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REPORT TO
EARLY WINTERS RESORT PROJECT

GROUNDWATER MODELING OF THE UPPER METHOW VALLEY

Submitted to:

Early Winters Resort Project

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Golder Associates

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1. INTRODUCTION

This report has been prepared to document the results of groundwater modeling performed for the Early Winters Resort Project in conjunction with the Resort's pending water rights application. The contents of this report include:

- A discussion of the background to the modeling and overall objectives;
- A general description of the modeling code and pre-/post-processors;
- A discussion of available data;
- A detailed description of model configuration;
- The results of the model calibration using existing data;
- An evaluation of the impacts of groundwater withdrawals for the Early Winters Project;
- A discussion of model sensitivity; and
- Summary and conclusions regarding the application of the model for water resources evaluations in the Methow Valley.

1.1 Background to Groundwater Modeling

The Early Winters Report plans to develop groundwater for drinking water supply purposes (irrigation needs will be supplied by surface water stored in reservoirs) from the alluvial materials which infill the Methow Valley. In meetings with the Department of Ecology in the Fall of 1989 regarding water rights for the new groundwater source, the Department indicated that groundwater modeling should be carried out to address the impacts of the new groundwater source on surface water flows and groundwater supplies in the Upper Methow.

Subsequent to the meetings with the Department of Ecology, the Early Winters Resort requested Golder Associates to develop a groundwater flow model capable of addressing Ecology's requirements. Golder selected the USGS MODFLOW model for the work.

The overall objective of the groundwater modeling was to develop a large-scale regional representation of the groundwater flow and groundwater/surface water interaction in the Upper Methow Valley, and to use the model to examine the broad impacts of the proposed groundwater development on groundwater levels, streamflow and overall availability of groundwater. In order to achieve these objectives, the model does not include small-scale hydrologic features such as deep pools in the Methow River bed, which may locally influence the hydrologic regime without affecting regional hydrologic conditions.

The first attempt to model the valley[1] consisted of a coarse grid (18 by 48) with 48 river reaches specified in the standard MODFLOW river package. The model was discretized into two six-month stress periods per year, with river reaches above Mazama Bridge disengaged one stress period, and active for the other. This representation of the river was selected to simulate dry river reaches above Mazama Bridge which are normally observed in the late fall and winter. Although, the configuration of the river and valley were somewhat crude, the model was able to address the relative impact of pumping on active river reaches downstream of Mazama Bridge during dry river periods.

A more detailed model was subsequently developed, at the request of Early Winters and Ecology, to better evaluate impacts of pumping on flow in the Methow River. The MODFLOW grid was re-configured with a finer grid (150 by 40). An add-on package to MODFLOW was also included to more accurately simulate river conditions, and one boundary condition was changed. The number of stress periods was also increased. This model produced similar results to the first model attempt, but became very unstable under fully unconfined conditions. This model was then adjusted to produce the final model configuration summarized in this document. The model is more complicated in terms of grid size, number and characteristics of river nodes, variability of tributary flows, number of stress periods, specification of aquifer properties, and pumping/recharge well schedule than previous modeling attempts. However, this model represents what we feel is the most detailed and realistic simulation of groundwater/surface-water interaction given the available data.

1.2 Previous Studies

Several previous studies[2 3 4] describing the hydrogeologic conditions of the Methow Valley have been generally inconclusive regarding the available groundwater resources of the valley due to a lack of detailed hydrogeologic data such as deep borehole data, comprehensive streamflow and groundwater-level measurements, and aquifer characterization data. More recently, Okanogan County, in cooperation with Washington State Department of Ecology, has commenced a Ground Water Management Program (GWMP) for the Methow River Basin. This program has so far involved the collection of

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[1] Golder Associates Inc. 1989, Draft Report to Early Winters Resort Project on Groundwater Flow Modeling for Proposed Groundwater Development Mazama Washington.

[2] Walters, K.L. and Nasser, E.G., 1974. Water in the Methow River Basin, Washington. Department of Ecology Water-Supply Bulletin 38. 73 p.

[3] CH2M Hill, 1976. Analysis of Geohydrologic Data Related to Water Supply and Land Disposal of Domestic Effluent. Early Winters Valley, Near Mazama, Washington.

[4] Milhous, R.T., Sorlie, G. and Richardson, D., 1976. The Water Resources of the Methow Basin. Department of Ecology Office Report No. 56. 54 p.

groundwater-level and streamflow data, and the drilling and testing of one deep test well. The available data indicates that the Methow valley aquifer is a highly transmissive aquifer of considerable extent and that the aquifer is directly influenced by seasonal fluctuations in streamflow in the Methow River.

2. MODEL DESCRIPTION

2.1 MODFLOW

MODFLOW is a quasi-three-dimensional finite-difference groundwater flow model developed by the U.S. Geological Survey. It has been used since 1983 to simulate a wide range of hydrogeologic conditions and has gained international acceptance by hydrogeologists. MODFLOW is a modularized program consisting of a "main" program and a number of independent packages (consisting of several subroutines) that will incorporate a variety of specific features of the hydrologic system into the "main" program. The specific features include aerial recharge and evapotranspiration, flow to drains, flow to/from rivers, and wells. The "main" program controls all the file operations, determines boundary conditions, formulates the basic finite-difference equation, and calls appropriate subroutines based on the packages included in the run. The equations are solved through a separate package by either the strongly implicit procedure (SIP) or slice-successive over-relaxation (SOR). MODFLOW will simulate confined or unconfined conditions and solve transient and steady-state flow problems.

The version of MODFLOW used is compiled in NDP FORTRAN. NDP is a standard FORTRAN, but allows array allocations of greater than 640K. The X-array used throughout the entire MODFLOW code, can therefore be very large, and accommodate very large grids and multiple package specifications.

Two minor modification have been made to the MODFLOW code, specifically for modeling the Methow Valley:

1. An additional subroutine MODFILE has been added to automatically open and initialize files required by a MODFLOW run. This routine takes the file flags specified in the basic input file, assigns file suffixes specific to each package, and opens the file for input/output using a root file name specified from an interactive input. For example, the flag specifying that wells will be used automatically causes a file "ROOT.WEL" to be opened for input, where ROOT is a filename root specified by the user. Output files have the same root name, but different suffixes.

2. Portions of the output control package have been "hardwired" to produce specific output on each run. The flag designating that head output will be printed to the output file has been disabled and replaced with a list of cells for which heads are to be saved on a separate head output file. MODFLOW therefore produces two head files, one for every cell in the model, and one for cells corresponding to observation well locations.

2.2 STREAM

An enhanced version of the river package has been substituted for the standard river simulation capabilities of MODFLOW because of the seasonably variable streamflow regime in the Methow River. This program, here termed STREAM[5], was also developed by the USGS and is used to simulate streamflow in the Methow River. The program tracks flow and optionally calculates stream stage in one or more streams interacting with an aquifer. Complex stream networks consisting of tributaries and diversions can be simulated with streamflows properly accounted for at designated stream junctions of two or more streams. Leakage through the streambed is calculated based on stream/aquifer head difference and a conductance term, and this flow is incorporated into the streamflow accounting. The stage in the stream can be calculated based on streamflow via the Manning equation, assuming a rectangular channel. The inputs required for this calculation are length, width and roughness of each river reach.

STREAM is much more realistic than the standard MODFLOW river package for simulating dynamic stream/aquifer interaction. MODFLOW's river package is essentially a constant-head boundary, and therefore can supply an endless amount of water. STREAM limits the amount of stream infiltration to the available streamflow, and re-calculates stream stage based on the resulting flow changes in a reach. Infiltration to the aquifer ceases, and the stream reach goes dry, when the calculated leakage into the aquifer (based on the stream/aquifer head difference) is greater than the streamflow entering from the upstream reach. The stream reach may flow again if upstream streamflow exceeds the necessary leakage to maintain hydraulic continuity, or if the head in the aquifer is above the elevation of the streambed. The only drawback to the program is that it assumes hydraulic continuity is maintained for any stream/aquifer interaction.

One modification to STREAM has been incorporated to accommodate the large number of stress periods used for the Methow simulations. The STREAM input file normally requires all of the stream information (cell location, conductance, stream connections, and tributary flows) to be specified for each stress period. Some of the initial simulations included over 100 stress periods, which would have resulted in unmanageable input files. The location and characteristics of each river reach was not changed between stress periods. Only the tributary inflows changed between stress periods. Therefore, the program was modified to read and prepare only tributary inflow data after the first stress period, and keep all other river parameters as specified for the first stress period.

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[5] Prudic, David E., 1988, Documentation of a Computer Program to Simulate Stream-Aquifer Relations using a Modular, Finite-Difference, Groundwater Flow Model, U.S.G.S. Open-File Report 88-729.

2.3 Pre-processing

Pre-processing of data for input to the model was accomplished with a CAD-type graphics program MODELCAD™ and several LOTUS worksheets. MODELCAD was used to accurately locate wells, river nodes, and model boundaries with respect to topographic and cultural features. A 1:24,000 base map of the valley was digitized and the model grid was superimposed over the digitized map on a computer. The MODFLOW basic input file and the grid locations for each river node were generated with MODELCAD. MODELCAD does not produce STREAM data files, and therefore this file was formatted in a LOTUS spreadsheet.

LOTUS spreadsheets were used to generate files for aquifer bottom elevation, well pumping schedule, output control and the STREAM data file.

2.4 Post-processing

MODFLOW produces a variety of output, but lacks a standardized post-processor for the presentation of model results. Presentation and analysis of the model results were therefore customized with specific post-processors. This was accomplished using TURBO BASIC, and LOTUS. Each simulation consisted of two separate runs; a base-case and a pumping case. The base-case run was needed to produce output to compare to various pumping scenarios under the same aquifer and river parameters, thus evaluating the impact of pumping on flow in the Methow River. The comparison of river flow, river/aquifer leakage, and modeled/observed aquifer head for base-case and pumping case runs was accomplished with LOTUS, allowing both graphical and numerical comparison.

BASIC programs were written to extract and separate river flow output by stress period; extract total volumetric flows of the model; re-format hydraulic head output for input to SURFER for contouring and to optionally calculate drawdown from a base-case simulation.

LOTUS was used to plot the distribution of river flow along the river profile; plot the variation of flow and head through time at specified cells or river nodes; plot the variation in total flow volumes (storage, streamflow, pumpage) into and out of the aquifer through time; and calculate the streamflow depletion along the river profile caused by pumping.

3. AVAILABLE HYDROLOGIC DATA

3.1 Observation Well Data

Groundwater elevations in 21 observation wells have been measured by Ecology in the Upper Methow Valley. Most of these wells have been measured on roughly a bi-weekly basis since the spring of 1989, but data gaps exist on many wells. Intermittent measurements are available for some of the wells during 1988. Hydrographs for each observation well generally show a similar pattern of rising and falling groundwater levels between December 1988 and April 1990. The majority of the wells are completed in the upper 50 feet of the aquifer. The average annual water-level fluctuation ranges from 6 to 15 feet. Water-level data are not presently available after April 4, 1990.

3.2 Aquifer Extent and Properties

The lateral extent of the alluvial aquifer is well defined by topography. The Methow Valley has steep sides and a relatively flat valley floor. This contact between the bedrock valley walls and the alluvial valley floor can be ~~can be~~ estimated fairly well from the topography of the valley.

The vertical extent of the aquifer is very poorly known at this time. Topographic comparison of the Methow Valley with Yosemite Valley in California and the upper Chelan Valley in Washington suggests bedrock depths of 600 to 1,200 feet[6]. In addition to the one recent deep well at Mazama Bridge, several geophysical surveys have been conducted along portions of the valley, but this information is not yet available. The deep well at Mazama Bridge extends to a depth of 527 feet without encountering bedrock, supporting the topographic estimate of bedrock depth. A preliminary well log indicates gravelly sand to about 300 feet, silty sand from 300 to 450 feet, and sandy gravel from 450 to 527 feet. Pump testing of the upper gravelly sand may not be conclusive regarding the hydraulic interconnection between the upper and lower sand and gravel units. Therefore, it is not yet known whether there are several interconnected aquifers in the Methow Valley or whether the entire thickness of unconsolidated sediments behave as a single aquifer.

