all the alternatives.
Middle River at Santa Fe RR (143)	Higher seaward and landward flow; about the same residual and incremental response for all the alternatives.

Hydro Application Summary

- Based on the assumptions about hydrology and the changes in geometry, the overall trends and conclusions are unaffected by the use of Hydro.
- Most of the differences between the results of the two models can be attributed to the differences in the base case geometry. DSM1 uses rectangular, prismatic channels. In contrast, DSM2 uses updated bathymetry data and can handle irregular cross sections and non-prismatic channels.
- Because of the differences in geometry, the amount of dredging or widening to meet a criterion could be potentially different for the two models. In the extreme case, in certain parts of Old River the CUWA enlargement requirements called for increases in channel dimensions in DSM1, but Hydro suggested that base case geometry already met the criteria. This inconsistency is easily seen in Figures 2-50 and 2-58, where DSM1 points to an increase in flow in Lower Old River for CUWA Alternative, but Hydro shows an opposite reaction. This example clearly illustrates the importance of having the correct channel dimensions for the base case to ensure the proper response by the model.

Future Directions

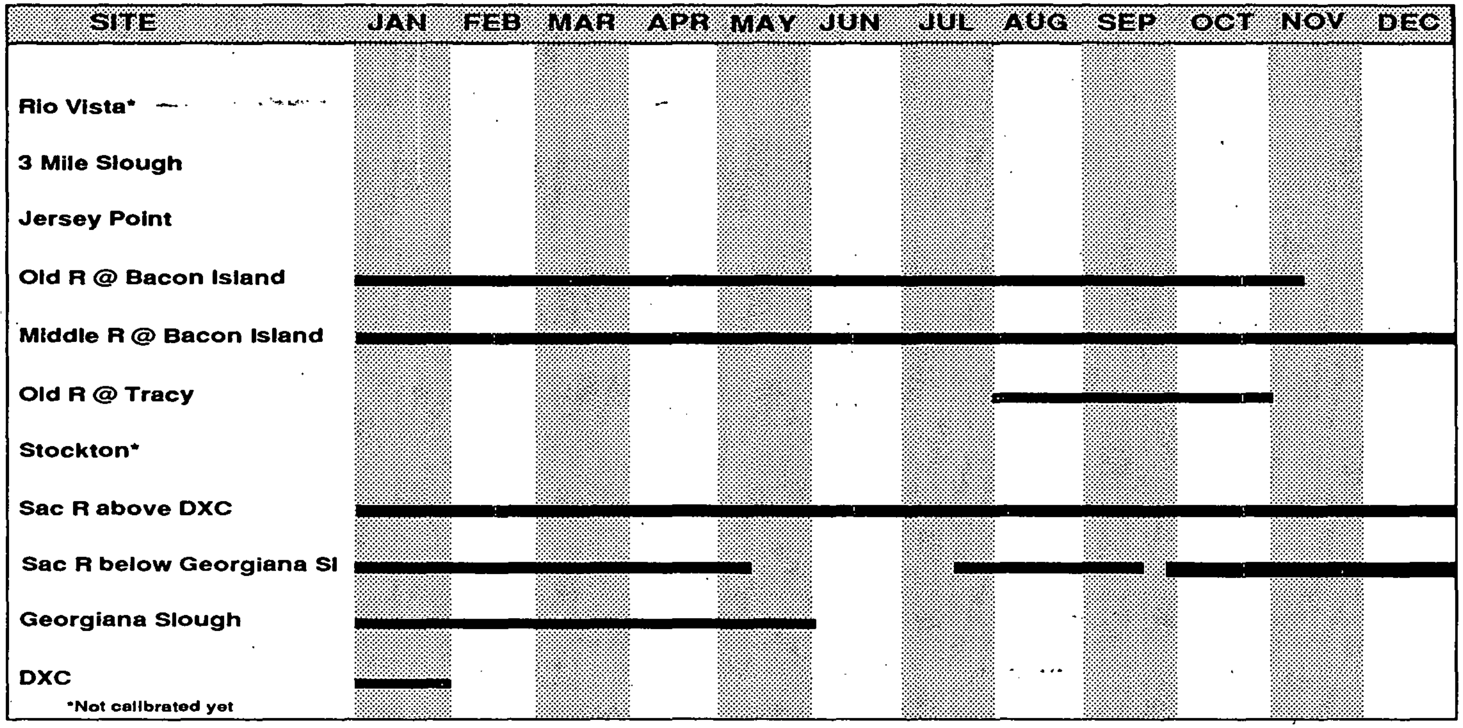
Many projects and tasks are planned for DSM2; these are usually listed in our home page at `http://wwwdelmod/docs/dsm2/dsm2.html#Future Directions`. Some of the more important tasks are listed here.

- **Adopt the Interagency Ecological Program (IEP) data naming convention.** Currently DSM2 input and output labels follow the Delta Modeling Section's convention. It would be advantageous to convert to the IEP naming convention for time-series data, as formulated by the Delta Modeling Section and the Environmental Services Office. This would allow access to the IEP historical data on the IEP web server.
- **Write manuals for theory, programmers, and users.** This would allow others to more easily understand, modify, and use DSM2.
- **Convert Hydro and Qual to a more object-oriented treatment of nodes and water bodies.** This would allow any number of sources and sinks at nodes, and a more generalized connection of time-varying values to locations.
- **Implement miscellaneous code changes** such as better runtime informative messages and input checking, checks for reasonable parameter values, and coherent error messages.
- **Convert to Fortran 90.** Hydro and Qual are written in Fortran 77 with a nonstandard use of structures to organize input and output data. Most, but not all, Fortran 77 compilers support structures. By using Fortran 90, we would be able to retain modern methods of organizing and structuring the code and data, while using a completely standard language. Also, most Fortran compiler manufacturers

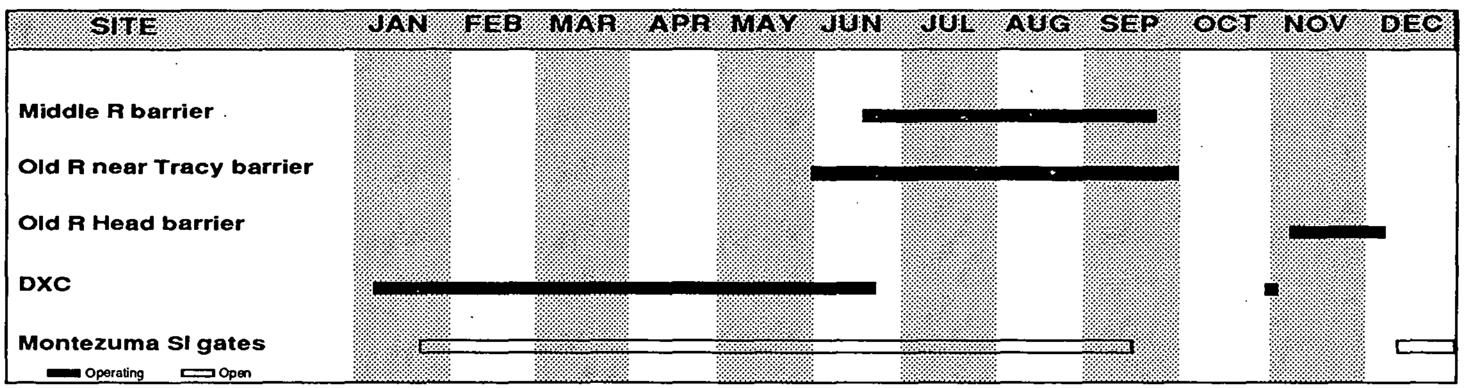
will be devoting their efforts in the future to improving their Fortran 90 compilers, and Fortran 77 will probably not be supported in the future.

- **Extend the upstream and downstream boundaries** to Shasta Dam and the Golden Gate respectively, and implement the operation of duck clubs in the Suisun Marsh.
- **Create a binary file output from Qual** for use in the PTM for simulating fish behavior.
- **Investigate techniques to speed up the models** (particularly Hydro) perhaps using parallelization.
- **Develop modern downstream stage and salinity generators,** based on artificial neural networks or other nonlinear techniques that can incorporate the effects of flow, wind, and atmospheric pressure.

1993
DWR & USGS 15 MINUTE FLOW DATA



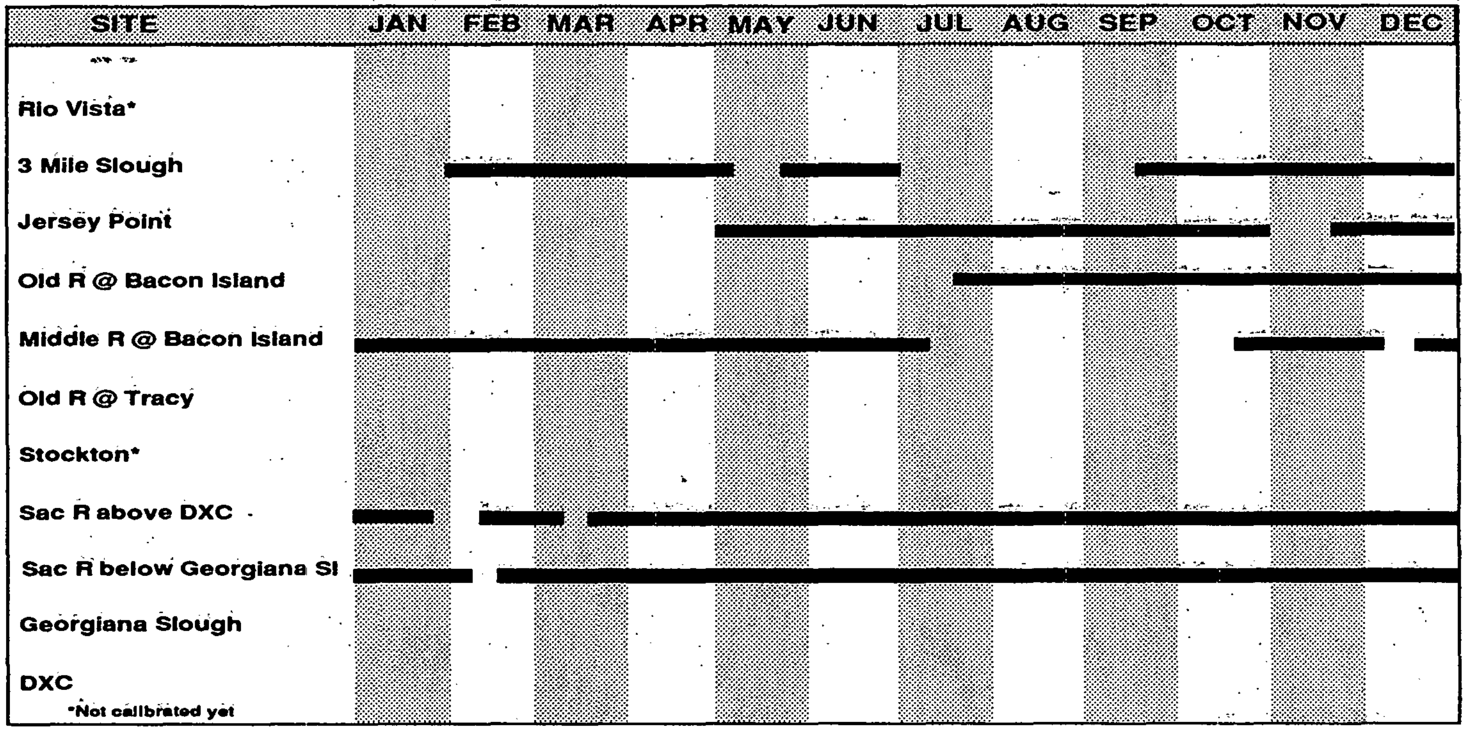
GATE OPERATION



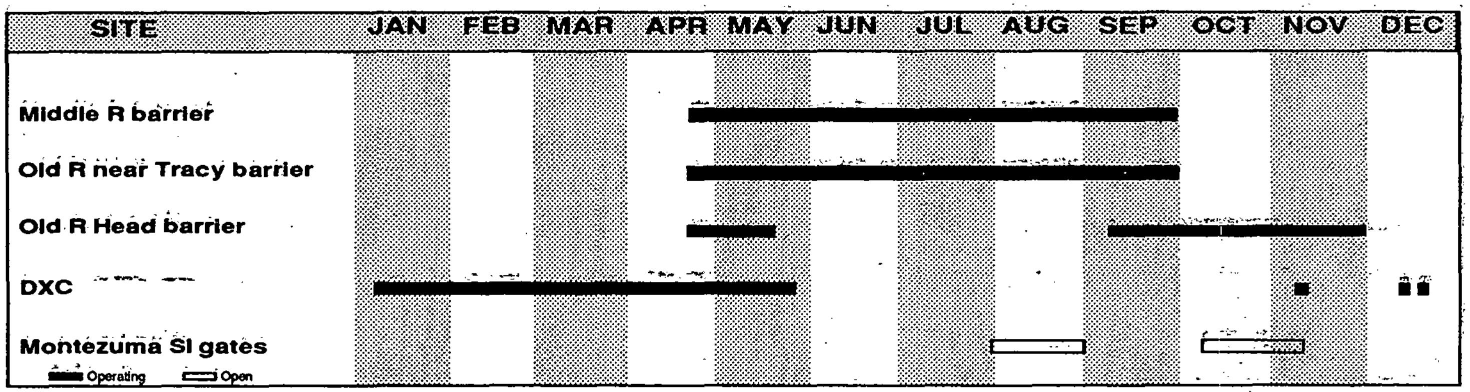
DELTA MODELING SECTION DRAFT, 3/8/96

Table 2–1a

1994
DWR & USGS 15 MINUTE FLOW DATA



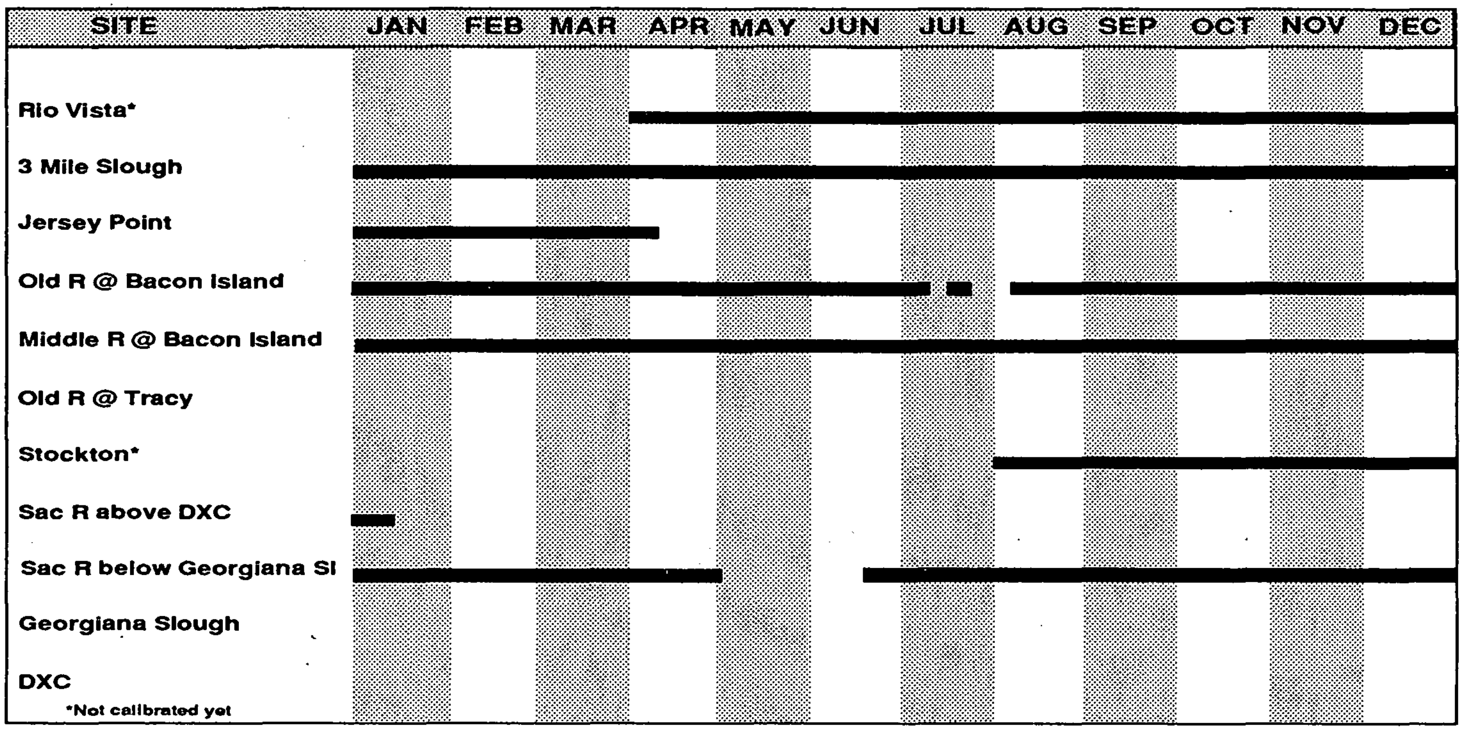
GATE OPERATION



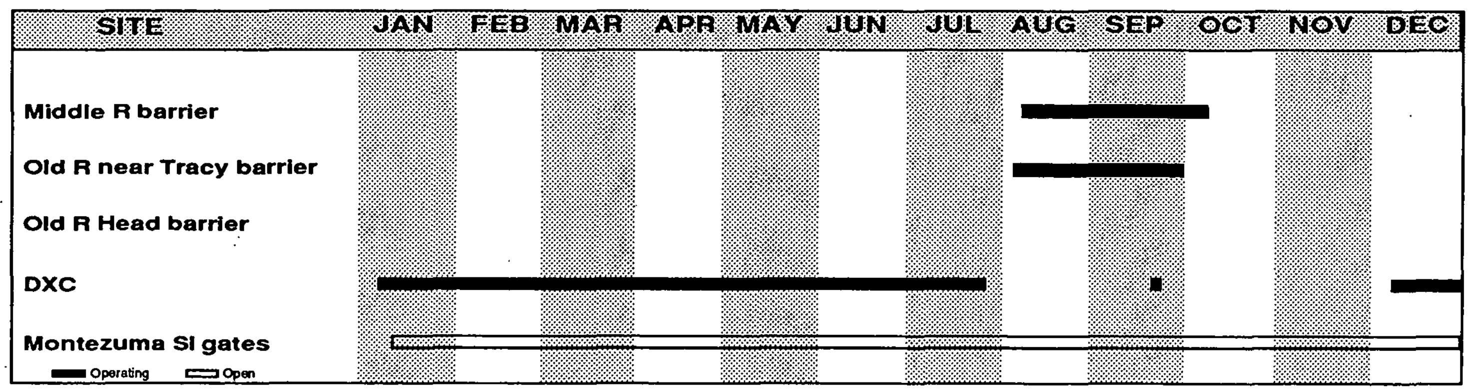
DELTA MODELING SECTION DRAFT, 3/8/96

Table 2-1b

1995
DWR & USGS 15 MINUTE FLOW DATA

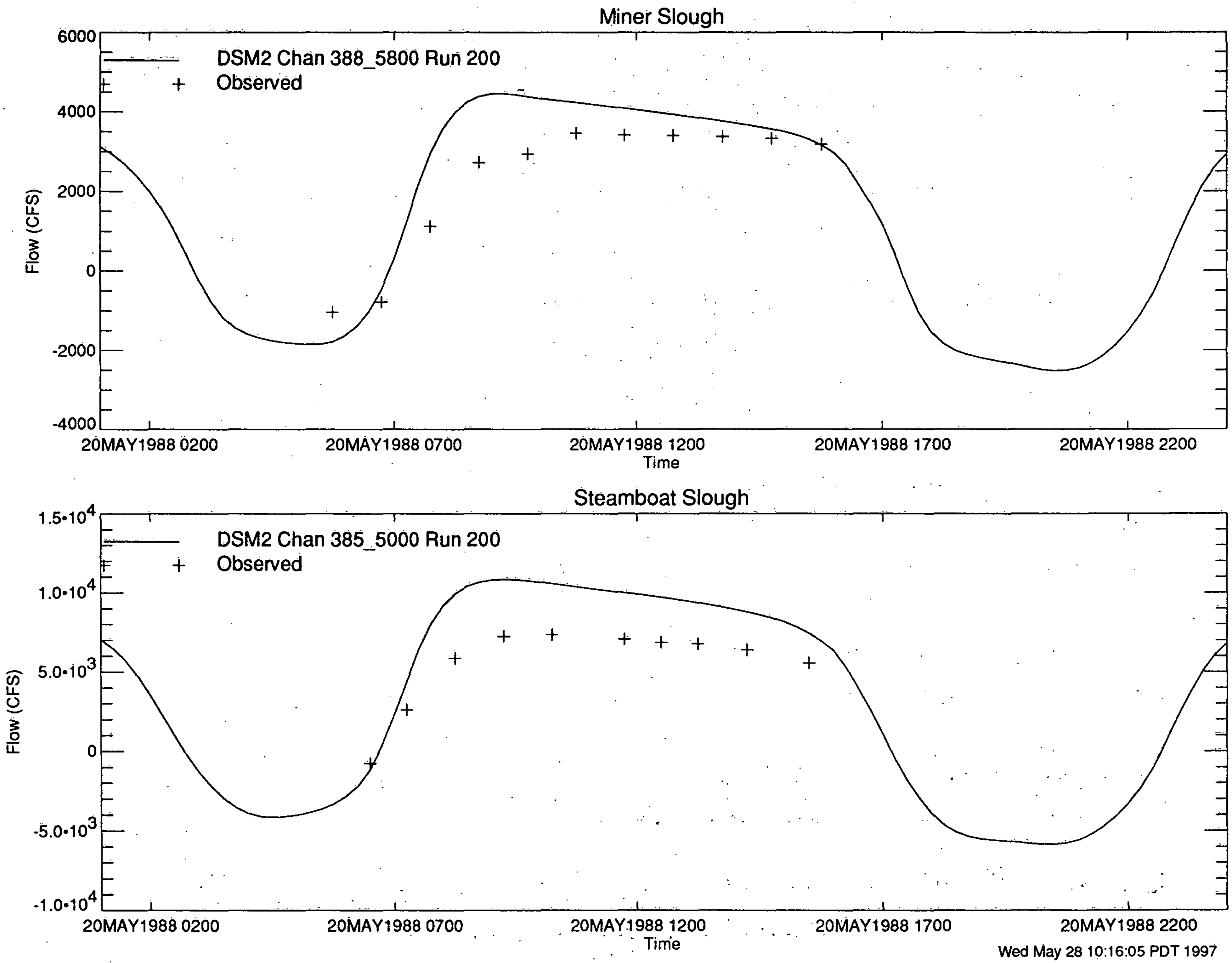


GATE OPERATION



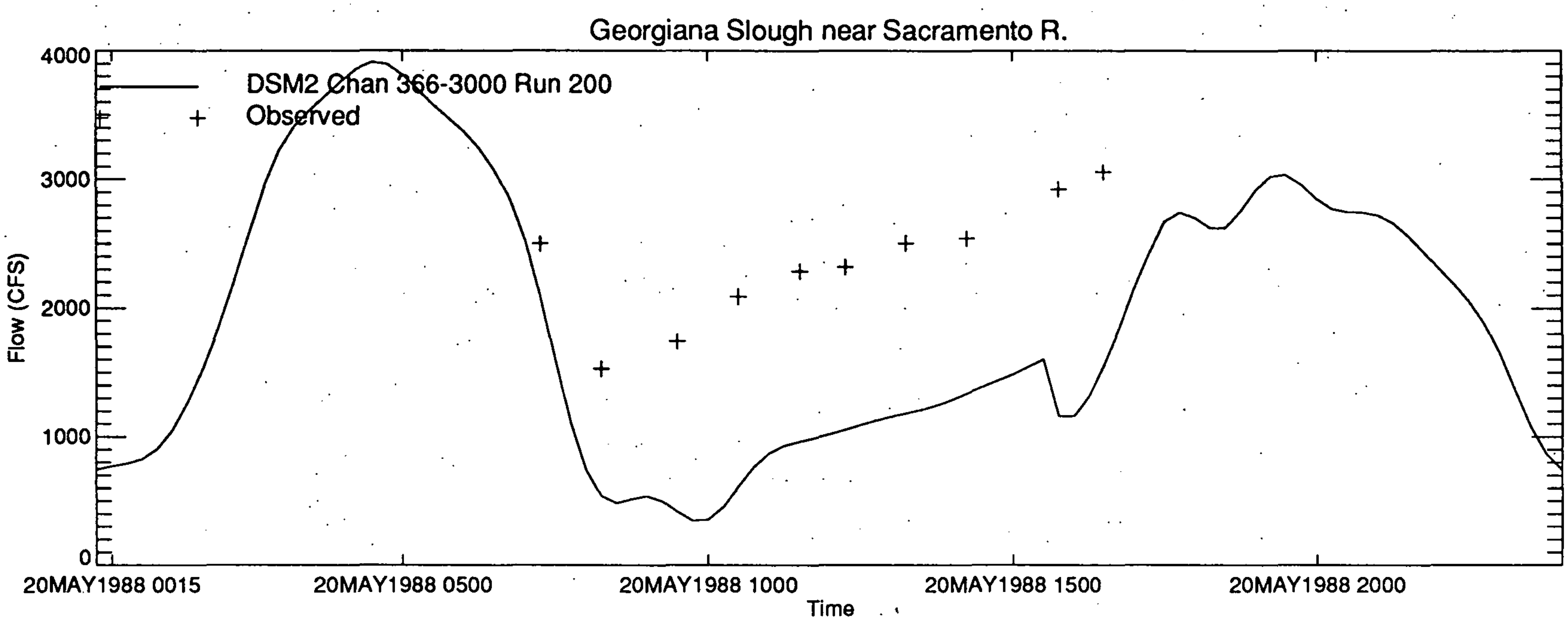
DELTA MODELING SECTION DRAFT, 3/8/96

Table 2-1c



Miner Slough
DSM2 Chan 388_5800 Run 200
Observed
Flow (CFS)
6000
4000
2000
0
-2000
-4000
20MAY1988 0200
20MAY1988 0700
20MAY1988 1200
20MAY1988 1700
20MAY1988 2200
Time
Steamboat Slough
DSM2 Chan 385_5000 Run 200
Observed
Flow (CFS)
1.5•10^4
1.0•10^4
5.0•10^3
0
-5.0•10^3
-1.0•10^4
20MAY1988 0200
20MAY1988 0700
20MAY1988 1200
20MAY1988 1700
20MAY1988 2200
Time
Wed May 28 10:16:05 PDT 1997

Figure 2-1



Tue May 27 15:03:33 PDT 1997

Figure 2-2

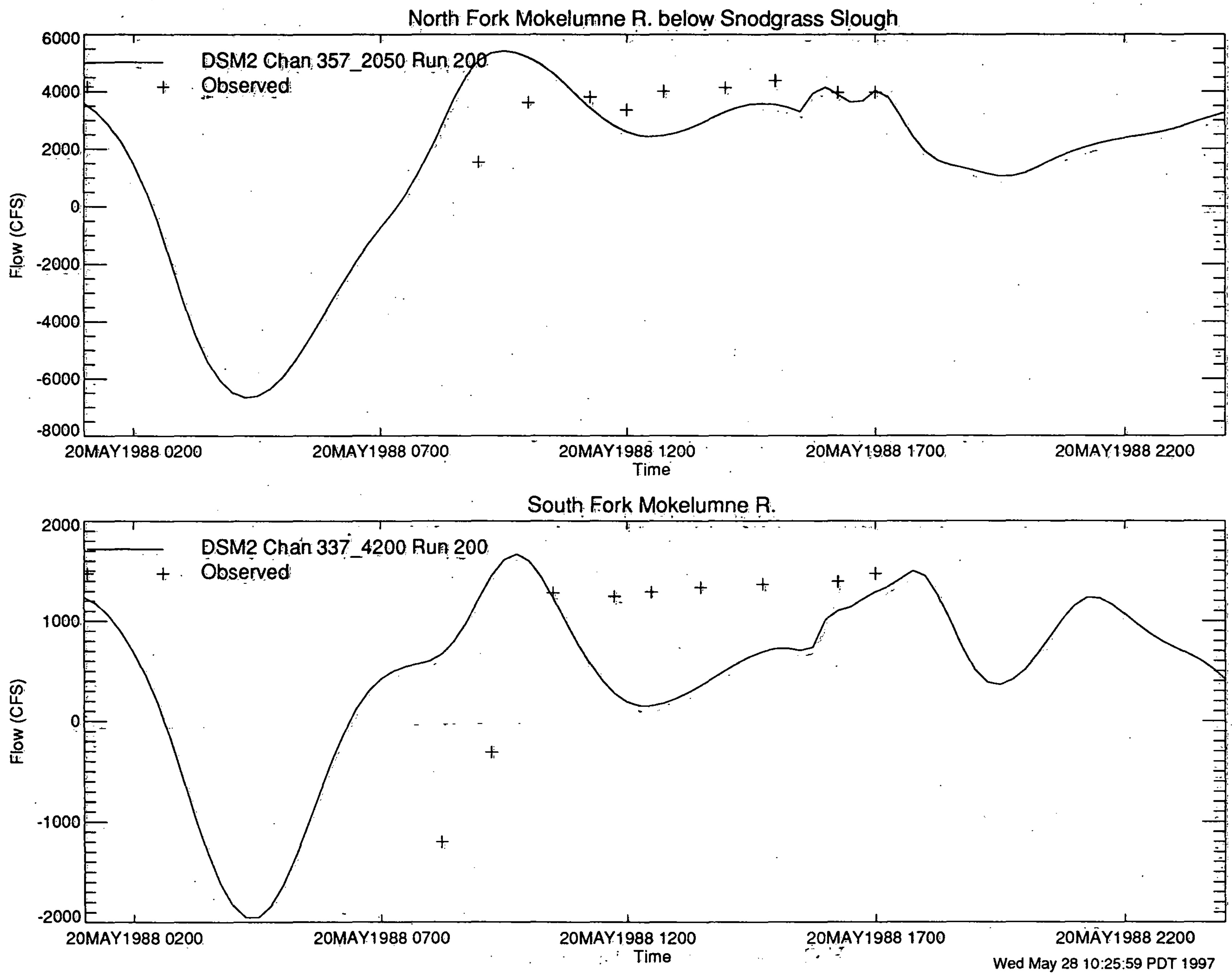
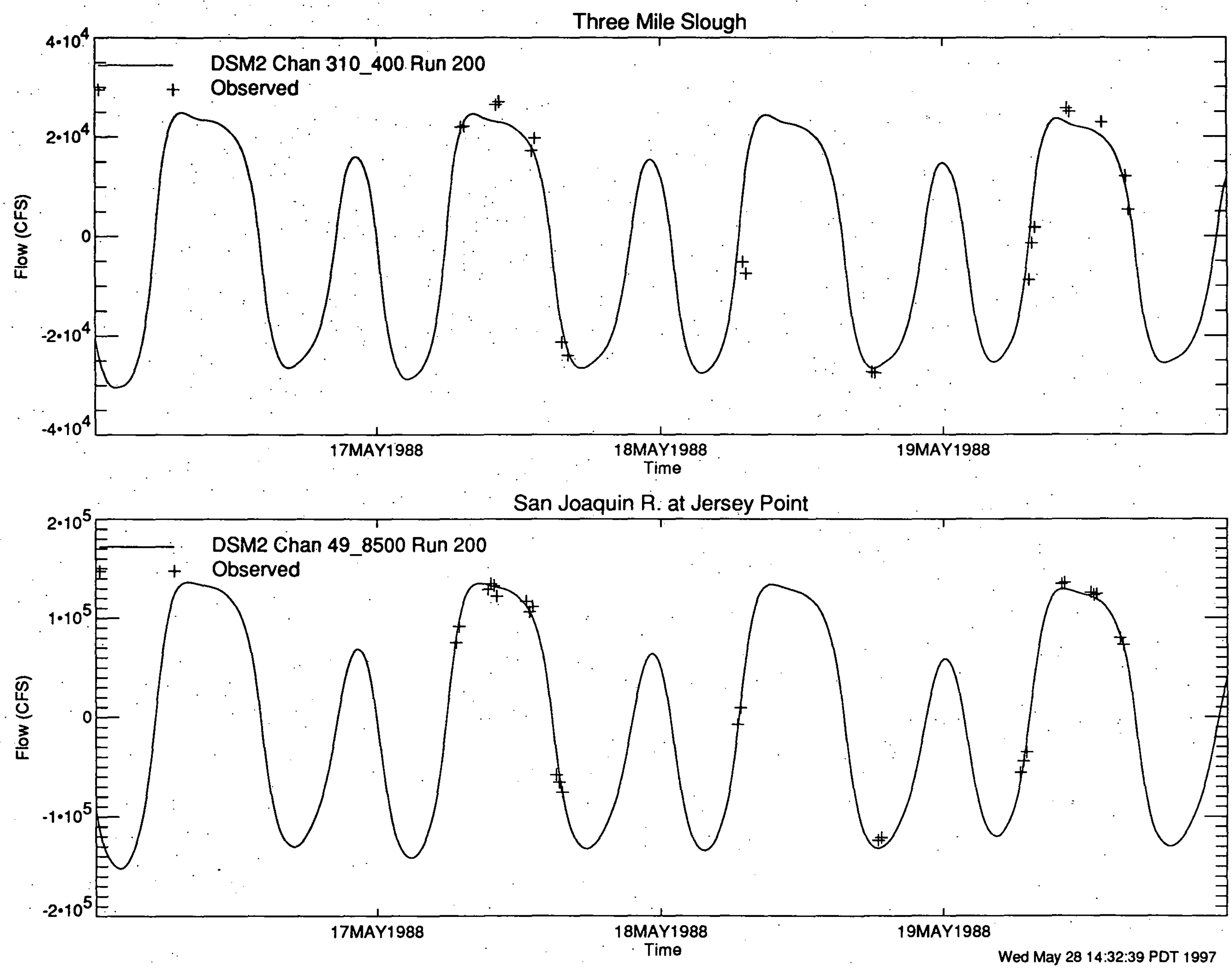
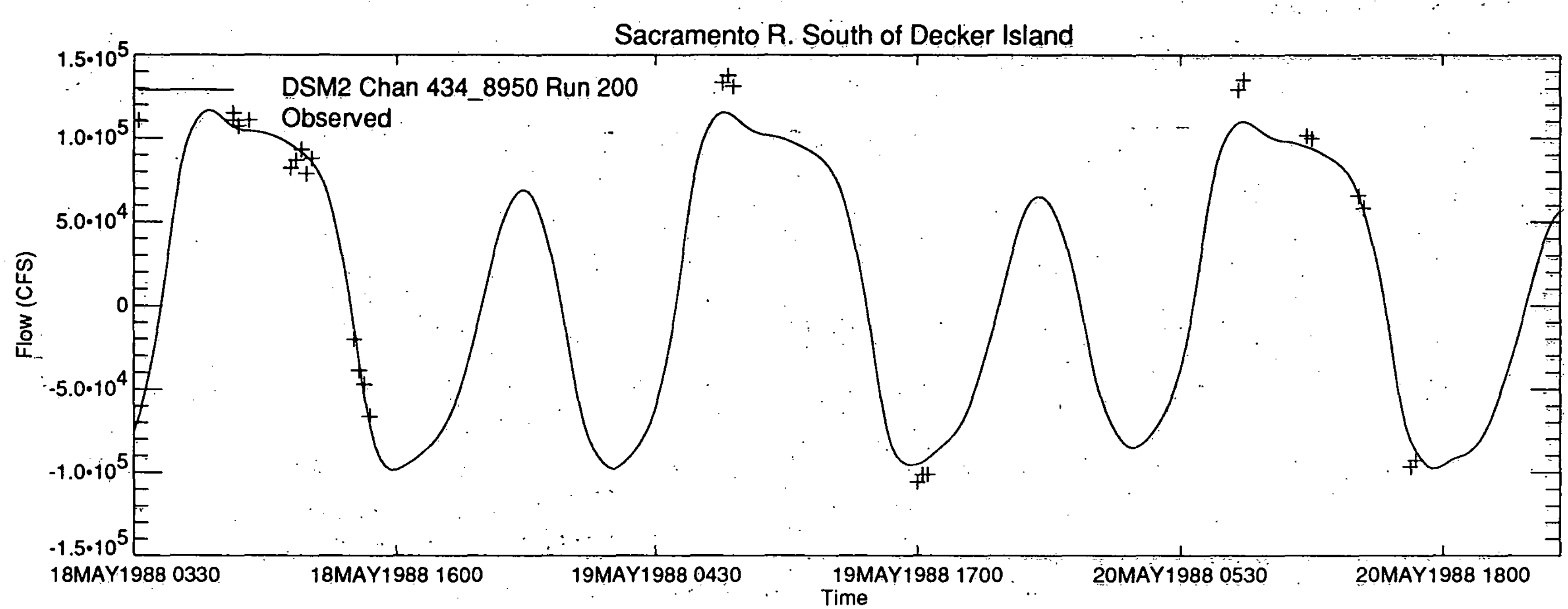

North Fork Mokelumne R. below Snodgrass Slough
DSM2 Chan 357_2050 Run 200
Observed
Flow (CFS)
6000
4000
2000
0
-2000
-4000
-6000
-8000
20MAY1988 0200
20MAY1988 0700
20MAY1988 1200
20MAY1988 1700
20MAY1988 2200
Time
South Fork Mokelumne R.
DSM2 Chan 337_4200 Run 200
Observed
Flow (CFS)
2000
1000
0
-1000
-2000
20MAY1988 0200
20MAY1988 0700
20MAY1988 1200
20MAY1988 1700
20MAY1988 2200
Time
Wed May 28 10:25:59 PDT 1997

Figure 2-3



Three Mile Slough
DSM2 Chan 310_400 Run 200
Observed
4•10^4
2•10^4
0
-2•10^4
-4•10^4
Flow (CFS)
17MAY1988
18MAY1988
19MAY1988
Time
San Joaquin R. at Jersey Point
DSM2 Chan 49_8500 Run 200
Observed
2•10^5
1•10^5
0
-1•10^5
-2•10^5
Flow (CFS)
17MAY1988
18MAY1988
19MAY1988
Time
Wed May 28 14:32:39 PDT 1997

Figure 2-4



Wed May 28 10:58:33 PDT 1997

Figure 2-5

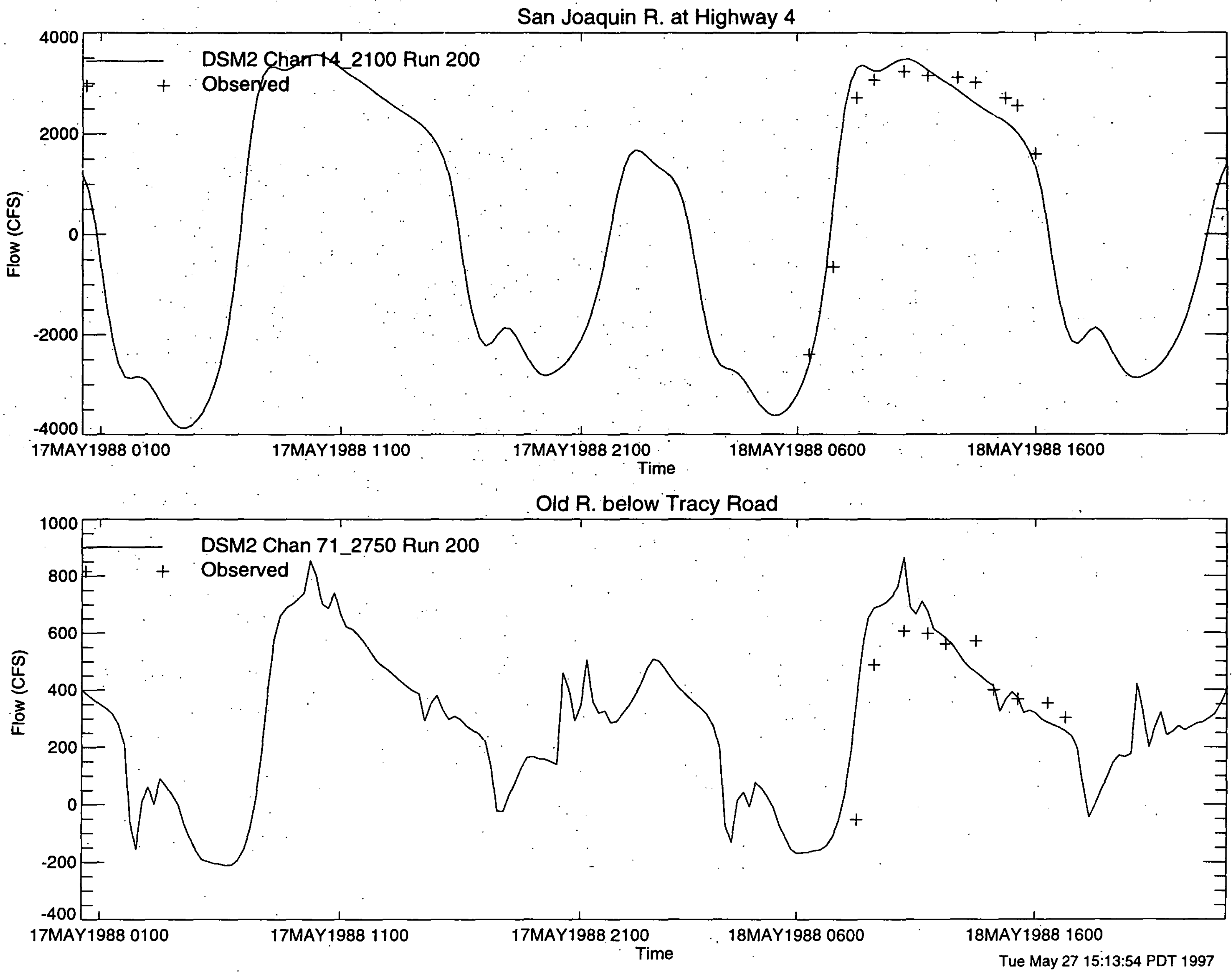

San Joaquin R. at Highway 4
DSM2 Chan 14_2100 Run 200
Observed
Flow (CFS)
4000
2000
0
-2000
-4000
17MAY1988 0100
17MAY1988 1100
17MAY1988 2100
18MAY1988 0600
18MAY1988 1600
Time
Old R. below Tracy Road
DSM2 Chan 71_2750 Run 200
Observed
Flow (CFS)
1000
800
600
400
200
0
-200
-400
17MAY1988 0100
17MAY1988 1100
17MAY1988 2100
18MAY1988 0600
18MAY1988 1600
Time
Tue May 27 15:13:54 PDT 1997