The hydraulic properties of the aquifer are not well known because of limited high capacity wells and large-scale pumping test data. One deep well has been drilled and tested at Mazama Bridge. The results suggest a transmissivity of between 10,000 and 200,000 ft^2/day (0.1 to 2.3 ft^2/sec). A pump test conducted in 1976[7] at the Rainbow Pines Subdivision well

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[6] Waitt, R.B., 1972. Geomorphology and Glacial Geology of the Methow Drainage Basin, Eastern North Cascade Range, Washington. Ph.D. Dissertation, University of Washington.

[7] CH2M Hill, 1976. Op. Cit.

17.3 ft²/sec

7 7.

17.3

indicated a transmissivity of about 1,500,000 gpd/ft, (2.3 ft²/sec). Aquifer storativity is not known, but may range from 0.1 to 0.3.

3.3 Streamflow Data

Bi-weekly stage measurements have been collected on the Methow River at Mazama Bridge and Weeman Bridge, and for Early Winters Creek at Highway SR20. Streamflow data from Early Winters Creek were used to develop tributary streamflow hydrographs for the model. Streamflow data from Mazama Bridge were compared with the simulated streamflows. Hosey and Associates began collecting comprehensive streamflow data for the upper Methow River basin in July of 1990. Data are available at seven gaging stations along the Methow River from above Lost River to above Weeman Bridge, Early Winters Creek and Early Winters Diversion. These data span the period July 20 to November 2, 1990. Streamflow data at Mazama Bridge and Early Winters Creek are not available after April 4, 1990.

3.4 Streambed Properties

Streambed properties necessary for input to the model include streambed elevation, channel width, and channel roughness. Streambed elevations for the Methow River are published as part of a flood insurance study[8] for Okanogan County and were determined by aerial survey techniques and field surveys. These elevations were used to develop a streambed profile for the model. Six subsequent spot measurements of riverbed elevation were made by Horton Dennis and Associates along the Methow River above Mazama Bridge. These measurements show discrepancies between the FEMA elevations of 1978 and present elevations. The differences in elevations are most likely due to differences in the river mile locations from the two surveys, and from inaccuracies in the FEMA elevations caused by indirect measurement techniques (aerial surveys). All of the present elevations except one are three to four feet higher than the FEMA elevations. The river bed elevation used in the model agree with the most recent survey data (see Section 4.5, Table 3).

Channel cross-sections are available at the gaging stations. Since the model assumes a rectangular channel, an average channel width was used and interpolated along the length of the river. Channel roughness (Manning coefficient) was calculated as part of the FEMA study and ranges from 0.032 to 0.045.

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[8] Federal Emergency Management Agency, 1978, Flood Insurance Study Okanogan County, Washington. Community Number 5301177

4. MODEL CONFIGURATION

The modeling was carried out in two stages, consisting of a calibration to observed measurements, followed by sensitivity runs and runs with pumping scenarios. The parameters required for the simulations are summarized in Table 1, and are divided into groundwater system parameters and stream system parameters. The aim of the calibration was to assign values to these variables that were consistent with the available data. The model parameters were not constrained to constant values along the entire length of the valley. In these instances, smooth functions were used so that the response of the model was not artificially controlled by parameters at a specific location.

The parameters used to produce the calibrated base-case simulation of groundwater/surface-water flow in the Methow Valley in 1990 are shown presented in Appendix A, Figures A-1 through A-10, and summarized in the following sections.

4.1 Basic Configuration

The groundwater model of the Methow Valley aquifer is configured as follows:

- A 40-by-150 cell grid extending from above Rattlesnake Creek to about 0.5 miles downstream of Weeman Bridge (Figure 1).

278,784 sq ft

- A uniform grid dimension of 528 feet per side, for a uniform cell area of 0.01 square mile. ÷ 6.4 acres
- An unconfined aquifer, such that aquifer transmissivity varies with saturated aquifer thickness.
- No-flow boundaries along the edge of the valley, corresponding to bedrock. The edge of the valley aquifer was estimated from a 1:24,000 topographic map.
- A general head boundary below Weeman Bridge, allowing down-valley flow based on a head far downstream.

There is no recharge, constant head, or constant-flux boundary to provide water to the aquifer. This is justified based on climatic and precipitation data which indicates that there is very little direct recharge to the aquifer. All water entering the aquifer is provided through the bed of the Methow River, which is itself dependent on tributary inflows from the surrounding mountains. Flows in the Methow River between Lost River and Weeman Bridge are controlled by tributary flows from the upper reaches of the Methow (including Robinson Creek), Lost River, Early Winters Creek, and Goat Creek, and Little Boulder Creek.

4.2 Model Time Steps

MODFLOW steps through time using two mechanisms; stress periods and time steps. Time steps are required to provide numerical stability in the solution of the transient groundwater flow equations. Time steps can be a uniform length or increase in length for successive time steps based on a multiplier. A stress period consists of one or more time steps. The external conditions imposed on the aquifer can change from one stress period to another. It is through this mechanism that the variable flow hydrographs of the Methow tributaries, and the variable pumping schedule of the wells are simulated. The model consists of cycles of 26 stress periods, corresponding to the bi-weekly time intervals shown on Table 2. One cycle of 26 stress periods equals one year of simulation, and a total of 3 to 5 years (or 78 to 130 stress periods) are simulated in a single run. Tests on the model showed that after two cycles of simulation, the model produced identical output at each stress period. The first two cycles had slight differences in results because of the initial model conditions and small changes in transient storage terms.

4.3 Aquifer Geometry

The horizontal extent of the aquifer was estimated from the topography of the valley. In the main portion of the valley, the 2,040 foot contour was arbitrarily chosen as the edge of the aquifer for use in MODELCAD. The bedrock sides and base of the valley are assumed to be impermeable. The aquifer is represented as rectangular at the edges and therefore does not reflect any cross-valley slope or rounding of the aquifer at the edges of the valley.

As discussed previously, the vertical extent of the aquifer is very poorly known. Several bedrock configurations were examined in the process of calibrating the model. Aquifer thickness ranges from a constant value of 40 feet above Lost River, to a maximum thickness of 700 feet at Weeman Bridge (Figure A-1). Aquifer thickness at Mazama Bridge is 360 feet, consistent with the upper water-bearing sands and gravels identified in the deep borehole at that location. The slope of the bedrock surface ranges from 40 ft/mile above Lost River, steepening to near 100 ft/mile between Lost River and Gate Creek, then stabilizing at 60 ft/mile to Weeman Bridge. This profile appears consistent with the estimated slope of the pre-existing ice surface, and possible over-deepening of the valley floor at the junction of Lost River and Methow River.

The assumed aquifer thickness is based on limited data regarding bedrock elevations and thickness of the upper gravelly sand. However, the 300 foot aquifer thickness is conservative for evaluating the impacts of pumping since:

1. A thicker aquifer would have a greater volume of flow to maintain the observed hydraulic gradient, assuming a constant hydraulic conductivity throughout the aquifer.

2. A leaky aquifer (with leakage from the underlying sediments) would reduce the amount of aquifer drawdown during pumping and therefore reduce the impact on streamflow.

4.4 Aquifer Properties

Aquifer properties were selected based on the 1976 pump test at Rainbow Pines and the most recent pump test at Mazama Bridge. The most recent test indicates transmissivities between 0.6 and 1.5 ft²/s. The hydraulic conductivity is therefore between .002 and .005 ft/s, assuming a 300 foot aquifer thickness. The aquifer thickness at Rainbow Pines is not known, but the transmissivity is 2.3 ft²/s. Assuming a hydraulic conductivity of .005 ft/s, an aquifer thickness of about 450 feet is calculated. In the process of calibrating the model, a constant hydraulic conductivity throughout the valley produced unsuitable results for calibration. It is reasonable to assume that the hydraulic conductivity decreases downvalley caused by transport and deposition of fine grained sediment downvalley. The aquifer hydraulic conductivity used in the calibration is equal to 0.007 ft/s above Lost River declining to 0.004 ft/s at Mazama Bridge, declining to 0.0035 ft/s at Weeman Bridge (Figure A-2). The hydraulic conductivity at Mazama Bridge is consistent with available pump test results at that location.

$\frac{2.3}{.005} = 460$

Transmissivity (the product of aquifer thickness and hydraulic conductivity) increases downvalley, from 0.15 ft²/s above Lost River to 2.2 ft²/s at Weeman Bridge (Figure A-3). Aquifer transmissivity at Mazama Bridge is 1.6 ft²/s (140,000 ft²/day).

aquife
proper

Storativity is estimated at between 0.1 and 0.2. Storativity could not be reliably determined from the available pump test data. A value of 0.2 was used in the base-case calibration run. A value of 0.1 was examined in a sensitivity analysis.

4.5 Streambed Characteristics

River width ranges from 20 feet at the upper reaches to 120 feet at Weeman Bridge (Figure A-4). The river appears to constrict between Lost River and Gate Creek, based on measured cross-sections at gages #2 and #3.

The river-bed profile is based on surveyed elevations at the seven gaging stations and the FEMA profile. The riverbed profile was smoothed with a 5-point average (0.5 mile) to reduce spikes in the data. The longitudinal profile is shown on Figure A-1. River-bed slope ranges from 0.03 to 0.01 above Lost River to between 0.01 and 0.005 below Lost River. Figure A-5 shows the effect of smoothing on the riverbed slope.

Simulation of stream-aquifer interaction using MODFLOW requires a riverbed conductance term, CRIV, to be defined based on the geometry and hydraulic properties of the riverbed. An implicit assumption in defining CRIV is that "all significant head loss occurs over a discrete streambed layer"[9] In cases where no discrete streambed exists, a single conductance terms must be defined to account for a three-dimensional flow process, which "is inherently an empirical exercise and [that] adjustment during calibration is almost always required."[10] Certain guidelines are suggested in applying river-bed conductance to this special case including:

1. The assumed cross-sectional area should be of the same order of magnitude as the product of channel width and length within the cell;
2. The assumed distance of flow (i.e. the length of the flowpath from aquifer to river) should not exceed the vertical interval between the streambed and aquifer node;
3. If distinct layers can be recognized between the streambed and aquifer node, they should be treated as conductances in series in formulating an equivalent conductance.

Additionally, theoretical studies by Stretslova[11] and Numerov[12] have indicated that open channels with significantly smaller dimensions than an underlying aquifer can be considered as partially penetrating boundaries, subject to additional seepage resistance at the channel/aquifer boundary. The additional seepage resistance is expressed as a lengthening of the flow path between the aquifer and channel, similar to guideline #2 suggested for MODFLOW. The limiting length of the flow path is shown to be approximately one-half the aquifer thickness, which is also similar to the MODFLOW guidelines. Riverbed conductance was defined with these guidelines in mind.

For a river reach width of 50 feet, a conductivity of .005 ft/s, and leakage flowpath length of one foot, the conductance of the riverbed would be 132 ft^2/s. The range of maximum flow path lengths (equal to one half the aquifer thickness) is between 10 and 150 feet. Therefore, bed conductance could range from 13 ft^2/s in the upper reaches to less than 1.0 ft^2/s in the lower reaches. During calibration it was found that a uniform decrease in conductance from 10 to 1 ft^2/s produced unsuitable results for calibration. The best fit was obtained by decreasing the riverbed conductance from 10 ft^2/s between the Upper Methow and Gate Creek, decreasing to 1 ft^2/s below Early Winters Creek Fan (Figure A-6). Geologically, this is reasonable since Early Winters Fan is composed of relatively finer-grained material which would decrease the conductivity of the "riverbed", or increase the vertical anisotropy and layering in the sediments.

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[9] McDonald and Harbaugh, 1988, Op Cit.

[10] McDonald and Harbaugh, 1988, Op Cit.