Figure 2-6

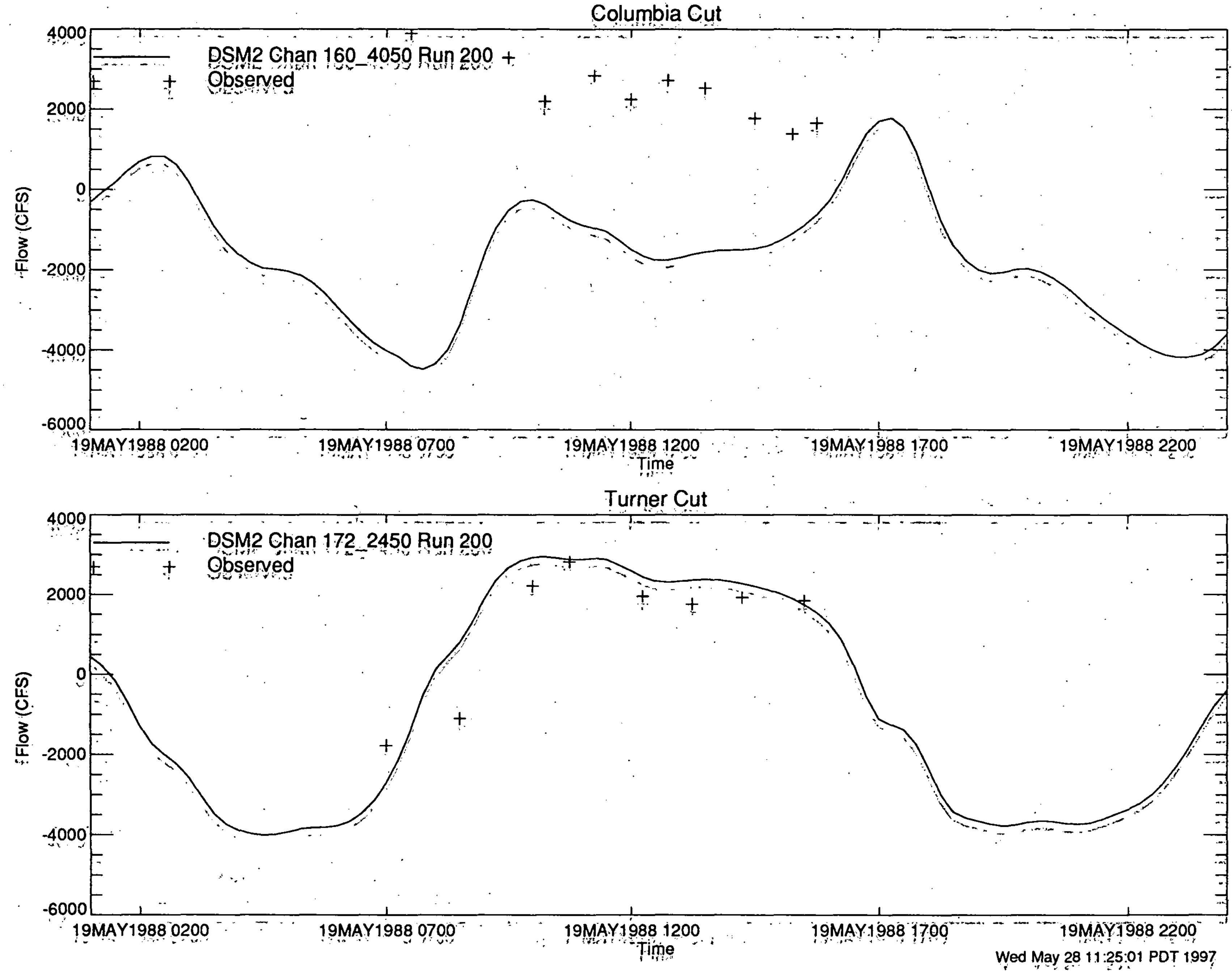

Columbia Cut
DSM2 Chan 160_4050 Run 200
Observed
Flow (CFS)
4000
2000
0
-2000
-4000
-6000
19MAY1988 0200
19MAY1988 0700
19MAY1988 1200
19MAY1988 1700
19MAY1988 2200
Time
Turner Cut
DSM2 Chan 172_2450 Run 200
Observed
Flow (CFS)
4000
2000
0
-2000
-4000
-6000
19MAY1988 0200
19MAY1988 0700
19MAY1988 1200
19MAY1988 1700
19MAY1988 2200
Time
Wed May 28 11:25:01 PDT 1997

Figure 2-7

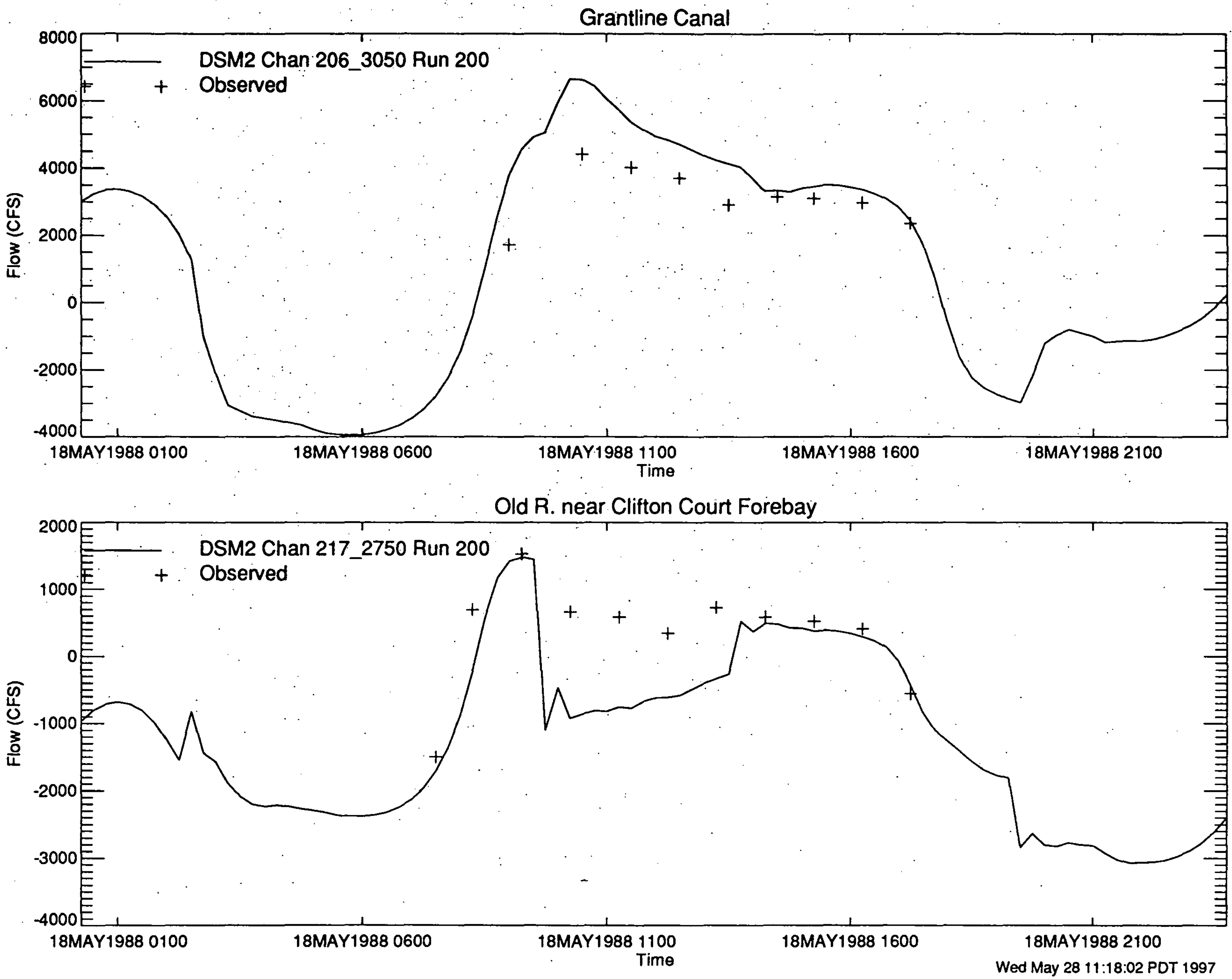

Grantline Canal
DSM2 Chan 206_3050 Run 200
Observed
Flow (CFS)
8000
6000
4000
2000
0
-2000
-4000
18MAY1988 0100
18MAY1988 0600
18MAY1988 1100
18MAY1988 1600
18MAY1988 2100
Time
Old R. near Clifton Court Forebay
DSM2 Chan 217_2750 Run 200
Observed
Flow (CFS)
2000
1000
0
-1000
-2000
-3000
-4000
18MAY1988 0100
18MAY1988 0600
18MAY1988 1100
18MAY1988 1600
18MAY1988 2100
Time
Wed May 28 11:18:02 PDT 1997

Figure 2-8

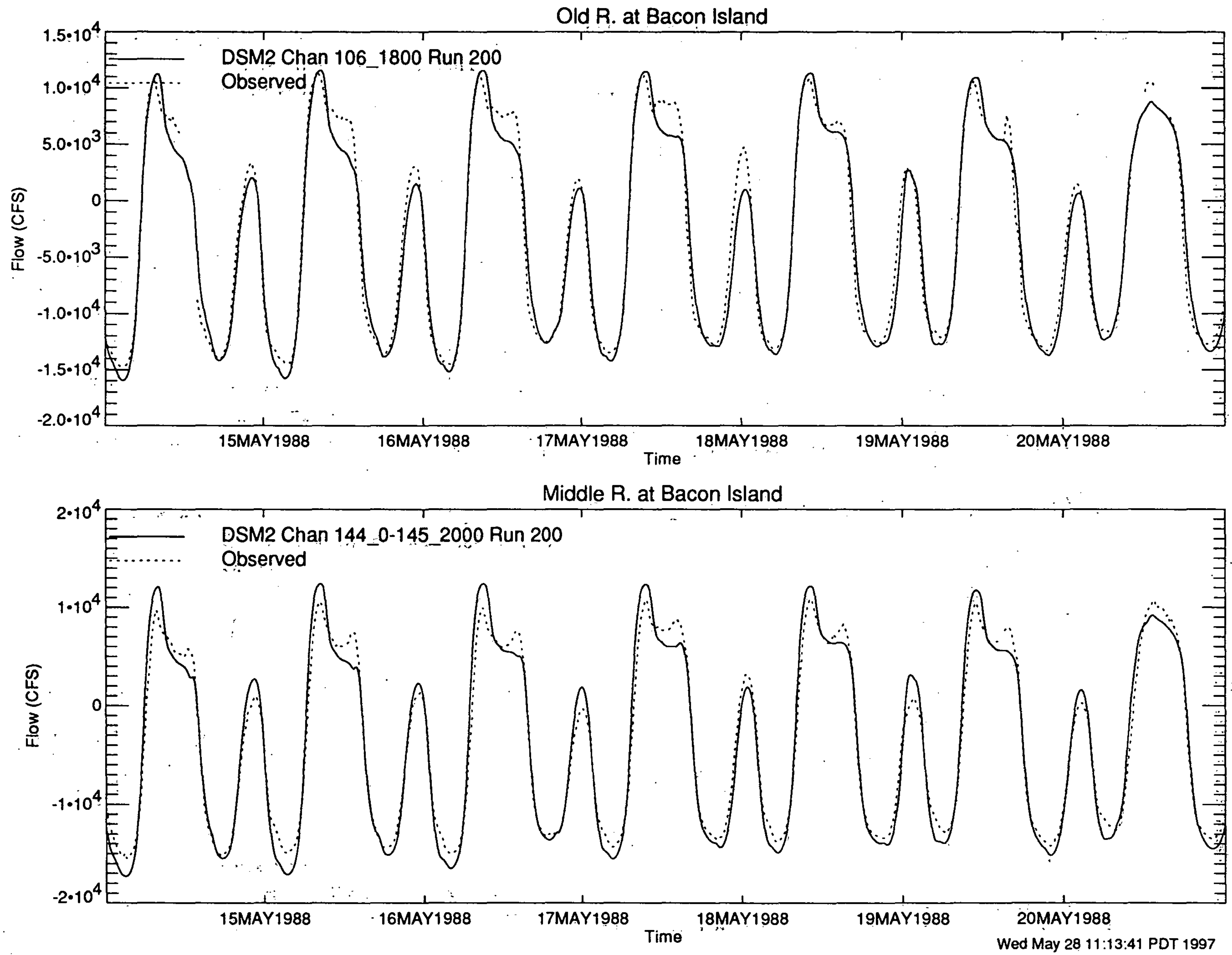

Old R. at Bacon Island
DSM2 Chan 106_1800 Run 200
Observed
1.5•10^4
1.0•10^4
5.0•10^3
0
-5.0•10^3
-1.0•10^4
-1.5•10^4
-2.0•10^4
Flow (CFS)
15MAY1988
16MAY1988
17MAY1988
18MAY1988
19MAY1988
20MAY1988
Time
Middle R. at Bacon Island
DSM2 Chan 144_0-145_2000 Run 200
Observed
2•10^4
1•10^4
0
-1•10^4
-2•10^4
Flow (CFS)
15MAY1988
16MAY1988
17MAY1988
18MAY1988
19MAY1988
20MAY1988
Time
Wed May 28 11:13:41 PDT 1997

Figure 2-9

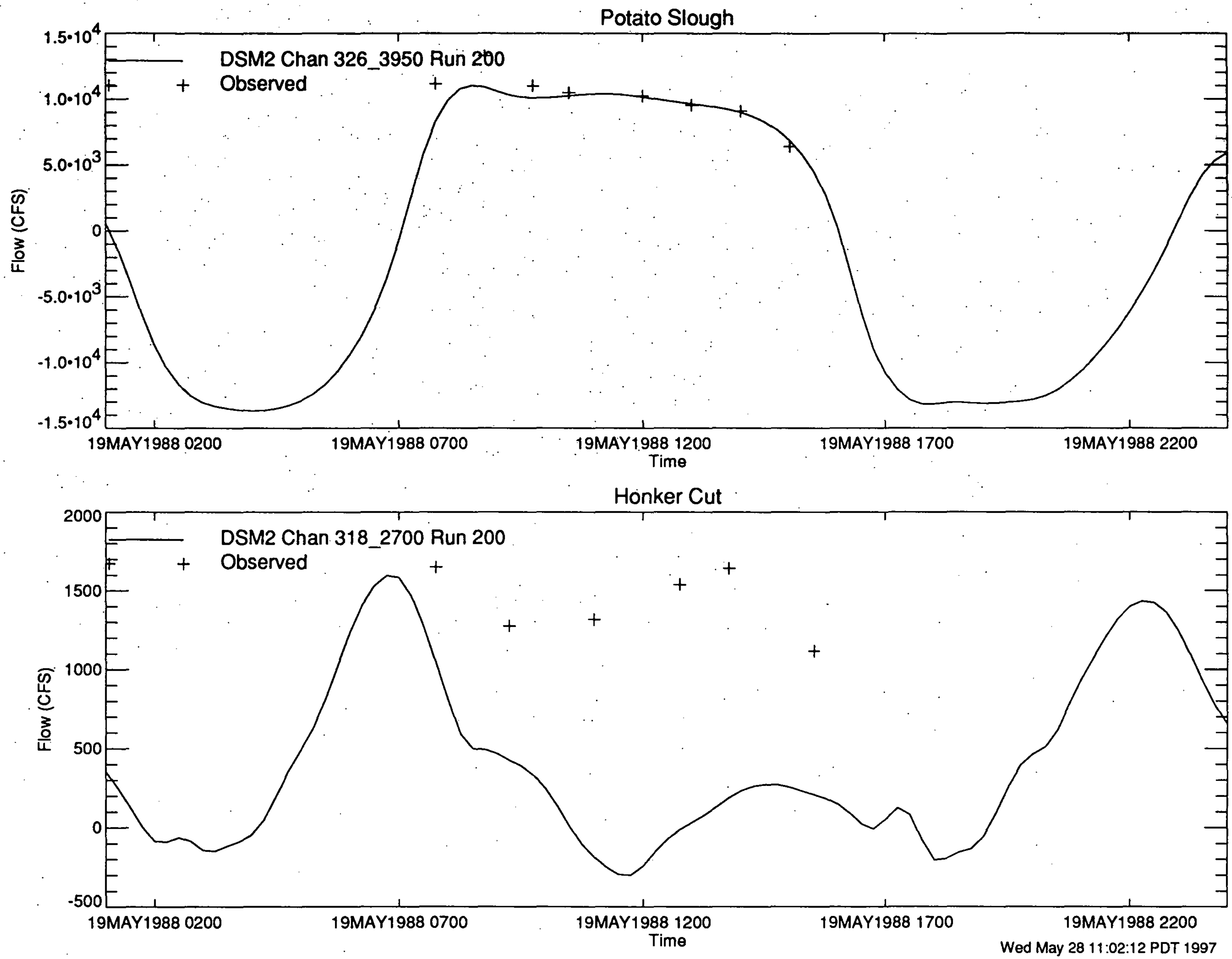
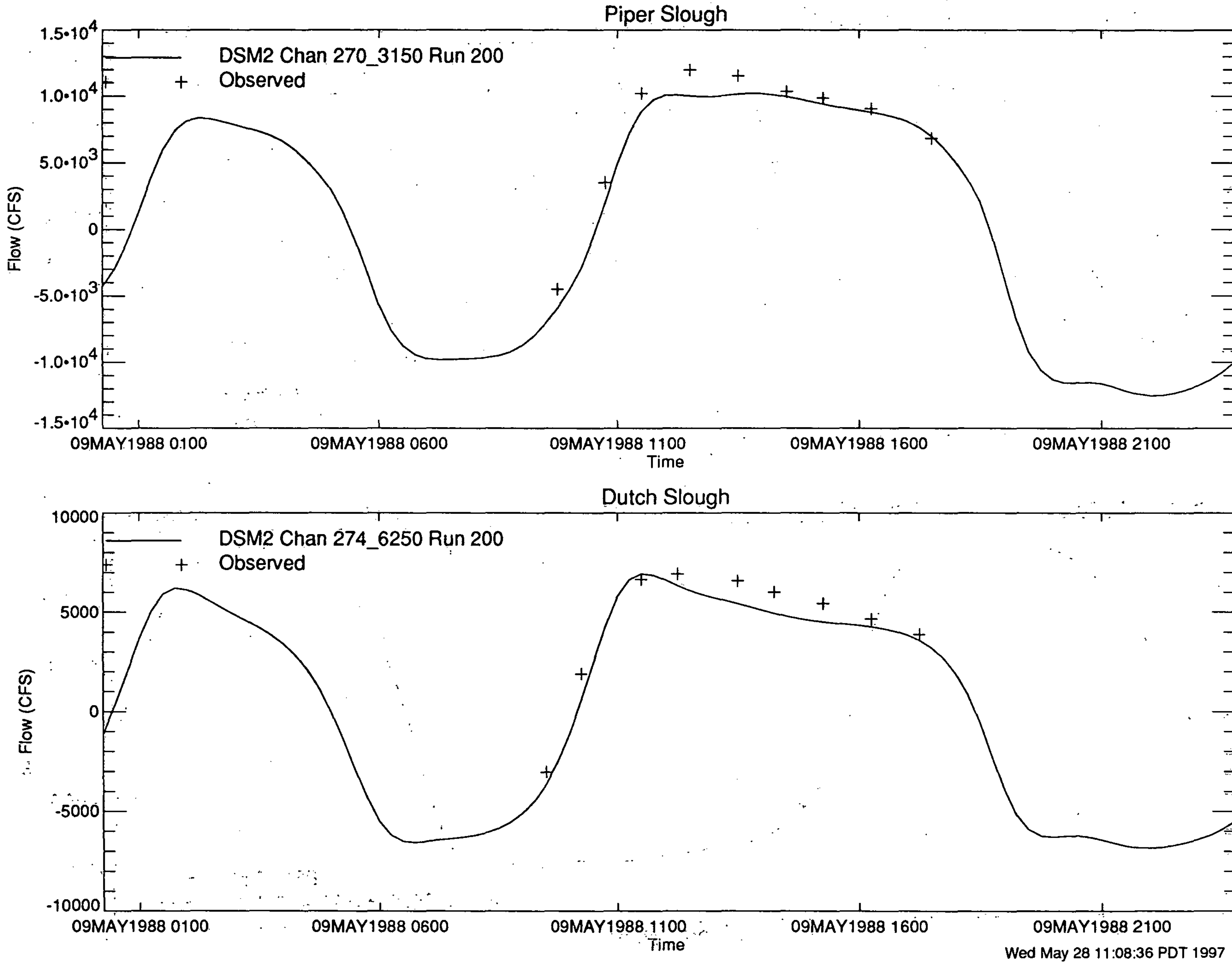

Potato Slough
DSM2 Chan 326_3950 Run 200
Observed
Flow (CFS)
1.5•10⁴
1.0•10⁴
5.0•10³
0
-5.0•10³
-1.0•10⁴
-1.5•10⁴
19MAY1988 0200
19MAY1988 0700
19MAY1988 1200
19MAY1988 1700
19MAY1988 2200
Time
Honker Cut
DSM2 Chan 318_2700 Run 200
Observed
Flow (CFS)
2000
1500
1000
500
0
-500
19MAY1988 0200
19MAY1988 0700
19MAY1988 1200
19MAY1988 1700
19MAY1988 2200
Time
Wed May 28 11:02:12 PDT 1997

Figure 2-10



Piper Slough
DSM2 Chan 270_3150 Run 200
Observed
1.5•10^4
1.0•10^4
5.0•10^3
0
-5.0•10^3
-1.0•10^4
-1.5•10^4
Flow (CFS)
09MAY1988 0100
09MAY1988 0600
09MAY1988 1100
09MAY1988 1600
09MAY1988 2100
Time
Dutch Slough
DSM2 Chan 274_6250 Run 200
Observed
10000
5000
0
-5000
-10000
Flow (CFS)
09MAY1988 0100
09MAY1988 0600
09MAY1988 1100
09MAY1988 1600
09MAY1988 2100
Time
Wed May 28 11:08:36 PDT 1997

Figure 2-11

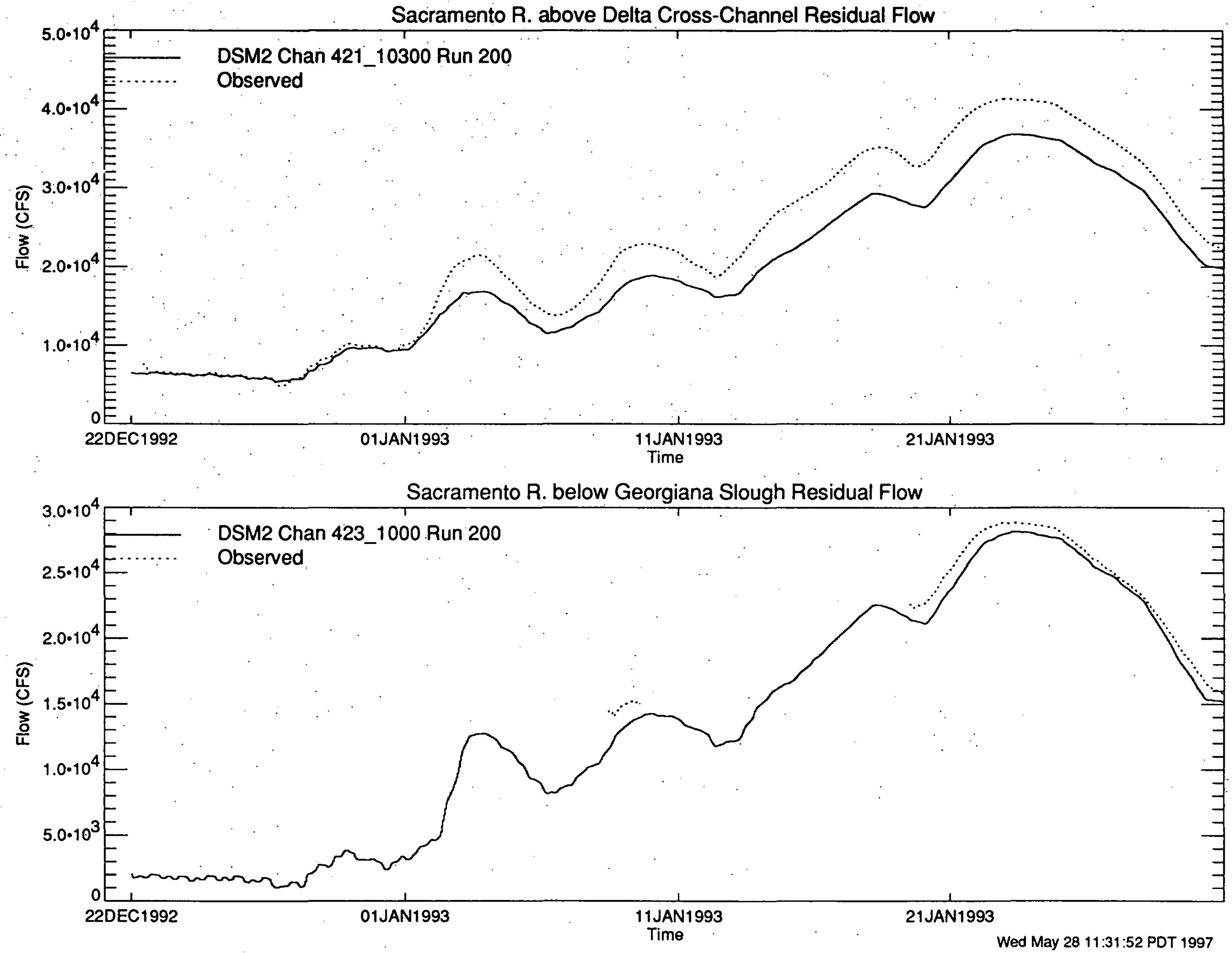
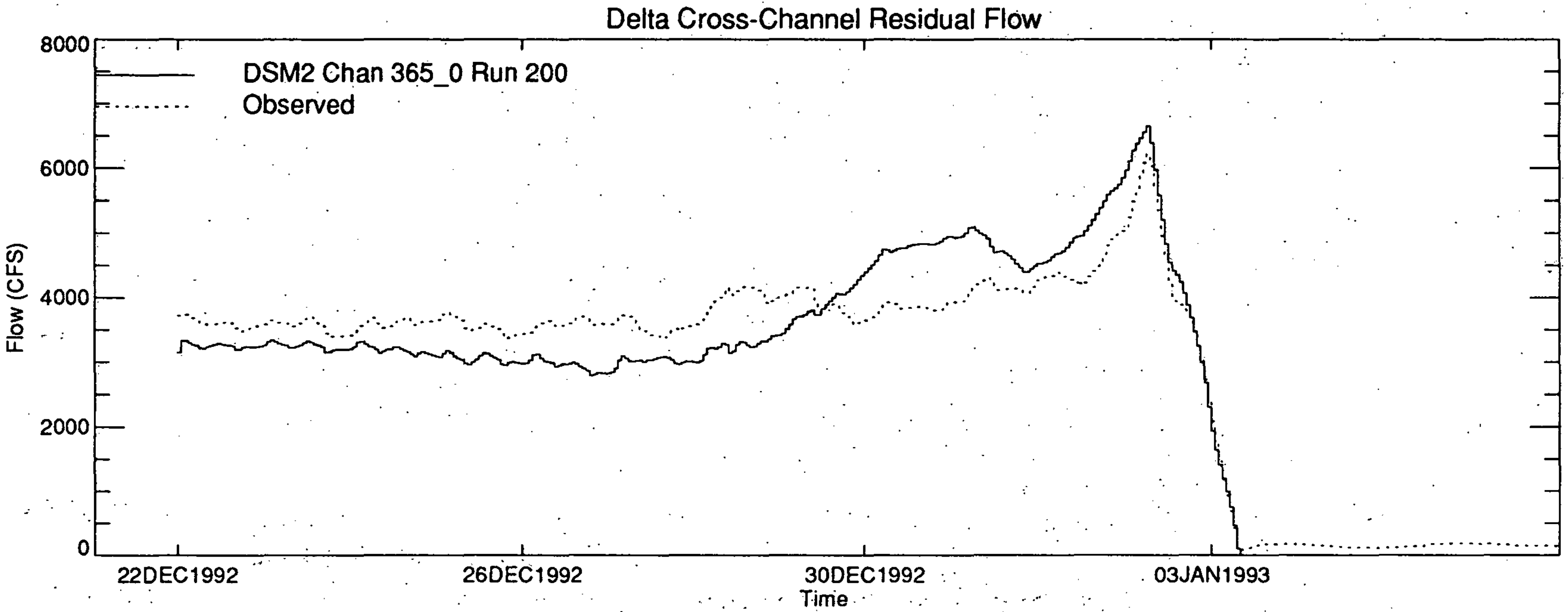

Sacramento R. above Delta Cross-Channel Residual Flow
DSM2 Chan 421_10300 Run 200
Observed
Flow (CFS)
5.0•10^4
4.0•10^4
3.0•10^4
2.0•10^4
1.0•10^4
0
22DEC1992
01JAN1993
11JAN1993
21JAN1993
Time
Sacramento R. below Georgiana Slough Residual Flow
DSM2 Chan 423_1000 Run 200
Observed
Flow (CFS)
3.0•10^4
2.5•10^4
2.0•10^4
1.5•10^4
1.0•10^4
5.0•10^3
0
22DEC1992
01JAN1993
11JAN1993
21JAN1993
Time
Wed May 28 11:31:52 PDT 1997

Figure 2-12



Wed May 28 11:35:49 PDT 1997

Figure 2-13

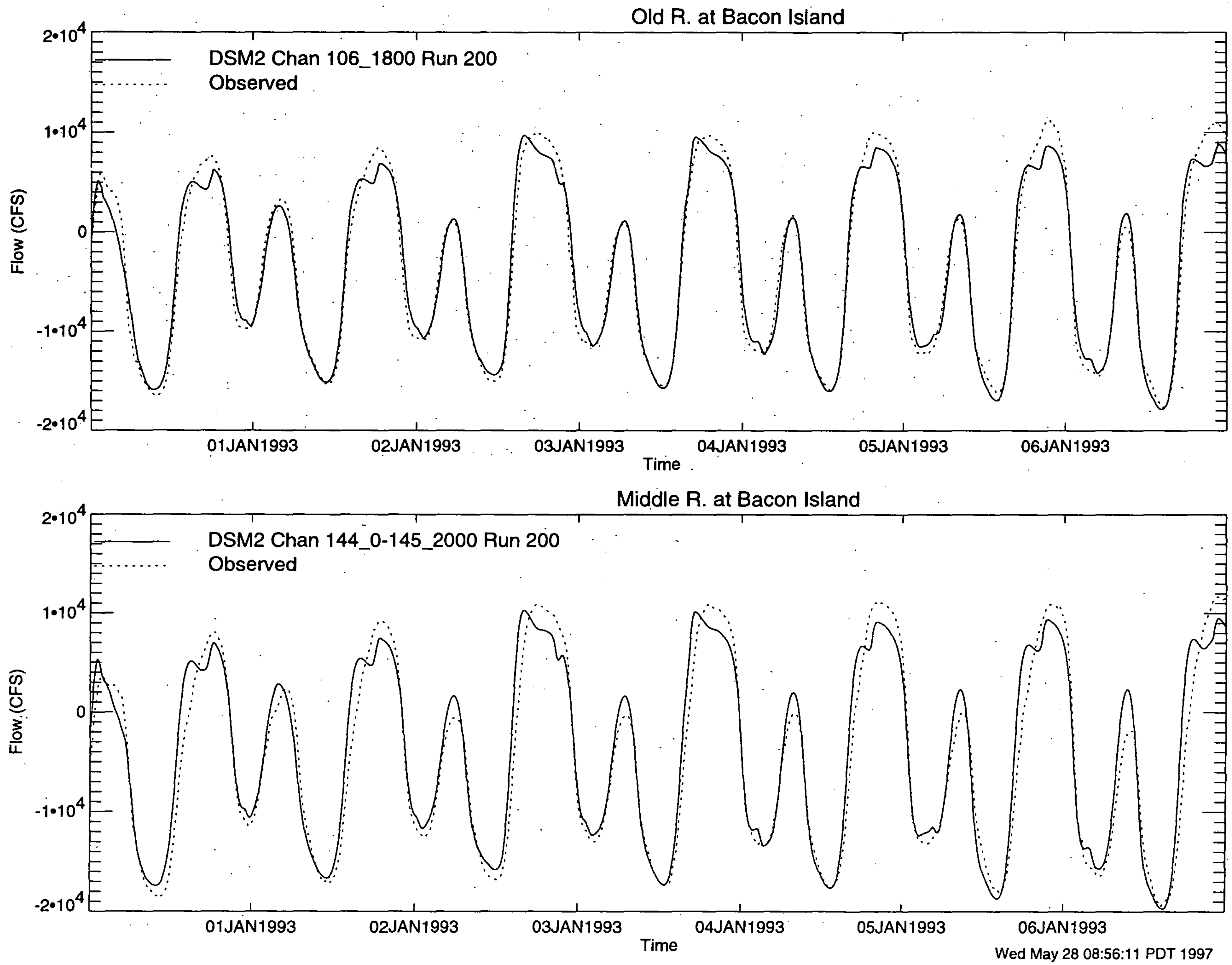

Old R. at Bacon Island
DSM2 Chan 106_1800 Run 200
Observed
Flow (CFS)
2•10^4
1•10^4
0
-1•10^4
-2•10^4
01JAN1993
02JAN1993
03JAN1993
04JAN1993
05JAN1993
06JAN1993
Time
Middle R. at Bacon Island
DSM2 Chan 144_0-145_2000 Run 200
Observed
Flow (CFS)
2•10^4
1•10^4
0
-1•10^4
-2•10^4
01JAN1993
02JAN1993
03JAN1993
04JAN1993
05JAN1993
06JAN1993
Time
Wed May 28 08:56:11 PDT 1997

Figure 2-14

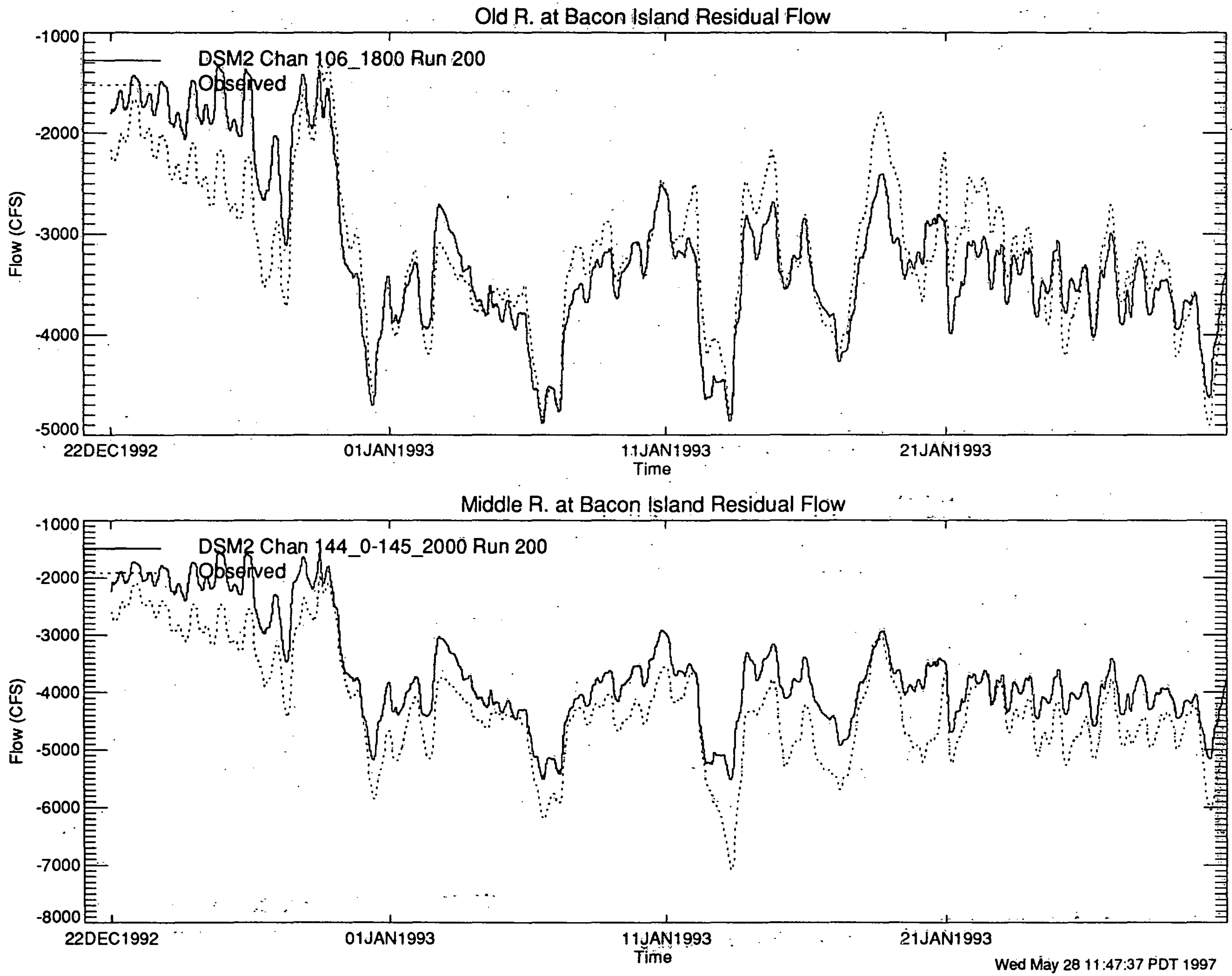
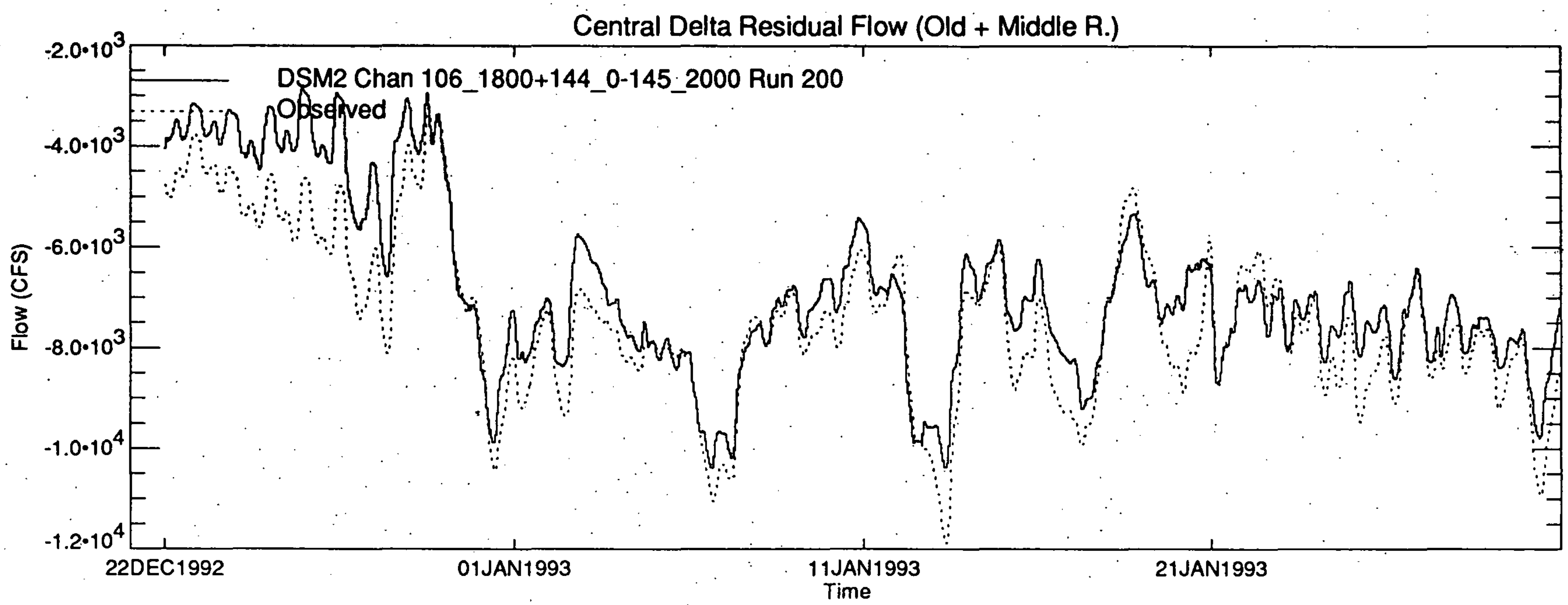

Old R. at Bacon Island Residual Flow
DSM2 Chan 106_1800 Run 200
Observed
Flow (CFS)
-1000
-2000
-3000
-4000
-5000
22DEC1992
01JAN1993
11JAN1993
21JAN1993
Time
Middle R. at Bacon Island Residual Flow
DSM2 Chan 144_0-145_2000 Run 200
Observed
Flow (CFS)
-1000
-2000
-3000
-4000
-5000
-6000
-7000
-8000
22DEC1992
01JAN1993
11JAN1993
21JAN1993
Time
Wed May 28 11:47:37 PDT 1997

Figure 2-15



Wed May 28 11:50:42 PDT 1997

Figure 2-16

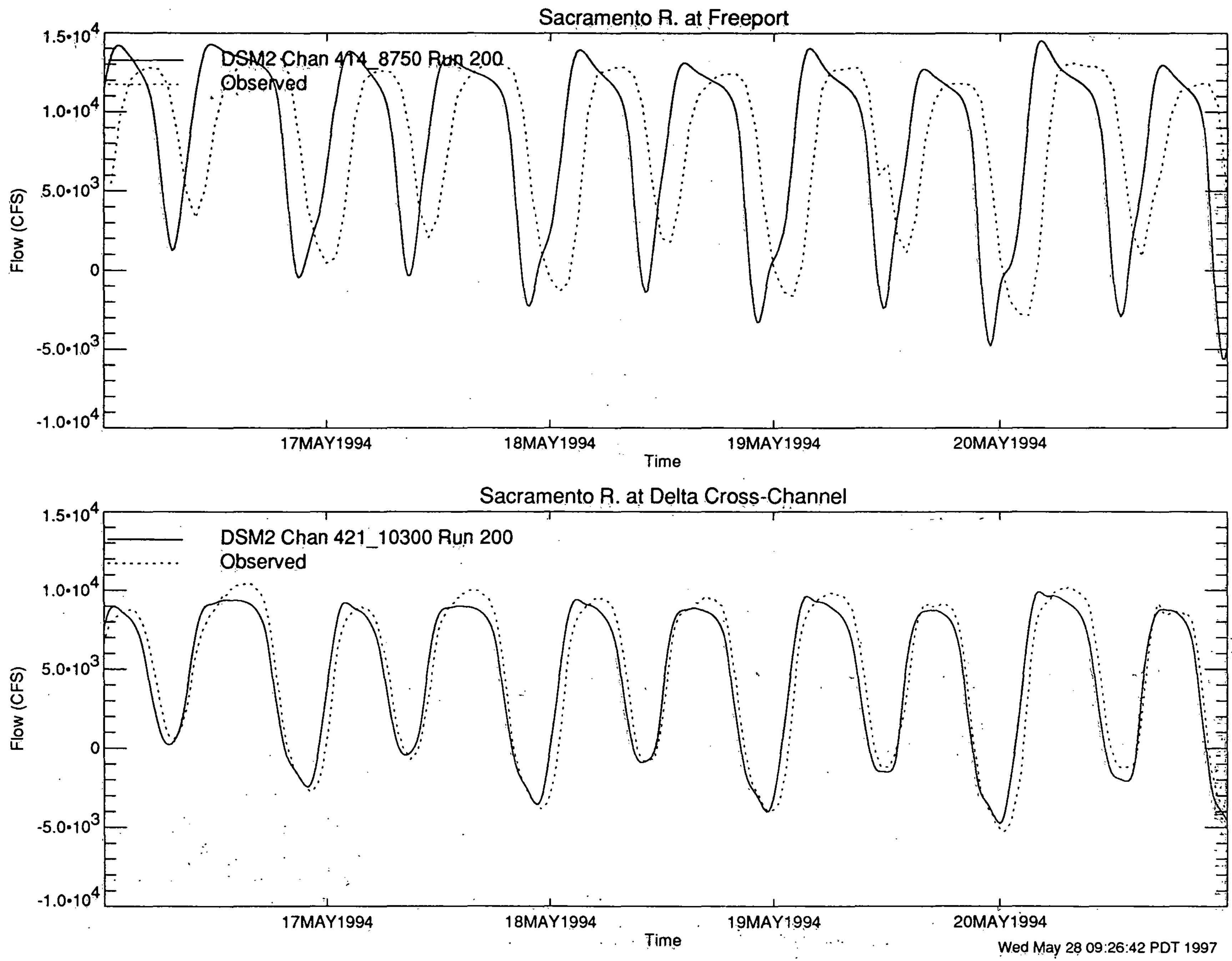
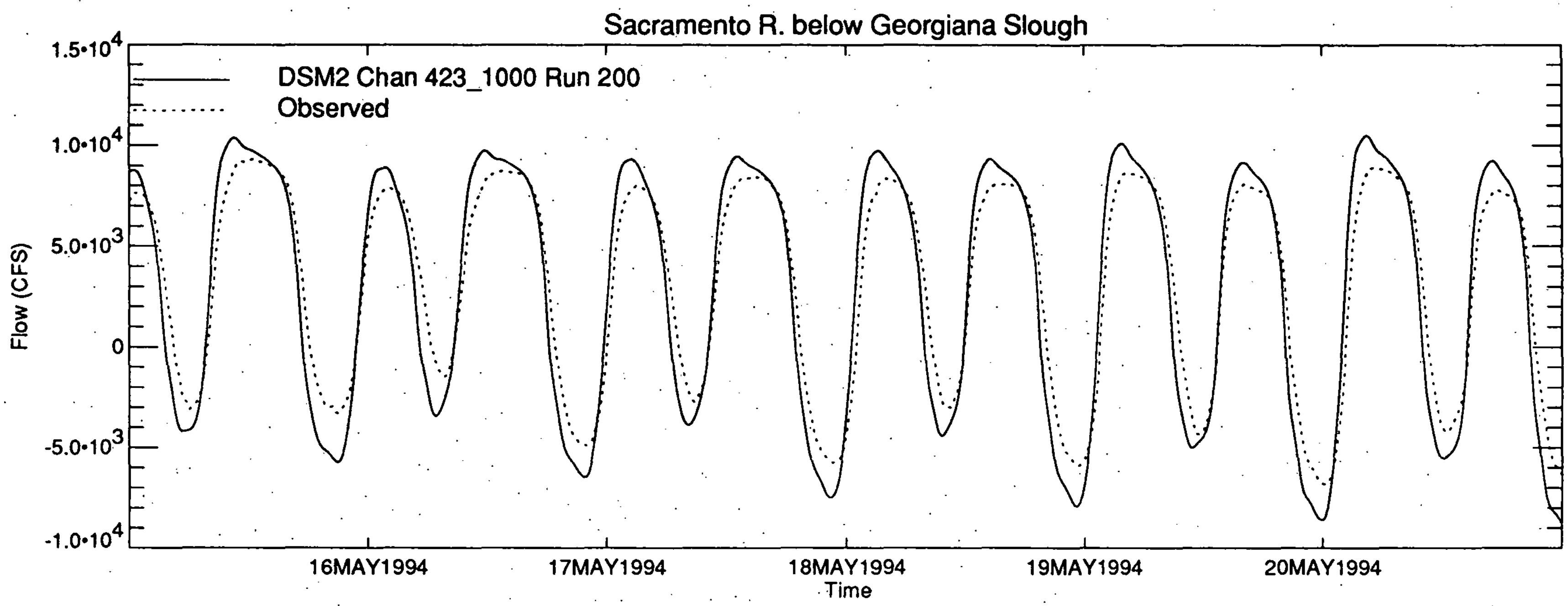

Sacramento R. at Freeport
DSM2 Chan 414_8750 Run 200
Observed
1.5•10^4
1.0•10^4
5.0•10^3
0
-5.0•10^3
-1.0•10^4
Flow (CFS)
17MAY1994
18MAY1994
19MAY1994
20MAY1994
Time
Sacramento R. at Delta Cross-Channel
DSM2 Chan 421_10300 Run 200
Observed
1.5•10^4
1.0•10^4
5.0•10^3
0
-5.0•10^3
-1.0•10^4
Flow (CFS)
17MAY1994
18MAY1994
19MAY1994
20MAY1994
Time
Wed May 28 09:26:42 PDT 1997

Figure 2-17



Wed May 28 11:41:25 PDT 1997

Figure 2-18

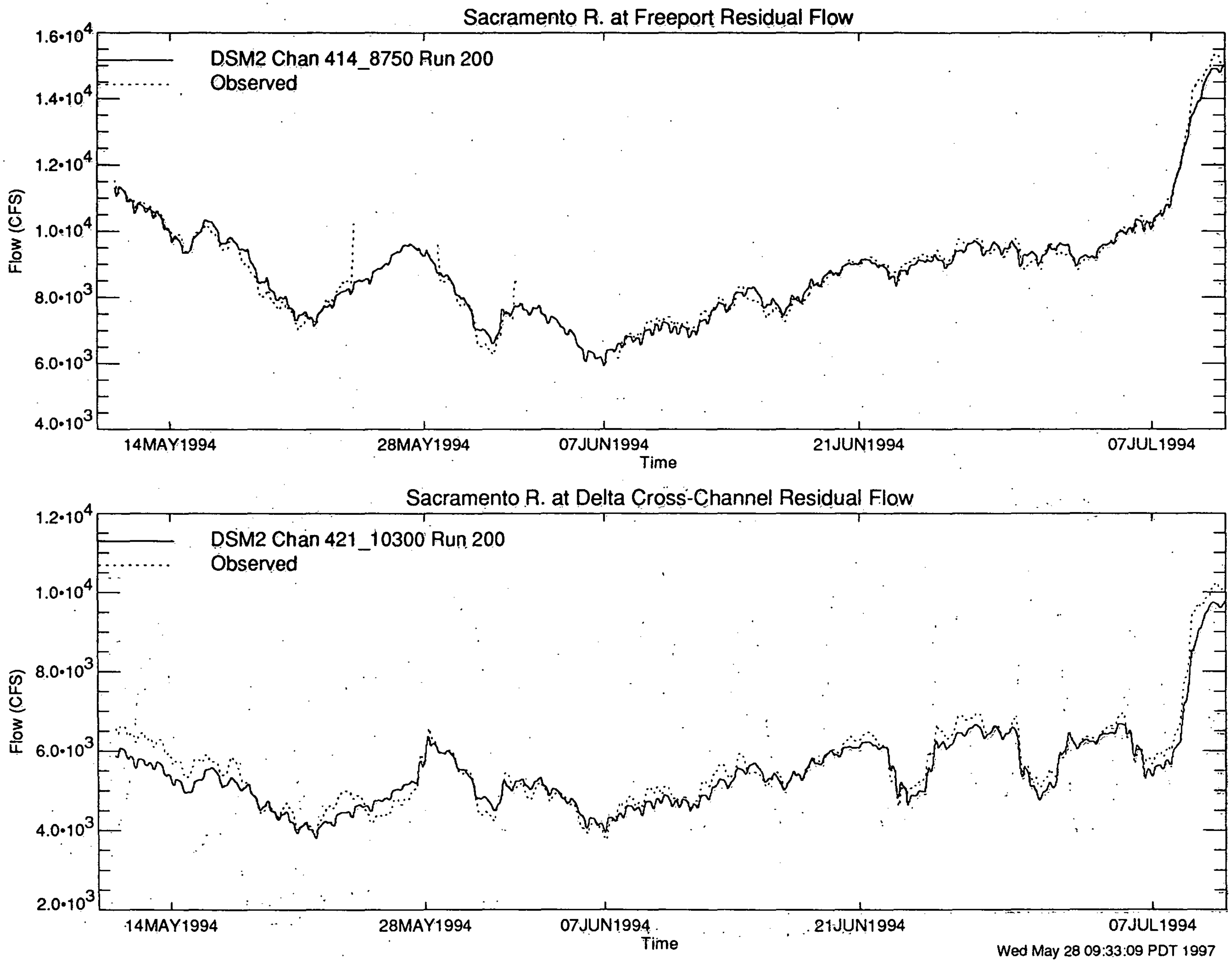
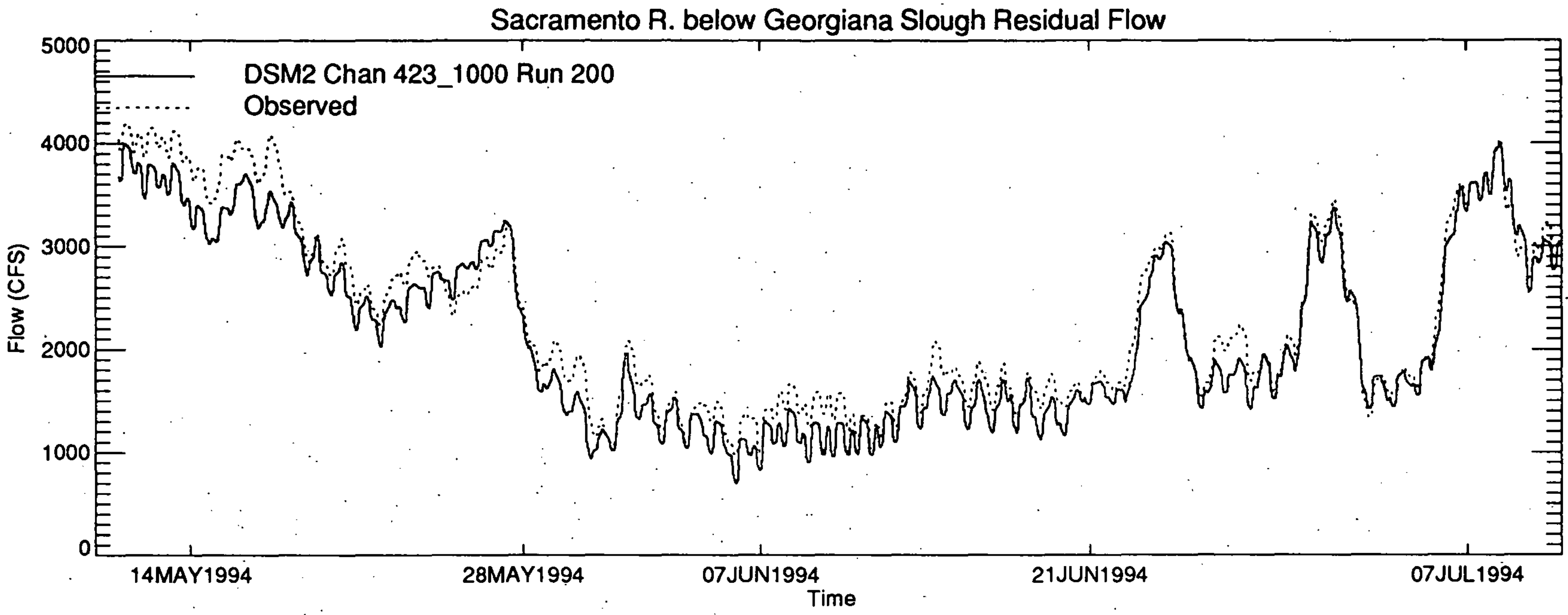
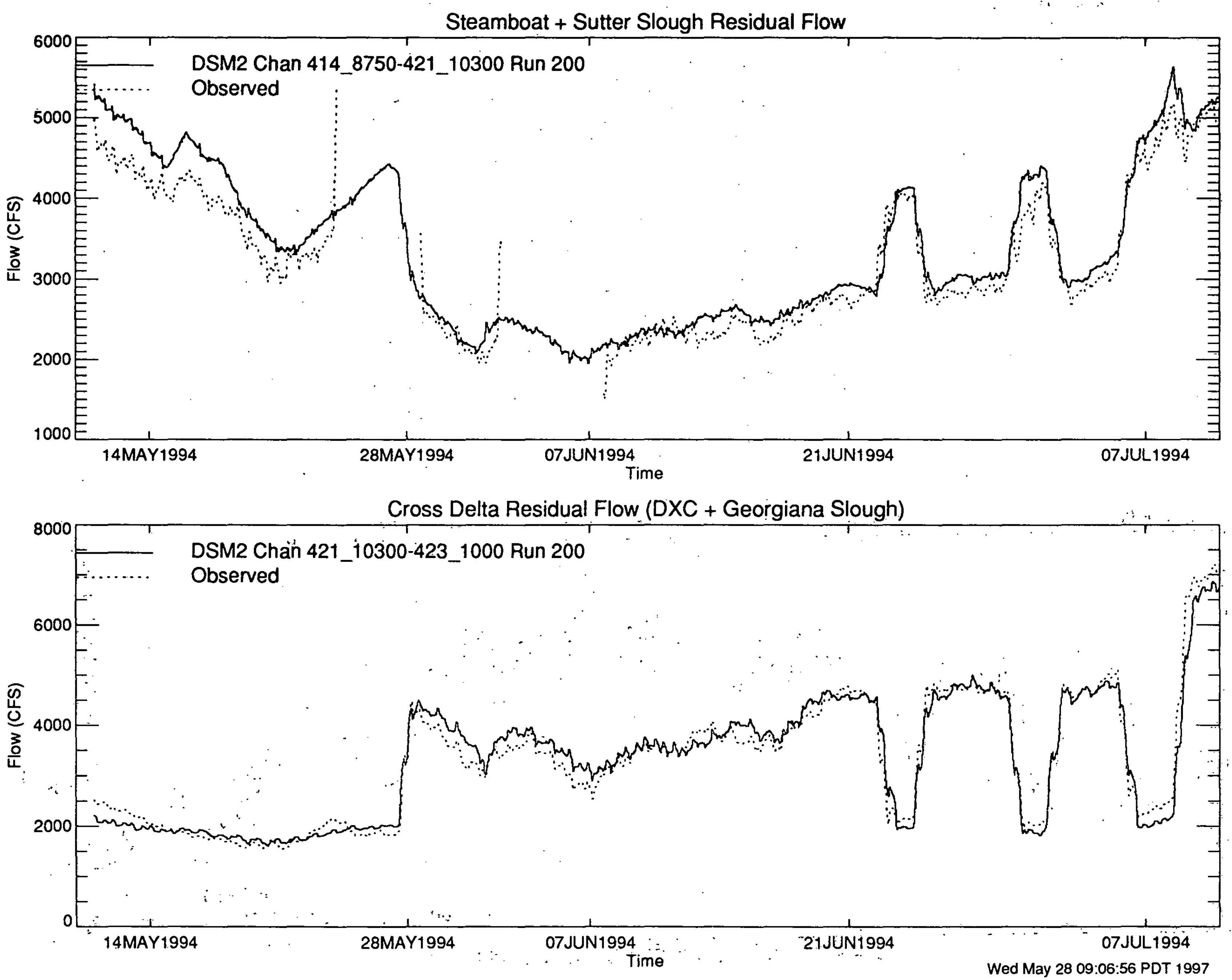

Sacramento R. at Freeport Residual Flow
DSM2 Chan 414_8750 Run 200
Observed
Flow (CFS)
1.6•10^4
1.4•10^4
1.2•10^4
1.0•10^4
8.0•10^3
6.0•10^3
4.0•10^3
14MAY1994
28MAY1994
07JUN1994
21JUN1994
07JUL1994
Time
Sacramento R. at Delta Cross-Channel Residual Flow
DSM2 Chan 421_10300 Run 200
Observed
Flow (CFS)
1.2•10^4
1.0•10^4
8.0•10^3
6.0•10^3
4.0•10^3
2.0•10^3
14MAY1994
28MAY1994
07JUN1994
21JUN1994
07JUL1994
Time
Wed May 28 09:33:09 PDT 1997

Figure 2-19



Wed May 28 09:33:09 PDT 1997

Figure 2-20



Steamboat + Sutter Slough Residual Flow
DSM2 Chan 414_8750-421_10300 Run 200
Observed
Flow (CFS)
6000
5000
4000
3000
2000
1000
14MAY1994
28MAY1994
07JUN1994
21JUN1994
07JUL1994
Time
Cross Delta Residual Flow (DXC + Georgiana Slough)
DSM2 Chan 421_10300-423_1000 Run 200
Observed
Flow (CFS)
8000
6000
4000
2000
0
14MAY1994
28MAY1994
07JUN1994
21JUN1994
07JUL1994
Time
Wed May 28 09:06:56 PDT 1997

Figure 2-21

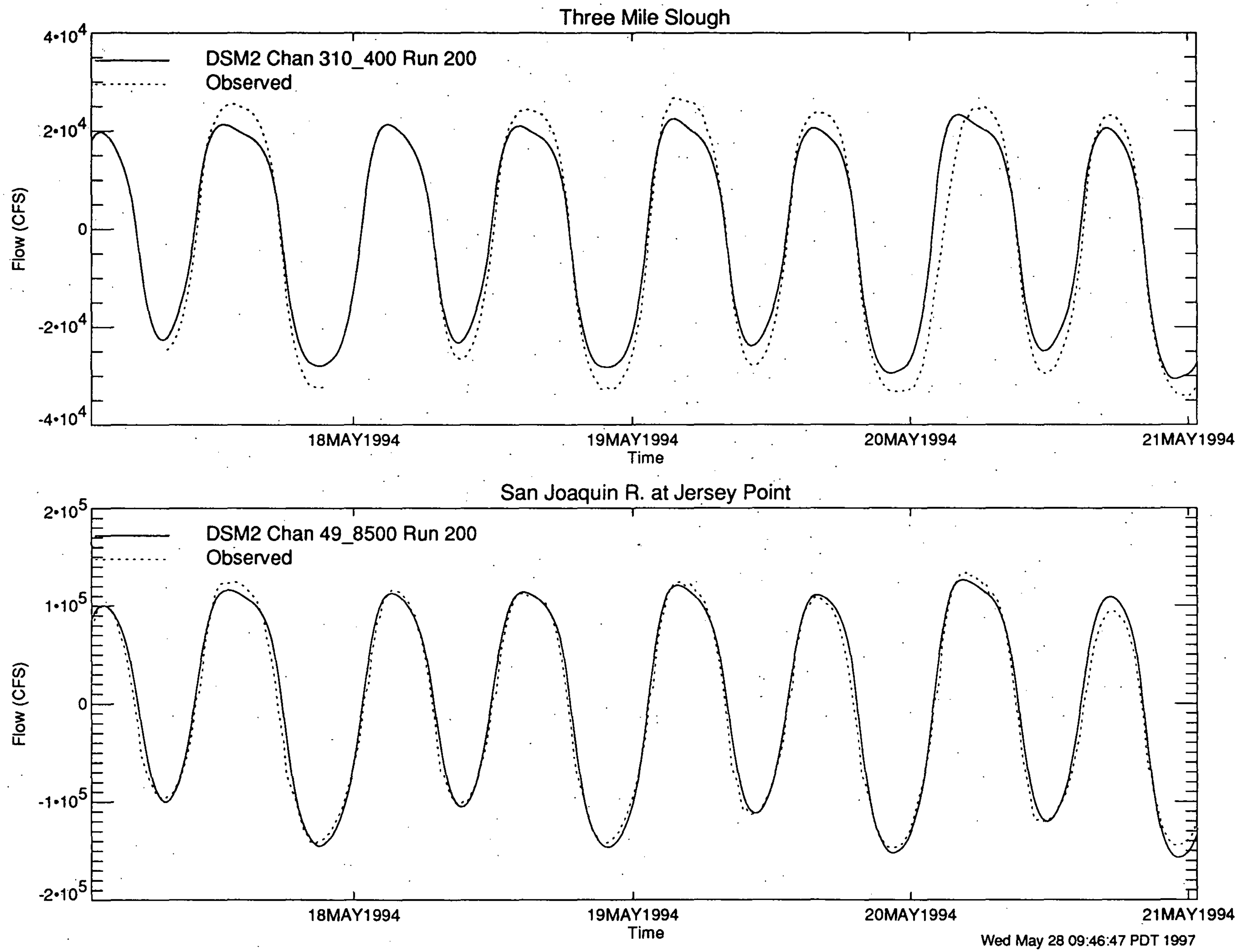
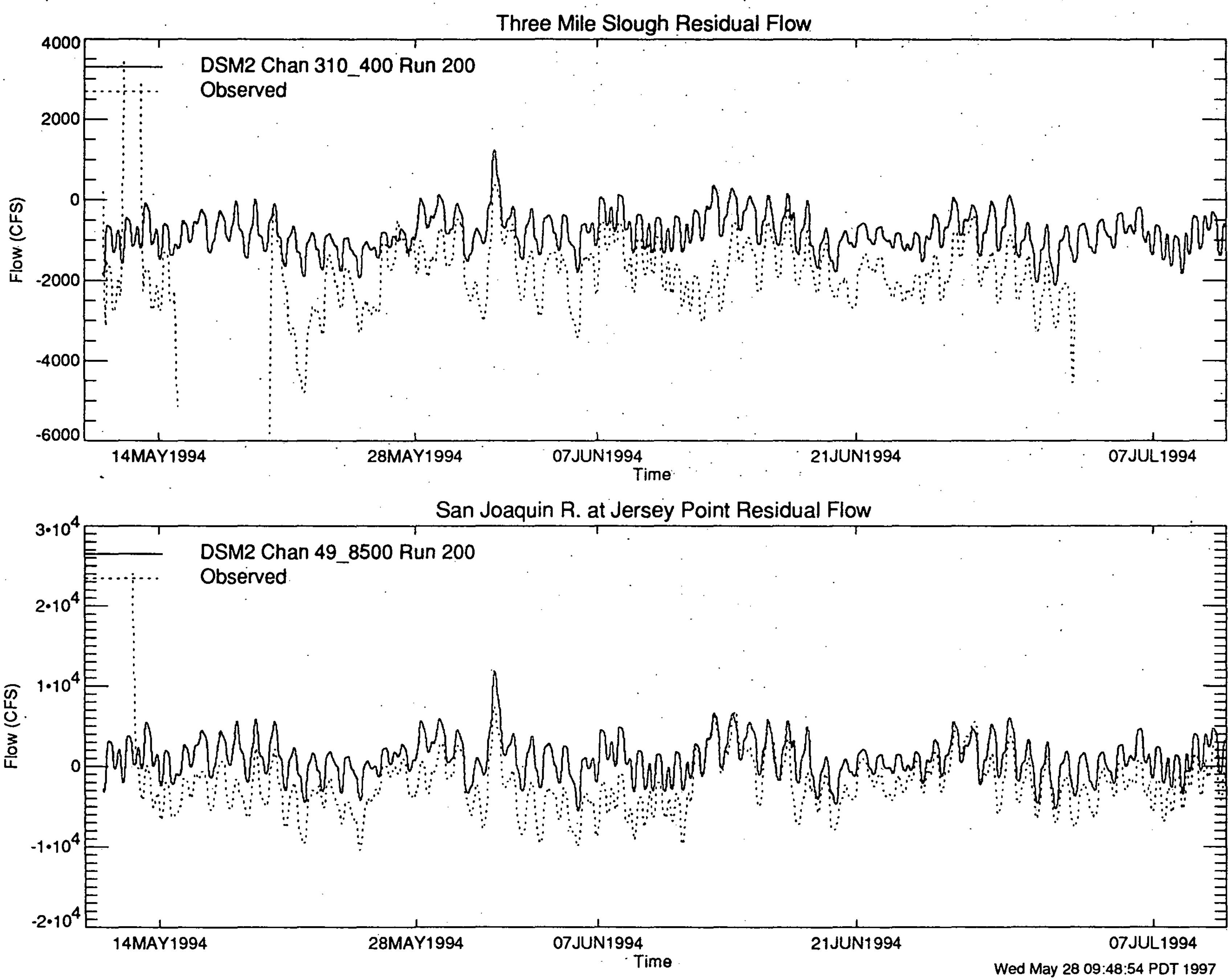

Three Mile Slough
DSM2 Chan 310_400 Run 200
Observed
Flow (CFS)
4•10^4
2•10^4
0
-2•10^4
-4•10^4
18MAY1994
19MAY1994
20MAY1994
21MAY1994
Time
San Joaquin R. at Jersey Point
DSM2 Chan 49_8500 Run 200
Observed
Flow (CFS)
2•10^5
1•10^5
0
-1•10^5
-2•10^5
18MAY1994
19MAY1994
20MAY1994
21MAY1994
Time
Wed May 28 09:46:47 PDT 1997

Figure 2-22



Three Mile Slough Residual Flow
DSM2 Chan 310_400 Run 200
Observed
4000
2000
0
-2000
-4000
-6000
Flow (CFS)
14MAY1994
28MAY1994
07JUN1994
21JUN1994
07JUL1994
Time
San Joaquin R. at Jersey Point Residual Flow
DSM2 Chan 49_8500 Run 200
Observed
3•10^4
2•10^4
1•10^4
0
-1•10^4
-2•10^4
Flow (CFS)
14MAY1994
28MAY1994
07JUN1994
21JUN1994
07JUL1994
Time
Wed May 28 09:48:54 PDT 1997

Figure 2-23

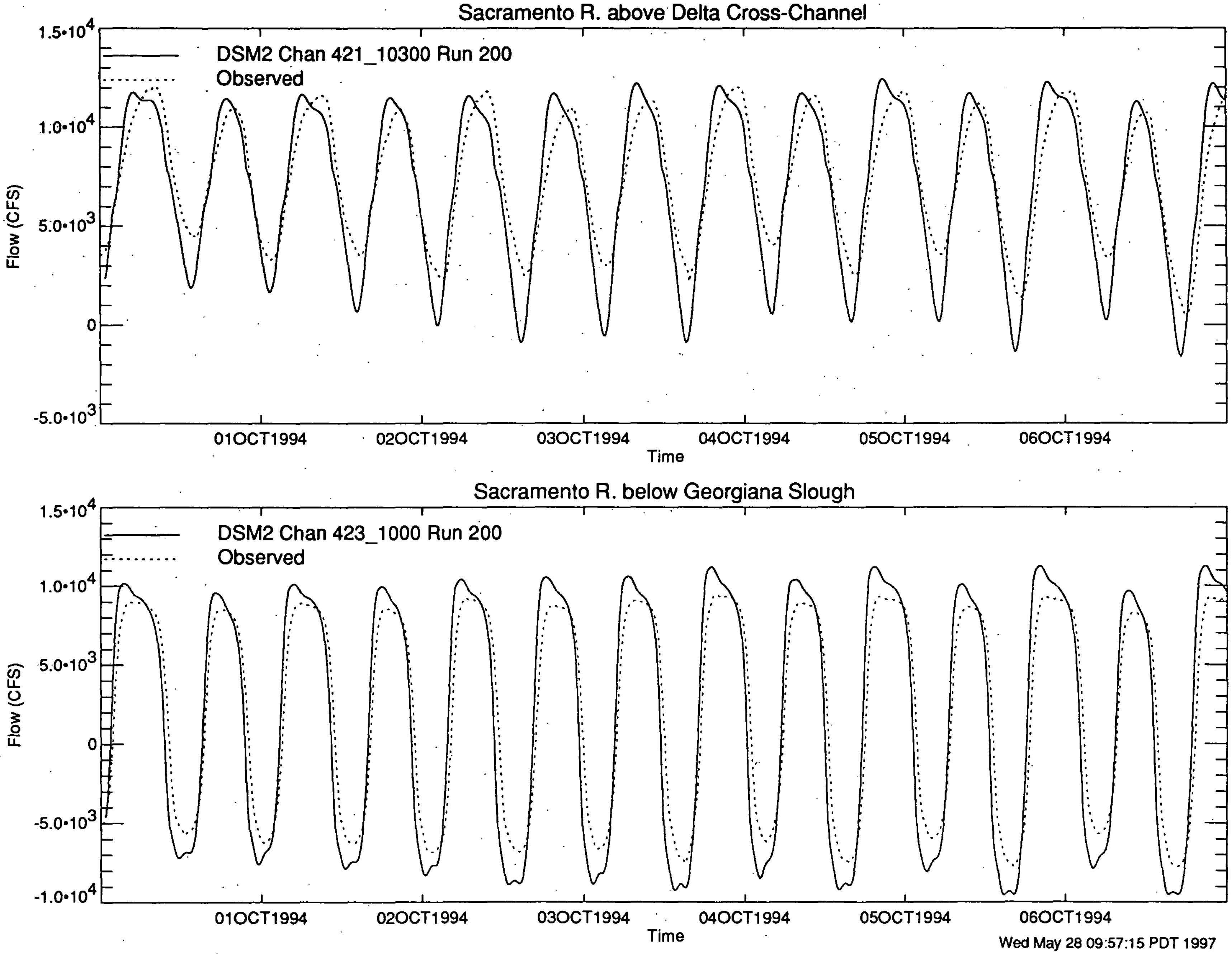
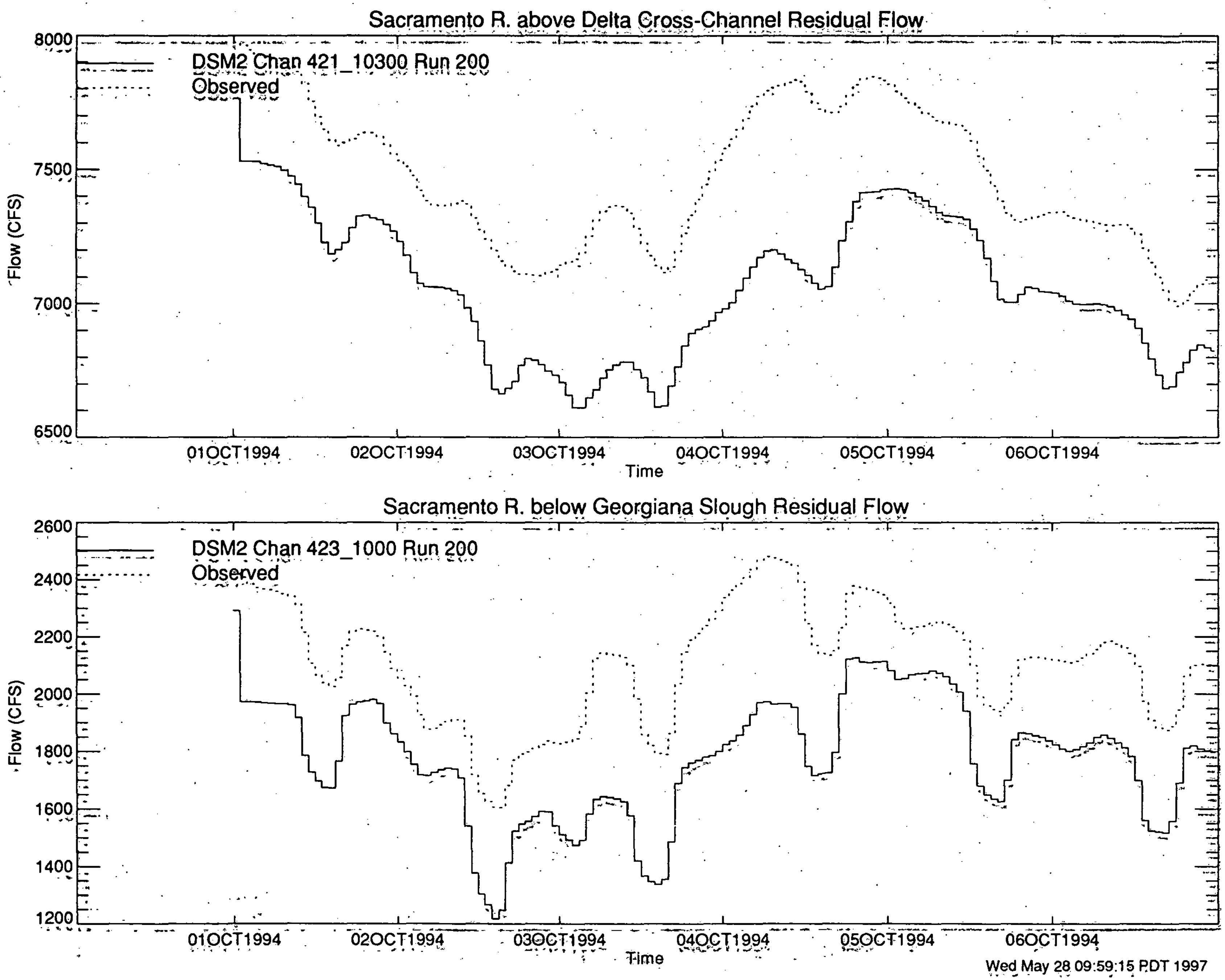

Sacramento R. above Delta Cross-Channel
DSM2 Chan 421_10300 Run 200
Observed
1.5•10^4
1.0•10^4
5.0•10^3
0
-5.0•10^3
Flow (CFS)
01OCT1994
02OCT1994
03OCT1994
04OCT1994
05OCT1994
06OCT1994
Time
Sacramento R. below Georgiana Slough
DSM2 Chan 423_1000 Run 200
Observed
1.5•10^4
1.0•10^4
5.0•10^3
0
-5.0•10^3
-1.0•10^4
Flow (CFS)
01OCT1994
02OCT1994
03OCT1994
04OCT1994
05OCT1994
06OCT1994
Time
Wed May 28 09:57:15 PDT 1997

Figure 2-24



Sacramento R. above Delta Cross-Channel Residual Flow
DSM2 Chan 421_10300 Run 200
Observed
Flow (CFS)
8000
7500
7000
6500
01OCT1994
02OCT1994
03OCT1994
04OCT1994
05OCT1994
06OCT1994
Time
Sacramento R. below Georgiana Slough Residual Flow
DSM2 Chan 423_1000 Run 200
Observed
Flow (CFS)
2600
2400
2200
2000
1800
1600
1400
1200
01OCT1994
02OCT1994
03OCT1994
04OCT1994
05OCT1994
06OCT1994
Time
Wed May 28 09:59:15 PDT 1997

Figure 2-25

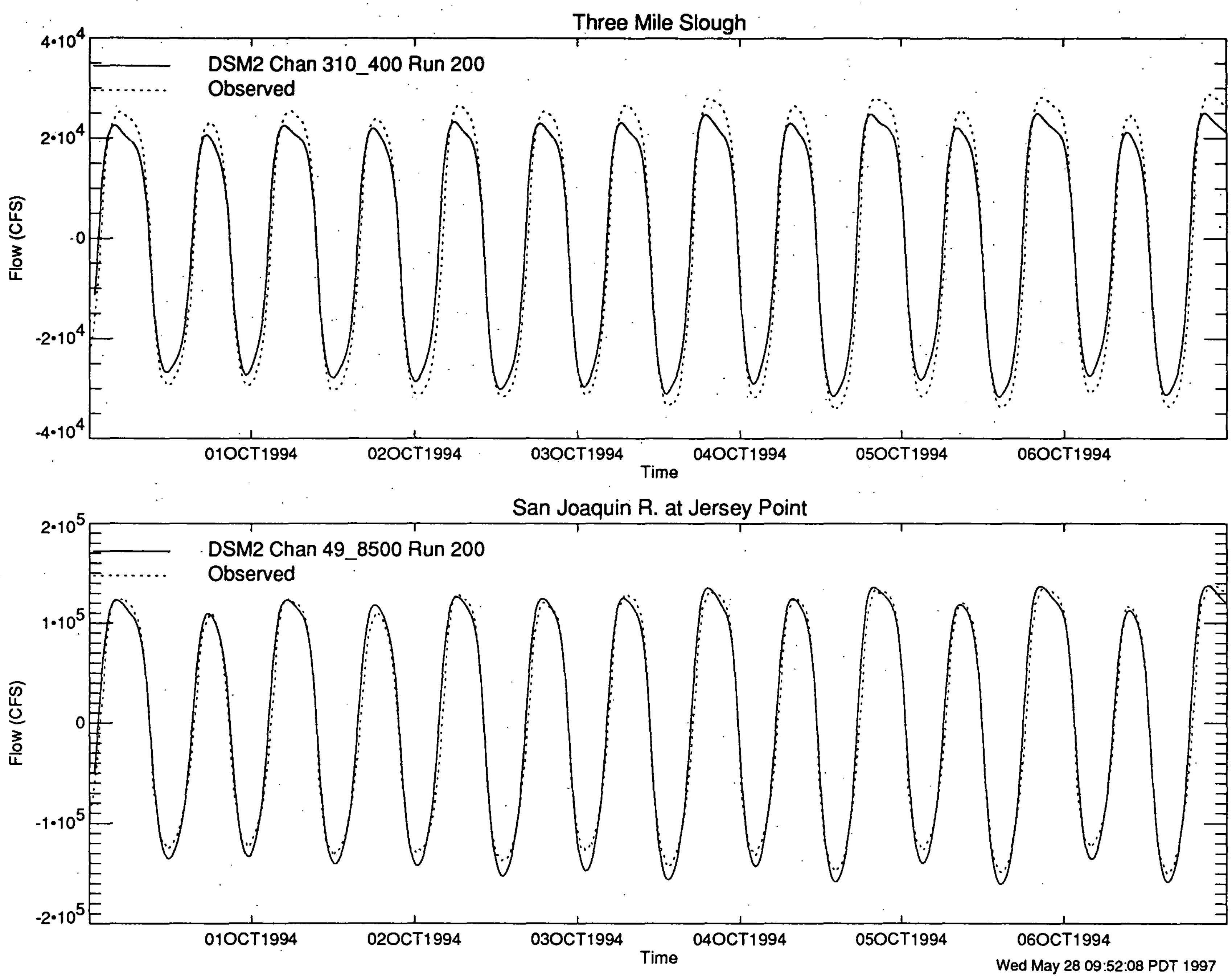
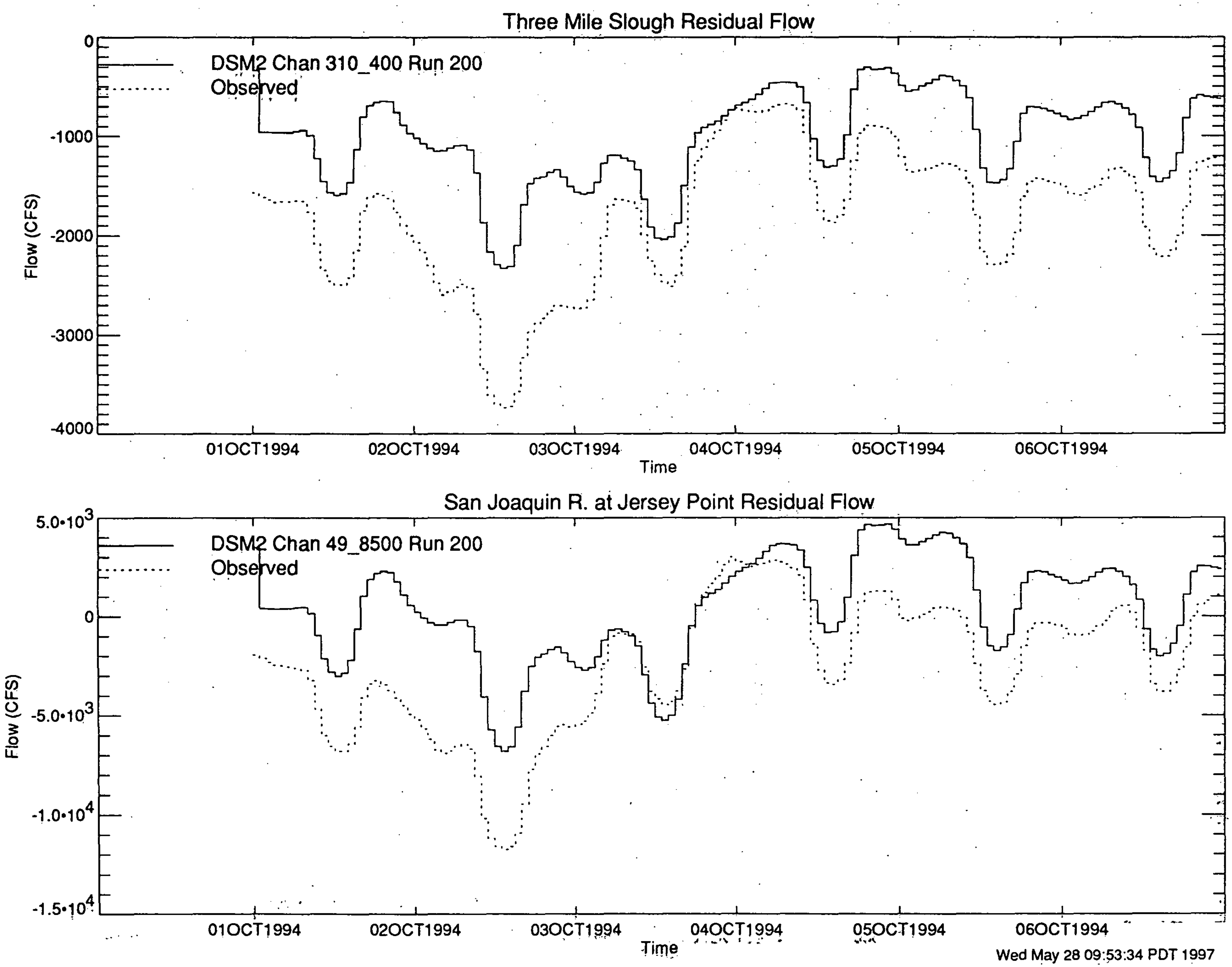

Three Mile Slough
DSM2 Chan 310_400 Run 200
Observed
Flow (CFS)
4•10^4
2•10^4
0
-2•10^4
-4•10^4
01OCT1994
02OCT1994
03OCT1994
04OCT1994
05OCT1994
06OCT1994
Time
San Joaquin R. at Jersey Point
DSM2 Chan 49_8500 Run 200
Observed
Flow (CFS)
2•10^5
1•10^5
0
-1•10^5
-2•10^5
01OCT1994
02OCT1994
03OCT1994
04OCT1994
05OCT1994
06OCT1994
Time
Wed May 28 09:52:08 PDT 1997