[11] Stretslova, Tatiana D., 1974, Method of Additional Seepage Resistances - Theory and Application. Journal of the Hydraulics Division, ASCE Vol. 100, No. HY8, pp. 1119-1131.

[12] Numberov, S.N., 1954, Flow to a Partially Penetrating Ditch in a Confined Aquifer. Izvestia VNIIG, Lenningrad, USSR, Vol. 52 (in Russian).

4.6 Streamflow Characteristics

Streamflow hydrographs for the tributaries to the Upper Methow River were generated using both observed flows from 1989-1990, and historical flows from other similar streams originating on the Eastern slopes of the Cascade Mountains. Lost River, Goat Creek, and the Upper Methow have not yet been gaged over an annual river cycle, although detailed data from July 20 to November 2, 1990 has been collected by Hosey and Associates. Bi-weekly stage and discharge is generally available for the Methow at Mazama Bridge and for Early Winters Creek at SR 20 from 1988 to the present.

Historical records between 1969 and 1979[13] for Andrews Creek near Mazama, White River near Plain, and Toats Creek near Loomis, were examined to evaluate the timing of peak discharge, and the relative range of flows in similar drainages to the Methow tributaries. Neglecting winter flood events, peak discharge occurs between May 17 and June 16 in all the basins. The magnitude of flow, relative to the yearly average, is shown on Figure A-7.

In general, peak flows are about 500% of the average flow, and low flows are 10% to 30% the average flow. Using these ratios and peak discharge times, a synthetic hydrograph was developed for the tributaries to the Methow River. Figures A-8 and A-9 show the synthetic hydrographs developed for Early Winters and Lost River respectively, along with available measurements from 1988, 1989 and 1990. Each of these hydrographs was discretized into two-week intervals and input to the STREAM data file. The resulting hydrograph is shown on Figure A-10 as a stacked bar graph, which depicts the cumulative total tributary inputs, subdivided into the relative contribution of each tributary. Table 4 shows the actual values used as input.

The base-case input hydrograph used in the model differs from the estimated average historical hydrograph in two respects:

- Flows during the late summer and fall are somewhat higher than normal. This is because the available data, to which the model was calibrated, was obtained during 1990. The 1990 flow data shows somewhat higher flows than normal during late summer and fall.
- Flows during the mid-winter are probably lower than normal. To avoid having too many base-case simulations, flows were kept very low throughout the winter to cause the river to dry up over a large area between Little Boulder Creek and Lost River. In evaluating the impacts of pumping, this period of dry river reaches can be viewed as equivalent to a dry summer and fall period, since similar impacts would result.

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[13] Williams, J.R. and Pearson, H.E., 1985, Streamflow Statistics and Drainage Basin Characteristics for the Southwestern and Eastern Regions, Washington. U.S.G.S. Open-File Report 84-145-B.

5. MODEL RESULTS

The aim of the modeling exercise was to develop a base-case simulation that predicted observed groundwater and streamflow conditions in the Upper Methow Valley based on the past two years of data collection. Using this "calibrated" simulation as a standard, additional runs were performed to examine the sensitivity of the various input parameters and the potential impacts of pumping on the system. Each model run generated a tremendous amount of output, which required a significant effort for comparing runs. A number of different plots of the model results were generated in evaluating the model including:

1. A plot of groundwater elevation versus time at a specific model cell;
2. A plot of streamflow/stage versus time at a specific river reach;
3. A plot of stream depletion versus time at a specific river reach;
4. A streamflow profile along the entire length of the Upper Methow at a specific time;
5. A plot of stream depletion along the entire length of the Upper Methow at a specific time;
6. Plots and/or tables of total water volumes attributed to aquifer storage, streamflow, pumping and down-valley flow; and
7. Total impact on streamflow and aquifer storage caused pumping when compared to the base case.

Plots of all of the possible combinations of river reaches, aquifer cells, and stress periods could not be examined. The output selected for inclusion in this report is presented in the Appendices, and is focused on locations (model cells or river reaches) where data exists; time periods where data exists; and low-flow time periods. The following sections provide an overview of the results, but do not go into detail regarding each component of the output summarized above.

5.1 Model Calibration

5.1.1 General Description

Calibration of a groundwater model involves adjusting various parameters in the model, based on assumed or measured values, until the model predicts observed hydrogeologic conditions within the model area to a specified degree of tolerance. Calibration of the groundwater model for the Methow Valley was complicated by the number of variables necessary to simulate stream/aquifer interaction, and by the need to calibrate to two types of data (streamflow and groundwater elevation) that fluctuate over a 26-period simulation. The model was calibrated based on the observed and predicted values at nine locations along the length of the valley. This included five well locations, and four stream gaging locations. The calibration points are summarized on Table 5. A statistical analysis of the "goodness-of-fit" of the entire model was not carried out because of the data set consisted of two data types (streamflow and groundwater elevation), varying in both space and time. Instead, plots of observed and predicted values through a yearly cycle at each calibration point were generated as discussed previously.

5.1.2 Calibration Results

The groundwater and streamflow hydrographs predicted by the model using the parameters discussed above are presented in Appendix B. In addition to the hydrographs, volumetric flows through the model were also summarized as part of the calibration process. The output used to calibrate the model included:

- Groundwater elevation hydrographs at five observation wells (EW-8, EW-19, EW-2, EW-10, EW-17) - Figures B-1 through B-5.
- Streamflow profiles along the Methow River at stress periods 5, 7, 9 and 11 (corresponding to the period September 24 to November 2). Observed values at the Hosey gages during these periods was used to evaluate predicted flows along the length of the river - Figures B-6 to B-9.
- Streamflow hydrographs and stage elevations at gaging stations (Mazama Bridge, Early Winters Creek, Gage 7, and the Methow River at Little Boulder Creek) - Figures B-10 to B-14.
- Plots of volumetric inflow (streamflow, storage) and outflow (streamflow, storage, downvalley flow) versus time - Figure B-15 and B-16.
- Plot of predicted streamflow profiles between October and February - Figure B-17.

Table 6 summarizes the predicted groundwater level fluctuation and shows that the model predicts groundwater levels to within 1 to 4 feet of the observed values. This level of accuracy is tolerable for the following reasons:

- The predicted groundwater level is an average value for an area of aquifer 0.01 square miles. The observation well data is a point measurement and does not represent the average groundwater level over a large area.
- The input hydrograph for the base case includes an extended low-flow period during the winter to cause the river to dry up between Little Beaver Creek and Lost River. The observed data (which does not include many measurements during the winter) was obtained between 1988 and 1990, when the river did not

dry up to this extent. Therefore, the model overestimates the range of groundwater fluctuations because of the extended period of dry river reaches.

Streamflow measurements at the seven gaging stations along the Upper Methow between July and November 1990 were used to calibrate the predicted distribution of streamflow. A range of observed streamflows was used because streamflows vary significantly over a two-week interval. The model predicts streamflow within about 20 cfs of the average observed streamflow between July 20 and November 2, 1990.

± 20 cfs.

The volumetric flow plots show that throughout the yearly cycle, between 10 and 50 cfs are released from aquifer storage during a two-week period of declining streamflows. This causes groundwater-levels to decline between peak and low-flow periods. During the extended low-flow period between January and April, storage releases are at a maximum. This occurs because the aquifer attempts to maintain a down-valley flow of about 50 cfs. Since water cannot originate from the river during extended low-flow periods, aquifer storage maintains the down-valley flux. When streamflows increase during fall or spring run-off periods, the aquifer is recharged, thus replenishing storage losses. The model predicts that during a two-week period of increasing streamflows, the aquifer is recharged by 30 cfs during the fall run-off, and up to 170 cfs during peak spring run-off. During smaller recharge events, such as the fall run-off, groundwater levels (which had been declining) stabilize as some aquifer storage is replenished. During peak recharge events, groundwater levels rise, fully replenishing lost aquifer storage.

In summary, the parameters used in formulating the calibrated model simulation are within the ranges of observed and estimated values based on available hydrologic data. The model predicts observed groundwater levels and streamflows within a reasonable level of tolerance given the grid size, observation well locations, and variability in the observed data.

5.2 Pumping Scenarios

Pumping scenarios were evaluated to determine the possible range of impacts on streamflows and aquifer drawdown caused by a projected groundwater withdrawal of 1 to 1.5 cfs. To evaluate the impact, various plots of stream depletion and drawdown at specific locations and times were examined.

Six pumping scenarios were evaluated with the model. Two simulations examined the impacts of pumping only. The other four simulations examined the impact of pumping combined with artificial recharge treated effluent. Well locations are shown on Figure 1 and include two pumping wells and one injection well at Early Winters (P-1, P-2, and I-1), one pumping well, one injection well at Cassel Ranch (P-3 and I-2), one injection well at Mazama Bridge (I-3) and one injection well at Early Winters Fan (I-4). The pumping scenarios are summarized on Tables 7 and 8.

Selected output from this pumping scenarios is presented in Appendix C. Tables 9, 10, and 11 show the net impact on streamflow and aquifer storage caused by pumping for each pumping scenario. These impacts were determined by subtracting volumetric flows for the pumping case from volumetric flows for the base case at the end of each stress period. Table 13 shows the predicted maximum drawdown at three observation wells along the valley. The results of the pumping analysis are discussed below.

5.2.1 Impacts Without Artificial Recharge

When the river is flowing continuously above 5 cfs, between 90 and 98 percent of the pumped water is derived directly from streamflow. This condition is simulated between Period 53 (June 15) and Period 65 (November 30). This is a total impact on the entire model area. The impact on individual reaches is less than the total pumped quantity. For example, the model predicts that streamflow reduction at gage 7 will be about 1 cfs when pumping 1.5 cfs from Early Winters Fan. Note that when the wells are initially turned on, between 48 and 30 percent of the pumped water is derived from aquifer storage for the first month of pumping (see Table 8). This occurs while all reaches of the river are flowing.

pumping = 1.5 cfs.

During this "high-flow" period, pumping causes a direct impact on aquifer/river interaction approximately 1 mile upstream and 0.5 miles downstream of the pumping wells. These reaches experience a reduction in groundwater flow discharging to the river, or an increase in river flow recharging the aquifer. Reaches downstream of this "impact zone" experience lower river flows as a result of lower streamflows originating from upstream reaches.

After stress period 66 (December 14) some reaches of the river begin to dry up. During low-flow periods when portions of the river are dry, between 26 and 87 percent of pumpage is derived from aquifer storage when pumping continuously at Early Winters (Case P101). The model does predict that pumping could accelerate the drying up of some reaches. For example, continuous pumping at Early Winters results in 3 dry reaches (0.3 miles) during stress period 69 (January 25) that were not dry during the base case simulation. However, the acceleration of the drying-up is dependent on a continuous low-flow of less than 5 cfs, maintained for an extended period of time over a large number of reaches adjacent to the well. Short-term increases in flow, such as those observed during the fall of 1990, would likely maintain flows in these reaches but it is difficult to predict impacts over a duration of less than two weeks.

Adjusting the operating schedule of the wells (Case P102) results in some benefit in terms of streamflow impact. Shifting pumpage upstream to Cassel Ranch at stress period 61 (October 5) reduces the predicted total reduction in streamflow by about 30 percent and increases storage withdrawal by about 50 percent during the onset of the mid-winter dry period. When a large portion of the river goes dry, the location of the pumping wells does not significantly reduce the impact on streamflows. Case P101 (continuous pumping at Early Winters) draws nearly 90 percent from storage when the entire river is dry, while P102 (pumping at Cassel Field) draws about 95 percent from storage. However, pumping at Cassel Ranch causes only one additional dry reach during stress period 69 (January 25) compared to three with all pumping located at Early Winters. This seems to indicate is that adjustment of the location of the pumping wells during the onset of low flows reduces the impact on streamflows, but that once dry reaches are fully established during the mid-winter, the location of the pumping wells is not significant - the wells will withdraw aquifer storage in either case.