Figure 2-26



Three Mile Slough Residual Flow
DSM2 Chan 310_400 Run 200
Observed
Flow (CFS)
0
-1000
-2000
-3000
-4000
01OCT1994
02OCT1994
03OCT1994
04OCT1994
05OCT1994
06OCT1994
Time
San Joaquin R. at Jersey Point Residual Flow
DSM2 Chan 49_8500 Run 200
Observed
Flow (CFS)
5.0•10^3
0
-5.0•10^3
-1.0•10^4
-1.5•10^4
01OCT1994
02OCT1994
03OCT1994
04OCT1994
05OCT1994
06OCT1994
Time
Wed May 28 09:53:34 PDT 1997

Figure 2-27

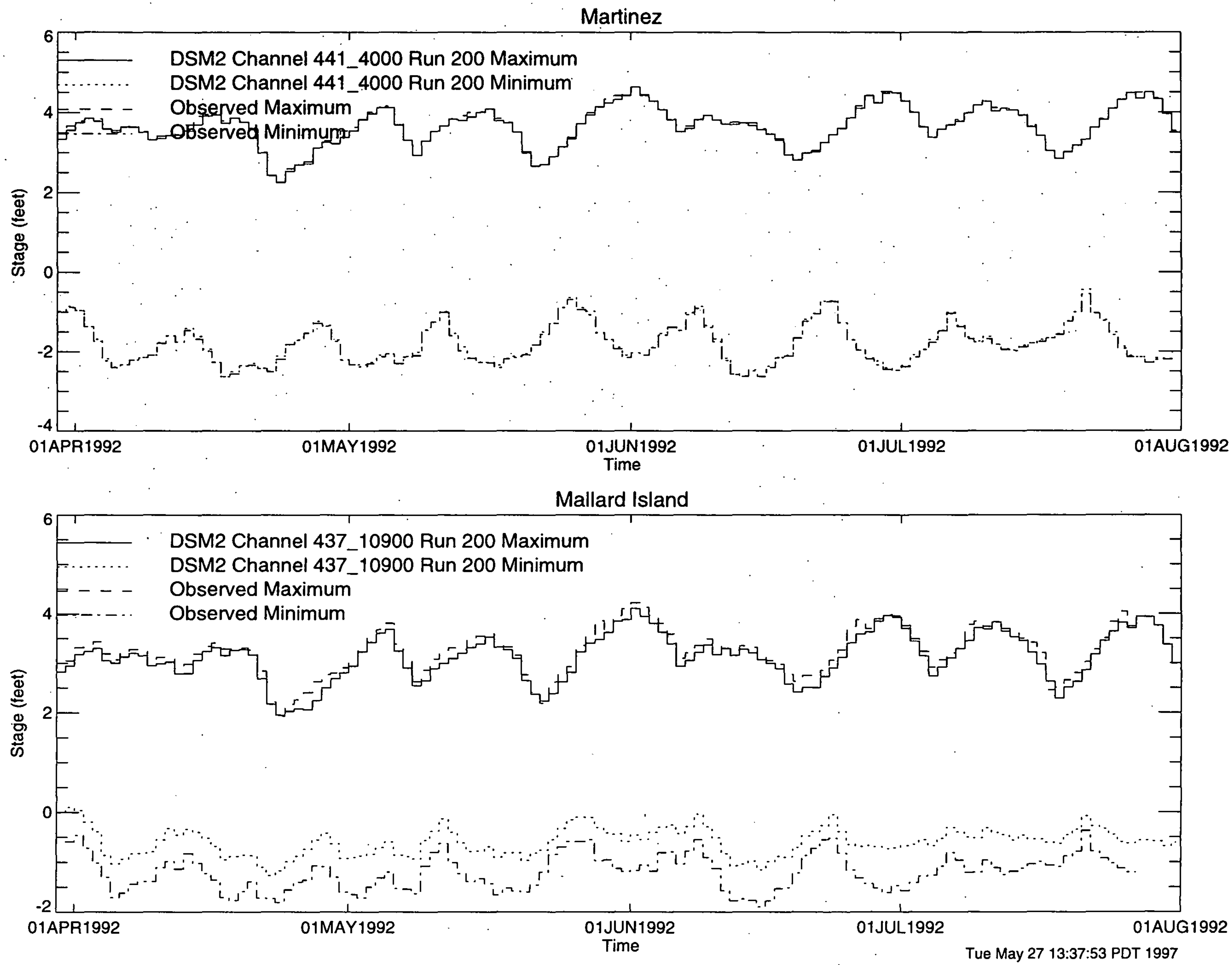

Martinez
DSM2 Channel 441_4000 Run 200 Maximum
DSM2 Channel 441_4000 Run 200 Minimum
Observed Maximum
Observed Minimum
Stage (feet)
6
4
2
0
-2
-4
01APR1992
01MAY1992
01JUN1992
01JUL1992
01AUG1992
Time
Mallard Island
DSM2 Channel 437_10900 Run 200 Maximum
DSM2 Channel 437_10900 Run 200 Minimum
Observed Maximum
Observed Minimum
Stage (feet)
6
4
2
0
-2
01APR1992
01MAY1992
01JUN1992
01JUL1992
01AUG1992
Time
Tue May 27 13:37:53 PDT 1997

Figure 2-28

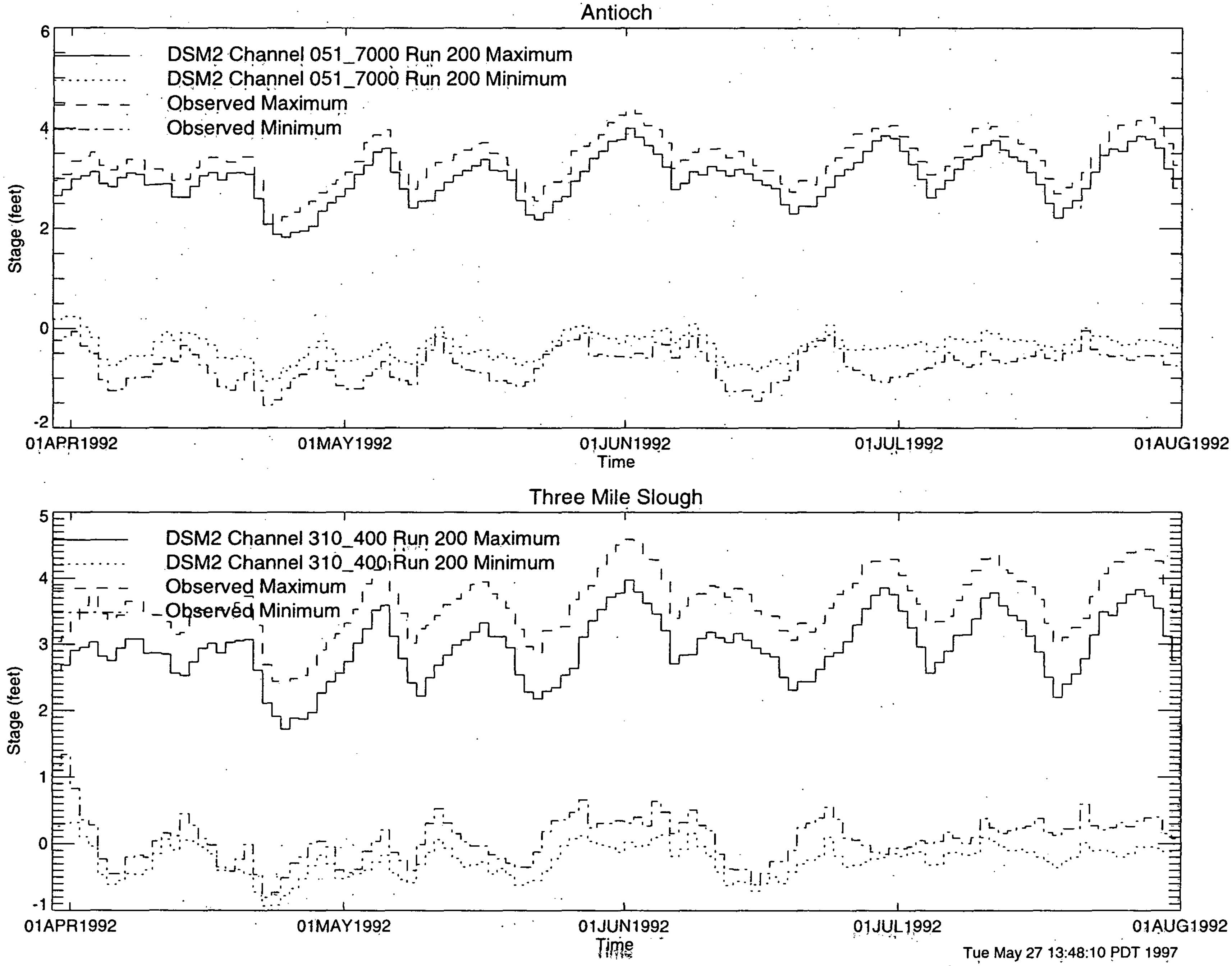
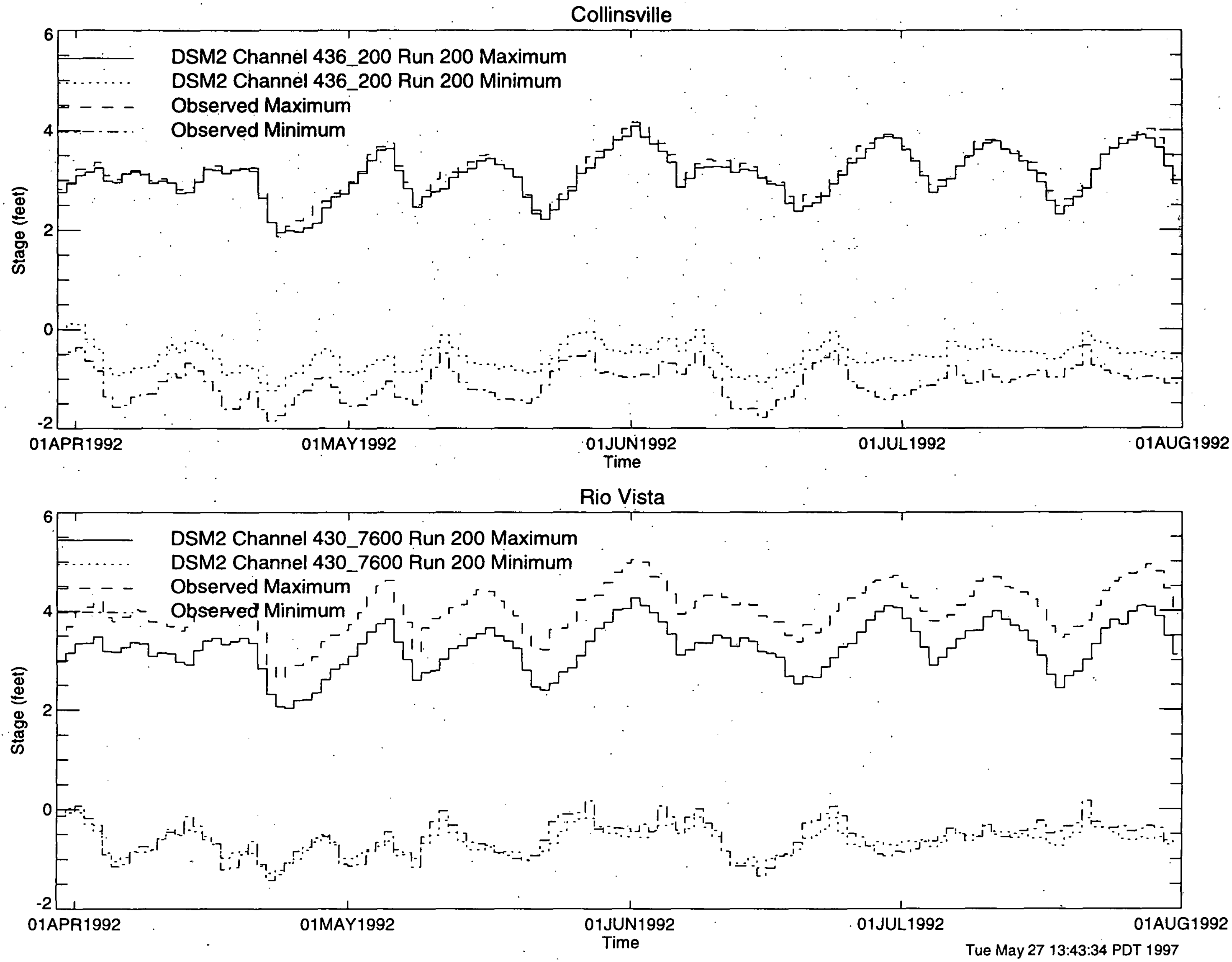

Antioch
DSM2 Channel 051_7000 Run 200 Maximum
DSM2 Channel 051_7000 Run 200 Minimum
Observed Maximum
Observed Minimum
Stage (feet)
Time
01APR1992
01MAY1992
01JUN1992
01JUL1992
01AUG1992
Three Mile Slough
DSM2 Channel 310_400 Run 200 Maximum
DSM2 Channel 310_400 Run 200 Minimum
Observed Maximum
Observed Minimum
Stage (feet)
Time
01APR1992
01MAY1992
01JUN1992
01JUL1992
01AUG1992
Tue May 27 13:48:10 PDT 1997

Figure 2-29



Collinsville
DSM2 Channel 436_200 Run 200 Maximum
DSM2 Channel 436_200 Run 200 Minimum
Observed Maximum
Observed Minimum
Stage (feet)
6
4
2
0
-2
01APR1992
01MAY1992
01JUN1992
01JUL1992
01AUG1992
Time
Rio Vista
DSM2 Channel 430_7600 Run 200 Maximum
DSM2 Channel 430_7600 Run 200 Minimum
Observed Maximum
Observed Minimum
Stage (feet)
6
4
2
0
-2
01APR1992
01MAY1992
01JUN1992
01JUL1992
01AUG1992
Time
Tue May 27 13:43:34 PDT 1997

Figure 2–30

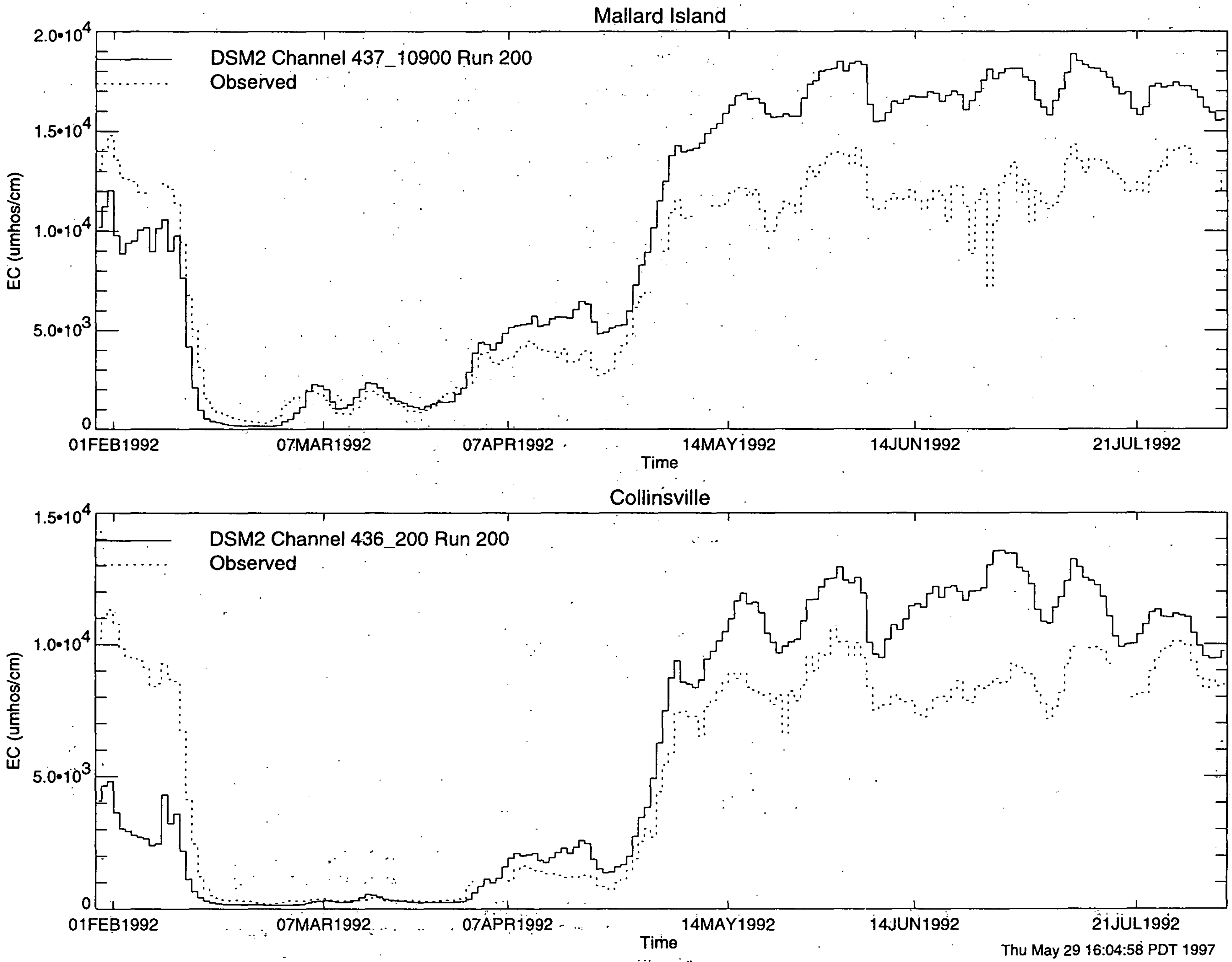
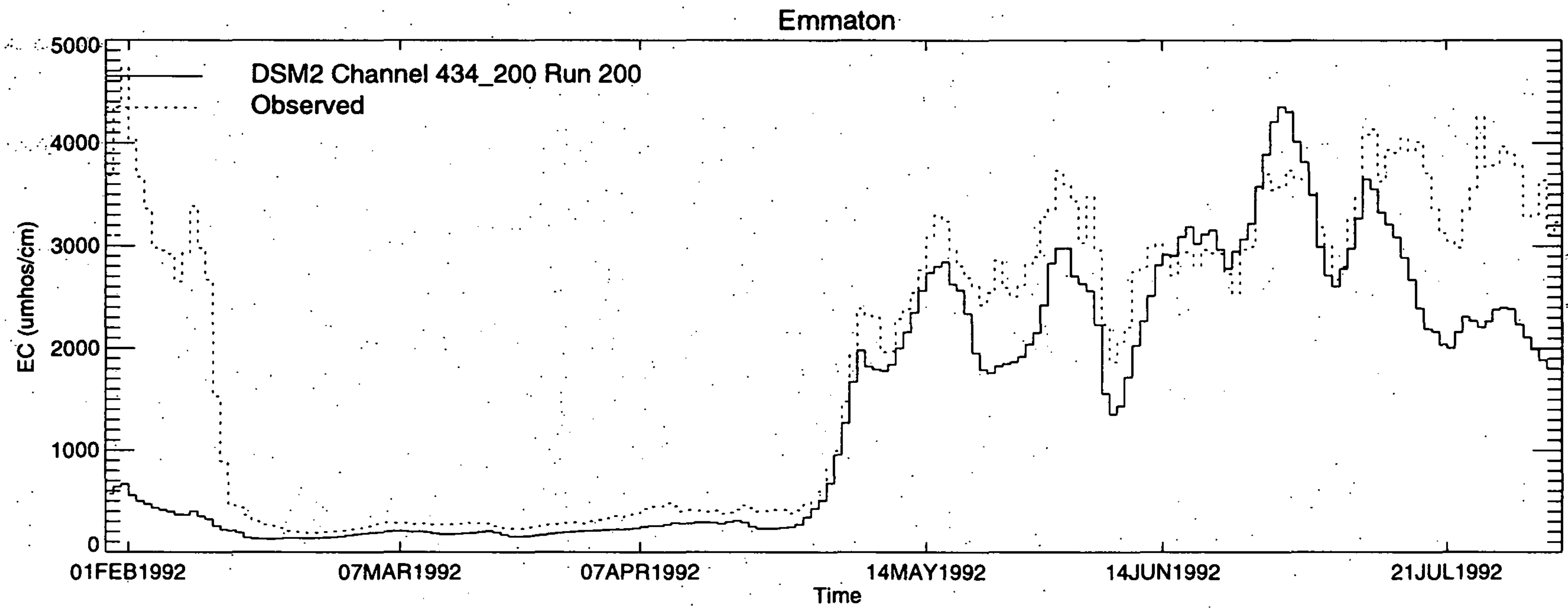

Mallard Island
DSM2 Channel 437_10900 Run 200
Observed
EC (umhos/cm)
2.0•10^4
1.5•10^4
1.0•10^4
5.0•10^3
0
01FEB1992
07MAR1992
07APR1992
14MAY1992
14JUN1992
21JUL1992
Time
Collinsville
DSM2 Channel 436_200 Run 200
Observed
EC (umhos/cm)
1.5•10^4
1.0•10^4
5.0•10^3
0
01FEB1992
07MAR1992
07APR1992
14MAY1992
14JUN1992
21JUL1992
Time
Thu May 29 16:04:58 PDT 1997

Figure 2-31


Emmaton
DSM2 Channel 434_200 Run 200
Observed
EC (umhos/cm)
5000
4000
3000
2000
1000
0
01FEB1992
07MAR1992
07APR1992
14MAY1992
14JUN1992
21JUL1992
Time

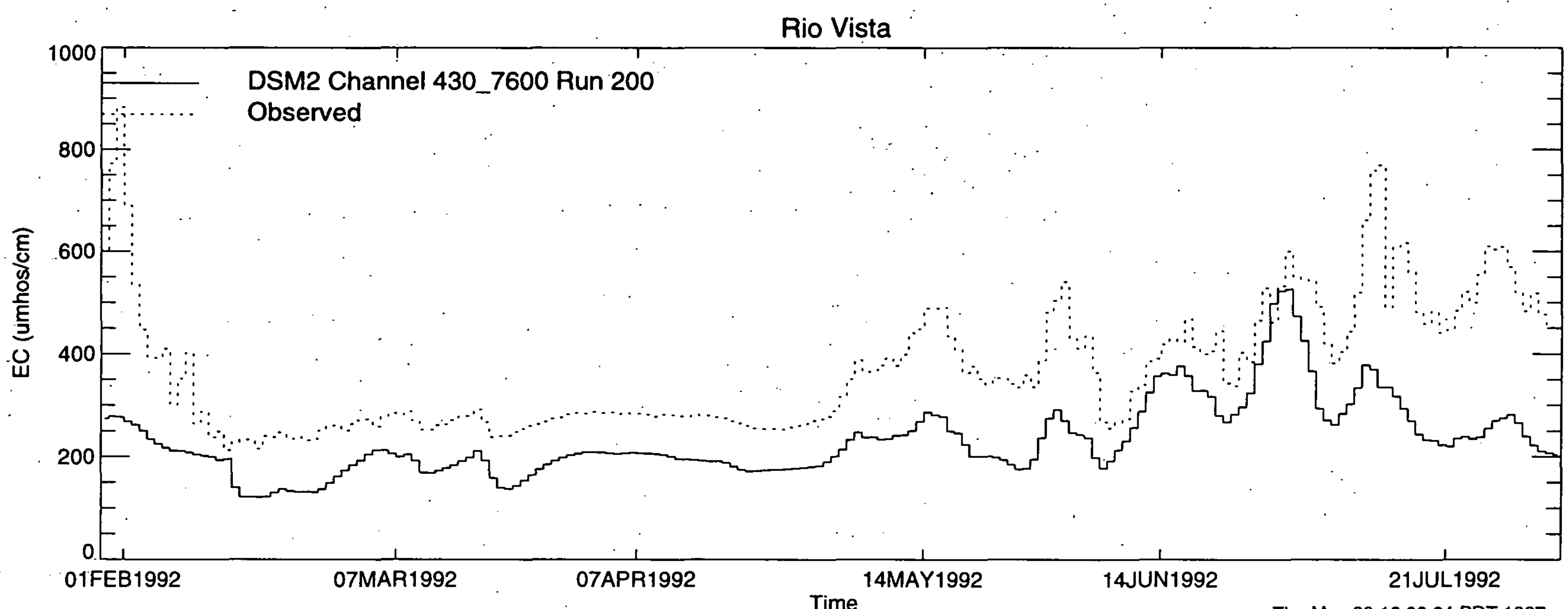
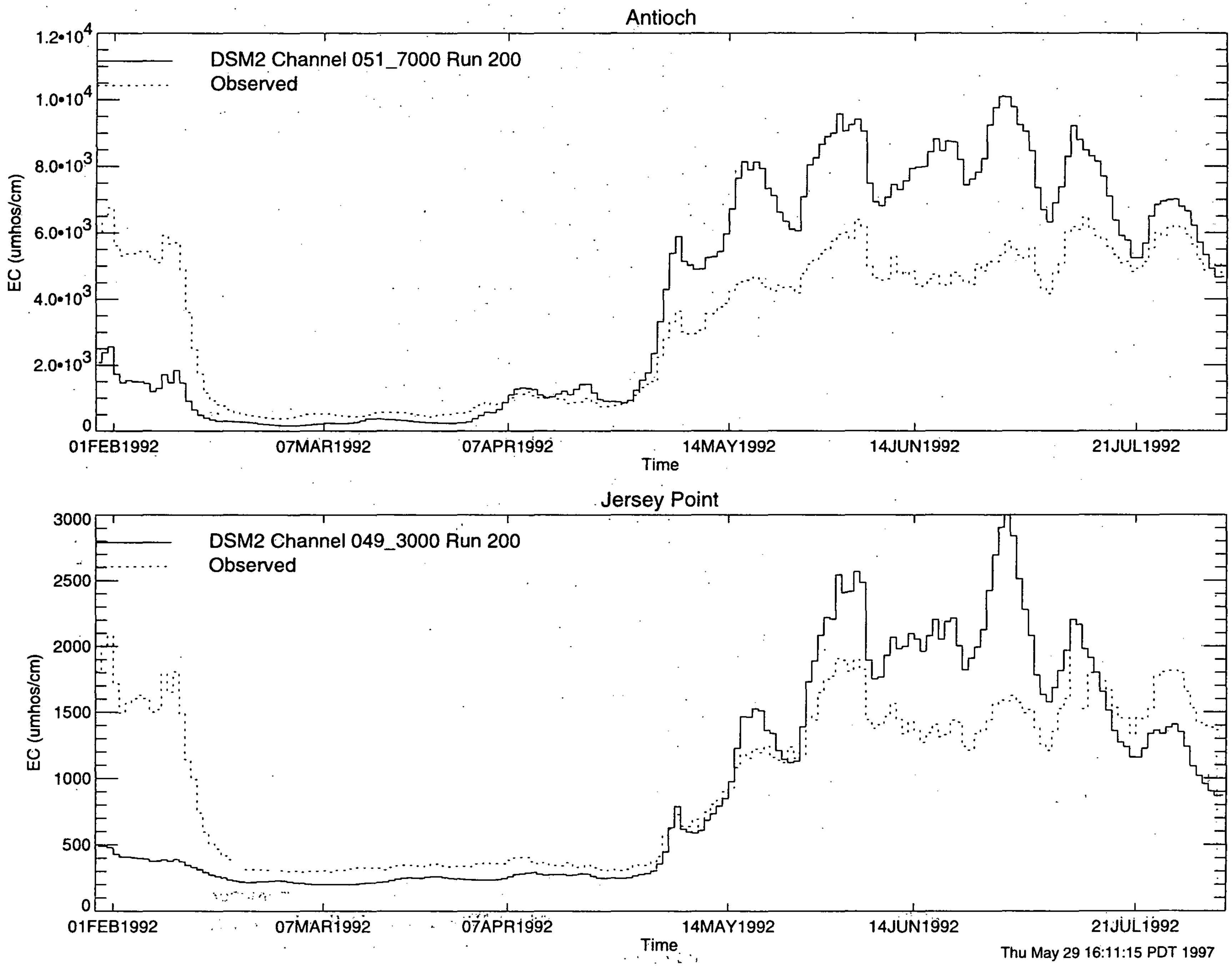

Rio Vista
DSM2 Channel 430_7600 Run 200
Observed
EC (umhos/cm)
1000
800
600
400
200
0
01FEB1992
07MAR1992
07APR1992
14MAY1992
14JUN1992
21JUL1992
Time
Thu May 29 16:08:24 PDT 1997

Figure 2-32



Antioch
1.2•10^4
1.0•10^4
8.0•10^3
6.0•10^3
4.0•10^3
2.0•10^3
0
EC (umhos/cm)
DSM2 Channel 051_7000 Run 200
Observed
01FEB1992
07MAR1992
07APR1992
14MAY1992
14JUN1992
21JUL1992
Time
Jersey Point
3000
2500
2000
1500
1000
500
0
EC (umhos/cm)
DSM2 Channel 049_3000 Run 200
Observed
01FEB1992
07MAR1992
07APR1992
14MAY1992
14JUN1992
21JUL1992
Time
Thu May 29 16:11:15 PDT 1997

Figure 2-33

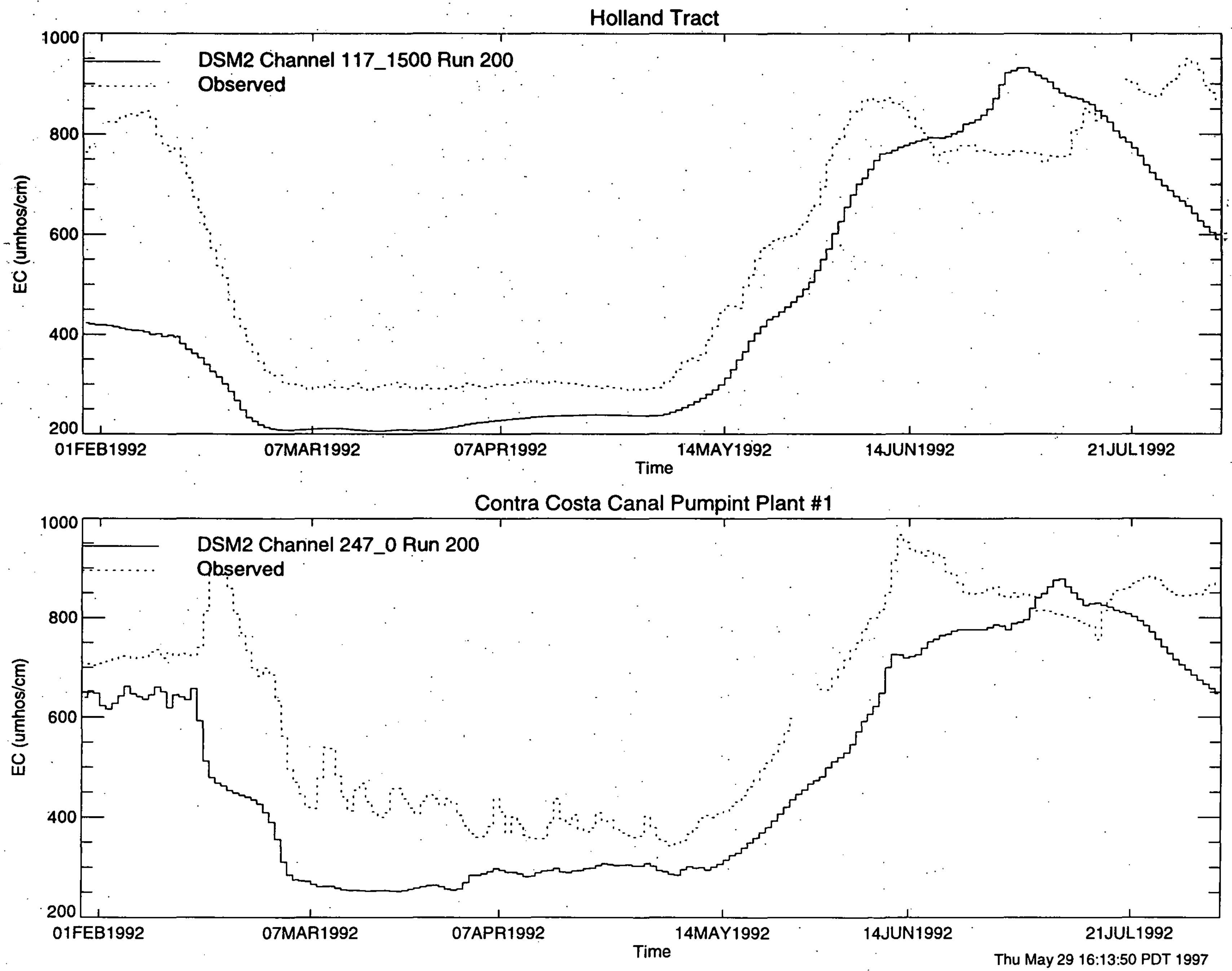

Holland Tract
DSM2 Channel 117_1500 Run 200
Observed
EC (umhos/cm)
1000
800
600
400
200
01FEB1992
07MAR1992
07APR1992
14MAY1992
14JUN1992
21JUL1992
Time
Contra Costa Canal Pumpint Plant #1
DSM2 Channel 247_0 Run 200
Observed
EC (umhos/cm)
1000
800
600
400
200
01FEB1992
07MAR1992
07APR1992
14MAY1992
14JUN1992
21JUL1992
Time
Thu May 29 16:13:50 PDT 1997

Figure 2-34

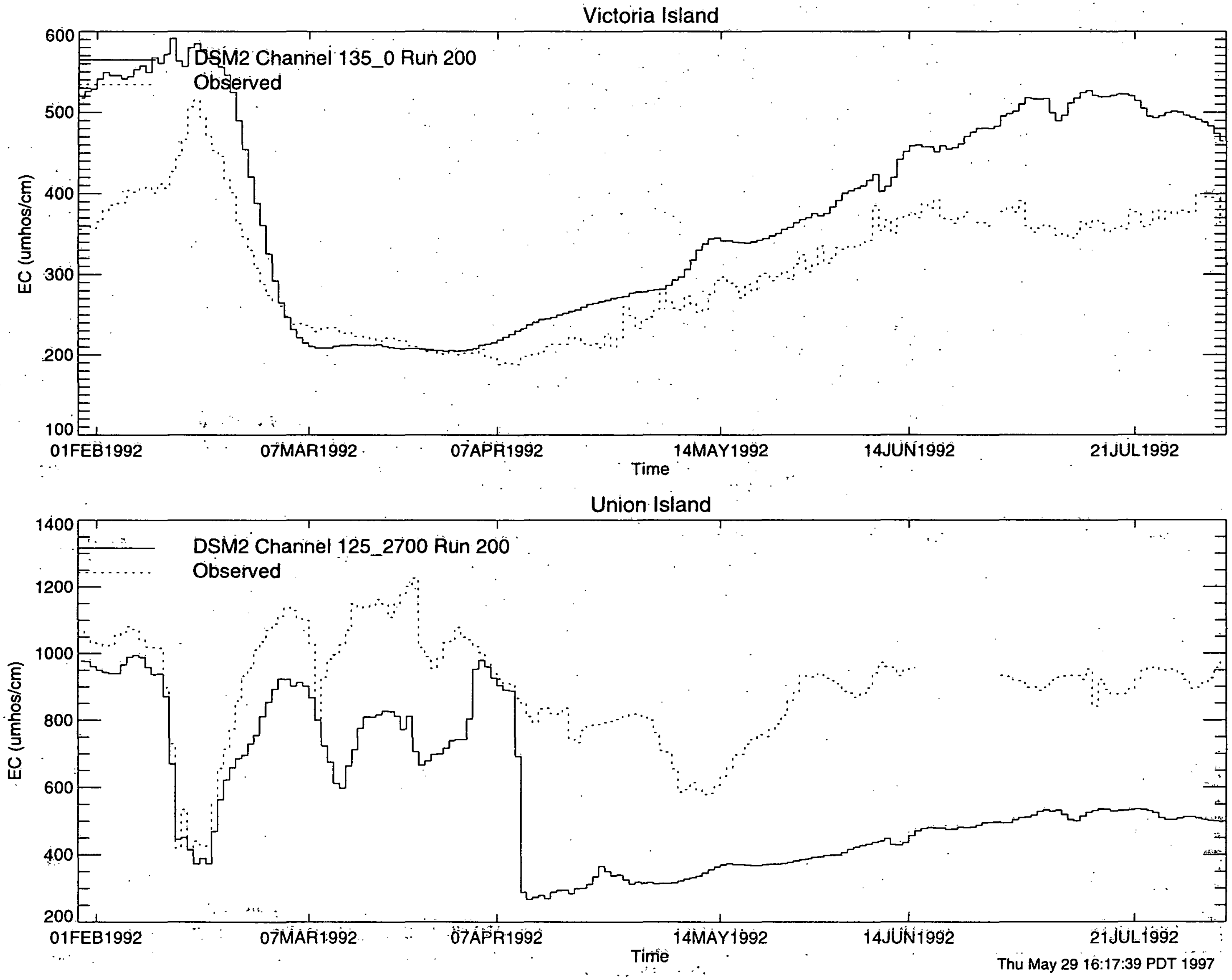

Victoria Island
DSM2 Channel 135_0 Run 200
Observed
EC (umhos/cm)
600
500
400
300
200
100
01FEB1992
07MAR1992
07APR1992
14MAY1992
14JUN1992
21JUL1992
Time
Union Island
DSM2 Channel 125_2700 Run 200
Observed
EC (umhos/cm)
1400
1200
1000
800
600
400
200
01FEB1992
07MAR1992
07APR1992
14MAY1992
14JUN1992
21JUL1992
Time
Thu May 29 16:17:39 PDT 1997

Figure 2-35

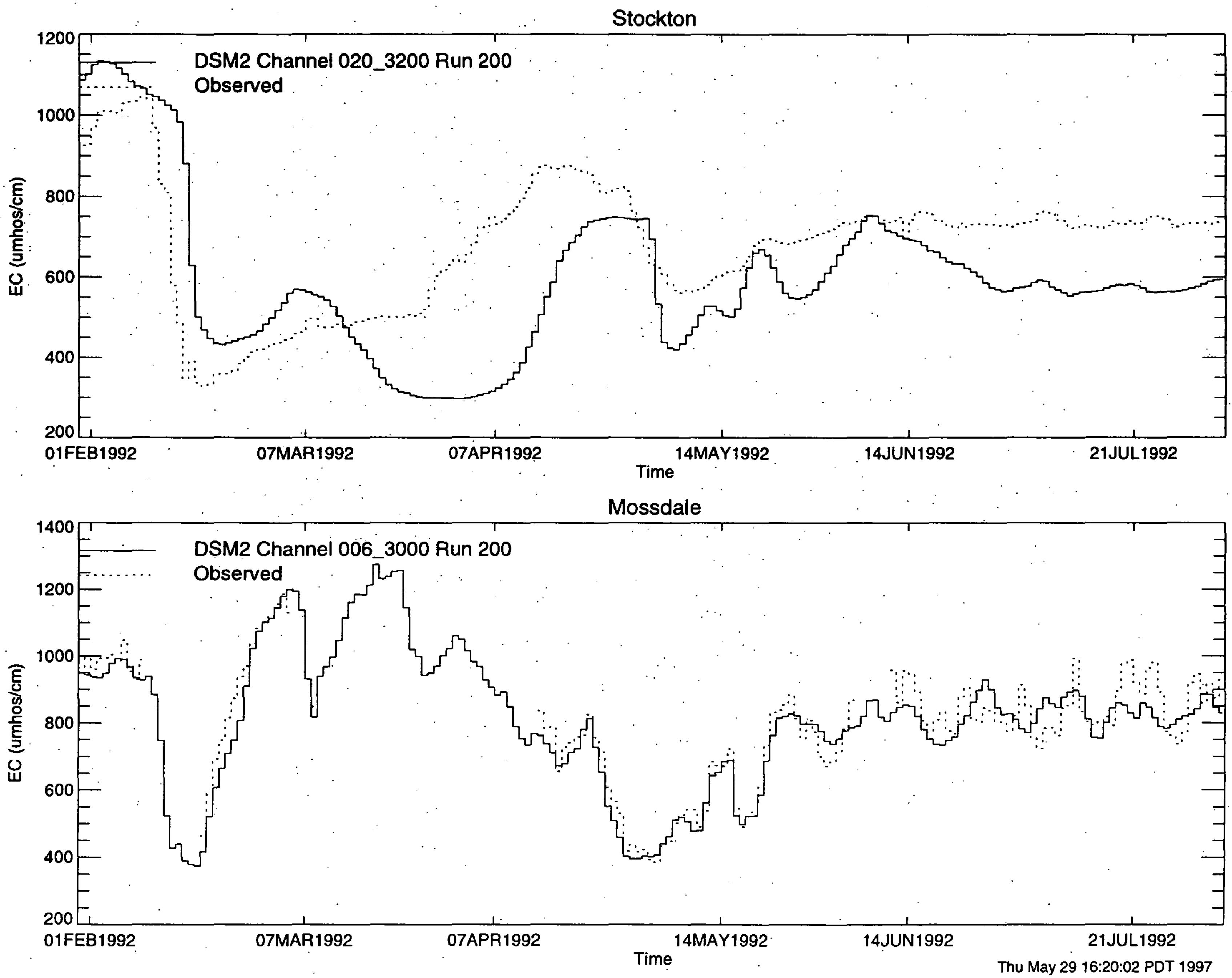

Stockton
DSM2 Channel 020_3200 Run 200
Observed
EC (umhos/cm)
1200
1000
800
600
400
200
01FEB1992
07MAR1992
07APR1992
14MAY1992
14JUN1992
21JUL1992
Time
Mossdale
DSM2 Channel 006_3000 Run 200
Observed
EC (umhos/cm)
1400
1200
1000
800
600
400
200
01FEB1992
07MAR1992
07APR1992
14MAY1992
14JUN1992
21JUL1992
Time
Thu May 29 16:20:02 PDT 1997

Figure 2-36

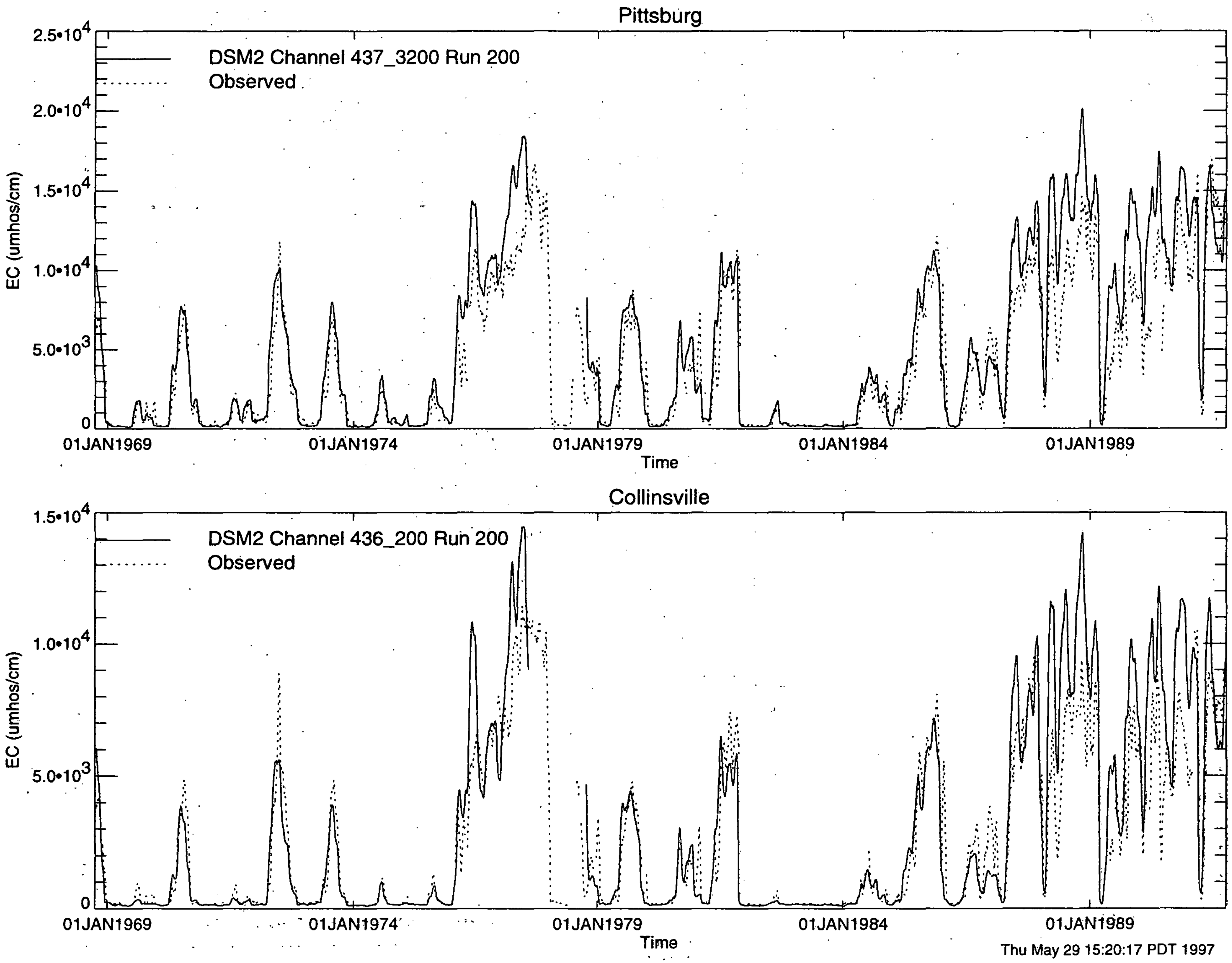

Pittsburg
DSM2 Channel 437_3200 Run 200
Observed
2.5•10⁴
2.0•10⁴
1.5•10⁴
1.0•10⁴
5.0•10³
0
EC (umhos/cm)
01JAN1969
01JAN1974
01JAN1979
01JAN1984
01JAN1989
Time
Collinsville
DSM2 Channel 436_200 Run 200
Observed
1.5•10⁴
1.0•10⁴
5.0•10³
0
EC (umhos/cm)
01JAN1969
01JAN1974
01JAN1979
01JAN1984
01JAN1989
Time
Thu May 29 15:20:17 PDT 1997

Figure 2–37

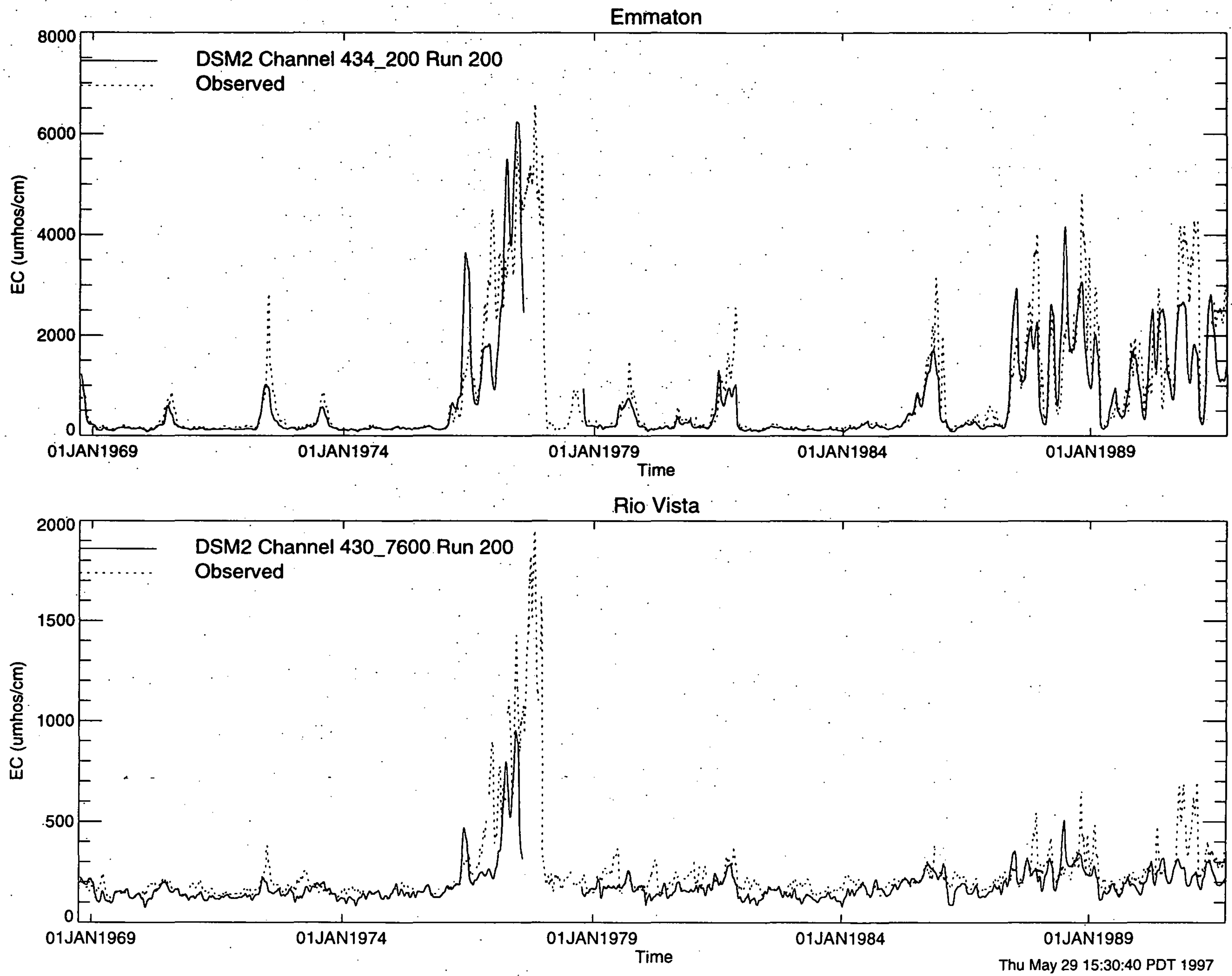

Emmaton
DSM2 Channel 434_200 Run 200
Observed
EC (umhos/cm)
8000
6000
4000
2000
0
01JAN1969
01JAN1974
01JAN1979
01JAN1984
01JAN1989
Time
Rio Vista
DSM2 Channel 430_7600 Run 200
Observed
EC (umhos/cm)
2000
1500
1000
500
0
01JAN1969
01JAN1974
01JAN1979
01JAN1984
01JAN1989
Time
Thu May 29 15:30:40 PDT 1997

Figure 2-38

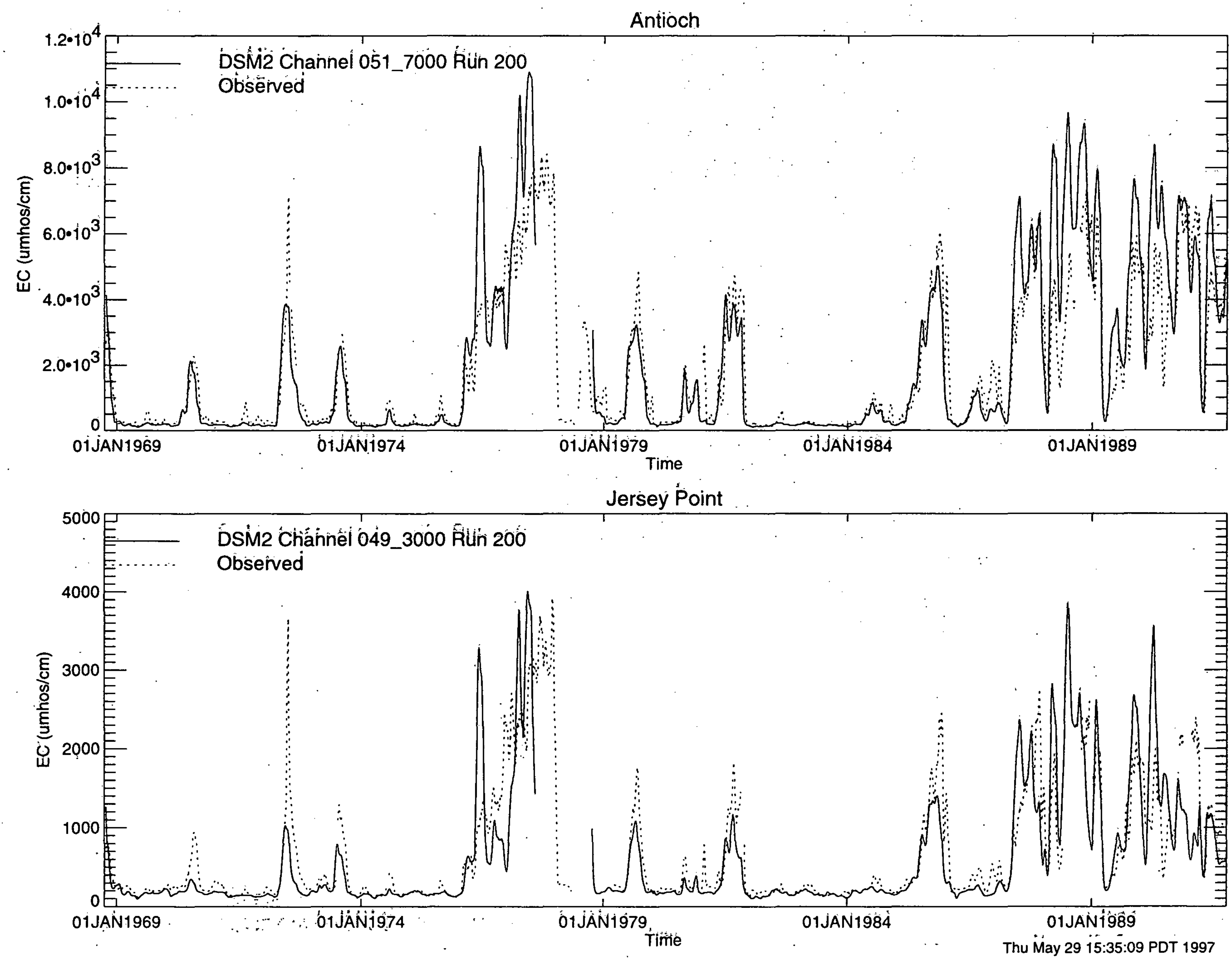

Antioch
DSM2 Channel 051_7000 Run 200
Observed
EC (umhos/cm)
1.2•10^4
1.0•10^4
8.0•10^3
6.0•10^3
4.0•10^3
2.0•10^3
0
01JAN1969
01JAN1974
01JAN1979
01JAN1984
01JAN1989
Time
Jersey Point
DSM2 Channel 049_3000 Run 200
Observed
EC (umhos/cm)
5000
4000
3000
2000
1000
0
01JAN1969
01JAN1974
01JAN1979
01JAN1984
01JAN1989
Time
Thu May 29 15:35:09 PDT 1997

Figure 2-39

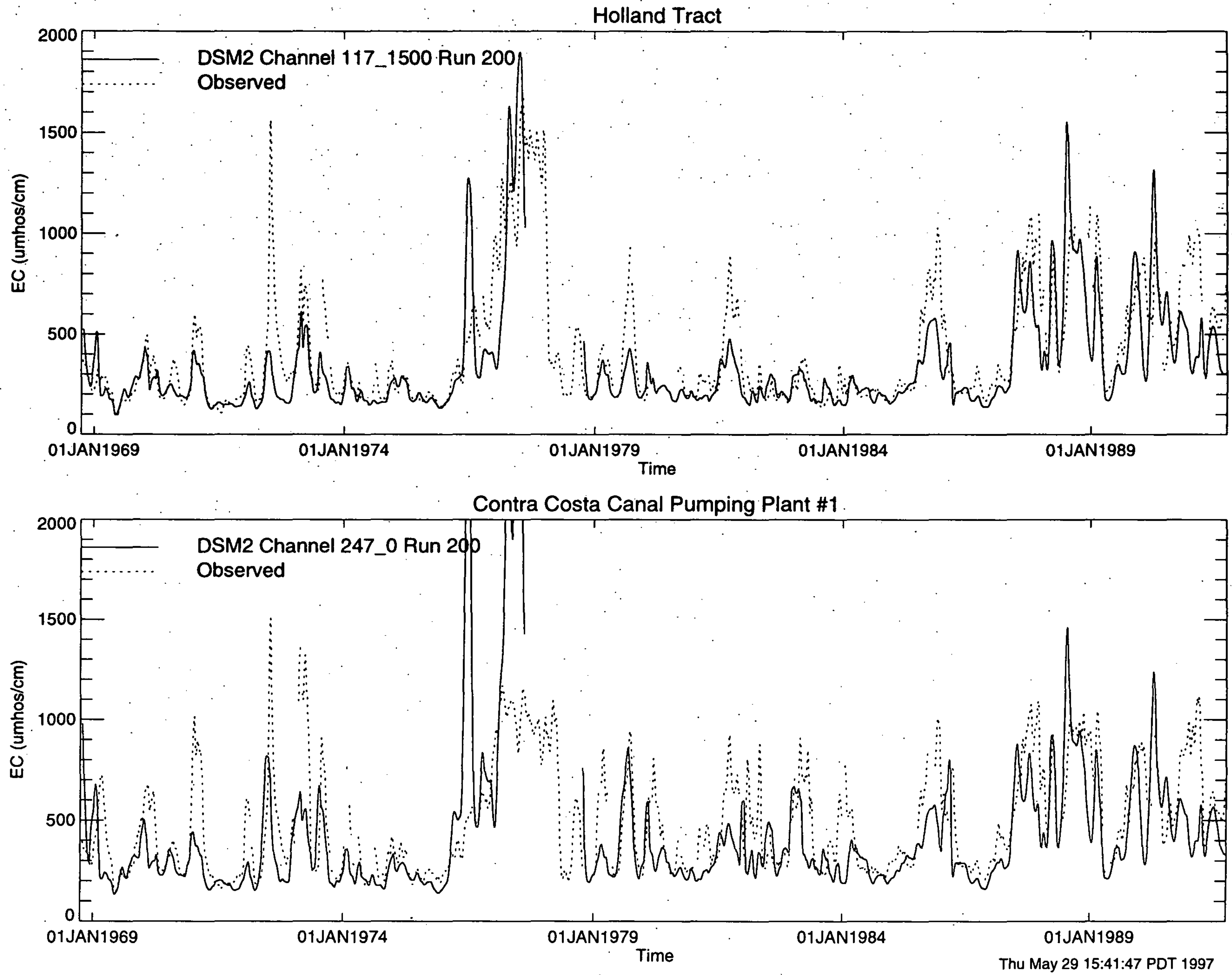
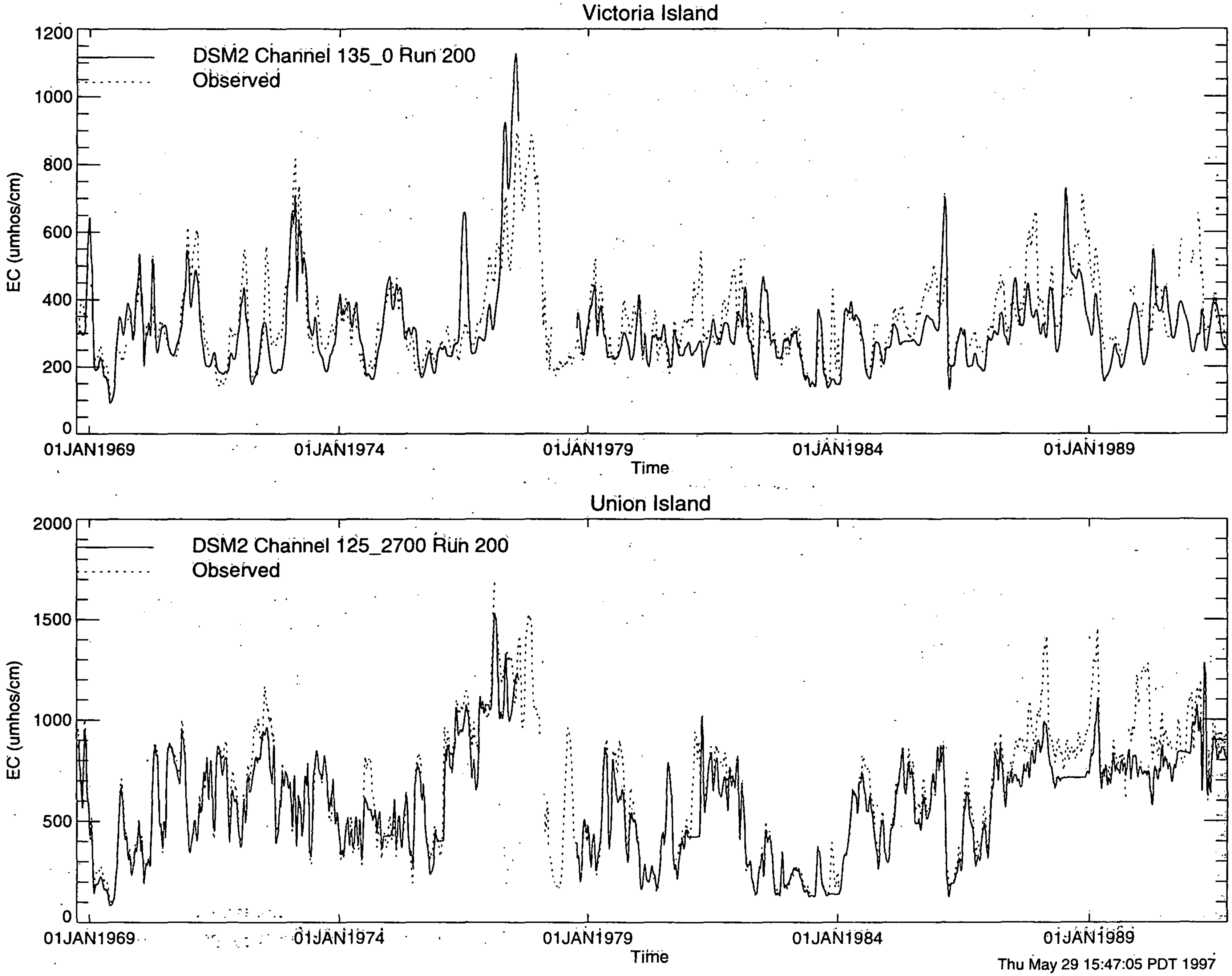

Holland Tract
DSM2 Channel 117_1500 Run 200
Observed
EC (umhos/cm)
0
500
1000
1500
2000
01JAN1969
01JAN1974
01JAN1979
01JAN1984
01JAN1989
Time
Contra Costa Canal Pumping Plant #1
DSM2 Channel 247_0 Run 200
Observed
EC (umhos/cm)
0
500
1000
1500
2000
01JAN1969
01JAN1974
01JAN1979
01JAN1984
01JAN1989
Time
Thu May 29 15:41:47 PDT 1997

Figure 2-40



Victoria Island
DSM2 Channel 135_0 Run 200
Observed
EC (umhos/cm)
0
200
400
600
800
1000
1200
01JAN1969
01JAN1974
01JAN1979
01JAN1984
01JAN1989
Time
Union Island
DSM2 Channel 125_2700 Run 200
Observed
EC (umhos/cm)
0
500
1000
1500
2000
01JAN1969
01JAN1974
01JAN1979
01JAN1984
01JAN1989
Time
Thu May 29 15:47:05 PDT 1997

Figure 2-41

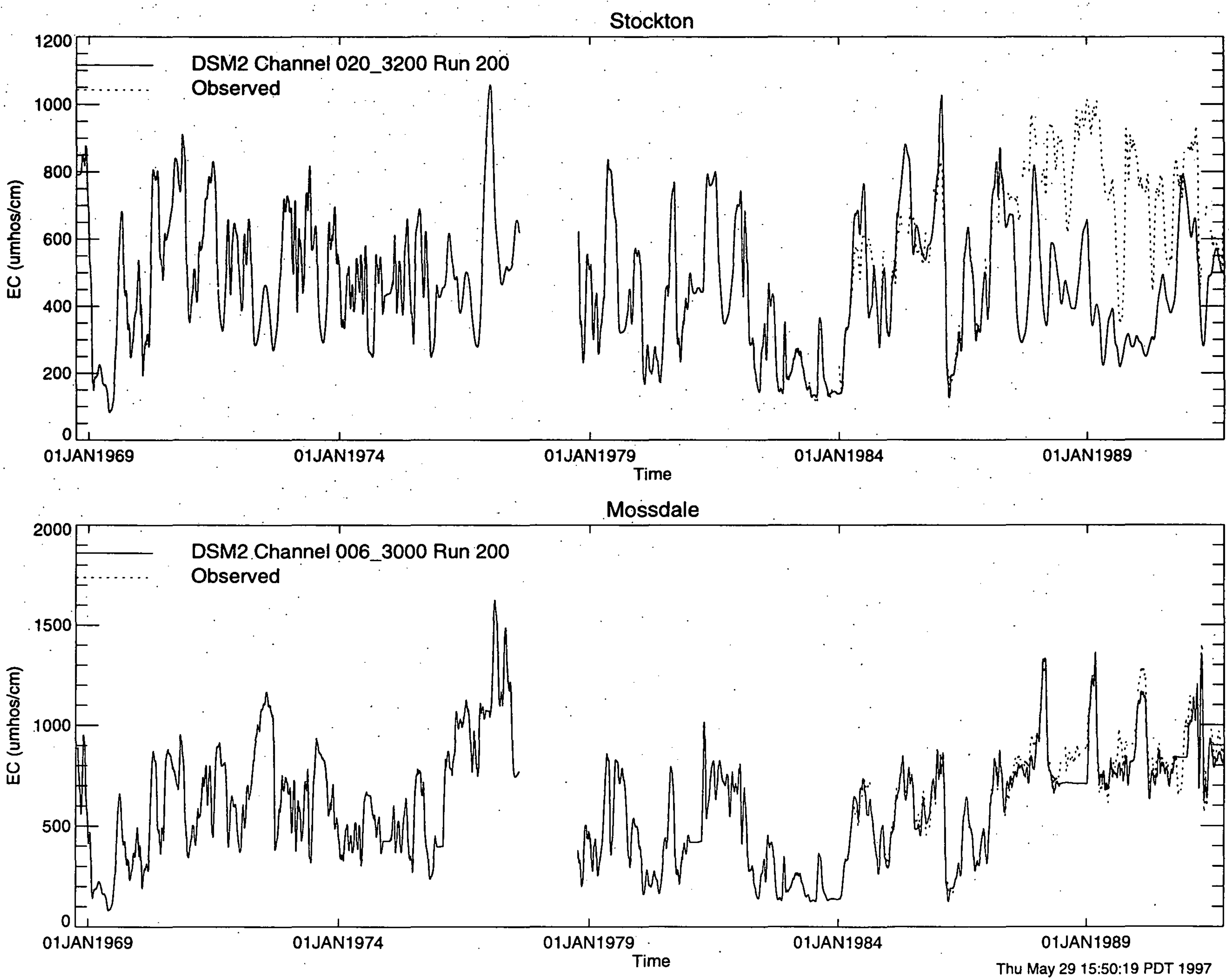

Stockton
DSM2 Channel 020_3200 Run 200
Observed
EC (umhos/cm)
0
200
400
600
800
1000
1200
01JAN1969
01JAN1974
01JAN1979
01JAN1984
01JAN1989
Time
Mossdale
DSM2 Channel 006_3000 Run 200
Observed
EC (umhos/cm)
0
500
1000
1500
2000
01JAN1969
01JAN1974
01JAN1979
01JAN1984
01JAN1989
Time
Thu May 29 15:50:19 PDT 1997

Figure 2-42

Run 39.0

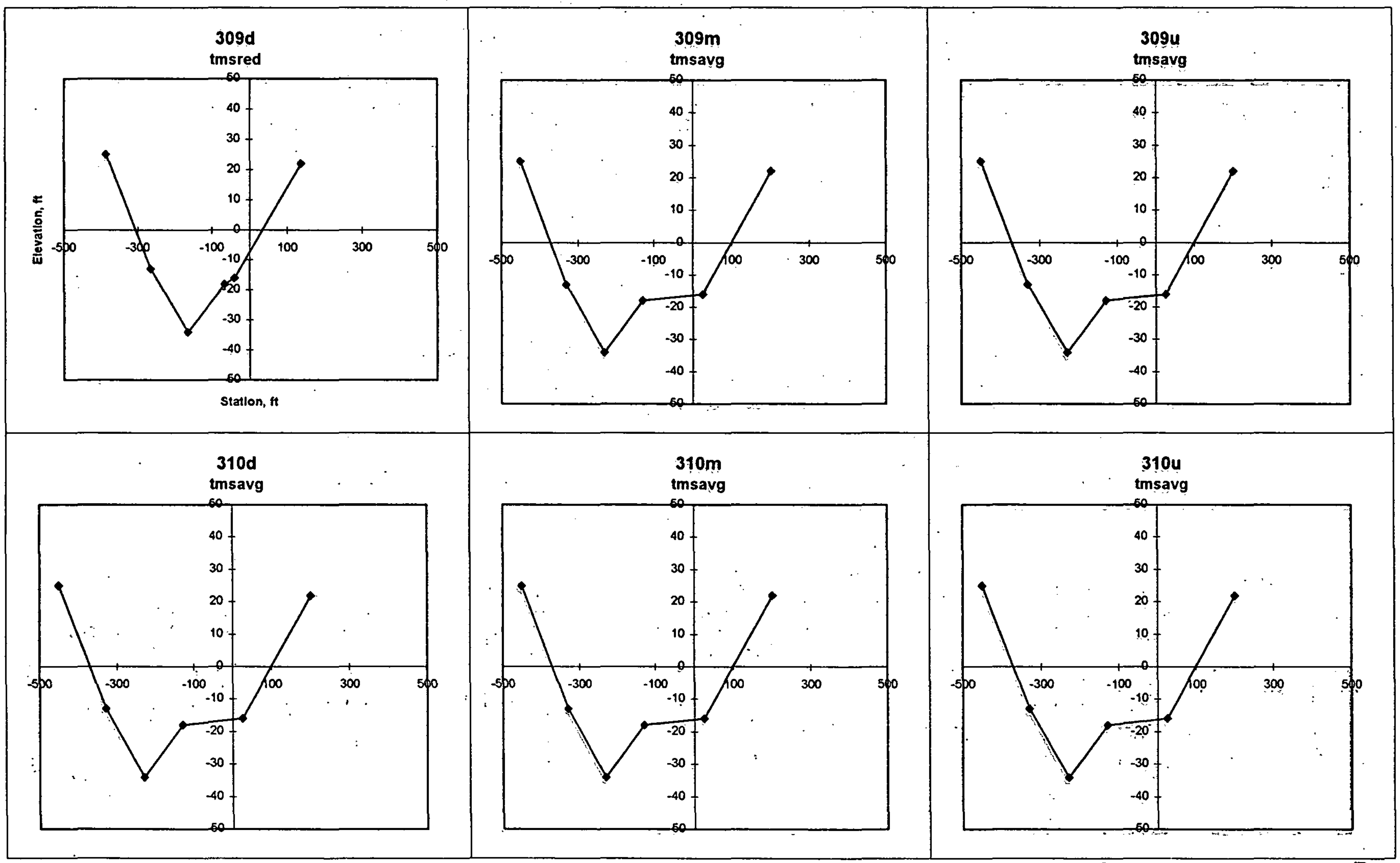


Figure 2-43

Run 38.2

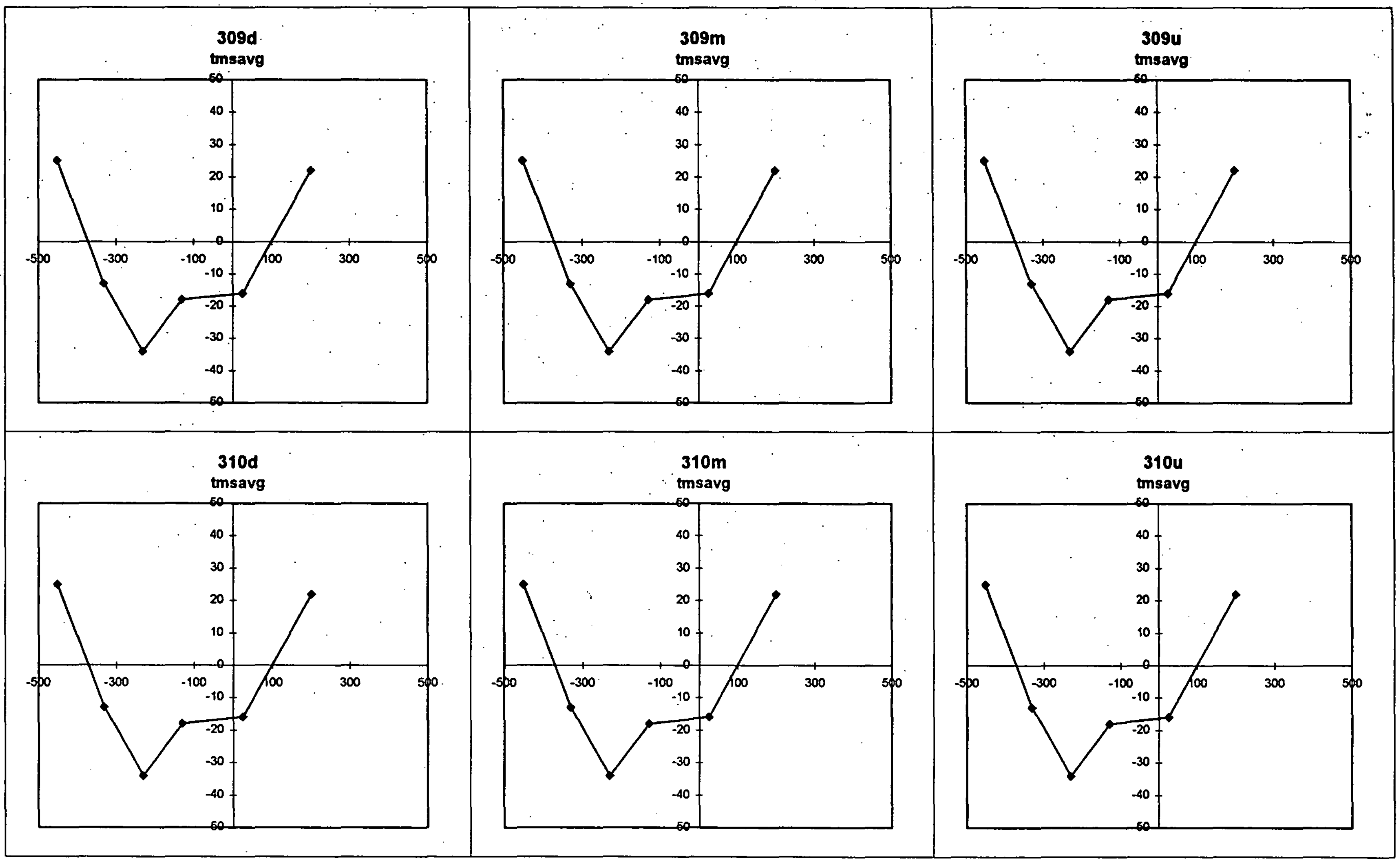


Figure 2-44

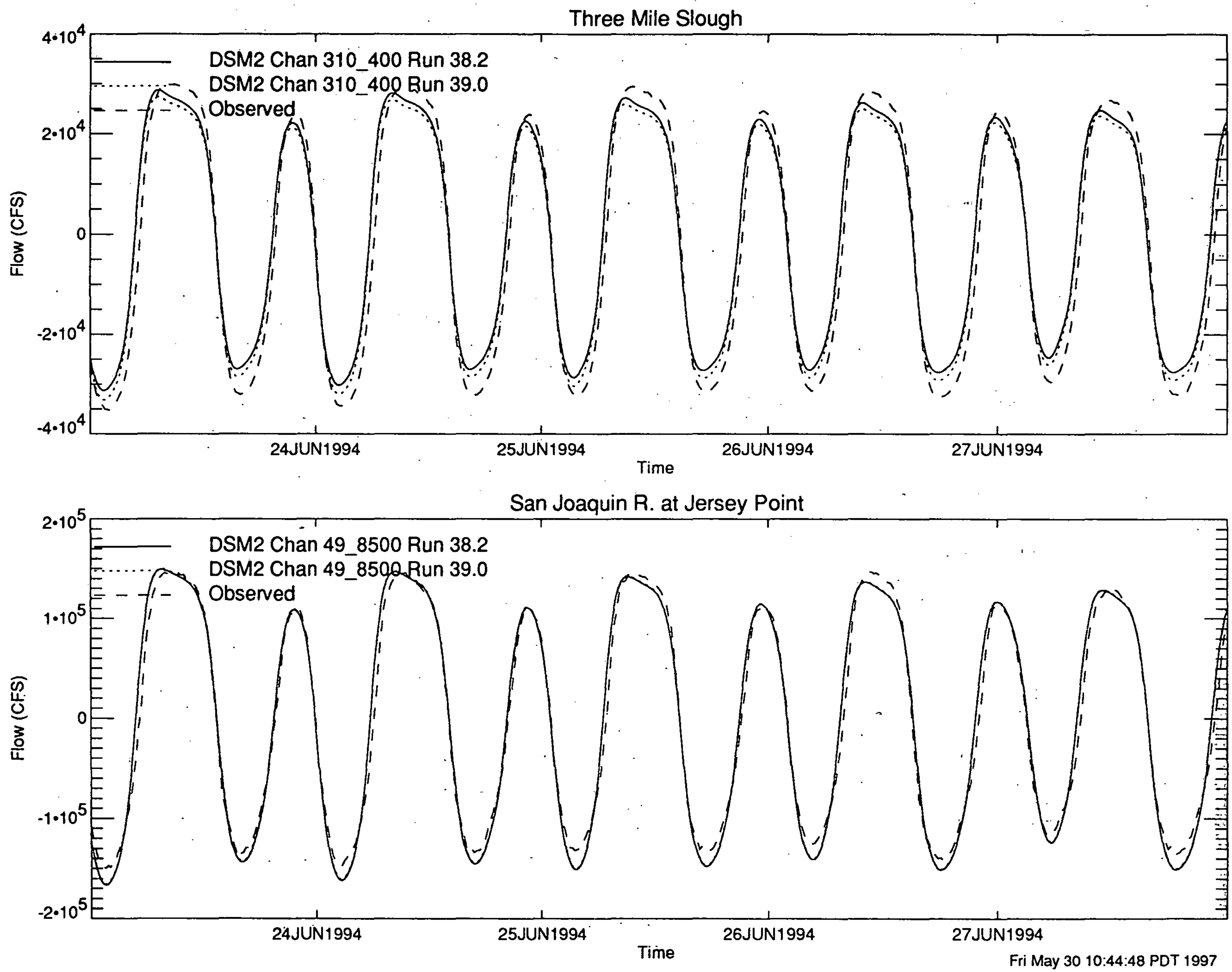

Three Mile Slough
DSM2 Chan 310_400 Run 38.2
DSM2 Chan 310_400 Run 39.0
Observed
Flow (CFS)
4•10⁴
2•10⁴
0
-2•10⁴
-4•10⁴
24JUN1994
25JUN1994
26JUN1994
27JUN1994
Time
San Joaquin R. at Jersey Point
DSM2 Chan 49_8500 Run 38.2
DSM2 Chan 49_8500 Run 39.0
Observed
Flow (CFS)
2•10⁵
1•10⁵
0
-1•10⁵
-2•10⁵
24JUN1994
25JUN1994
26JUN1994
27JUN1994
Time
Fri May 30 10:44:48 PDT 1997

Figure 2-45

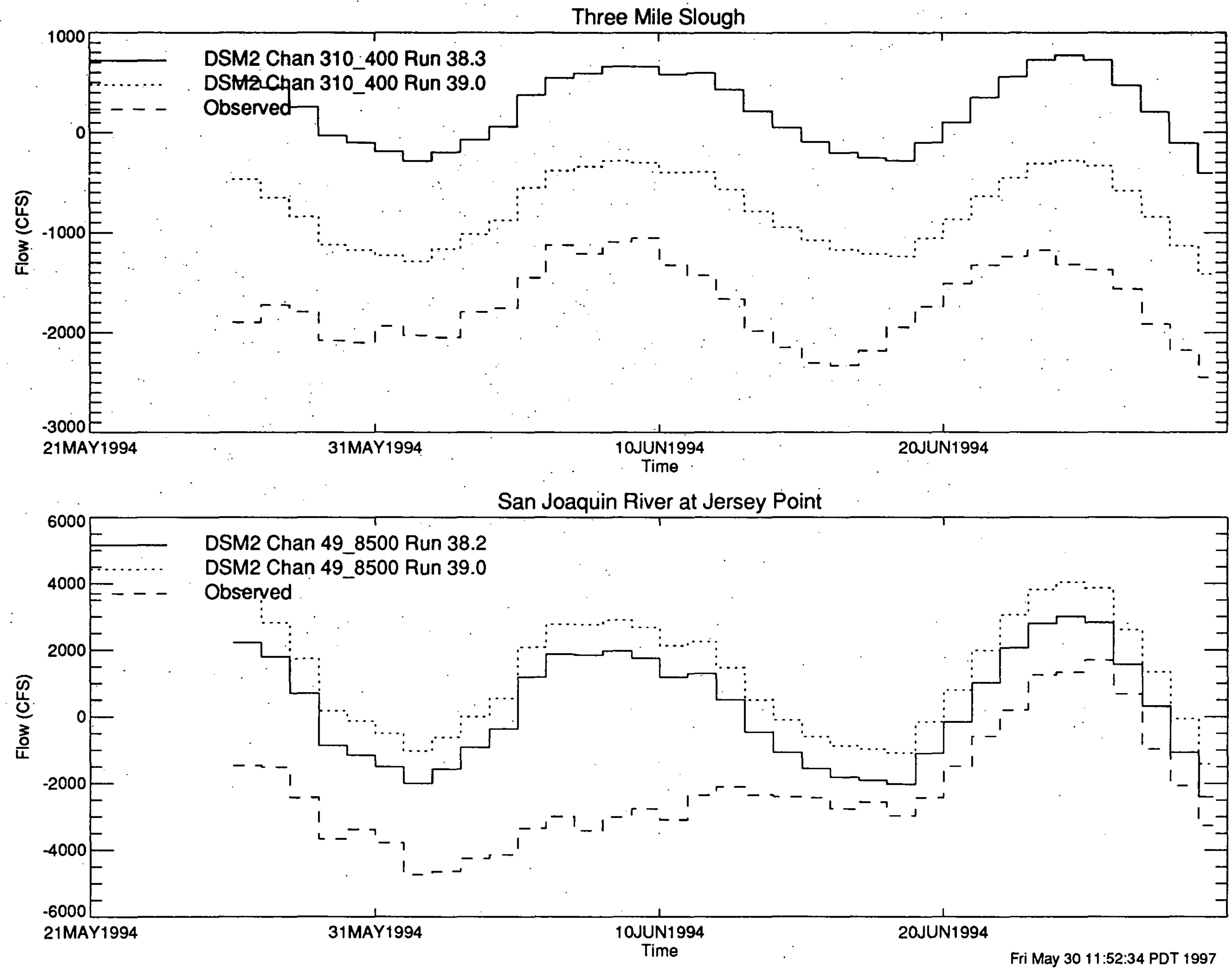

Three Mile Slough
DSM2 Chan 310_400 Run 38.3
DSM2 Chan 310_400 Run 39.0
Observed
1000
0
-1000
-2000
-3000
Flow (CFS)
21MAY1994
31MAY1994
10JUN1994
20JUN1994
Time
San Joaquin River at Jersey Point
DSM2 Chan 49_8500 Run 38.2
DSM2 Chan 49_8500 Run 39.0
Observed
6000
4000
2000
0
-2000
-4000
-6000
Flow (CFS)
21MAY1994
31MAY1994
10JUN1994
20JUN1994
Time
Fri May 30 11:52:34 PDT 1997