Because of the impact of aquifer storage, streamflow at Little Boulder Creek during mid-winter is reduced by less than 0.2 cfs, as compared to the base case, for either pumping schedule. This is because the reaches above Little Boulder Creek are dry during this period and pumping reduces aquifer storage rather than impacting streamflow farther downstream. Therefore, it appears that if there are dry river reaches between a pumping well and Little Boulder Creek, there may be little impact on the observed flow at the compliance point on Little Boulder Creek. The minimum streamflow requirement at Little Boulder Creek is between 32 and 42 cfs during the early fall and mid-winter low-flow periods. The observed flows from October 1990 show that even though dry reaches were observed near Gate Creek, flows were at or above the in-stream flow requirement at Little Boulder Creek. Shifting the pumping well to Cassel Ranch may therefore minimize streamflow reduction at Little Boulder Creek, or in any downstream reach separated by one or more dry river reaches.

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During increasing flows in the Methow River, the calculated impact on streamflow exceeds the pumped quantity and the impact on aquifer storage impact becomes negative (see Table 9). This occurs because additional water is added to aquifer storage and lost from streamflow as compared to the base case. This is a correct response because pumping lowers the water table further than if there were no pumping. The additional storage losses (lower water-levels) caused by pumping are replenished during high-flow periods before the onset of the summer low-flow period. Therefore the model predicts that pumping will not cause a continued loss of streamflow or depletion of aquifer storage over an extended period of time.

Estimated maximum drawdowns under the no-recharge scenario are presented on Table 13. These drawdowns are at specified monitored wells in the valley and indicate a drawdown of less than one foot, and in most areas less than 0.5 feet. This additional drawdown is not considered sufficient to impact the performance of existing wells. There could be some minor impacts on wetland areas supplied by groundwater discharge close to the wells since the water table will be lowered compared to the pre-pumping conditions.

The wetland near the Shaefer well appears to be supplied by groundwater discharge from the valley walls to the south of the wetland area and is not a representation of the groundwater level. We believe that the groundwater discharge which feeds these wetlands would not be impacted by pumping.

5.2.2 Impacts With Artificial Recharge

Re-injection of treated wastewater was evaluated as a potential mitigating measure for maintaining streamflows and reducing aquifer drawdown due to pumping. Four recharge scenarios were examined:

- A single injection site near Mazama Bridge returning 80% of the pumped quantity; pumping at Early Winters and Cassel Field.
- Two injection sites (one at Cassel Field and one near Early Winters) returning 80% of the pumping rate of the adjacent wells. This simulation represents re-injection at the point of use; pumping of Early Winters and Cassel Field.
- A single injection site near Mazama Bridge returning 100% of the pumped quantity; pumping at Early Winters only.
- A single injection site at Early Winters returning 100% of the pumped quantity; pumping at Early Winters only.

? 95%

For a recharge site near Mazama returning 80% of the pumpage, the net impact on streamflow is reduced to between 10% and 20% of the pumped quantity during periods of continuous streamflow (Table 10). During the onset of peak spring flows, pumping continues to withdraw nearly 100% of pumpage from streamflow. The distribution of stream depletion at each river reach during these periods of continuous river flow is similar to the no-recharge scenario upstream of the injection site, reaching a maximum value about 1 mile upstream of the injection site. Net stream depletion then begins to decline as streamflows are augmented by recharge. Net stream depletion reaches a steady value of 20% about 1 mile downstream of the injection site. During low-flow periods, the river reaches augmented by recharge begin at the first flowing reach downstream of the injection site. Net streamflows are increased by as much as 13% (compared to the base case scenario) by recharging 80% of pumpage. Flowing reaches in the Early Winters Fan area are still impacted during the low-flow period, but the impact is about 20% less than if there were no re-injection.

For recharge sites near the pumping wells returning 80% of pumpage, the net impact on streamflow is similar to the previous case at between 10 and 30 percent of the pumped quantity during periods of continuous streamflow (Table 10). During the onset of peak spring flows, pumping withdraws up to 85% of pumpage from streamflow. The distribution of stream depletion at each river reach during these continuous flow periods is less than the previous case because of recharge near the point of withdrawal. The net downstream impact remains the same as the previous case at 20% of the pumped quantity. During low-flow periods, there is no net increase in streamflows downstream of Mazama, as was shown in the previous case. ~~Flowing reaches in the Early Winters area are not impacted.~~ There is a slight impact on flowing reaches near Cassel Field.

For a recharge site near Mazama returning 100% of pumpage, impact on streamflow varies from a net increase in streamflow of 5% of pumpage during the early summer, to a net decrease in streamflow of 3% of pumpage during the fall months (Table 11). During the onset of peak spring flows, pumping withdraws up to 40% of pumpage from streamflow. The distribution of stream depletion during these flowing periods of continuous flow is similar to the 80% re-injection scenario, but the net downstream impact on river flow declines to zero. During low-flow periods, streamflows downstream of Mazama are increased by as much as 20% of pumpage by artificial recharge. Flowing reaches in the Early Winters Fan area, however, are still impacted during the low-flow period.

For a recharge site returning 100% of pumpage at Early Winters Fan, upstream of the pumping wells, all streamflow impacts (both positive and negative) are less than 10% of the pumped quantity throughout the year (Table 11). The distribution of stream depletion during the high-flow period indicates a slight increase in streamflows in the Early Winters Fan area, and no impact on streamflow downstream of Mazama. However, during the low-flow period, there is a slight decrease in streamflow in the Early Winters Fan area. This causes an overall impact on streamflows of about 5% during the low-flow period.

The generalized impacts on various portions of the river for each pumping/reinjection scenario are summarized in Table 12. The predicted drawdowns in observation wells based on the above pumping and recharge scenarios are shown on Table 13. In all cases, the drawdowns are less than 0.3 feet. Artificial recharge causes slightly higher groundwater levels when the injection site is located at or downstream of Early Winters Fan.

6. MODEL PERFORMANCE

6.1 Sensitivity

As discussed previously, simulation of stream/aquifer interaction is complicated because of the number of variables necessary to simulate the interaction, and by the need to evaluate two types of output data (streamflow and groundwater elevation) that fluctuate in both space and time. A sensitivity analysis was performed to evaluate changes in the model solution caused by changes in the input parameters. Plots from the base-case simulations were compared with six sensitivity simulations. The six simulations are summarized in Table 11. Sensitivity was evaluated by comparing the sensitivity run with the base-case run. Appendix D contains selected output from the sensitivity analysis including a plot of predicted groundwater elevations at Mazama Bridge (well EW-10); a plot of predicted streamflow at Gage 7; and a plot of river flow along the entire length of the river for a stress period in late fall or winter.

The sensitivity analysis indicates that variation of any of the input parameters can produce significant changes in the model response, in terms of the predicted groundwater elevations or streamflow in either space or time. This suggests that there may be other combinations of parameters that could produce an equally viable "calibration" to the base case used in this analysis. However, the magnitude and distribution of all of the input parameters used in the model were developed to some extent from actual measurements, and in this respect are the best available estimates for these parameters. In addition, the model predicts observed groundwater elevations and streamflows with a reasonable accuracy in both space and time. Therefore, the base case used in this analysis can be considered viable representation of groundwater/surface water interaction in the Upper Methow Valley. A

6.2 Limitations

This attempt to simulate the complex stream/aquifer system in the Upper Methow Valley is a somewhat unusual groundwater modeling exercise. The level of detail and analysis presented in this report has been possible only through advances in modeling software over the past two years. The application of groundwater models in general to problems of in-stream flow management is, to our knowledge, not common, but is potentially a comprehensive water resource management tool. However, any numerical model is subject to limitations which must be understood to properly interpret the model results and determine how appropriate the model is to specific issues. The following discussion highlights the limitations of the model.

There are a number of small-scale aspects of the system that cannot be addressed with the model including:

- Simulation groundwater/streamflow fluctuations of less than two-week duration; or within a 528 foot distance;

- Simulation of individual river pools during low-flow;
- Evaluation of the impact of short-term (less than two-week) fluctuations in streamflow;
- Simulation of the vertical movement of groundwater;
- Simulation of the complex flood irrigation network; and
- Simulation of groundwater withdrawal from other groundwater wells.

The model is a regional description of the stream/aquifer system. Simulation of all of the items listed above would require a level of detail that would far surpass our ability to assign parameters, and physically construct a model grid with the available data. Large-scale regional impacts are, in our opinion, the most critical in evaluating water resources, and the model has focused on these types of impacts. We feel that the regional approach is conservative because many of the small-scale observations (streamflow fluctuations, vertical anisotropy, flood irrigation, and low-flow pools) would tend to lessen the overall impact of pumping on the system.

Therefore, although there are small-scale aspects of the system that cannot be simulated, regional impacts are conservative and the best possible estimate from the available data.

7. SUMMARY

A groundwater model has been developed to simulate stream/aquifer interaction in the Upper Methow Valley, and to evaluate the potential impacts of continuous groundwater withdrawals for the proposed Early Winters Resort. The model is extremely complicated and involves parameters and predicted outcomes that vary in both space and time, and cannot be measured directly or continuously. However, virtually all of the available data on aquifer properties and extent, groundwater levels, stream properties, and streamflows were used in some form in developing the model. No attempt has been made to force the model to a particular solution with unreasonable parameters or constraints, and every parameter input into the model is based in part on actual measurements or observations of the hydrologic system.

Despite the present level of complexity in the model, additional hydrogeologic data (borings, water levels, and pump tests throughout the valley) and further refinement of the existing model would be required to simulate the complex, short-term, three-dimensional interaction between the aquifer, river, and pumping wells. However, the model is a good representation of the stream/aquifer system in the valley based on our present knowledge of the system, and as such is the best available planning tool for managing surface and groundwater resources in the valley.

The base-case simulation, without pumpage for the Early Winters Resort, predicts observed groundwater and streamflow fluctuations with reasonable accuracy and was used as a standard for comparing subsequent pumping runs. Six pumping scenarios were simulated including continuous pumping at Early Winters; variable pumping between Early Winters and Cassel Field; pumping with 80% re-injection at Mazama Bridge, pumping with re-injection near the wells at Early Winters and Cassel Field, pumping with 100% re-injection at Mazama Bridge and pumping with 100% re-injecion at Early Winters.

For continuous pumping at Early Winters without re-injection, the model predicts that 90 to 98 percent of the water pumped from a well would be derived directly from streamflow from adjacent river reaches when those river reaches are flowing. The area of influence of the wells extends about 1 mile upstream and 0.5 miles downstream of the pumping well. As the river begins to dry up, additional water is supplied to the wells from aquifer storage, which reduces the observed impact on streamflows as compared to the base case. When large portions of the river are dry, up to 90 percent of the pumped water is derived from aquifer storage.

Adjusting the operating schedule of the wells can lessen the predicted impact on streamflows during the onset of low-flow, when there are relatively few dry river reaches. When flows decline to below 5 cfs in reaches adjacent to the wells at Early Winters, moving the pumping well upstream to Cassel Field (where there are dry reaches) increases the amount of water drawn from aquifer storage. As more of the river goes dry, however, pumping wells in either location will draw mainly from aquifer storage. The impacts on streamflow decrease dramatically when large segments of the river go dry because of increased storage withdrawals. Therefore, the maximum impact on streamflow caused by pumping without re-injection will occur when there are continuous flowing reaches between Lost River and Little Boulder Creek.

Re-injection of treated wastewater is an effective mitigating measure in lessening impacts on streamflow and aquifer drawdown. When the recharge site is located at, or downstream of, the pumping wells in Early Winters Fan, the impact of pumping on river reaches upstream of the injection site is not changed. Depending on the percentage of recharge, downstream impacts on stream flow are reduced to zero (100% re-injection) or 20% (80% re-injection) during flowing river conditions. During low-flow/dry river conditions, downstream flows are increased by up to 0.2 cfs compared to the base case as a result of artificial recharge. Recharge sites located near the pumping wells reduce the impact on adjacent river reaches but do not increase streamflow in downstream reaches during low-flow periods.