Figure 2-46

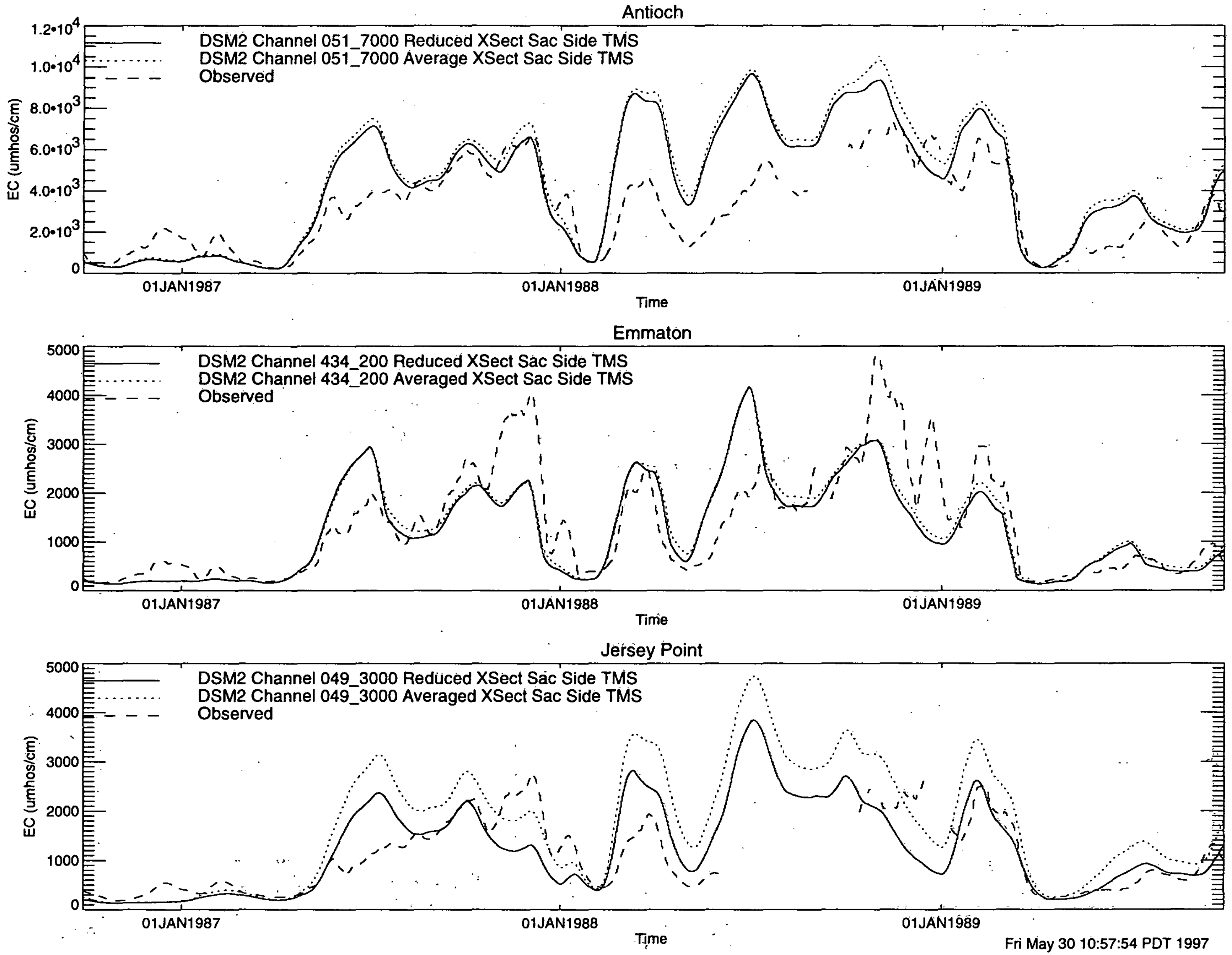
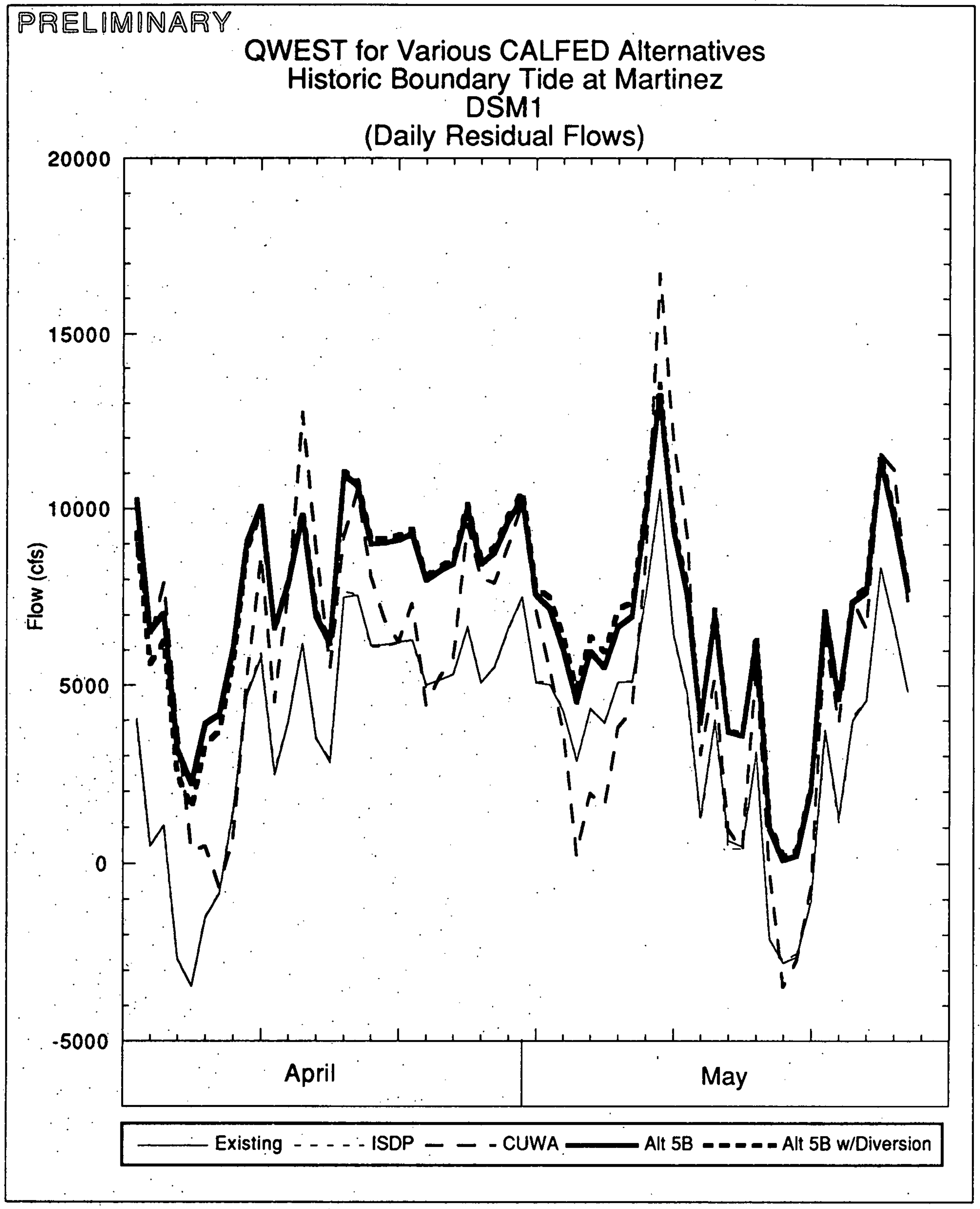
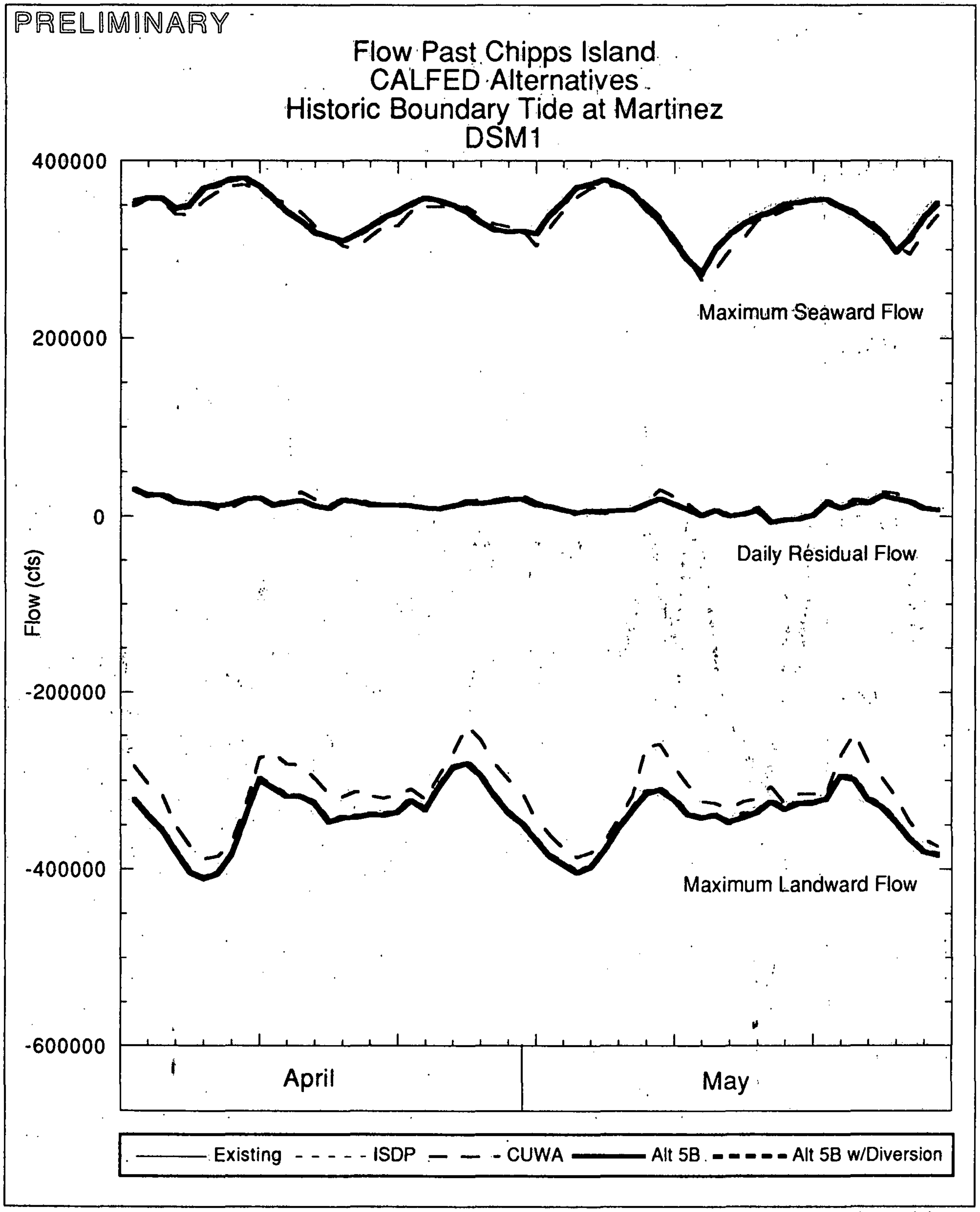

Antioch
DSM2 Channel 051_7000 Reduced XSect Sac Side TMS
DSM2 Channel 051_7000 Average XSect Sac Side TMS
Observed
EC (umhos/cm)
1.2•10^4
1.0•10^4
8.0•10^3
6.0•10^3
4.0•10^3
2.0•10^3
0
01JAN1987
01JAN1988
01JAN1989
Time
Emmaton
DSM2 Channel 434_200 Reduced XSect Sac Side TMS
DSM2 Channel 434_200 Averaged XSect Sac Side TMS
Observed
EC (umhos/cm)
5000
4000
3000
2000
1000
0
01JAN1987
01JAN1988
01JAN1989
Time
Jersey Point
DSM2 Channel 049_3000 Reduced XSect Sac Side TMS
DSM2 Channel 049_3000 Averaged XSect Sac Side TMS
Observed
EC (umhos/cm)
5000
4000
3000
2000
1000
0
01JAN1987
01JAN1988
01JAN1989
Time
Fri May 30 10:57:54 PDT 1997

Figure 2-47



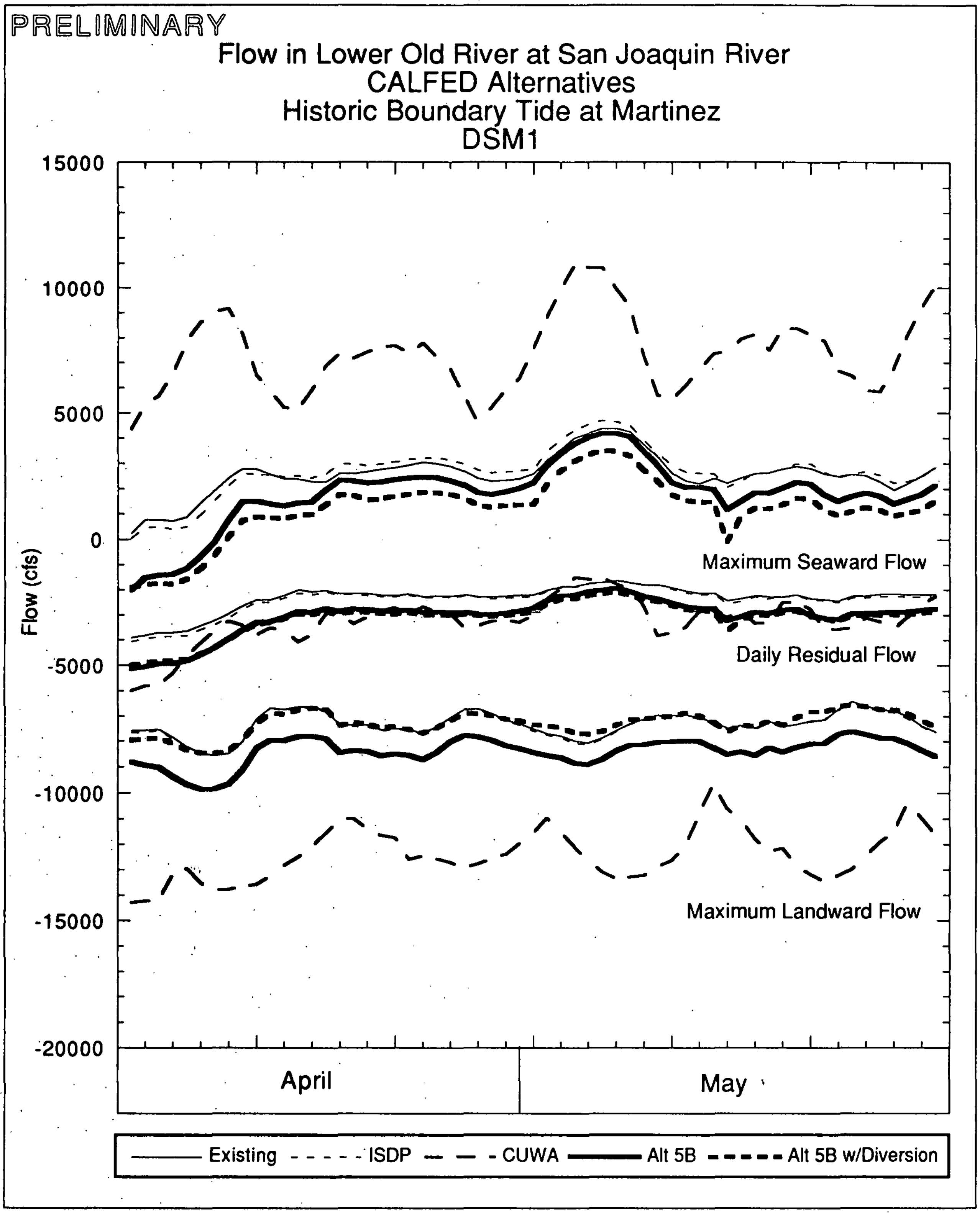
2/19/97

Figure 2-48



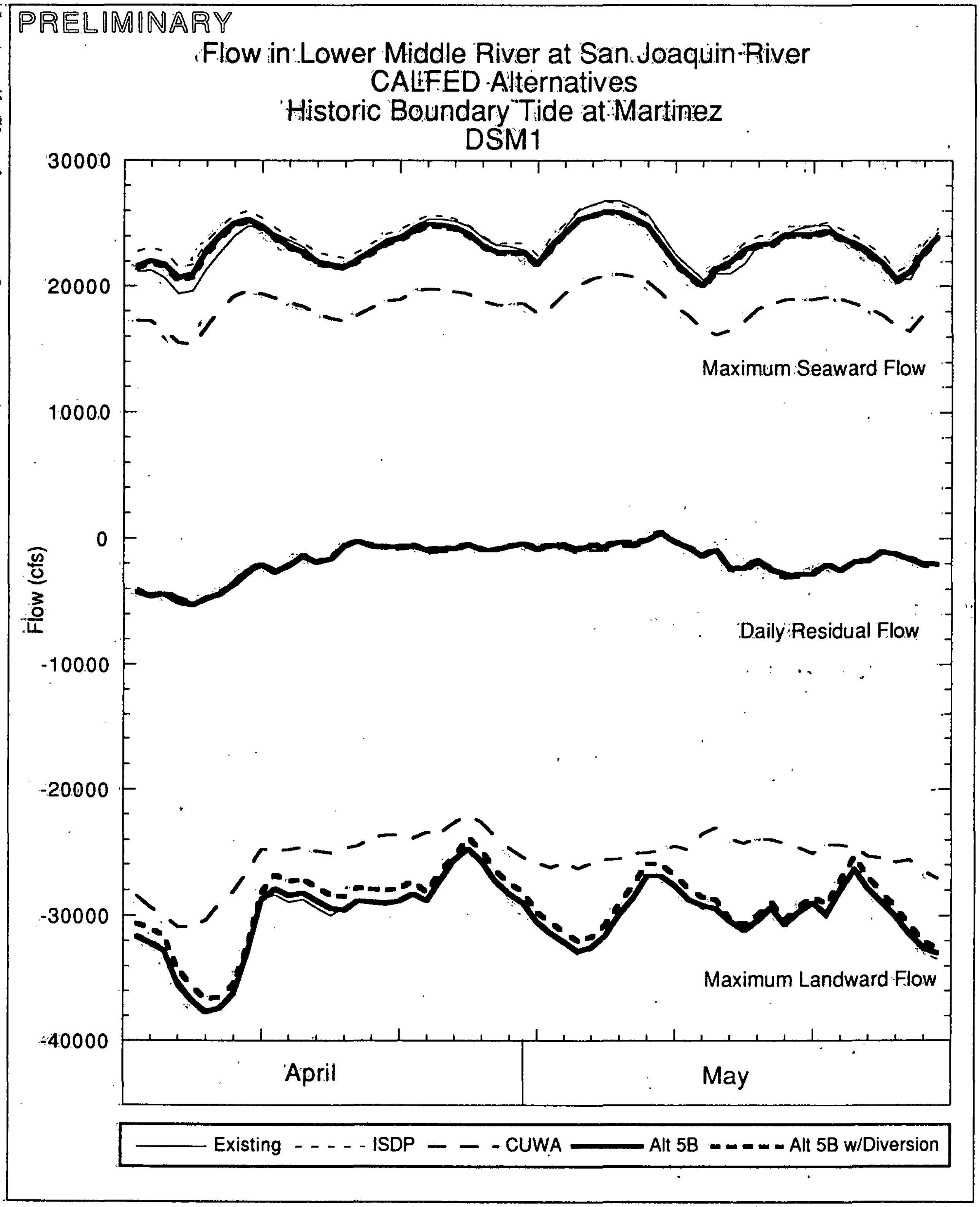
2/19/97

Figure 2-49



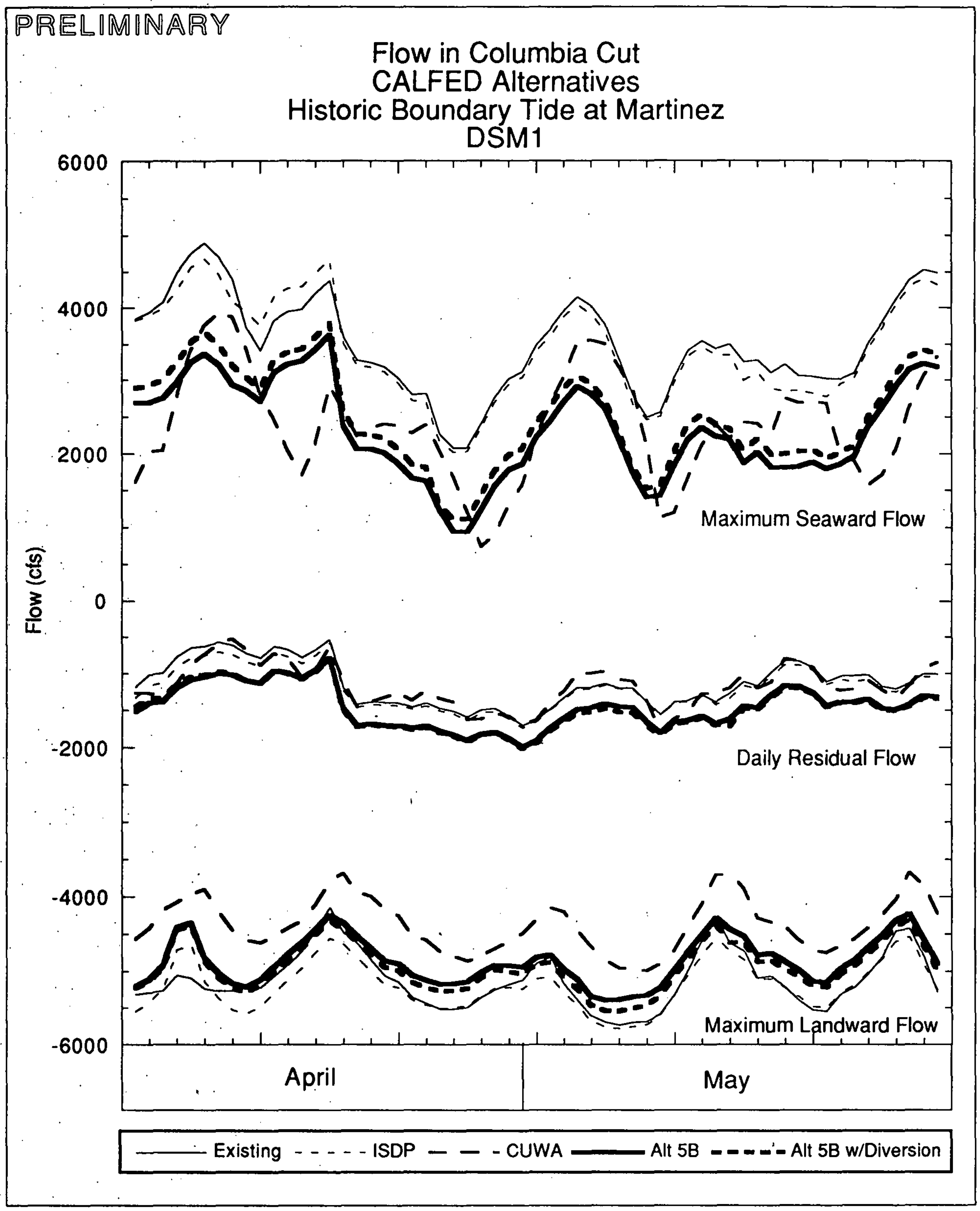
2/19/97

Figure 2-50



2/19/97

Figure 2-51



2/19/97

Figure 2-52

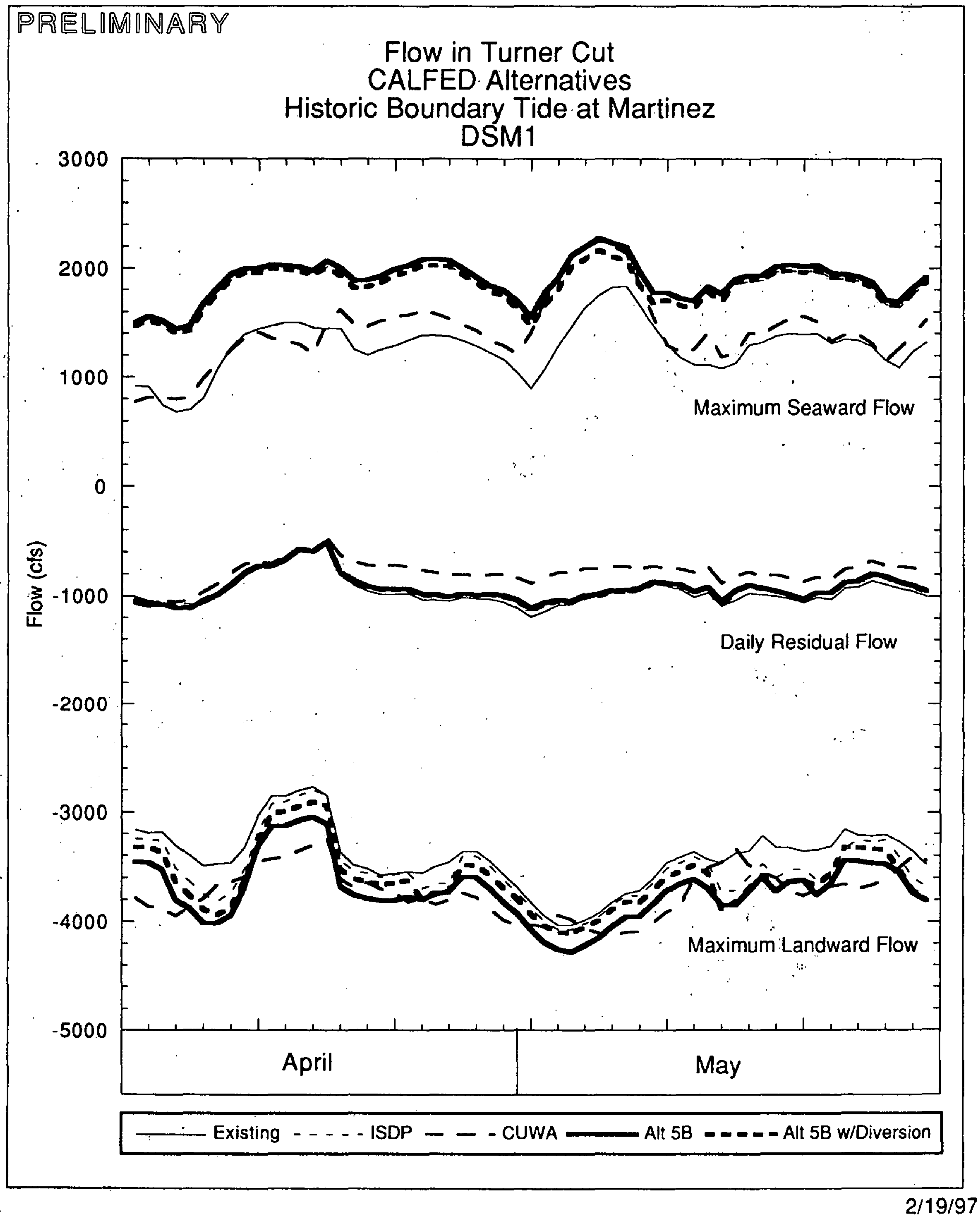
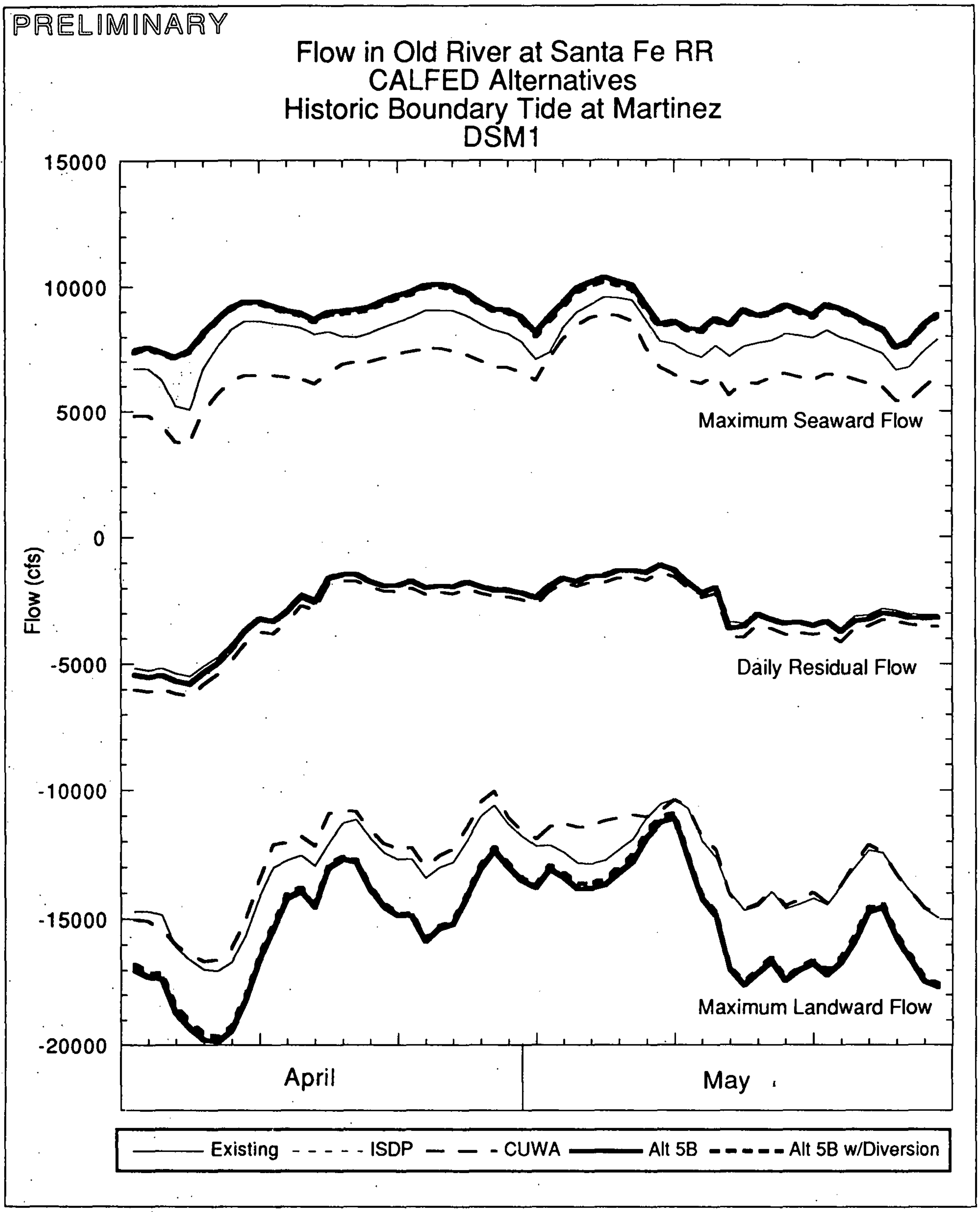
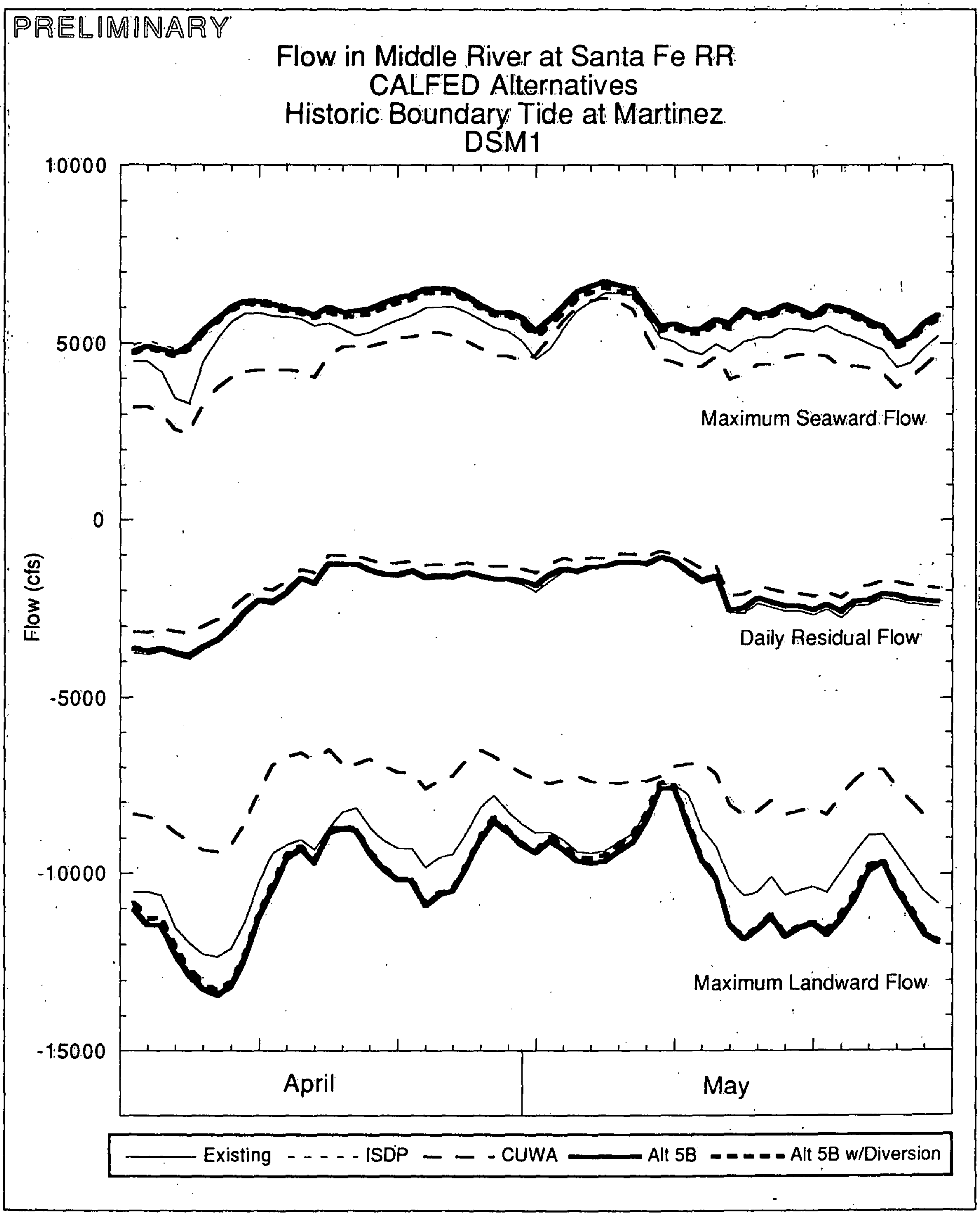

PRELIMINARY
Flow in Turner Cut
CALFED Alternatives
Historic Boundary Tide at Martinez
DSM1
3000
2000
1000
0
-1000
-2000
-3000
-4000
-5000
Flow (cfs)
Maximum Seaward Flow
Daily Residual Flow
Maximum Landward Flow
April
May
Existing
ISDP
CUWA
Alt 5B
Alt 5B w/Diversion
2/19/97