8. CONCLUSIONS

1. The stream/aquifer system is characterized by cyclic fluctuation of streamflow and aquifer storage, with a relatively constant down-valley aquifer flow of around 50 cfs. To maintain down-valley flow, declining streamflows cause the release of water from aquifer storage, which results in declining groundwater levels. During increasing streamflows, aquifer storage is replenished causing an increase in groundwater levels.

2. There are very large quantities of water being exchanged through aquifer storage. Observed water level increases of up to six feet in a two week period during spring run-off indicate that even for a very conservative estimate of storage (0.01) up to 30 cfs is recharged to the aquifer during spring run-off. A more typical unconfined storativity of 0.1 increases this value to 300 cfs. During declining summer/fall flows, water levels decline six feet over a two month period, indicating storage losses of 7.5 cfs (for low storativity) to 75 cfs (for higher storativity). The model predicts similar declines in water levels and storage volumes.

3. The groundwater model can predict the observed fluctuations in groundwater levels and streamflows based on the best available information regarding aquifer and river parameters. The model can therefore be considered a calibrated, viable tool for evaluating potential large-scale impacts to streamflows and groundwater levels caused by pumping.

4. The streamflows and groundwater levels predicted by the model are sensitive to the input parameter values, and it is possible that other combinations of in arameters
could produce similar model results. However, the
were developed from available measurements and
estimates.

5. The model predicts that 90 to 98 percent of the wa
derived directly from streamflow from adjacent riv
reaches are flowing. The area of influence of the
and 0.5 miles downstream of the pumping well.

6. Although the model predicts that pumping may accelerate the rate at which some river reaches dry up, this response is based on an extended period of continuous low-flow (5 cfs or less) in reaches adjacent to the well. Available flow data indicates that sustained low-flows do not always occur during the late summer and fall. Therefore, pumping would only accelerate drying-up during extended periods of low-flow.

7. Streamflow impacts during low-flow periods can be lessened by shifting the active pumping wells up-valley, adjacent to reaches that regularly go dry. This increases the amount of water withdrawn from aquifer storage and reduces the number of reaches that go dry because of pumping.

8. Impacts on streamflow decrease when large segments of the river go dry because of increased storage withdrawals. Therefore, during critical low-flow periods with dry river reaches, the downstream impact on streamflows is far less than the quantity pumped. The model predicts a difference in streamflow of 0.2 cfs or less at Little Boulder Creek during extended dry periods.

9. Recharge of treated wastewater at a site near Mazama has a net benefit on downstream flows during extended low-flow periods. Recharge at sites near the pumping wells reduces the impact on streamflow in adjacent reaches, but does not augment downstream flows.

10. Predicted drawdowns in adjacent observation wells are less than 1 foot. The maximum predicted impact on water-levels at any location greater than 1,000 feet from a well, including wetland areas, or individual pools in the river during dry reach periods, is one foot or less. Increased groundwater levels develop in the vicinity of injection wells not located adjacent to pumping wells in response to effluent recharge.

11. The modeling exercise is conservative in evaluating streamflow impacts based on the results of pump testing at Mazama Bridge. The pump test indicated significant components of vertical flow, which are not incorporated into this one-layer numerical model. Stratification and vertical anisotropy in the aquifer will likely further reduce the impact of pumping on streamflows for wells completed in deeper portions of the aquifer.

TABLES

TABLE 1

MODEL PARAMETERS

Groundwater System

B - Aquifer Thickness (Aquifer Bottom Elevation)

K_A - Aquifer Hydraulic Conductivity

T - Aquifer Transmissivity ($T = K*B$)

S - Aquifer Storativity

GHB - Down-valley Head and Conductance

Streamflow System

W - Width of river reach

L - Length of river reach

K_R - Hydraulic conductivity of river bed

$CRIV = \frac{K_R*L*W}{M}$ = Conductance of river bed

M - Thickness of river bed or assumed flow path length

S - Slope of river bed

RBOT - Elevation of river bed bottom

RTOP - Elevation of river bed top

N - Roughness of river bed

Q_i - Tributary inflows

TABLE 2 : MODEL DATE/STRESS PERIOD

	Stress Period		
Date	Cycle 1	Cycle 2	Cycle 3
15–Jun	1	27	53
29–Jun	2	28	54
13–Jul	3	29	55
27–Jul	4	30	56
10–Aug	5	31	57
24–Aug	6	32	58
07–Sep	7	33	59
21–Sep	8	34	60
05–Oct	9	35	61
19–Oct	10	36	62
02–Nov	11	37	63
16–Nov	12	38	64
30–Nov	13	39	65
14–Dec	14	40	66
28–Dec	15	41	67
11–Jan	16	42	68
25–Jan	17	43	69
08–Feb	18	44	70
22–Feb	19	45	71
08–Mar	20	46	72
22–Mar	21	47	73
05–Apr	22	48	74
19–Apr	23	49	75
03–May	24	50	76
17–May	25	51	77
31–May	26	52	78

TABLE 3

SUMMARY OF RIVERBED ELEVATIONS AT SELECTED LOCATIONS

River Mile	FEMA Elevation (ft)	1990 Survey[1] (ft)	Model Elevation[2] (ft)	Model-1990 Survey (ft)
65.2	2086	2090.04 +4	2088.4	-1.60
64.4	2088	2092.54 +2	2093.2	+0.66
66.9	2133	2136.19 +3	2137.2	+1.01
69.4	2220	2215.76 -5	2227.6	+11.84[3]
70.7	2261	2265.60 +4	2265.8	+0.2
72.0	2309	2319.10 +1	2317.2	-1.9

[1] 1990 Streambed survey performed by Horton Dennis and Associates

[2] Average elevation across 528 foot river reach

[3] Discrepancy possibly due to horizontal location error.

TABLE 4 : SIMULATED TRIBUTARY INFLOWS

DATE	STRESS PERIOD	UPPER METHOW (cfs)	LOST RIVER (cfs)	EARLY WINTERS (cfs)	GOAT CREEK (cfs)	ARLY WTRS DIVERSION (cfs)
15-Jun	1	600	1000	360	360	50
29-Jun	2	360	600	240	180	50
13-Jul	3	180	300	120	90	50
27-Jul	4	120	200	80	60	24
10-Aug	5	60	100	90	30	16
24-Aug	6	40	80	80	15	8
07-Sep	7	30	65	70	10	4
21-Sep	8	20	50	60	10	4
05-Oct	9	10	40	40	5	0
19-Oct	10	30	65	70	5	0
02-Nov	11	40	80	60	5	0
16-Nov	12	30	60	40	5	0
30-Nov	13	15	30	20	5	0
14-Dec	14	15	25	20	5	0
28-Dec	15	15	25	20	5	0
11-Jan	16	5	10	5	0	0
25-Jan	17	5	10	5	0	0
08-Feb	18	5	10	5	0	0
22-Feb	19	5	10	5	0	0
08-Mar	20	15	25	20	5	0
22-Mar	21	15	25	20	5	0
05-Apr	22	75	125	50	30	0
19-Apr	23	600	1000	400	300	0
03-May	24	750	1250	500	375	0
17-May	25	900	1500	600	450	0
31-May	26	1050	1750	500	375	0

TABLE 5

MODEL CALIBRATION POINTS

Observation Wells		Cell Location
EW-8:	Devin Schaeffer	(20, 56)
EW-19:	Roberts Base Camp	(21, 68)
EW-2:	Early Winters Ranger Station	(21, 78)
EW-10:	Mazama Realty	(14, 92)
EW-17:	Deer Run	(15, 98)
Stream Gages		
Gage #1		(26, 28)
Gage #2		(26, 28)
Gage #3		(21, 46)
Gage #4		(18, 60)
Gage #7		(19, 82)
Gage #6		(14, 105)
Lost River		(26, 21)
Early Winters Creek		(25, 77)
Methow at Mazama		(15, 92)
Methow at Little Boulder Creek		(14, 109)

TABLE 6

PREDICTED GROUNDWATER FLUCTUATIONS

WELL	OBSERVED RANGE (12/88-4/90)	PREDICTED RANGE	DIFFERENCE
EW-8: Cassel Field	13.66	14.72	1.06
EW-19: Roberts Camp	7.08	9.25	2.17
EW-2: Ranger Stn.	5.31	7.46	2.15
EW-10: Mazama Bridge	5.18	6.64	1.46
EW-17: Deer Run	4.67	8.23	3.56

Note: Predicted range of groundwater levels exceeds observed range because the base-case simulation included an extended low-flow period that caused much of the river to go dry.

TABLE 7 : PUMPING SCHEDULES

		RUN P101 ALL PUMPING AT EARLY WINTERS		RUN P102 SHIFT PUMPING UP-VALLEY		RUN P103 SHIFT PUMPING UP-VALLEY RE-INJECT NEAR WELLS				RUN P104 SHIFT PUMPING UP-VALLEY RE-INJECT NEAR MAZAMA		
DATE	STRESS PERIOD	Early Winters	Cassel Ranch	Early Winters	Cassel Ranch	Early Winters	Re-inject	Cassel Ranch	Re-inject	Early Winters	Cassel Ranch	Re-inject
15-Jun	53	1.50	0.00	1.50	0.00	1.50	1.20	0.00	0.00	1.50	0.00	1.20
29-Jun	54	1.50	0.00	1.50	0.00	1.50	1.20	0.00	0.00	1.50	0.00	1.20
13-Jul	55	1.50	0.00	1.50	0.00	1.50	1.20	0.00	0.00	1.50	0.00	1.20
27-Jul	56	1.50	0.00	1.50	0.00	1.50	1.20	0.00	0.00	1.50	0.00	1.20
10-Aug	57	1.50	0.00	1.50	0.00	1.50	1.20	0.00	0.00	1.50	0.00	1.20
24-Aug	58	1.50	0.00	1.50	0.00	1.50	1.20	0.00	0.00	1.50	0.00	1.20
07-Sep	59	1.50	0.00	1.50	0.00	1.50	1.20	0.00	0.00	1.50	0.00	1.20
21-Sep	60	1.50	0.00	1.50	0.00	1.50	1.20	0.00	0.00	1.50	0.00	1.20
05-Oct	61	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.80	0.00	1.00	0.80
19-Oct	62	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.80	0.00	1.00	0.80
02-Nov	63	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.80	0.00	1.00	0.80
16-Nov	64	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.80	0.00	1.00	0.80
30-Nov	65	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.80	0.00	1.00	0.80
14-Dec	66	1.50	0.00	0.00	1.50	0.00	0.00	1.50	1.20	0.00	1.50	1.20
28-Dec	67	1.50	0.00	0.00	1.50	0.00	0.00	1.50	1.20	0.00	1.50	1.20
11-Jan	68	1.50	0.00	0.00	1.50	0.00	0.00	1.50	1.20	0.00	1.50	1.20
25-Jan	69	1.50	0.00	0.00	1.50	0.00	0.00	1.50	1.20	0.00	1.50	1.20
08-Feb	70	1.50	0.00	0.00	1.50	0.00	0.00	1.50	1.20	0.00	1.50	1.20
22-Feb	71	1.50	0.00	0.00	1.50	0.00	0.00	1.50	1.20	0.00	1.50	1.20
08-Mar	72	1.50	0.00	0.00	1.50	0.00	0.00	1.50	1.20	0.00	1.50	1.20
22-Mar	73	1.50	0.00	0.00	1.50	0.00	0.00	1.50	1.20	0.00	1.50	1.20
05-Apr	74	1.00	0.00	1.00	0.00	1.00	0.80	0.00	0.00	1.00	0.00	0.80
19-Apr	75	1.00	0.00	1.00	0.00	1.00	0.80	0.00	0.00	1.00	0.00	0.80
03-May	76	1.00	0.00	1.00	0.00	1.00	0.80	0.00	0.00	1.00	0.00	0.80
17-May	77	1.00	0.00	1.00	0.00	1.00	0.80	0.00	0.00	1.00	0.00	0.80
31-May	78	1.00	0.00	1.00	0.00	1.00	0.80	0.00	0.00	1.00	0.00	0.80

TABLE 8 : PUMPING SCHEDULES

		RUN P105 ALL PUMPING AT EARLY WINTERS RE-INJECT AT MAZAMA				RUN P106 ALL PUMPING AT EARLY WINTERS RE-INJECT AT EARLY WINTER		
DATE	STRESS PERIOD	Early Winters	Cassel Ranch	Re-inject		Early Winters	Cassel Ranch	Re-inject
15-Jun	53	1.50	0.00	1.50		1.50	0.00	1.50
29-Jun	54	1.50	0.00	1.50		1.50	0.00	1.50
13-Jul	55	1.50	0.00	1.50		1.50	0.00	1.50
27-Jul	56	1.50	0.00	1.50		1.50	0.00	1.50
10-Aug	57	1.50	0.00	1.50		1.50	0.00	1.50
24-Aug	58	1.50	0.00	1.50		1.50	0.00	1.50
07-Sep	59	1.50	0.00	1.50		1.50	0.00	1.50
21-Sep	60	1.50	0.00	1.50		1.50	0.00	1.50
05-Oct	61	1.50	0.00	1.50		1.50	0.00	1.50
19-Oct	62	1.50	0.00	1.50		1.50	0.00	1.50
02-Nov	63	1.00	0.00	1.00		1.00	0.00	1.00
16-Nov	64	1.00	0.00	1.00		1.00	0.00	1.00
30-Nov	65	1.00	0.00	1.00		1.00	0.00	1.00
14-Dec	66	1.00	0.00	1.00		1.00	0.00	1.00
28-Dec	67	1.00	0.00	1.00		1.00	0.00	1.00
11-Jan	68	1.00	0.00	1.00		1.00	0.00	1.00
25-Jan	69	1.50	0.00	1.50		1.00	0.00	1.00
08-Feb	70	1.50	0.00	1.50		1.00	0.00	1.00
22-Feb	71	1.50	0.00	1.50		1.00	0.00	1.00
08-Mar	72	1.50	0.00	1.50		1.00	0.00	1.00
22-Mar	73	1.50	0.00	1.50		1.00	0.00	1.00
05-Apr	74	1.50	0.00	1.50		1.00	0.00	1.00
19-Apr	75	1.50	0.00	1.50		1.00	0.00	1.00
03-May	76	1.00	0.00	1.00		1.50	0.00	1.50
17-May	77	1.00	0.00	1.00		1.50	0.00	1.50
31-May	78	1.00	0.00	1.00		1.50	0.00	1.50

TABLE 9: PUMPING IMPACT SUMMARY - CASE P101, P102

		P101 : ALL PUMPING AT EARLY WINTERS				P102: SHIFT PUMPING TO CASSEL FIELD			
DATE	TOTAL PUMPAGE (cfs)	TOTAL STREAM IMPACT (cfs)	TOTAL STORAGE IMPACT (cfs)	PERCENT STREAM DEPLETION	PERCENT STORAGE DEPLETION	TOTAL STREAM IMPACT (cfs)	TOTAL STORAGE IMPACT (cfs)	PERCENT STREAM DEPLETION	PERCENT STORAGE DEPLETION
15-Jun	1.50	0.98	0.48	65.33	31.85	0.98	0.48	65.33	31.85
29-Jun	1.50	1.19	0.30	79.33	19.87	1.19	0.30	79.33	19.87
13-Jul	1.50	1.36	0.14	90.67	9.27	1.36	0.14	90.67	9.27
27-Jul	1.50	1.37	0.12	91.33	7.87	1.37	0.12	91.33	7.87
10-Aug	1.50	1.44	0.07	96.00	4.60	1.44	0.07	96.00	4.60
24-Aug	1.50	1.44	0.04	96.00	2.80	1.44	0.04	96.00	2.80
07-Sep	1.50	1.47	0.04	98.00	2.40	1.47	0.04	98.00	2.40
21-Sep	1.50	1.47	0.03	98.00	2.07	1.47	0.03	98.00	2.07
05-Oct	1.50	1.45	0.05	96.80	3.13	1.45	0.05	96.80	3.13
19-Oct	1.00	1.47	-0.47	147.50	-46.53	1.27	-0.24	126.80	-23.97
02-Nov	1.00	1.27	-0.24	126.80	-23.97	1.13	-0.40	112.90	-39.95
16-Nov	1.00	1.23	-0.22	123.10	-22.50	1.05	-0.04	105.30	-3.87
30-Nov	1.00	1.13	-0.40	112.90	-39.95	0.94	0.06	93.70	5.60
14-Dec	1.50	1.05	-0.04	105.30	-3.87	1.07	0.39	71.20	26.00
28-Dec	1.50	0.94	0.06	93.70	5.60	1.08	0.36	71.93	24.07
11-Jan	1.50	1.07	0.39	71.20	26.00	0.14	1.32	9.47	87.93
25-Jan	1.50	1.08	0.36	71.93	24.07	0.18	1.35	11.87	89.73
08-Feb	1.50	0.14	1.32	9.47	87.93	0.19	1.32	12.80	87.93
22-Feb	1.50	0.18	1.35	11.87	89.73	0.20	1.32	13.20	87.80
08-Mar	1.50	0.19	1.32	12.80	87.93	0.23	1.25	15.07	83.53
22-Mar	1.50	0.20	1.32	13.20	87.80	0.31	1.17	20.87	78.33
05-Apr	1.00	0.23	1.25	15.07	83.53	3.75	-2.65	374.70	-265.00
19-Apr	1.00	0.31	1.17	20.87	78.33	3.46	-2.47	346.50	-247.00
03-May	1.00	3.75	-2.65	374.70	-265.00	1.88	-0.89	188.00	-88.60
17-May	1.00	3.46	-2.47	346.50	-247.00	1.35	-0.35	135.00	-35.20
31-May	1.00	1.88	-0.89	188.00	-88.60	1.17	-0.12	117.00	-11.84

TABLE 10: PUMPING IMPACT SUMMARY - CASE P103, P104

			P103 : SHIFT PUMPING TO CASSEL FIELD 80% REINJECTION NEAR WELLS					P104 : SHIFT PUMPING TO CASSEL FIELD 80% REINJECTION NEAR WELLS			
DATE	TOTAL PUMPAGE (cfs)		TOTAL STREAM IMPACT (cfs)	TOTAL STORAGE IMPACT (cfs)	PERCENT STREAM DEPLETION	PERCENT STORAGE DEPLETION		TOTAL STREAM IMPACT (cfs)	TOTAL STORAGE IMPACT (cfs)	PERCENT STREAM DEPLETION	PERCENT STORAGE DEPLETION
15-Jun	1.50		0.13	0.16	8.67	10.80		0.30	-0.01	20.00	-0.59
29-Jun	1.50		0.18	0.11	12.00	7.60		0.19	0.10	12.67	6.93
13-Jul	1.50		0.24	0.06	16.00	3.93		0.25	0.05	16.67	3.40
27-Jul	1.50		0.26	0.04	17.33	2.93		0.21	0.08	14.00	5.20
10-Aug	1.50		0.28	0.02	18.67	1.67		0.26	0.04	17.33	2.53
24-Aug	1.50		0.28	0.01	18.67	0.93		0.27	0.02	18.00	1.07
07-Sep	1.50		0.30	0.01	20.00	0.73		0.30	0.01	20.00	0.47
21-Sep	1.50		0.30	0.01	20.00	0.67		0.30	0.01	20.00	0.73
05-Oct	1.50		0.29	0.01	19.60	0.87		0.29	0.02	19.13	1.20
19-Oct	1.00		0.36	-0.15	36.00	-14.51		0.27	-0.05	27.10	-5.44
02-Nov	1.00		0.31	-0.55	31.10	-55.18		0.24	-0.32	23.80	-31.69
16-Nov	1.00		0.26	-0.05	25.70	-5.13		0.23	-0.02	22.60	-1.54
30-Nov	1.00		0.17	0.03	16.60	3.00		0.22	-0.02	21.80	-1.80
14-Dec	1.50		0.13	0.15	8.93	10.00		0.24	0.06	15.73	3.80
28-Dec	1.50		0.14	0.16	9.53	10.93		0.15	0.13	10.00	8.40
11-Jan	1.50		0.02	0.26	1.00	17.53		-0.06	0.35	-4.20	23.33
25-Jan	1.50		0.01	0.28	0.87	18.60		-0.10	0.41	-6.73	27.33
08-Feb	1.50		0.01	0.29	0.80	19.60		-0.14	0.44	-9.13	29.27
22-Feb	1.50		0.01	0.31	0.60	20.73		-0.18	0.50	-11.93	33.40
08-Mar	1.50		0.01	0.29	0.60	19.07		-0.20	0.51	-13.53	33.93
22-Mar	1.50		0.01	0.30	0.93	19.83		-0.19	0.49	-12.87	32.99
05-Apr	1.00		0.85	-0.96	85.20	-96.00		1.00	-0.72	100.00	-72.00
19-Apr	1.00		0.32	-0.53	31.80	-53.00		0.99	-0.80	99.30	-80.00
03-May	1.00		-0.07	-0.14	-7.00	-13.60		0.48	-0.29	48.00	-28.60
17-May	1.00		-0.16	-0.04	-16.00	-4.00		0.33	-0.14	33.00	-13.80
31-May	1.00		-0.18	-0.01	-18.00	-1.35		0.28	-0.05	28.00	-4.70

TABLE 11: PUMPING IMPACT SUMMARY - CASE P105, P106

			P105 : ALL PUMPING AT EARLY WINTERS 100% REINJECTION NEAR MAZAMA					P105 : ALL PUMPING AT EARLY WINTERS 100% REINJECTION NEAR EARLY WINTERS			
DATE	TOTAL PUMPAGE (cfs)		TOTAL STREAM IMPACT (cfs)	TOTAL STORAGE IMPACT (cfs)	PERCENT STREAM DEPLETION	PERCENT STORAGE DEPLETION		TOTAL STREAM IMPACT (cfs)	TOTAL STORAGE IMPACT (cfs)	PERCENT STREAM DEPLETION	PERCENT STORAGE DEPLETION
15-Jun	1.50		0.12	-0.13	8.00	-8.55		-0.12	0.10	-8.00	6.74
29-Jun	1.50		-0.07	0.05	-4.67	3.53		-0.12	0.11	-8.00	7.07
13-Jul	1.50		-0.04	0.03	-2.67	2.00		-0.05	0.04	-3.33	2.87
27-Jul	1.50		-0.08	0.07	-5.33	4.47		-0.05	0.05	-3.33	3.07
10-Aug	1.50		-0.03	0.03	-2.00	1.87		-0.02	0.02	-1.33	1.20
24-Aug	1.50		-0.02	0.01	-1.33	0.60		-0.01	0.01	-0.67	0.47
07-Sep	1.50		0.01	0.00	0.67	0.00		0.01	0.01	0.67	0.33
21-Sep	1.50		0.00	0.01	0.00	0.40		0.01	0.00	0.67	0.27
05-Oct	1.50		-0.01	0.01	-0.73	0.87		0.01	0.00	0.47	-0.20
19-Oct	1.00		0.03	-0.01	2.60	-0.93		0.06	-0.05	6.10	-4.50
02-Nov	1.00		0.02	-0.29	2.20	-29.49		0.03	-0.11	2.80	-10.83
16-Nov	1.00		0.02	-0.01	1.60	-0.84		0.01	-0.02	0.70	-1.57
30-Nov	1.00		0.04	-0.03	3.50	-3.10		0.05	-0.04	4.60	-3.80
14-Dec	1.50		0.02	-0.02	1.13	-1.13		0.06	-0.06	4.27	-4.00
28-Dec	1.50		-0.09	0.06	-5.80	4.07		0.08	-0.15	5.20	-9.87
11-Jan	1.50		-0.11	0.11	-7.60	7.40		0.02	-0.02	1.40	-1.27
25-Jan	1.50		-0.17	0.16	-11.40	10.60		0.05	-0.03	3.00	-2.13
08-Feb	1.50		-0.22	0.23	-14.67	15.00		0.06	-0.05	3.87	-3.67
22-Feb	1.50		-0.27	0.30	-18.27	20.07		0.06	-0.04	4.20	-2.93
08-Mar	1.50		-0.31	0.32	-20.87	21.07		0.07	-0.08	4.87	-5.07
22-Mar	1.50		-0.33	0.33	-21.67	21.89		0.09	-0.10	6.27	-6.62
05-Apr	1.00		0.29	-0.20	28.80	-20.00		-0.08	-0.02	-8.00	-2.00
19-Apr	1.00		0.39	-0.39	38.80	-39.00		-0.14	0.15	-14.00	15.00
03-May	1.00		0.14	-0.14	14.00	-14.00		0.02	-0.03	2.00	-2.60
17-May	1.00		0.08	-0.09	8.00	-8.50		0.02	-0.01	2.00	-1.20
31-May	1.00		0.05	-0.03	5.00	-2.65		0.01	-0.01	1.00	-0.63