Figure 2-53



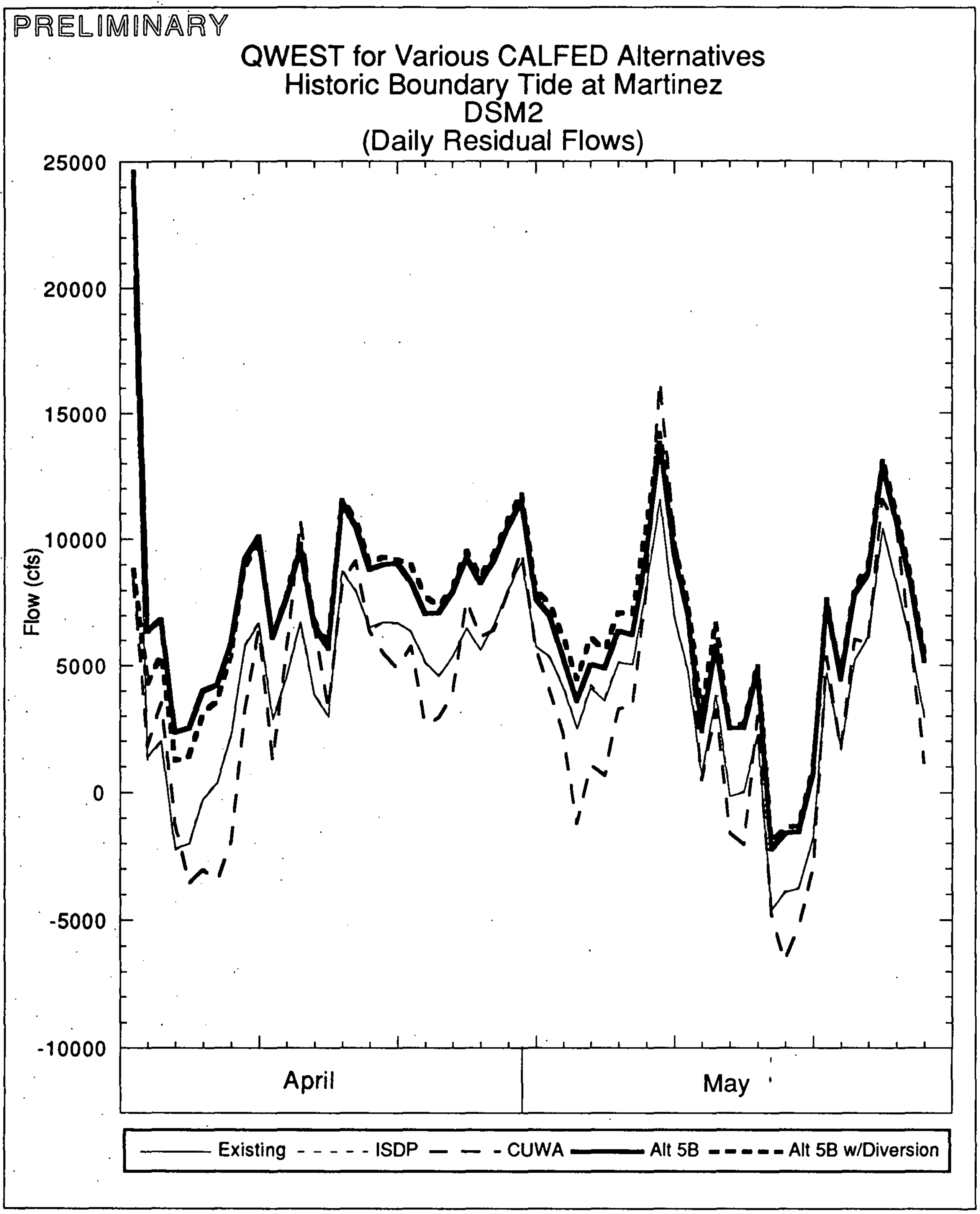
2/19/97

Figure 2-54



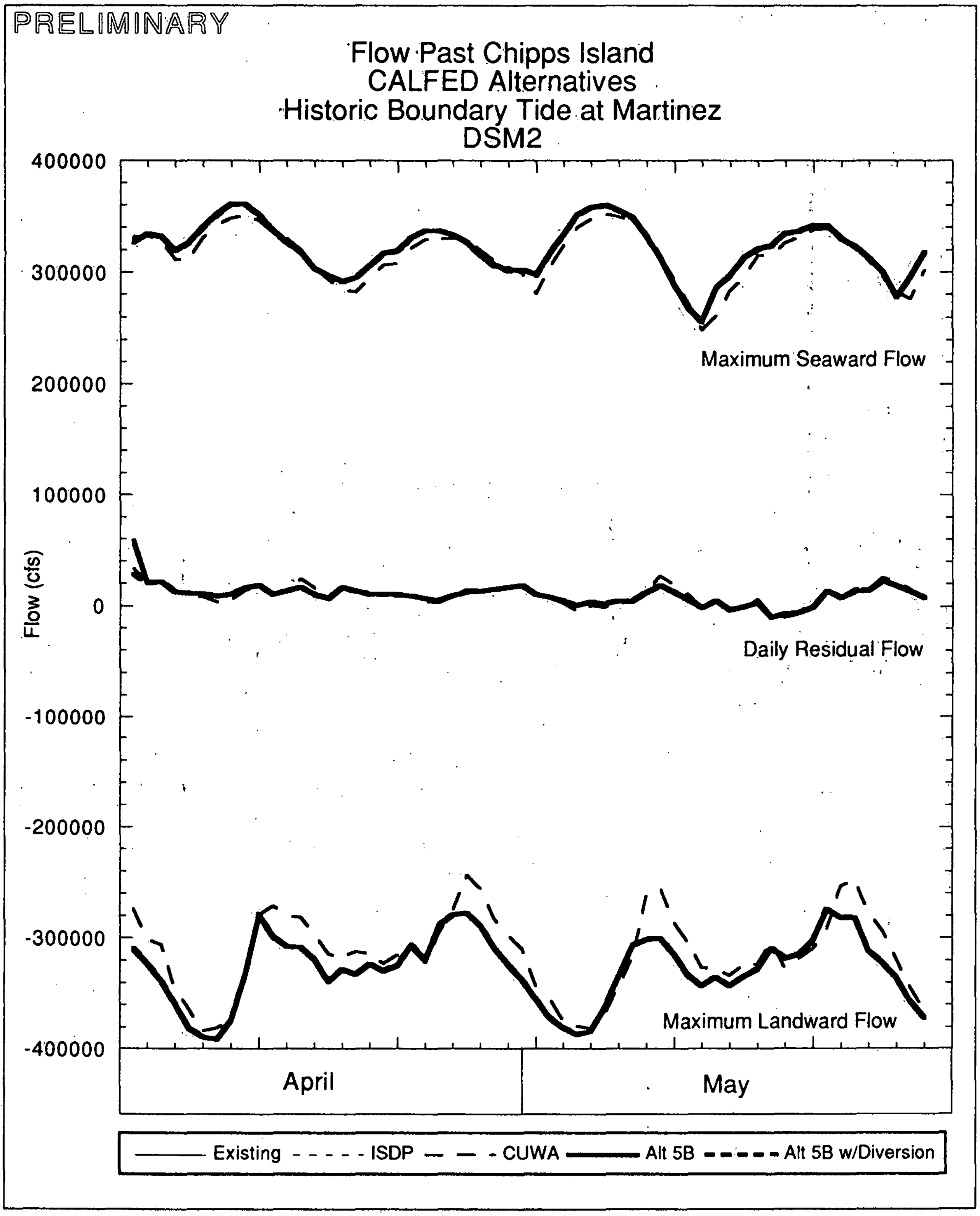
2/19/97

Figure 2-55



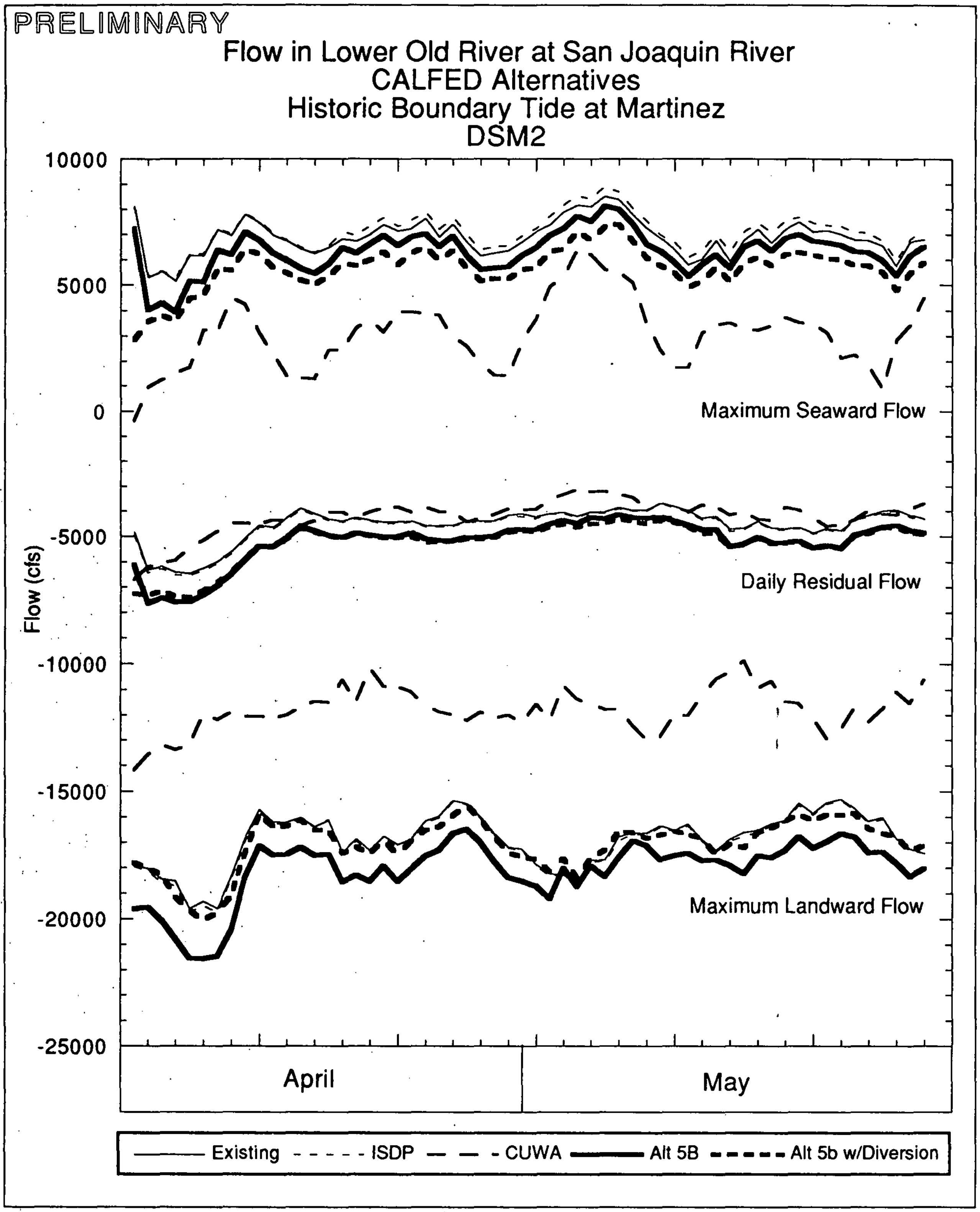
5/19/97

Figure 2-56



5/19/97

Figure 2-57



5/19/97

Figure 2-58

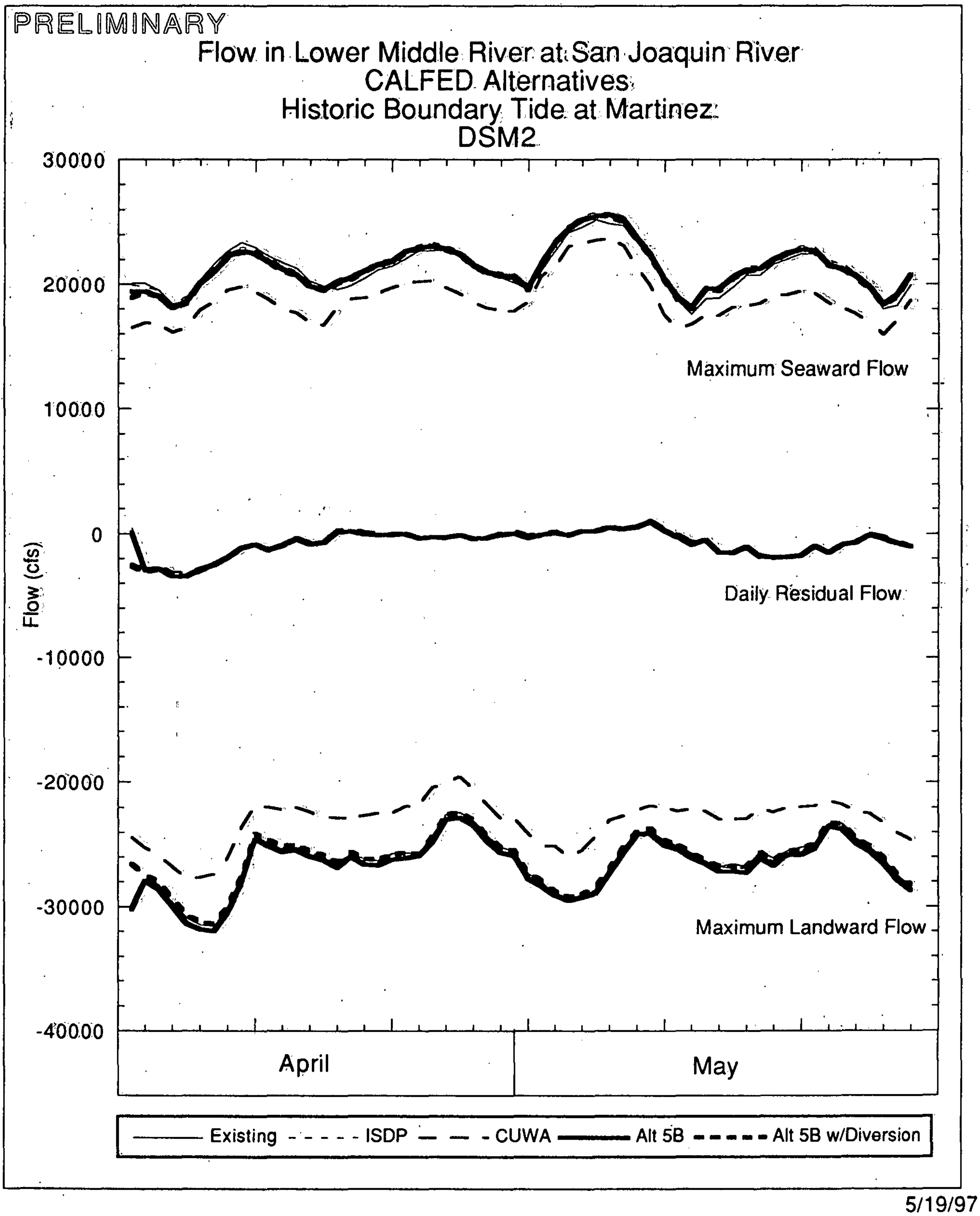
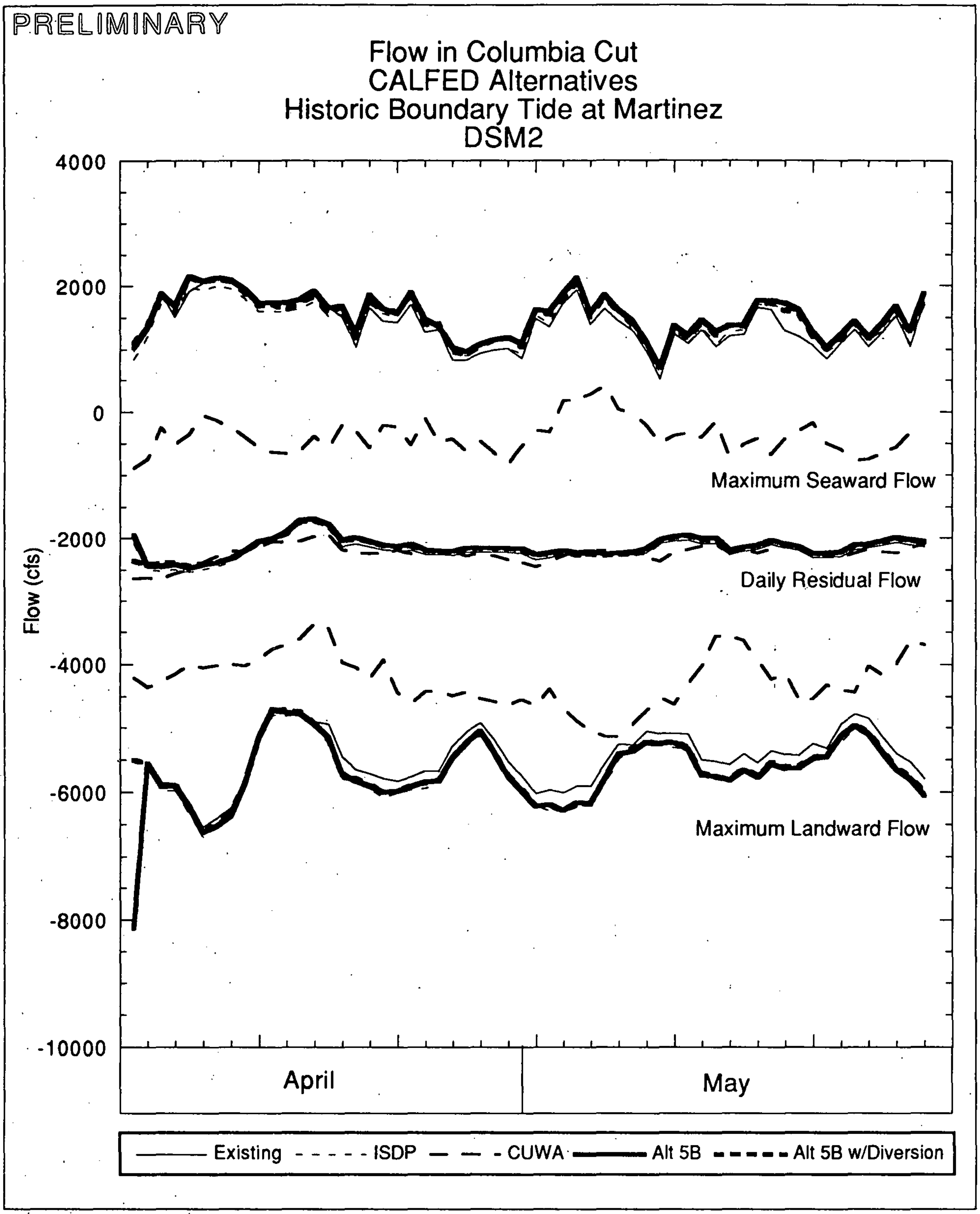

PRELIMINARY
Flow in Lower Middle River at San Joaquin River
CALFED Alternatives
Historic Boundary Tide at Martinez
DSM2
30000
20000
10000
0
-10000
-20000
-30000
-40000
Flow (cfs)
Maximum Seaward Flow
Daily Residual Flow
Maximum Landward Flow
April
May
Existing
ISDP
CUWA
Alt 5B
Alt 5B w/Diversion
5/19/97

Figure 2-59



5/19/97

Figure 2-60

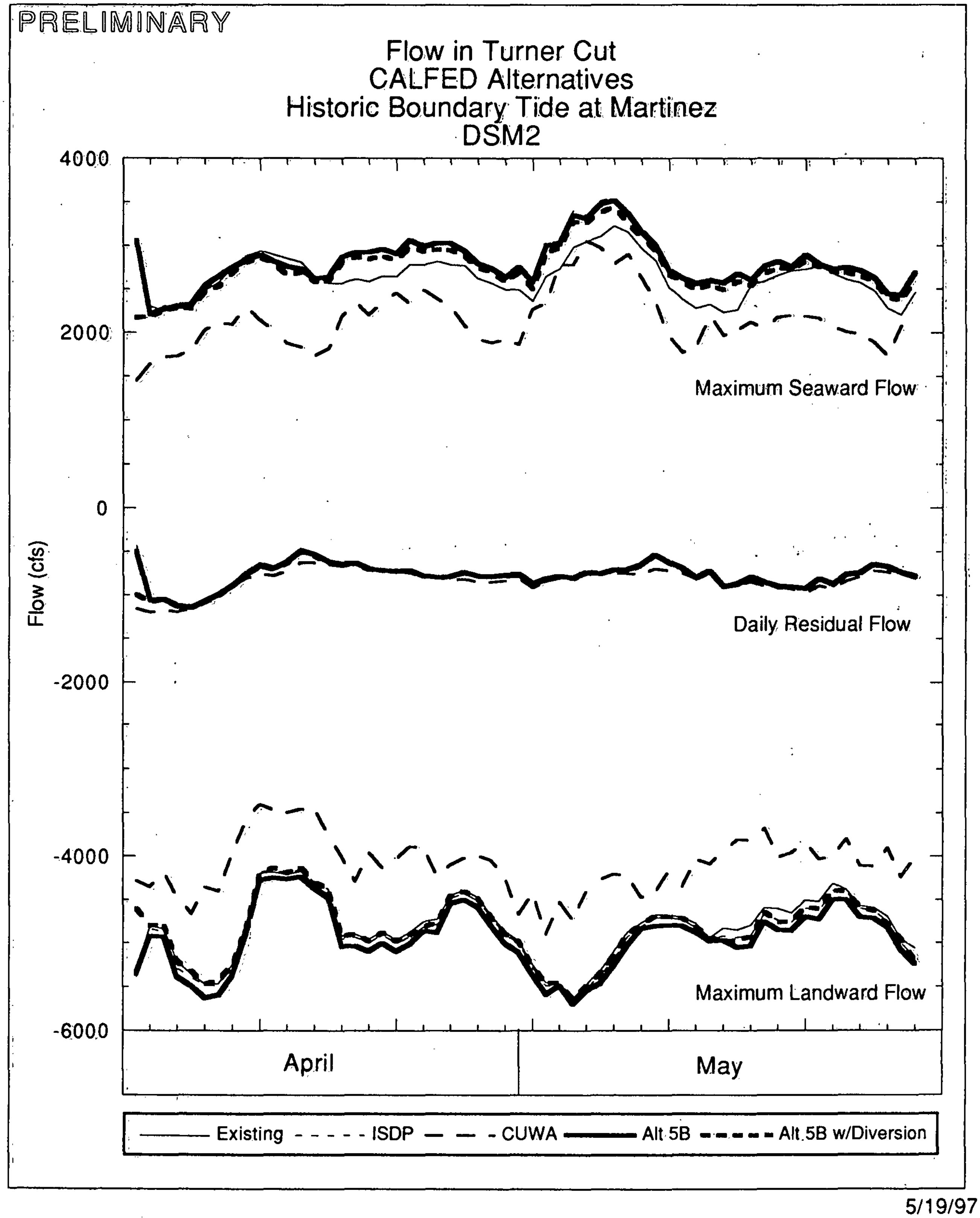
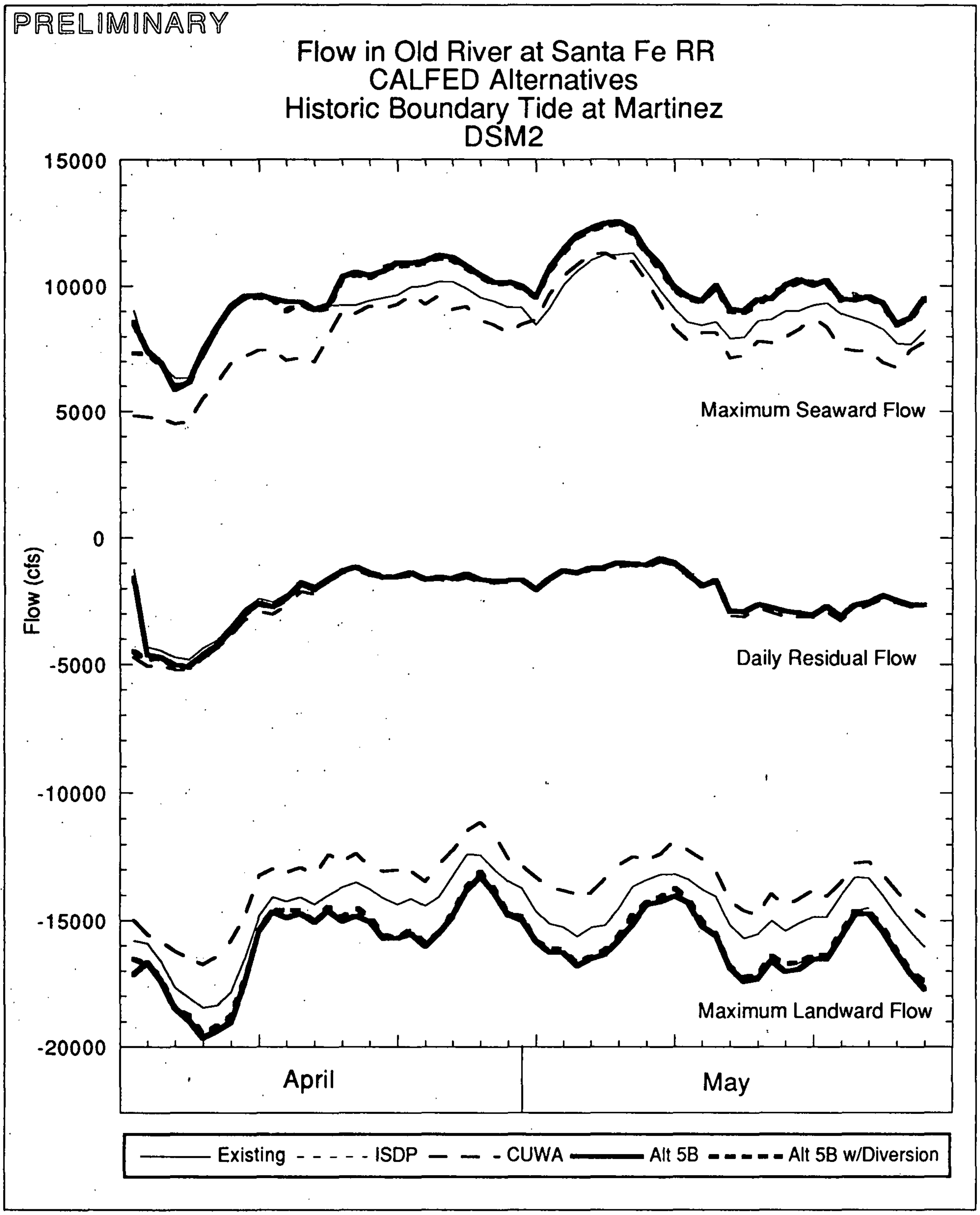

PRELIMINARY
Flow in Turner Cut
CALFED Alternatives
Historic Boundary Tide at Martinez
DSM2
4000
2000
0
-2000
-4000
-6000
Flow (cfs)
Maximum Seaward Flow
Daily Residual Flow
Maximum Landward Flow
April
May
Existing
ISDP
CUWA
Alt 5B
Alt 5B w/Diversion
5/19/97

Figure 2-61



5/19/97

Figure 2-62

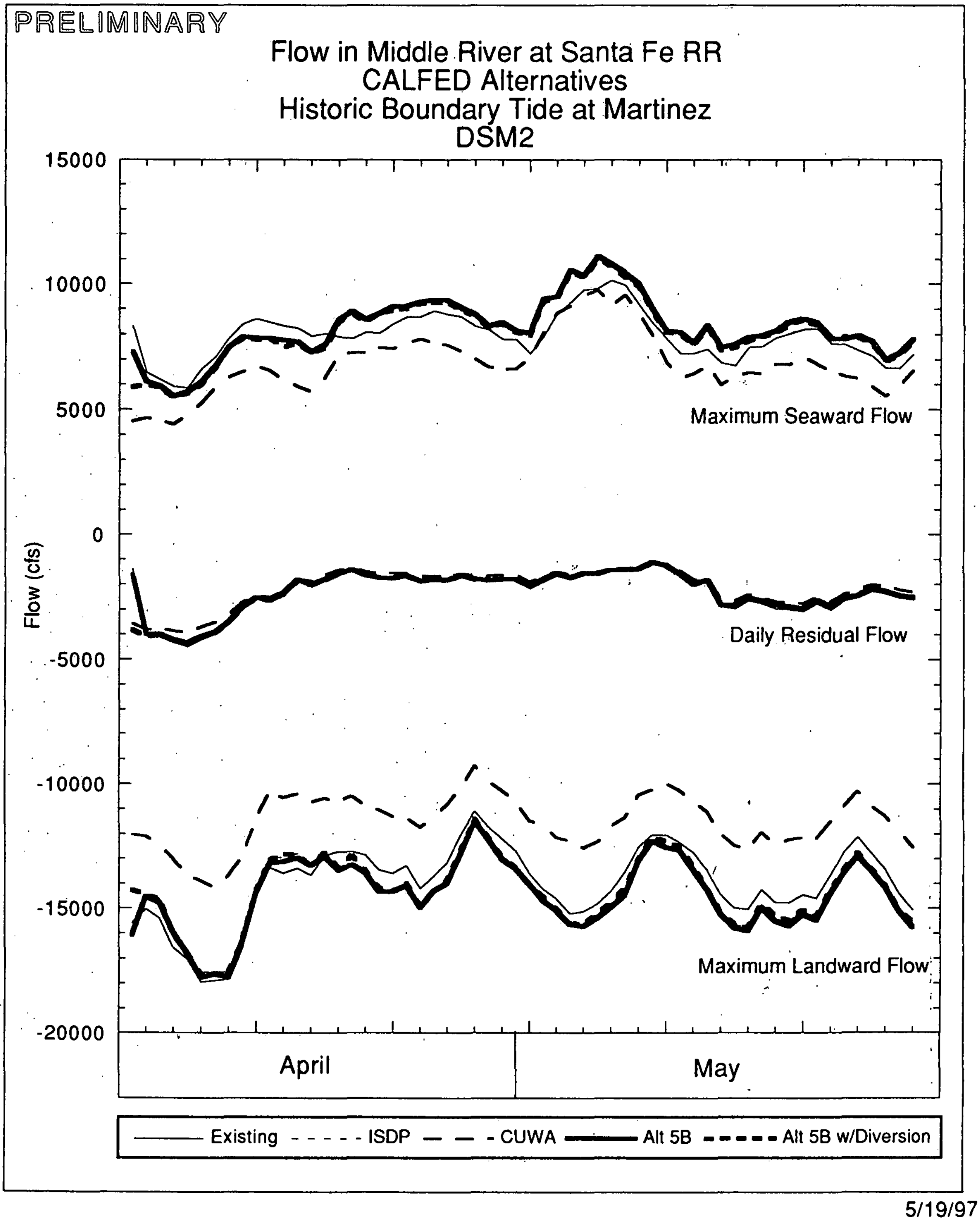

PRELIMINARY
Flow in Middle River at Santa Fe RR
CALFED Alternatives
Historic Boundary Tide at Martinez
DSM2
15000
10000
5000
0
-5000
-10000
-15000
-20000
Flow (cfs)
Maximum Seaward Flow
Daily Residual Flow
Maximum Landward Flow
April
May
Existing
ISDP
CUWA
Alt 5B
Alt 5B w/Diversion
5/19/97

Figure 2-63

3 Marginal Export Cost and MDO Replacement

A fast, accurate model to estimate salinities in the Sacramento–San Joaquin Delta when given flow inputs is an important tool, but not an easy one to develop. Such a model can be used to estimate Marginal Export Cost (MEC, also known as carriage water); as a replacement for the MDO routine in the statewide planning model DWRSIM; as a realtime flow/salinity estimation model; and in reservoir release optimization studies. Attempts at developing such a model have been made for many years with less than full success. A fairly recent mathematical and programming technique known as Artificial Neural Networks (ANNs) was applied to the problem with considerable success. ANNs offer several advantages over previous methods because they are nonlinear; allow multiple, arbitrary inputs; easily allow "memory" to be incorporated; and are not confined to pre–determined impulse–response function shapes. ANN models are developed by first calibrating the internal coefficients of an ANN with sequences of flows and salinities at a location of interest. After the ANN has been calibrated, new flow inputs are provided and estimated salinities produced.

There is a strong need to "model" a model of the Delta; in other words, to calibrate an ANN on the salinity output of another numerical model such as DSM2, for use in DWRSIM. Ideally, DSM2 would be incorporated into DWRSIM directly, but this is impractical because of tremendous differences in running time between the two models. Instead, a faithful and fast imitation of DSM2 can be developed using ANNs and used in DWRSIM.

A description of ANNs and preliminary investigations of MEC was given in the June 1995 *Annual Report*. Further investigation of MEC was conducted and a draft report prepared, "*Modeling Flow-Salinity Relationships in the Sacramento-San Joaquin Delta Using Artificial Neural Networks*", January 1997, which is available from the Delta Modeling Section. In this annual report, we summarize our findings from that report.

Carriage Water Findings Using Artificial Neural Networks

1. Multiple flow inputs—as opposed to a single, lumped flow parameter such as Net Delta Outflow—provide a significant increase in the accuracy of salinity estimates when given flows (Figure 3–1, 3–2), as well as the sequence of flows to meet a required salinity standard (Figures 3–3, 3–4). It is especially important in the interior Delta to model salinities using separate flows, such as the Sacramento and San Joaquin rivers and Banks and Tracy pumping, instead of lumping them into a single parameter. Furthermore, a single–input model must, by definition, assume the Marginal Export Cost to be zero, which in our opinion can be a significant error.

2. Marginal Export Cost (carriage water) exists and it is not a trivial or negligible quantity. It is highly variable, depending on the controlling salinity location,

duration and quantity of through–Delta flow, and current and past hydrology. It can range from −100% of export increases (Emmaton controlling) to +100% or greater of export increases (Rock Slough and Clifton Court Forebay). Typical ranges would seem to be 10% to 30% at Jersey Point, Rock Slough, and Clifton Court Forebay if they are assumed to be the only controlling stations. In other words, an increase in export pumping causes salinity to change at that station. In order to bring the salinity back to the historical level, the amount of Sacramento flows needed in excess of the increase in pumping were estimated with the ANNs. The Marginal Export Cost is lowest in the western Delta, and increases to higher values in the interior Delta and the export pumps (Figures 3–5 through 3–8).

3. It is difficult to estimate the effect of the Cross Channel gate operation on Delta salinities from historical data, probably because the gate has been operated according to past flow regimes. Historically the gate has been closed during high flows in the Sacramento River and open during low flows. This colinearity between Sacramento flow and gate position confuses a black–box model such as multiple regression or ANNs. Therefore, the impact of gate position must be estimated from a simulation model where inputs can be deliberately decoupled.

This issue is critical, as the ability to simulate internal Delta operations will be important to the use of ANNs with DWRSIM. Therefore, we conducted a separate investigation to see if this bias in historical data could be removed with the use of a numerical model such as DSM1.

Replacement of MDO with ANNs in DWRSIM

Historic flow data, along with DSM1–simulated Total Dissolved Solids (TDS), was used to train Artificial Neural Networks (ANNs) to model water quality as a function of input flows and Delta Cross Channel (DXC) gate position. ANNs were developed to estimate water quality, which is measured in TDS at various locations in the Delta.

These networks were tested using a Java–based simulator for varying flows and DXC operation. The ANNs' output for different scenarios revealed some problems with these historically–trained TDS networks.

Opening the DXC gate allows fresh water from the Sacramento River to flow into the interior Delta, which should result in better water quality in the interior Delta. Western Delta locations like Pittsburg should be relatively insensitive to DXC operation. The initial ANNs developed at Contra Costa Canal and at Pittsburg did not give the expected results (Figures 3–9 and 3–10).

Figure 3–9 illustrates several problems with the initial TDS ANN at Contra Costa Canal. At some points keeping the DXC closed seems to result in lower TDS than historic operation and at other points keeping the DXC gate open seems to increase TDS values, when compared to the historic case.

Similarly, Figure 3–10 shows that the ANN–simulated TDS at Pittsburg is highest when the DXC gate is open, and TDS is much lower when the DXC is closed, which should not be the case.

This unanticipated behavior can be attributed to bias in the data used to prepare our ANNs. Historically, the Delta Cross Channel has been opened during periods when TDS values were relatively high. An ANN may then associate higher TDS values with the opening of the DXC gate. The historic correlation between DXC operation and high TDS values keeps the neural network from accurately modeling the effects of DXC operation.

Training our ANNs using DSM1-modeled TDS allowed us to create additional training data to negate the bias present in the historic data. In order to develop an unbiased training set, we used an additional DSM1 run to augment our original training set. The first half of the new training set was the original historic flows and DXC position with DSM1-simulated TDS. The second half of the new training set also used historic rimflows; however the DXC position was inverted, resulting in different daily TDS values.

Whenever the gate was closed in the original training set, the gate was set open in the second half of the training set, and vice versa. This was done in an attempt to "cancel out" the correlated operation of the gate in the original, unaugmented training set.

The results of this experiment appear to be successful (Figures 3–11 and 3–12).

The new Contra Costa Canal ANN (Figure 3–11) shows that when DXC was kept closed for the entire simulation period, the TDS was generally higher than the baseline case (historic operation). Similarly, when DXC was kept open lower TDS values than the baseline case resulted.

The new Pittsburg ANN (Figure 3–12) shows that TDS is relatively insensitive to DXC operation, as expected.

The approach of combining ANN technology with a physically-based model like DSM1 or DSM2 seems to be a promising one. Once trained and calibrated, ANNs are much faster than the comparable physically-based numerical model; however, the predictive ability of our ANNs is directly related to the quality of our training sets. Using DSM1 or DSM2 output, we can continue to optimize ANN performance to combine the reliability of calibrated, physically-based models with the speed and ease of ANN-based models.

Future Directions

In the next year, we anticipate the use of a multiple-input ANN module within DWRSIM to replace the current MDO or G model routine. Models which use only Net Delta Outflow have more difficulty than multiple-input models in handling the non-historical operation of the Delta as proposed in various planning studies.

We also plan to calculate historical Marginal Export Costs during periods of through-Delta water transfers. This would involve estimating which water quality station was controlling flows and the amount of water transferred; then the ANN and reverse-solver would estimate the MEC penalty incurred for the water transfer. Confirmation of the estimated MEC could be performed by a traditional numerical model such as DSM2.

PITTSBURG TIME SERIES PLOT
HISTORICAL DATA

FIGURE 3-1a. ANN MULTIPLE INPUT MODEL

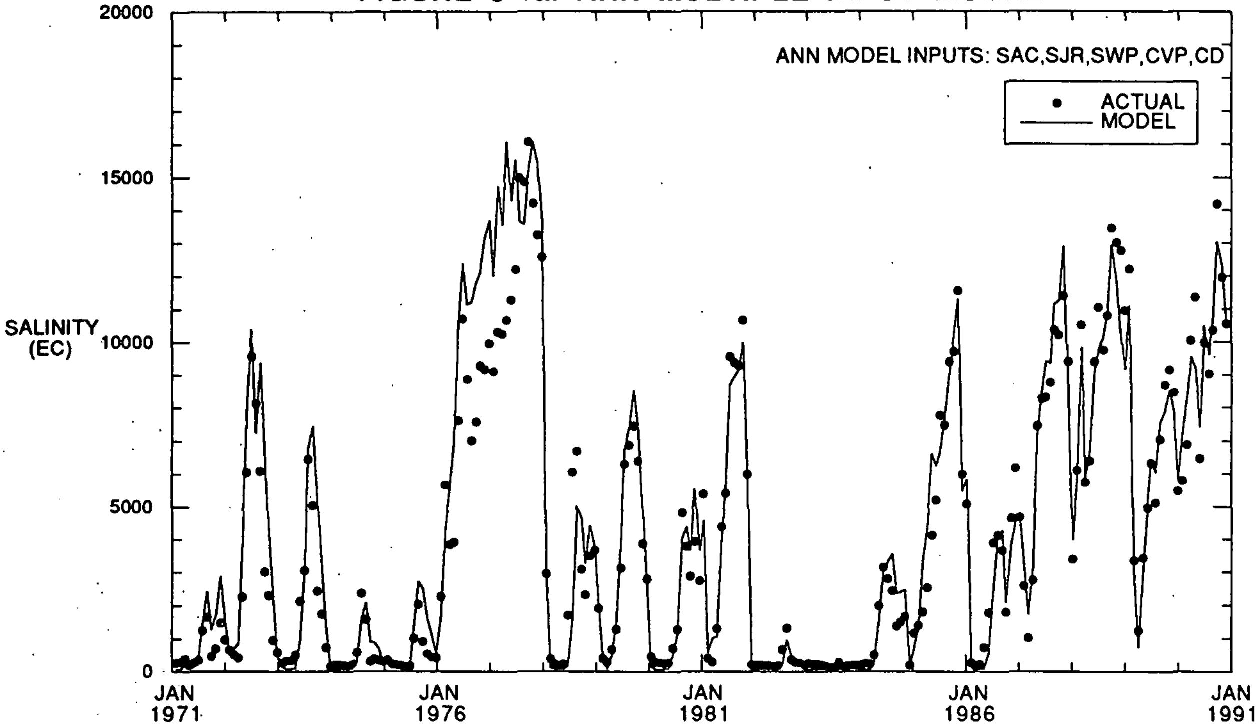


FIGURE 3-1b. ANN NDO ONLY MODEL

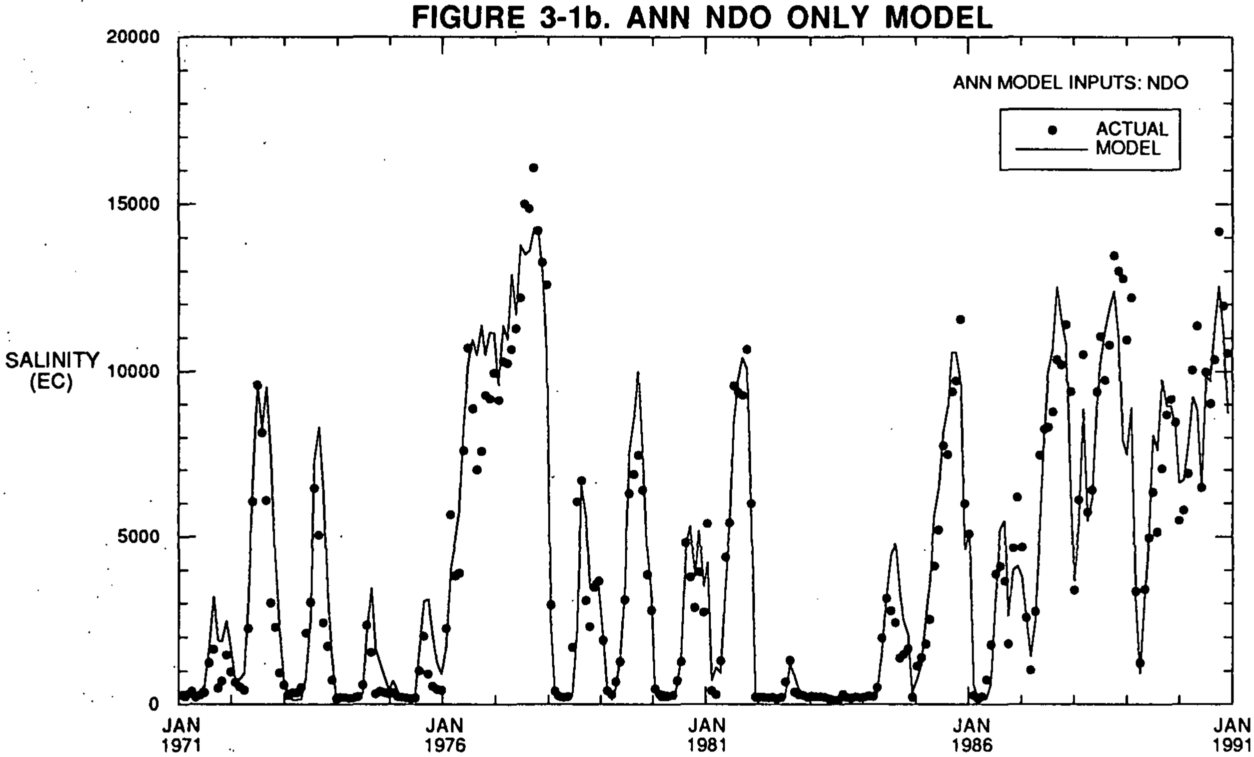


Figure 3-1

CONTRA COSTA CANAL TIME SERIES PLOT
HISTORICAL DATA

FIGURE 3-2a. ANN MULTIPLE INPUT MODEL

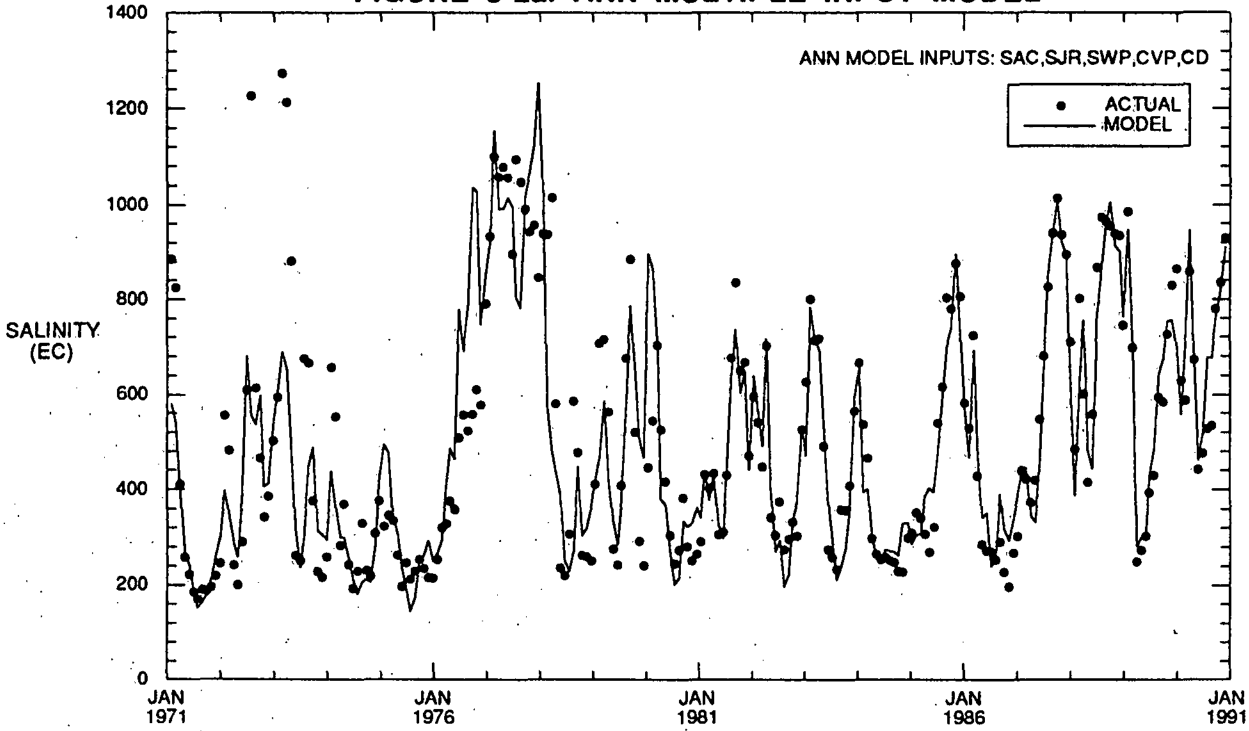


FIGURE 3-2b. ANN NDO ONLY MODEL

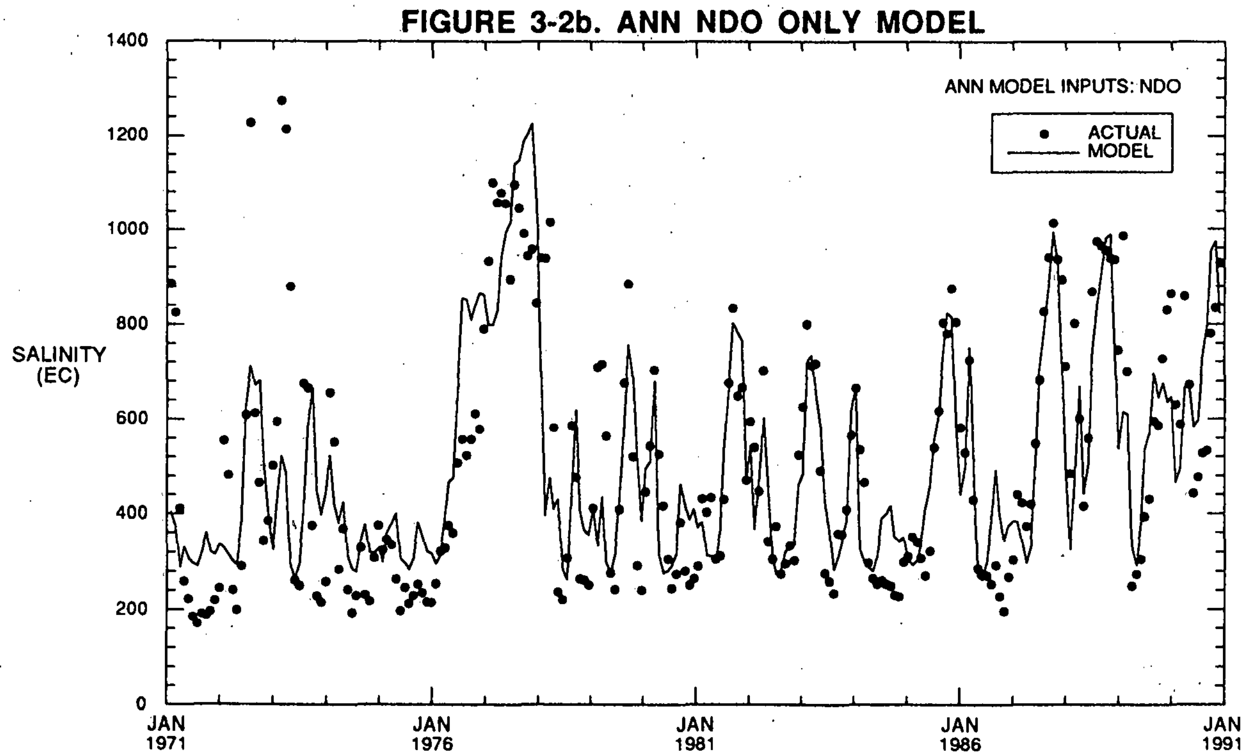
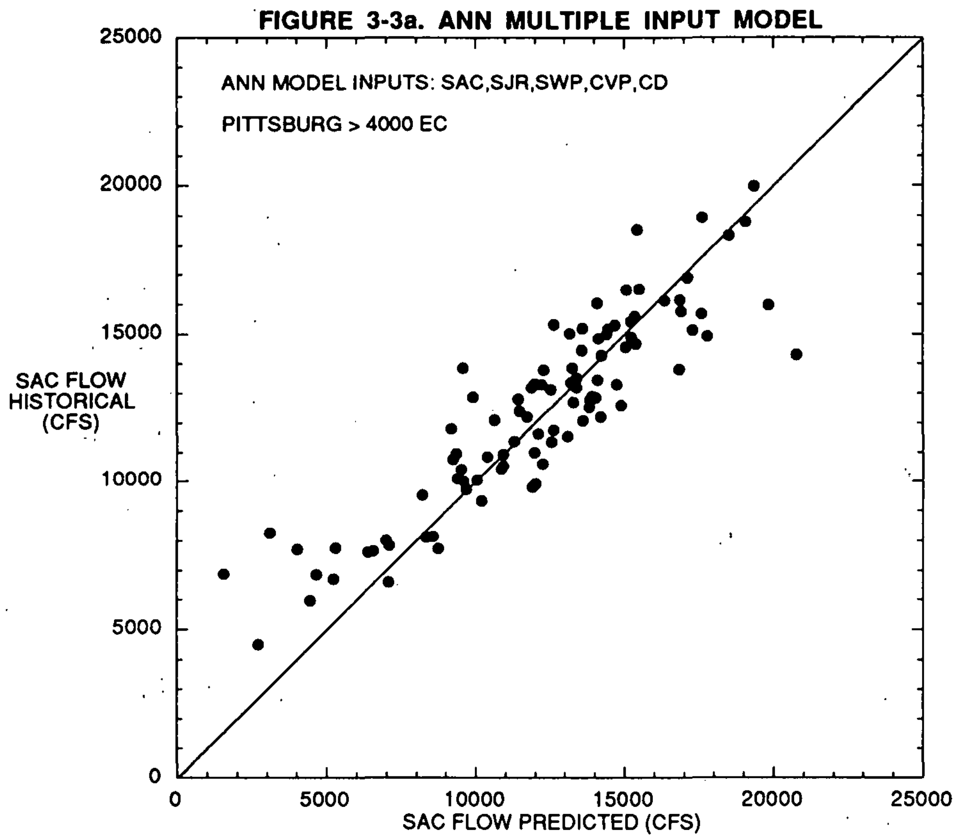