TABLE 12

SUMMARY OF PREDICTED STREAMFLOW WITH ARTIFICIAL RECHARGE

Scenario	High Flow	Low Flow
Pumping at Early Winters and Cassel Ranch or Early Winters only. Injection at Mazama.	• Impacts to 1.3 cfs at Early Winters Fan • 0-0.2 cfs impact at Little Boulder Creek • No impact above McGee Creek	• Impacts to 0.7 at Early Winters Fan • 0-0.2 cfs increase in flow at Little Boulder Creek • Minimal impact above McGee Creek
Pumping at Early Winters and Cassel Ranch. Injection near Wells.	• Impacts up to 0.5 cfs at Early Winters Fan • 0-0.2 cfs impact at Little Boulder Creek • No impact above McGee Creek	• Minimal impacts at Early Winters Fan • Minimal impact at Little Boulder Creek • Minimal impact above McGee Creek
Pumping at Early Winters only. Injection at Early Winters Fan.	• Increase flows 0-0.5 cfs in Early Winters Fan • 0-0.2 cfs impacts at Little Boulder Creek • Minimal impact above McGee Creek	• Impacts to 0.4 cfs in Early Winters Fan • 0.1 cfs impact at Little Boulder Creek • Minimal impact above McGee Creek.

TABLE 13

MAXIMUM PREDICTED DRAWDOWNS AT OBSERVATION WELLS

Well	Name	Aquifer Drawdown (feet)					
		Case P101	Case P102	Case P103	Case P104	Case P105	Case P106
EW-8	Devin-Schaeffer	-0.14	-0.83	0.26	-0.26	-0.12	-0.12
EW-19	Roberts Base Camp	-0.31	-0.5	-0.12	-0.12	-0.26	-0.18
EW-2	Early Winters Ranger Station	-0.28	-0.17	-0.02	-0.23	-0.21	+0.05
EW-10	Mazama Realty	-0.52	-0.19	-0.02	+0.18	+0.27	+0.11
EW-17	Deer Run	-0.37	-0.16	-0.02	+0.15	+0.23	+0.10

Case P101: All Pumping at Early Winters
Case P102: Shift Pumping to Cassell Ranch
Case P103: Re-Inject Near Wells (80%), Shift Pumping to Cassel Ranch
Case P104: Re-Inject Near Mazama (80%), Shift Pumping to Cassel Ranch
Case P105: Re-Inject Near Mazama (100%), All Pumping at Early Winters
Case P106: Re-Inject at Early Winters (100%), All Pumping at Early Winters

\+ indicates increase in groundwater levels

TABLE 14

SENSITIVITY RUNS

Run	Description
S101	Constant hydraulic conductivity of .005 ft/sec throughout valley
S102	Deeper bedrock elevation resulting in higher transmissivity. Hydraulic conductivity profile is the same as the base case.
S103	Transition in river bed conductance from 10 ft^2/s to 1 ft^2/sec is moved up-valley 1 mile.
S105	Constant river bed conductance of 10 ft^2/sec.
S107	Storativity of 0.1.

FIGURE 1

Paper Oversized Drawing of Figure 1 Enclosed

APPENDIX A

MODEL INPUT PARAMETERS

AQUIFER PROFILE

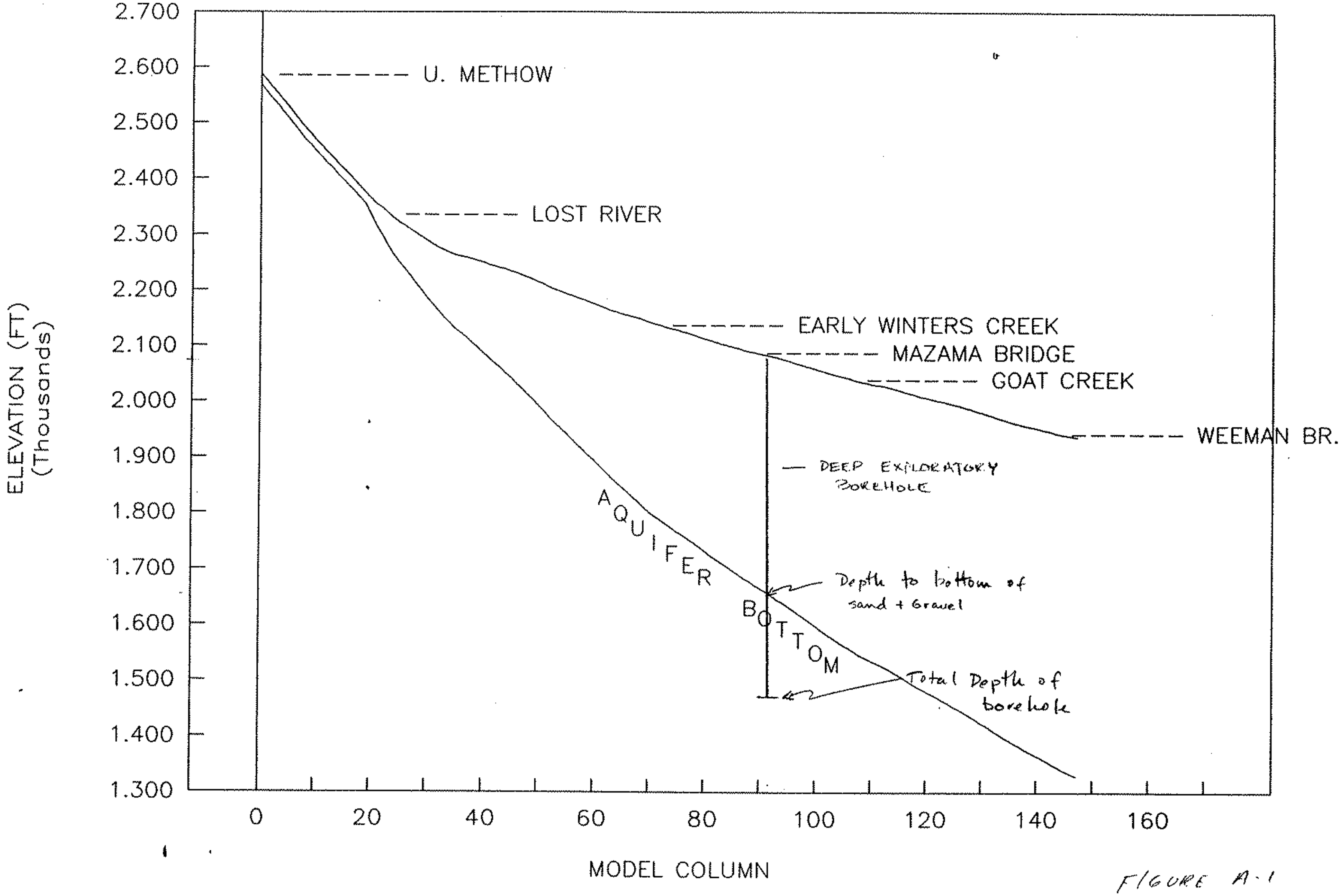
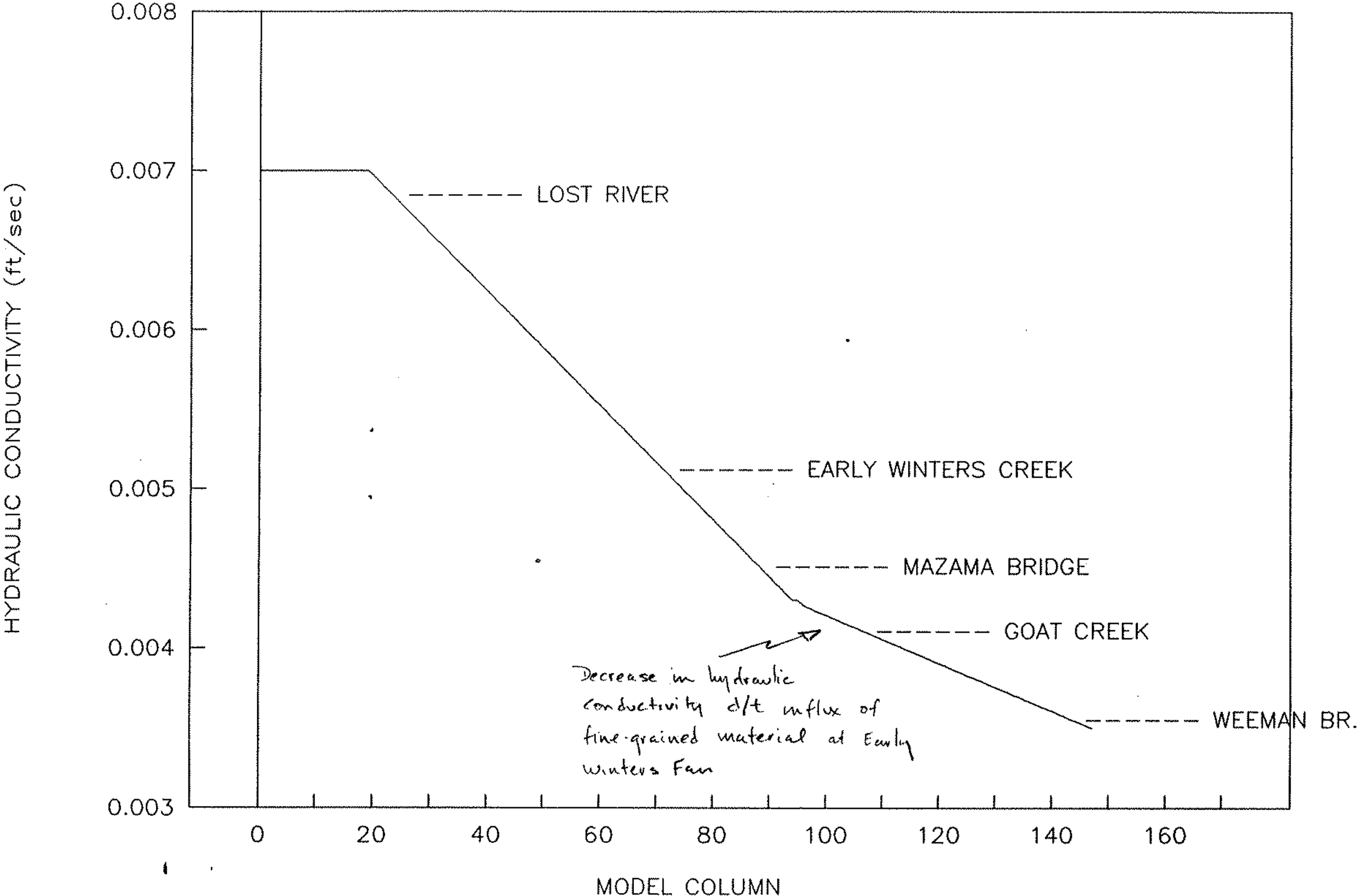