Figure 3-2

SAC PREDICTIONS FROM PITTSBURG SALINITY HISTORICAL DATA



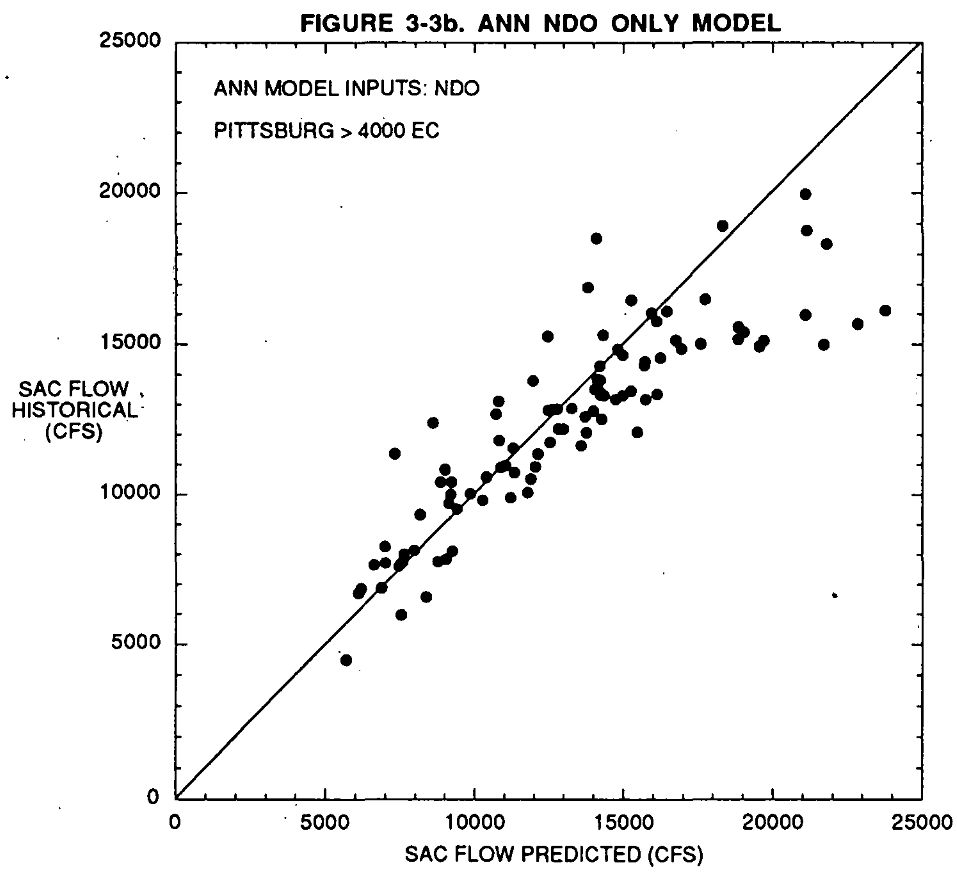


Figure 3-3

SAC PREDICTIONS FROM CONTRA COSTA CANAL SALINITY HISTORICAL DATA

FIGURE 3-4a. ANN MULTIPLE INPUT MODEL

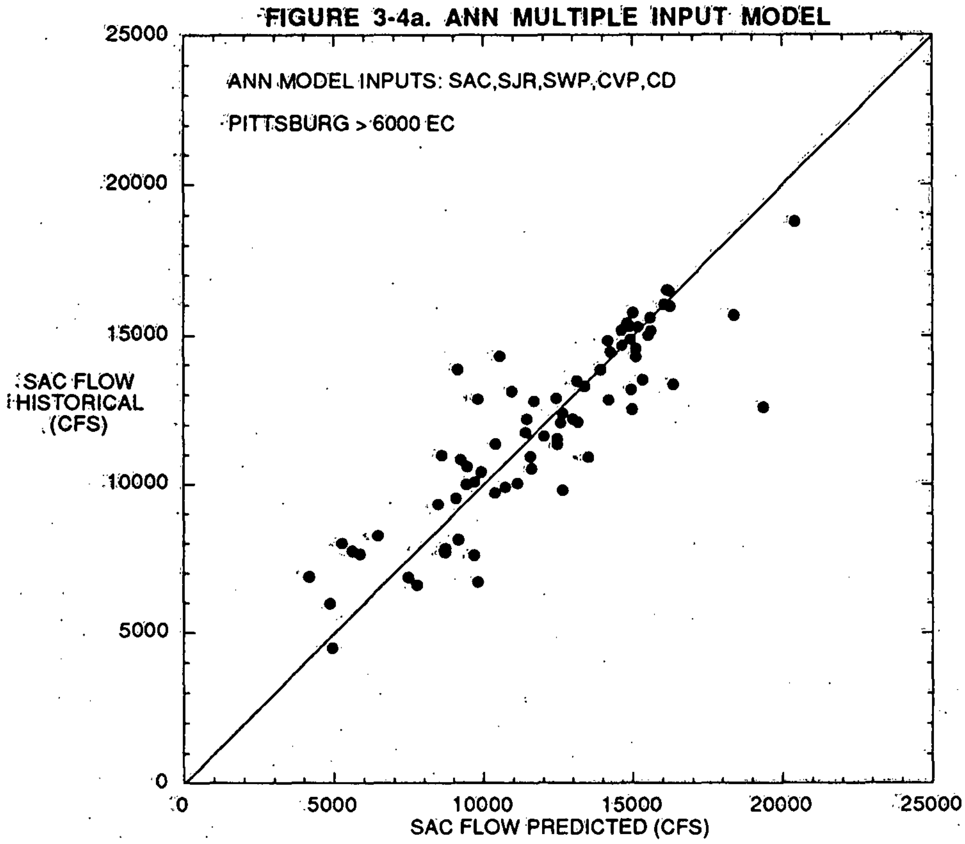


FIGURE 3-4b. ANN NDO ONLY MODEL

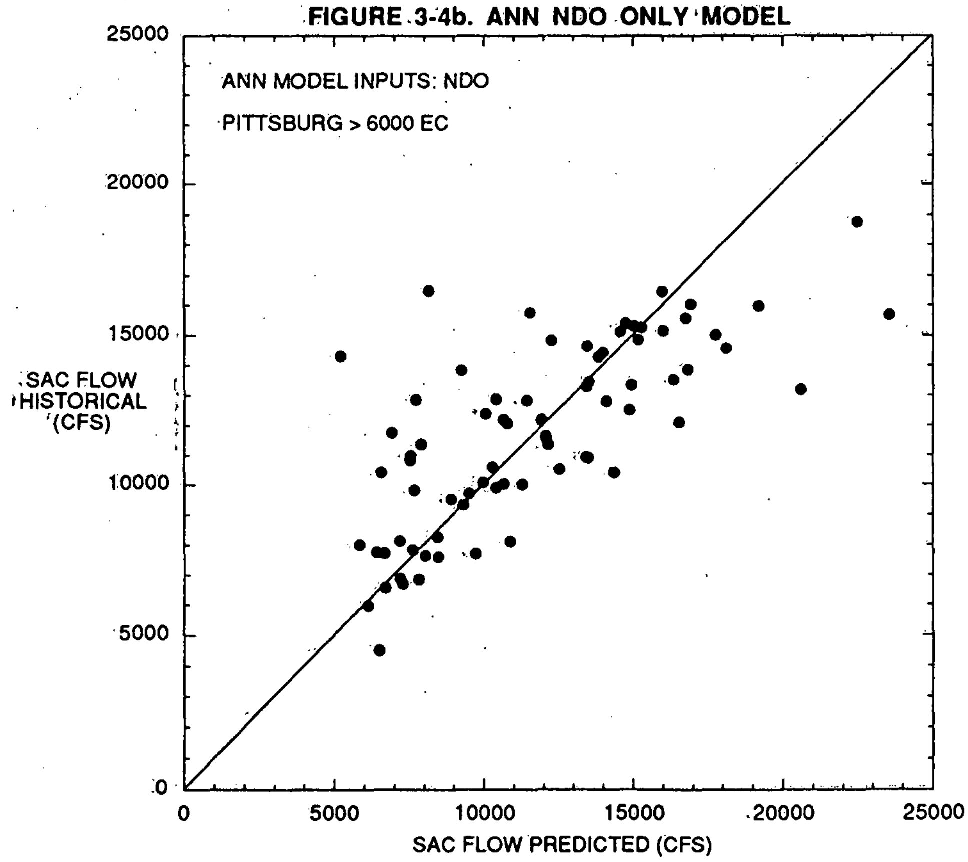


Figure 3-4

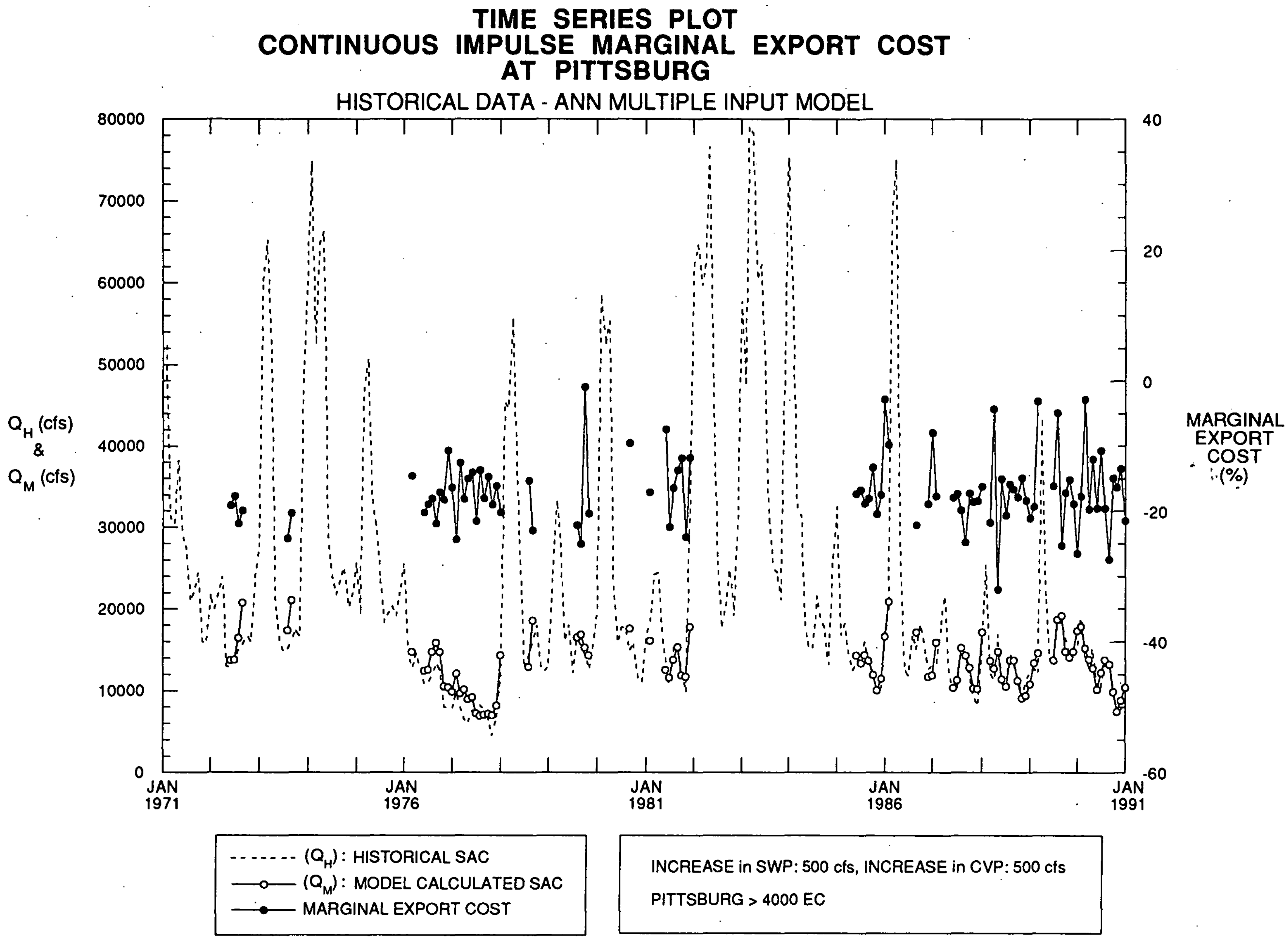

TIME SERIES PLOT
CONTINUOUS IMPULSE MARGINAL EXPORT COST
AT PITTSBURG
HISTORICAL DATA - ANN MULTIPLE INPUT MODEL
Q_H (cfs) & Q_M (cfs)
MARGINAL EXPORT COST (%)
80000
70000
60000
50000
40000
30000
20000
10000
0
40
20
0
-20
-40
-60
JAN 1971
JAN 1976
JAN 1981
JAN 1986
JAN 1991
(Q_H): HISTORICAL SAC
(Q_M): MODEL CALCULATED SAC
MARGINAL EXPORT COST
INCREASE in SWP: 500 cfs, INCREASE in CVP: 500 cfs
PITTSBURG > 4000 EC

Figure 3-5

TIME SERIES PLOT
CONTINUOUS IMPULSE MARGINAL EXPORT COST
AT JERSEY POINT

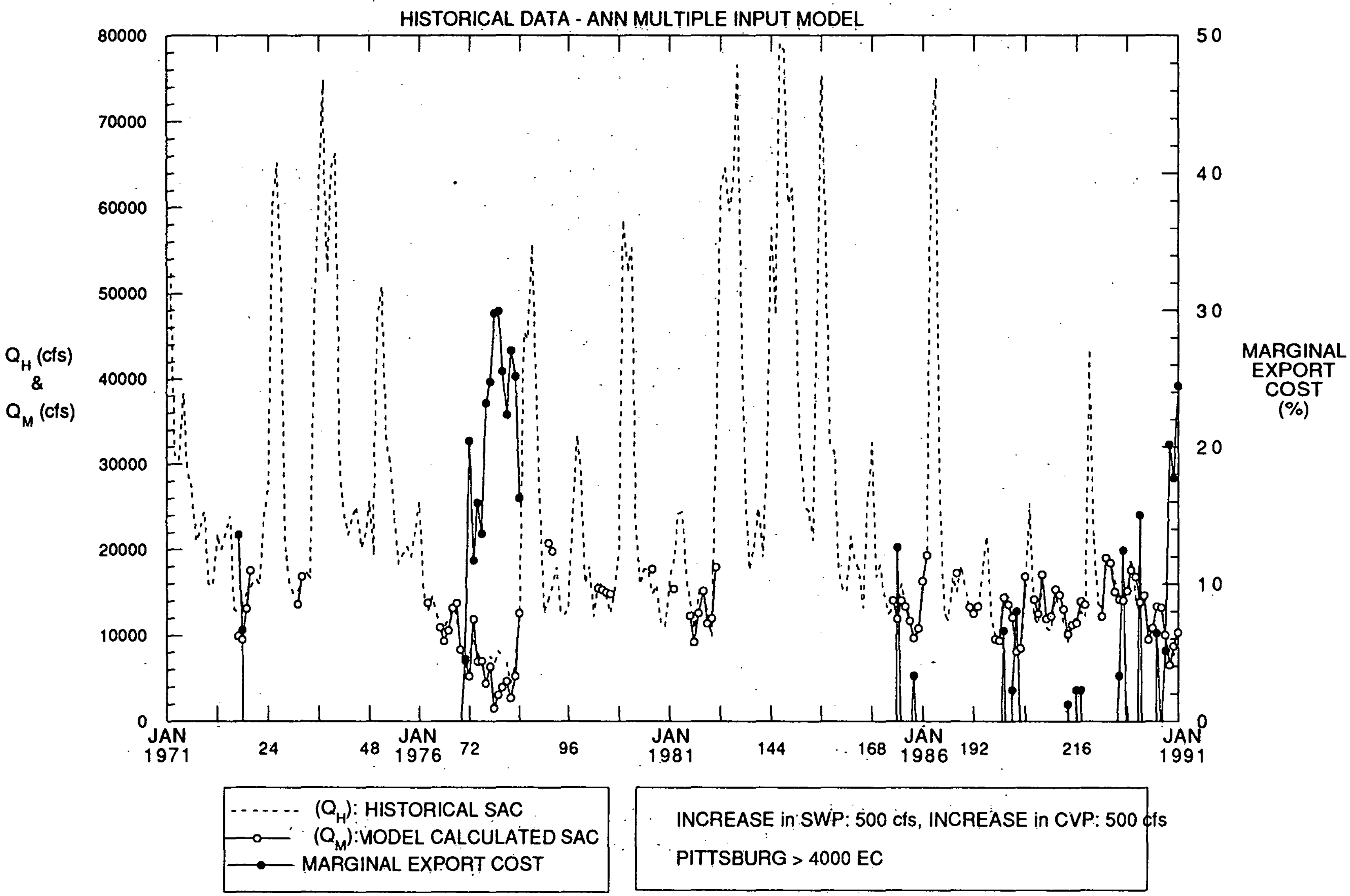


Figure 3-6

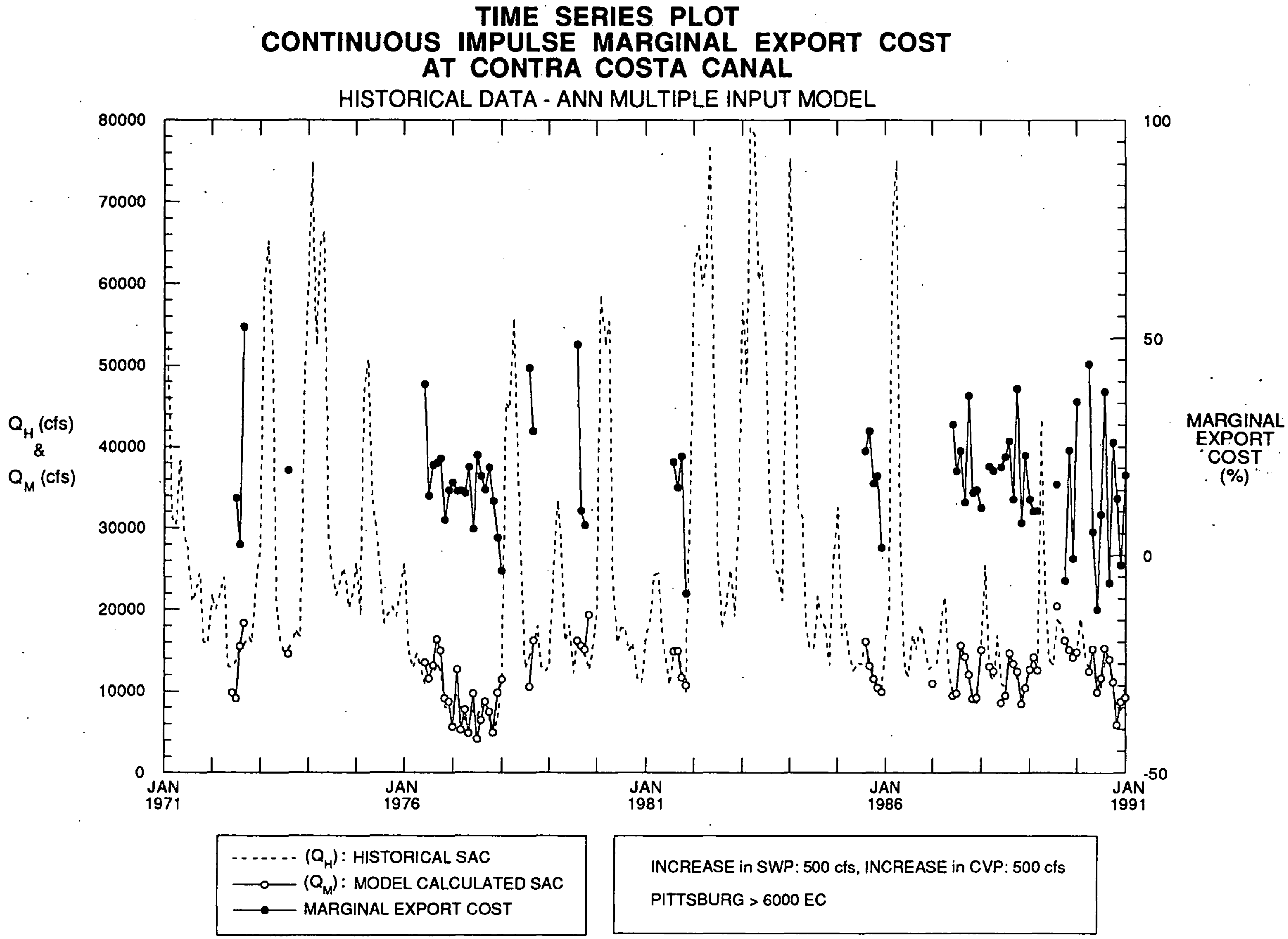

TIME SERIES PLOT
CONTINUOUS IMPULSE MARGINAL EXPORT COST
AT CONTRA COSTA CANAL
HISTORICAL DATA - ANN MULTIPLE INPUT MODEL
80000
70000
60000
50000
40000
30000
20000
10000
0
Q_H (cfs) & Q_M (cfs)
100
50
0
-50
MARGINAL EXPORT COST (%)
JAN 1971
JAN 1976
JAN 1981
JAN 1986
JAN 1991
(Q_H): HISTORICAL SAC
(Q_M): MODEL CALCULATED SAC
MARGINAL EXPORT COST
INCREASE in SWP: 500 cfs, INCREASE in CVP: 500 cfs
PITTSBURG > 6000 EC

Figure 3-7

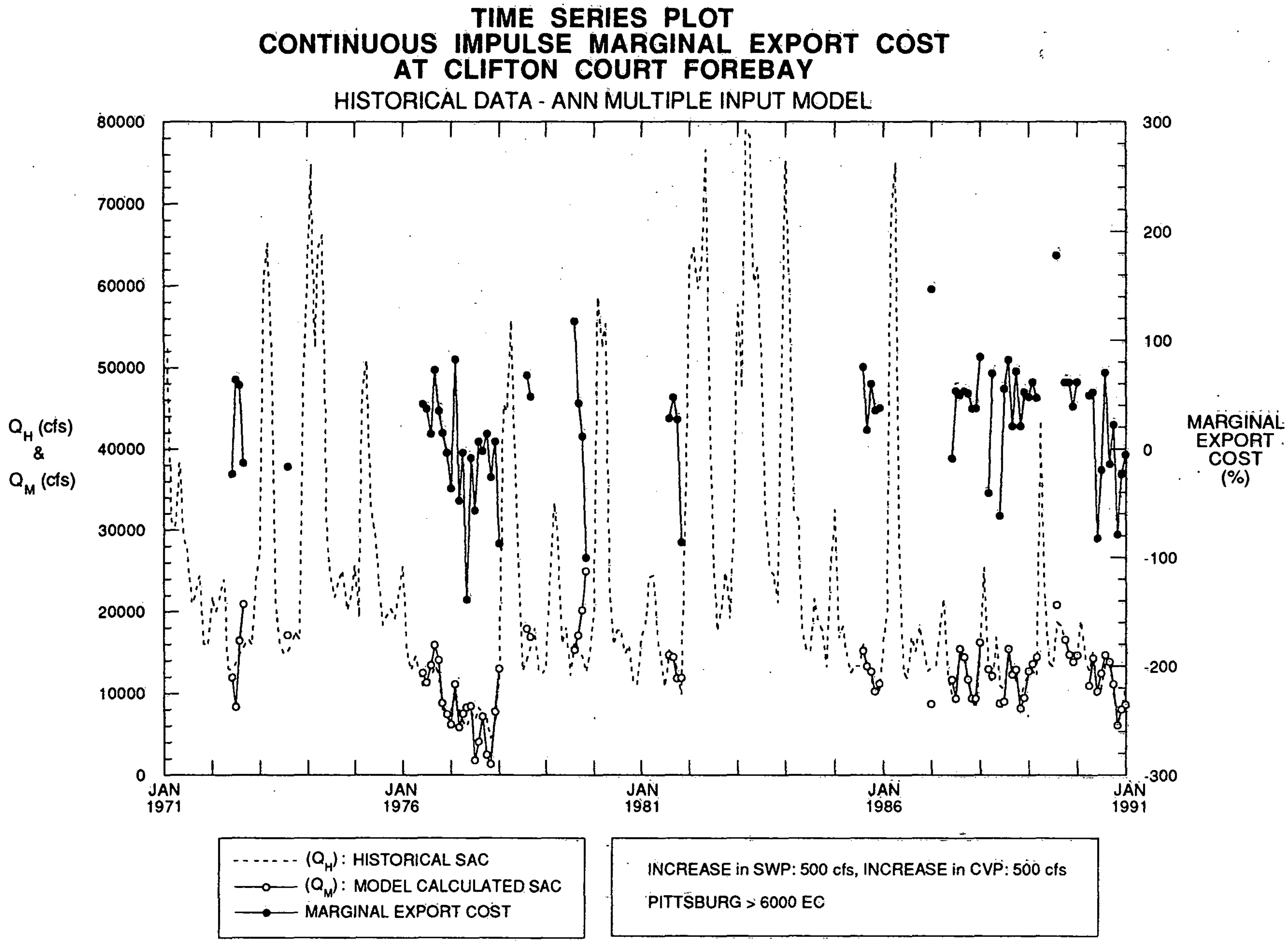
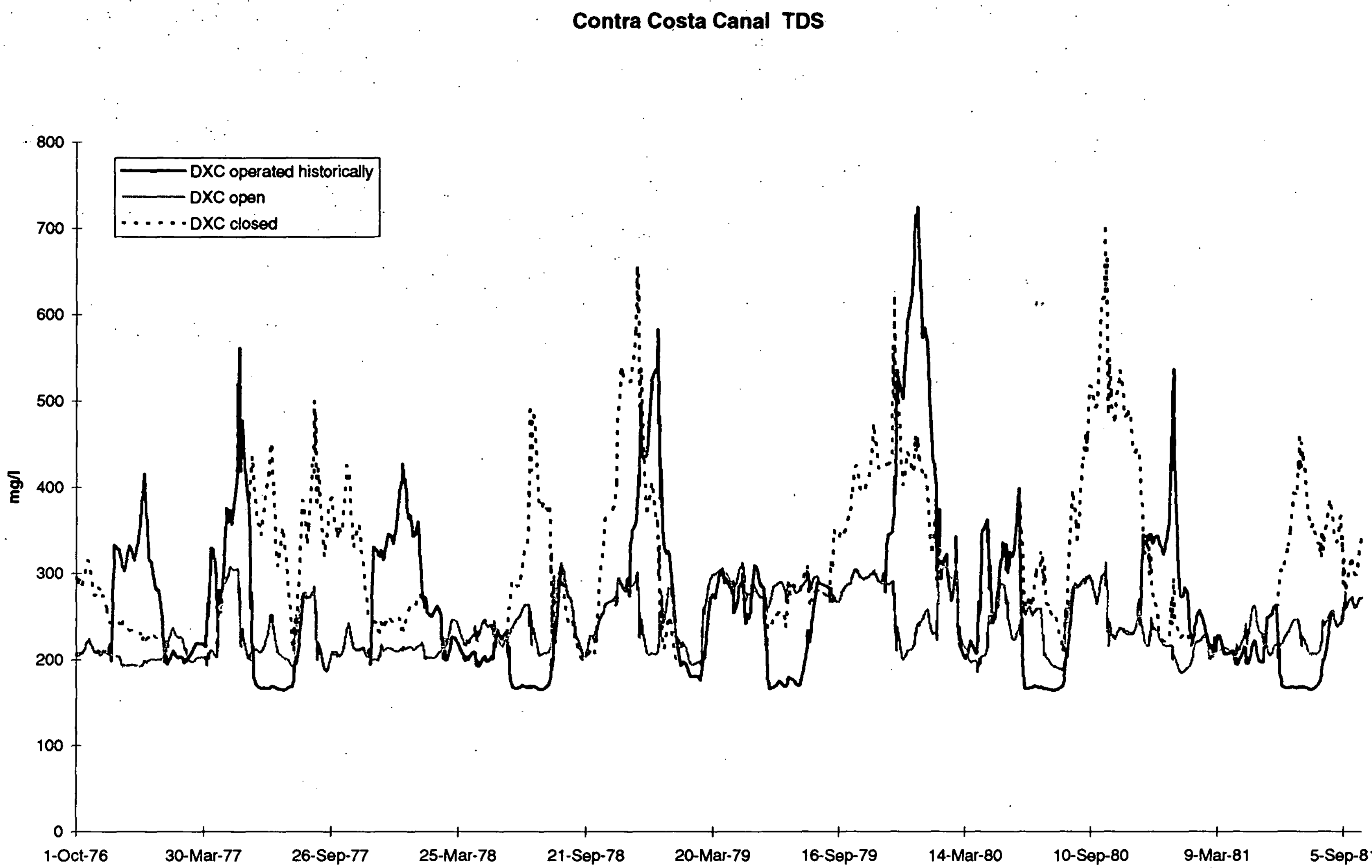
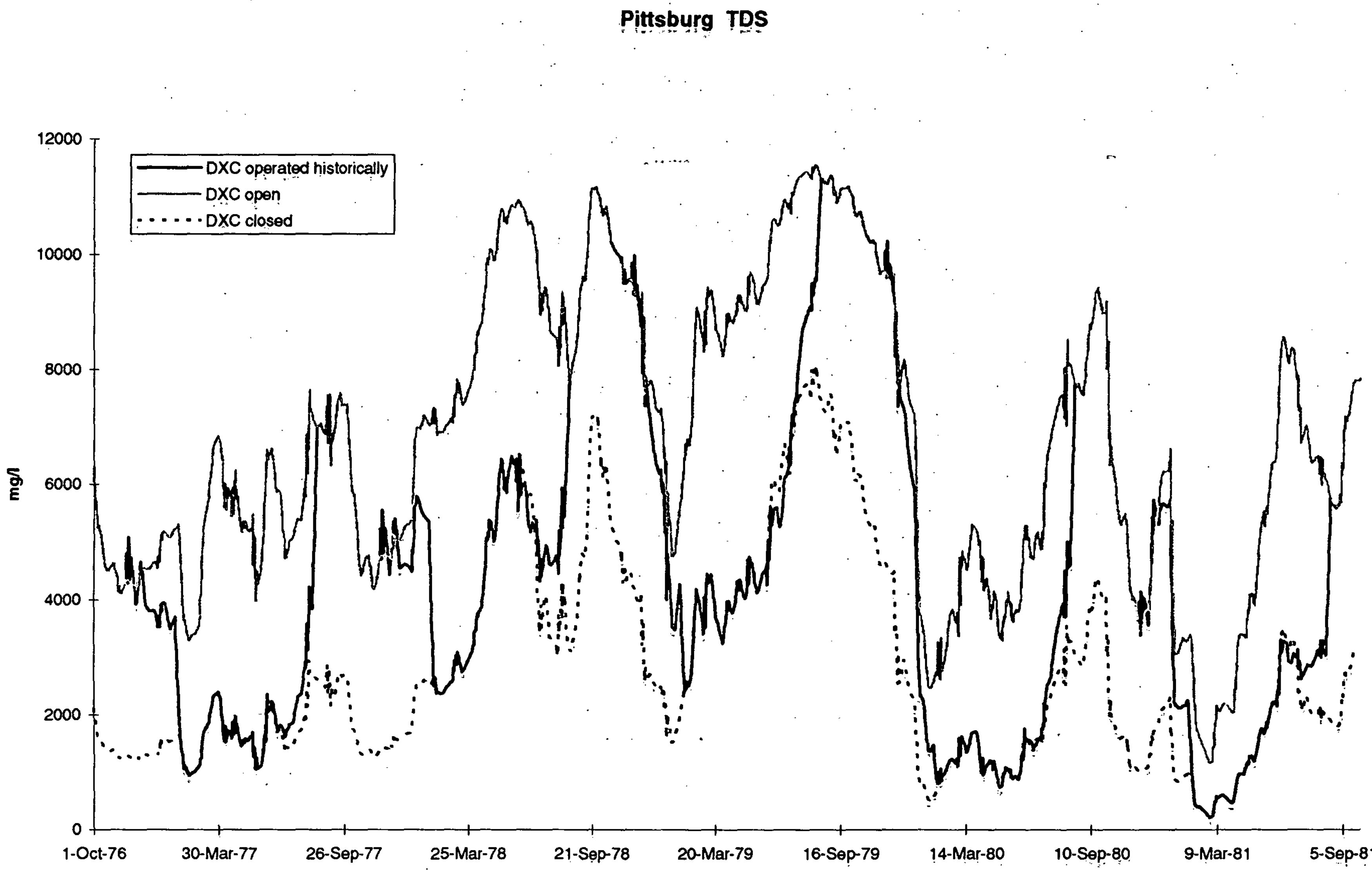

TIME SERIES PLOT
CONTINUOUS IMPULSE MARGINAL EXPORT COST
AT CLIFTON COURT FOREBAY
HISTORICAL DATA - ANN MULTIPLE INPUT MODEL
Q_H (cfs) & Q_M (cfs)
80000
70000
60000
50000
40000
30000
20000
10000
0
MARGINAL EXPORT COST (%)
300
200
100
0
-100
-200
-300
JAN 1971
JAN 1976
JAN 1981
JAN 1986
JAN 1991
(Q_H): HISTORICAL SAC
(Q_M): MODEL CALCULATED SAC
MARGINAL EXPORT COST
INCREASE in SWP: 500 cfs, INCREASE in CVP: 500 cfs
PITTSBURG > 6000 EC

Figure 3-8



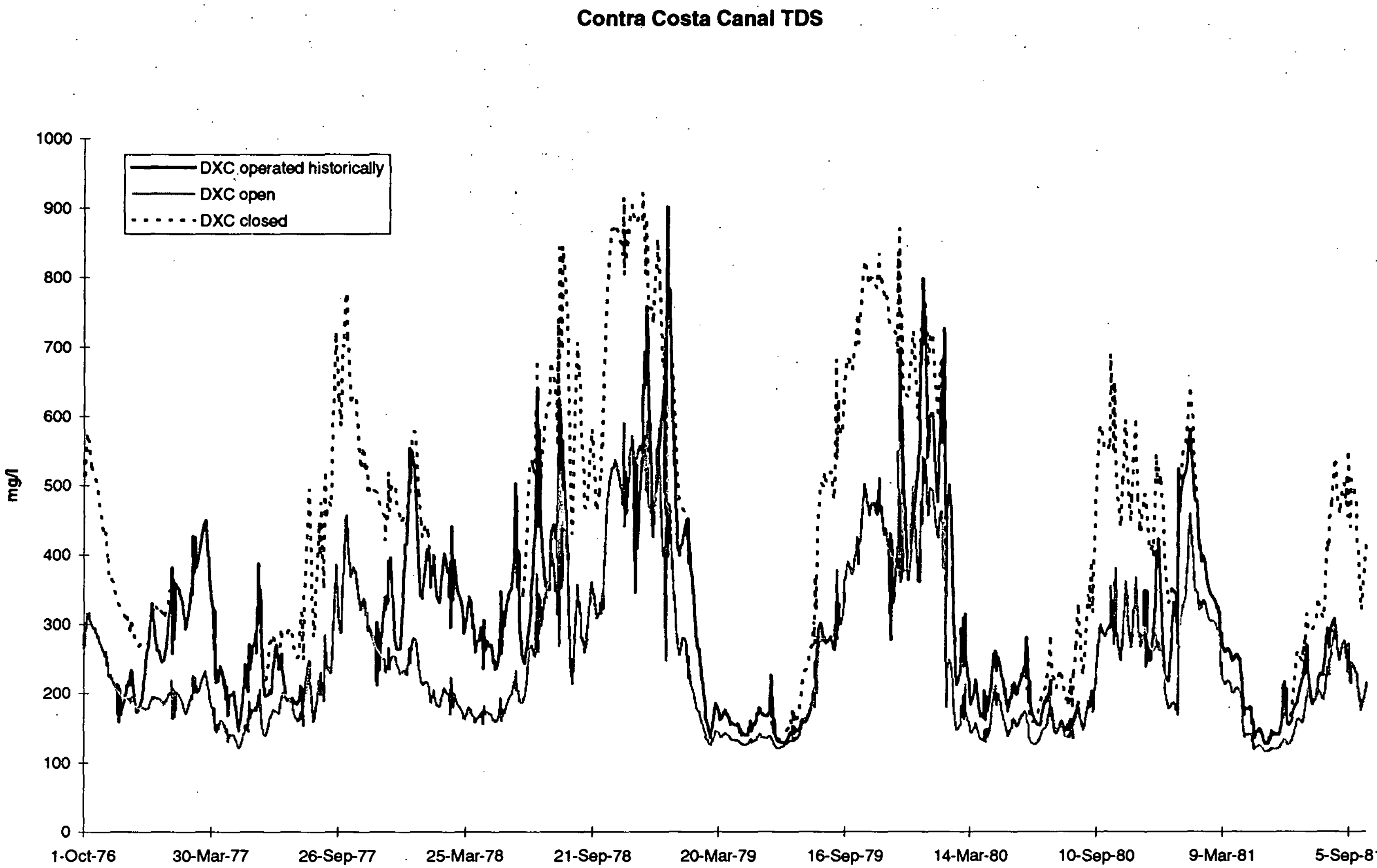
TDS at Contra Costa Canal (ANN trained with historic DXC)
Oct. 1, 1976 - Sept. 30, 1981

Figure 3-9



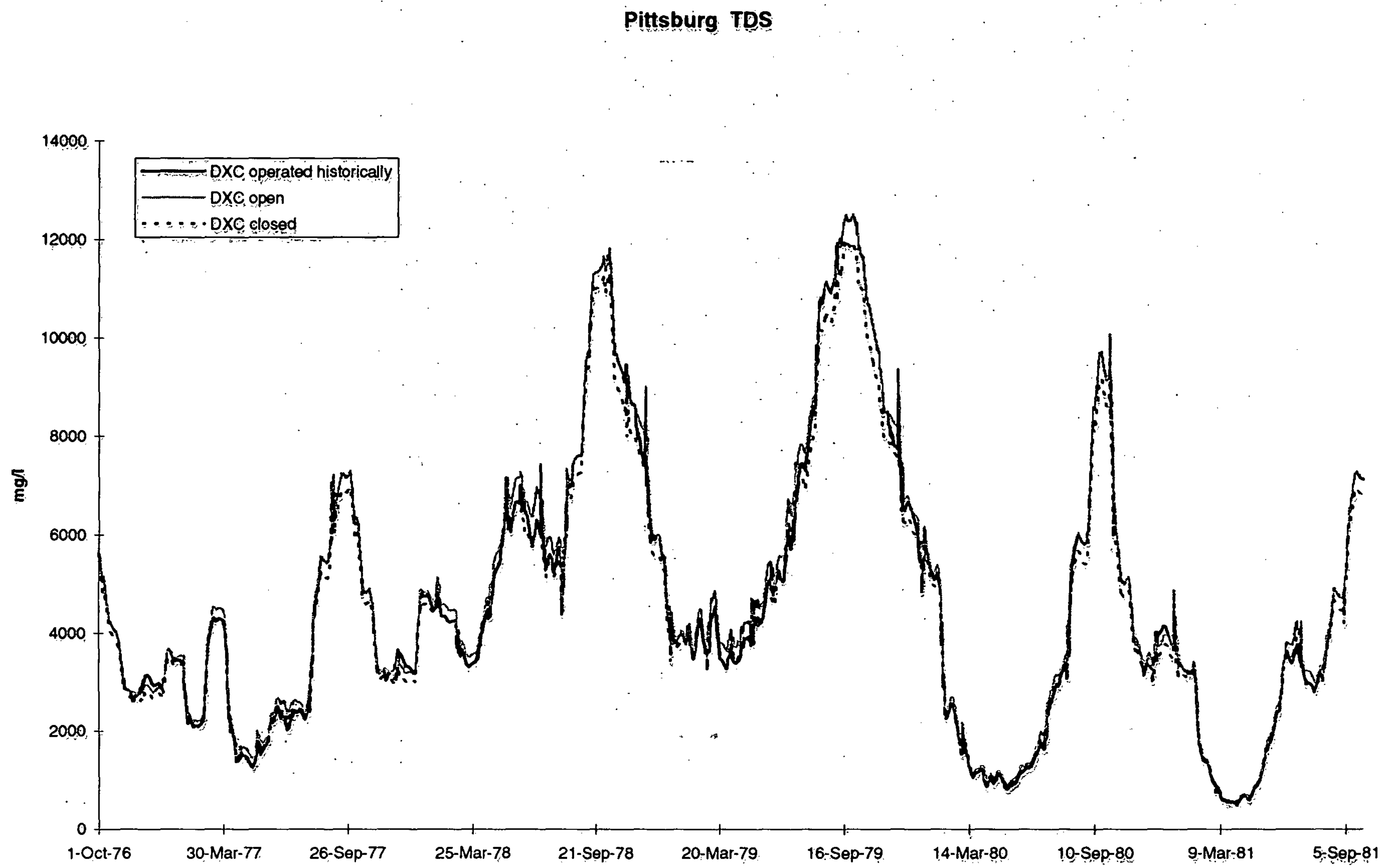
TDS at Pittsburg (ANN trained with historic DXC)
Oct. 1, 1976 - Sept. 30, 1981

Figure 3-10



TDS at Contra Costa Canal (ANN trained with historic and inverted DXC)
Oct. 1, 1976 - Sept. 30, 1981

Figure 3-11



TDS at Pittsburg (ANN trained with historic and inverted DXC)
Oct. 1, 1976 - Sept. 30, 1981

Figure 3-12

4 Home Page Status

Extensive additions and development of the Delta Modeling Section Home Page (`http://wwwdelmod.water.ca.gov`) occurred last year. Highlights include:

- **DSM2 source code, executables, and sample input/output files.** A complete DSM2 package is available to run and test DSM2. Source code is provided for those who wish to modify DSM2, or do not have either an Intel-NT or Sparc-Solaris computer.
- **Particle Tracking Model animation using Java and MPEG.** Particle movement from the PTM can be displayed using either Java or MPEG.
- **Interactive Delta simulator** using artificial neural networks (ANNs) and Java to calculate salinities when given flows. In the simulator, flows are historical daily values, modified by the user by adding or multiplying by a constant value. After setting the flow values at different locations and selecting one of several locations in the Delta, the user can choose to plot the historic (observed) salinity, the computed salinity using the ANN with historic flow values, and the computed salinity using the modified flow values. This allows the user to check the accuracy of the ANN, as well as perform experiments with carriage water estimates and the response of the Delta to different flow inputs.
- **Interactive Total Trihalomethane calculator,** using a hybrid ANN model and Java to calculate total trihalomethane concentration and individual THM species concentrations. Raw water inputs include total organic carbon (TOC) concentration, bromide concentration, ultraviolet absorption at 254 nm (UV-254), and ammonia concentration. Water treatment inputs to the ANN include chlorine dose, reaction time, temperature and pH, and fractional removal of TOC and UV-254 prior to chlorination. This simulator allows the user to test the response of THM formation in treated Delta water to changes in Delta operations for a user-defined set of water treatment conditions.
- **Continued dissemination of Section reports and study results,** such as CALFED studies. The World Wide Web is an efficient and cost-effective method of distributing results of work performed by staff. We will continue to use and expand our use of this medium for future work.

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