FIGURE A-1

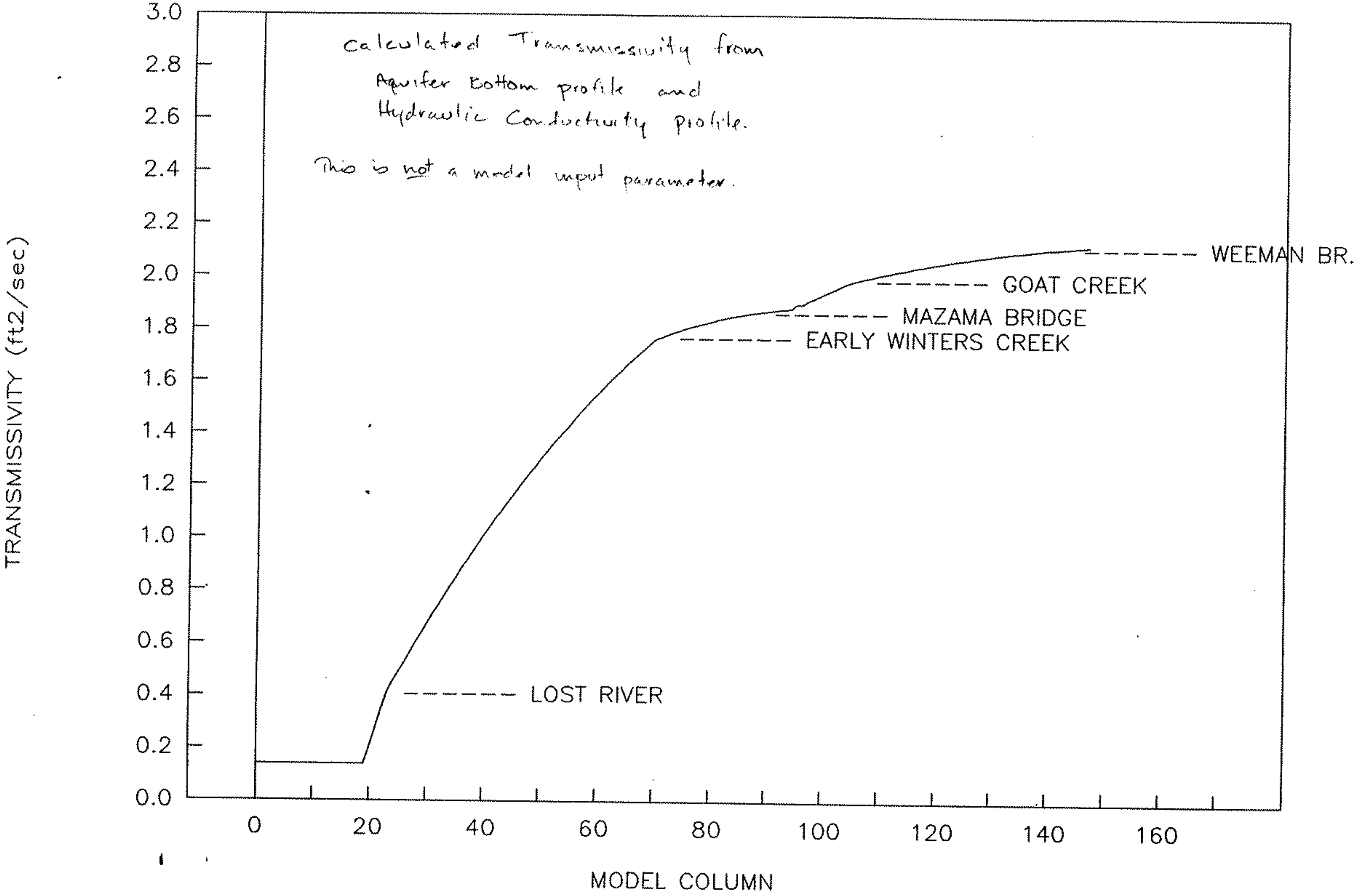


HYDRAULIC CONDUCTIVITY PROFILE

Decrease in hydraulic conductivity d/t influx of fine-grained material at Early Winters Fan

FIGURE A·2

TRANSMISSIVITY PROFILE



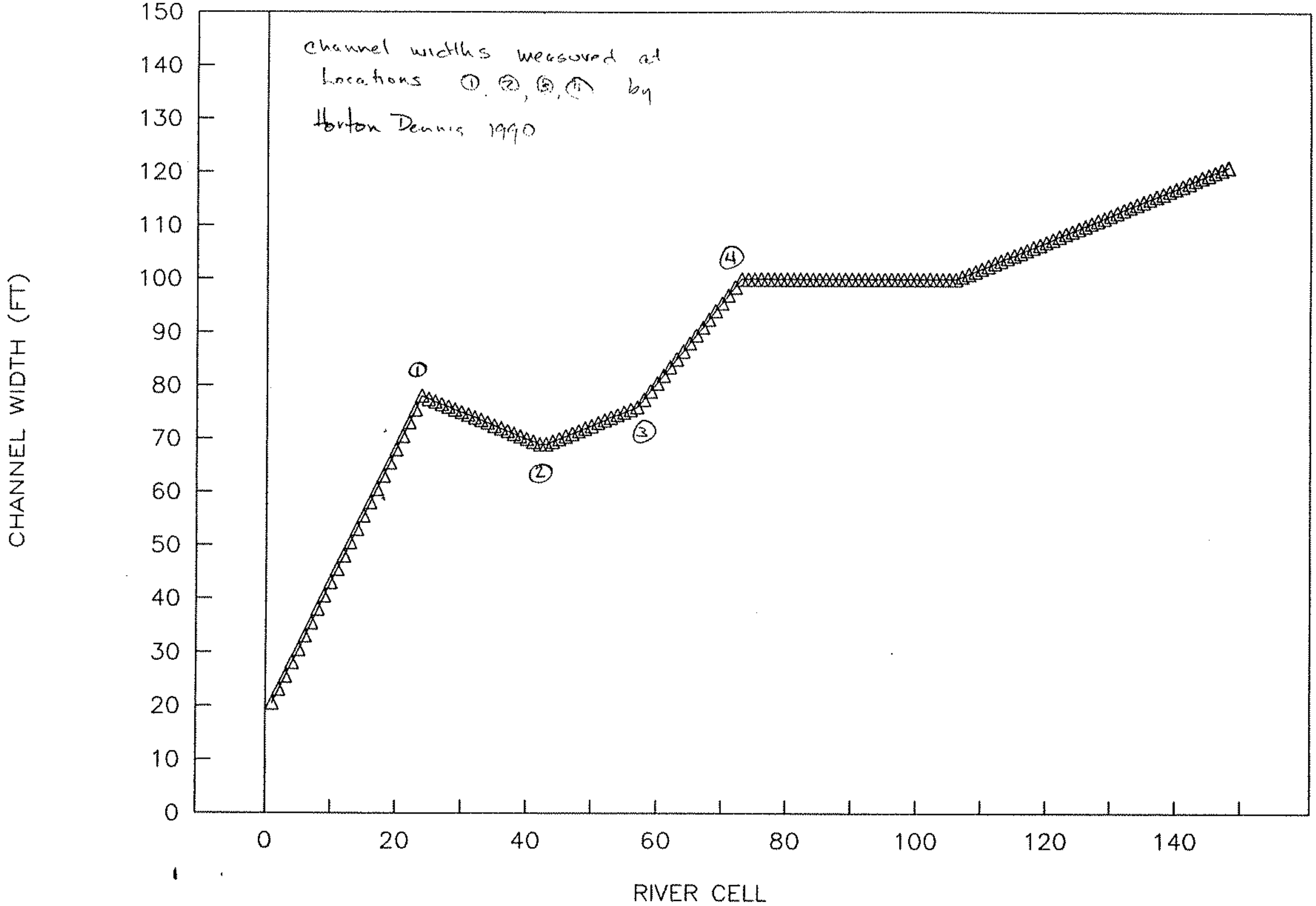
Calculated Transmissivity from Aquifer bottom profile and Hydraulic Conductivity profile.

This is <u>not</u> a model input parameter.

FIGURE A-3

CHANNEL WIDTH

RUN 140

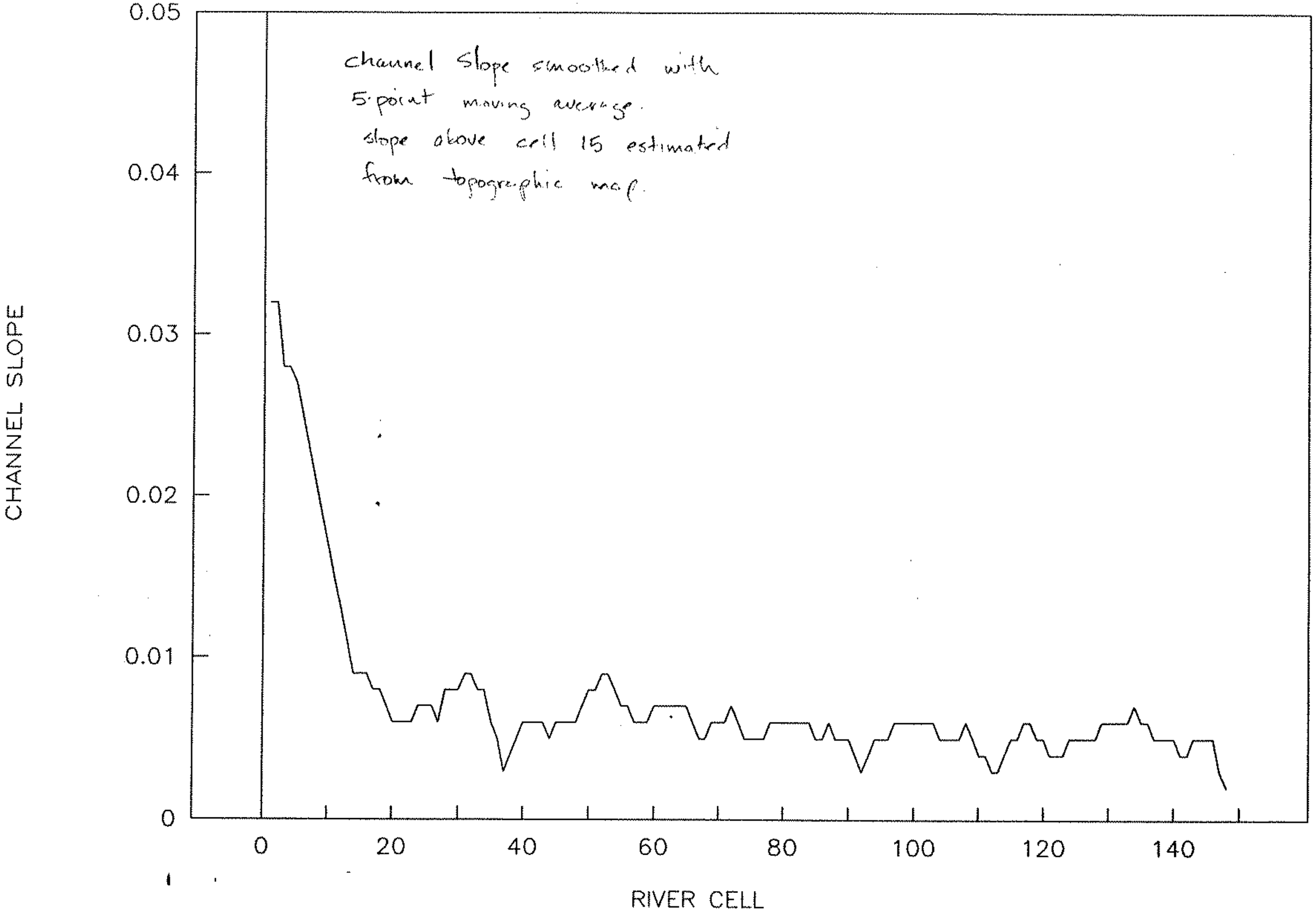


Channel widths measured at locations ①, ②, ③, ④ by Horton Dennis 1990

FIGURE A-41

CHANNEL SLOPE

RUN 140



channel slope smoothed with 5 point moving average.
slope above cell 15 estimated from topographic map.

FIGURE A-5

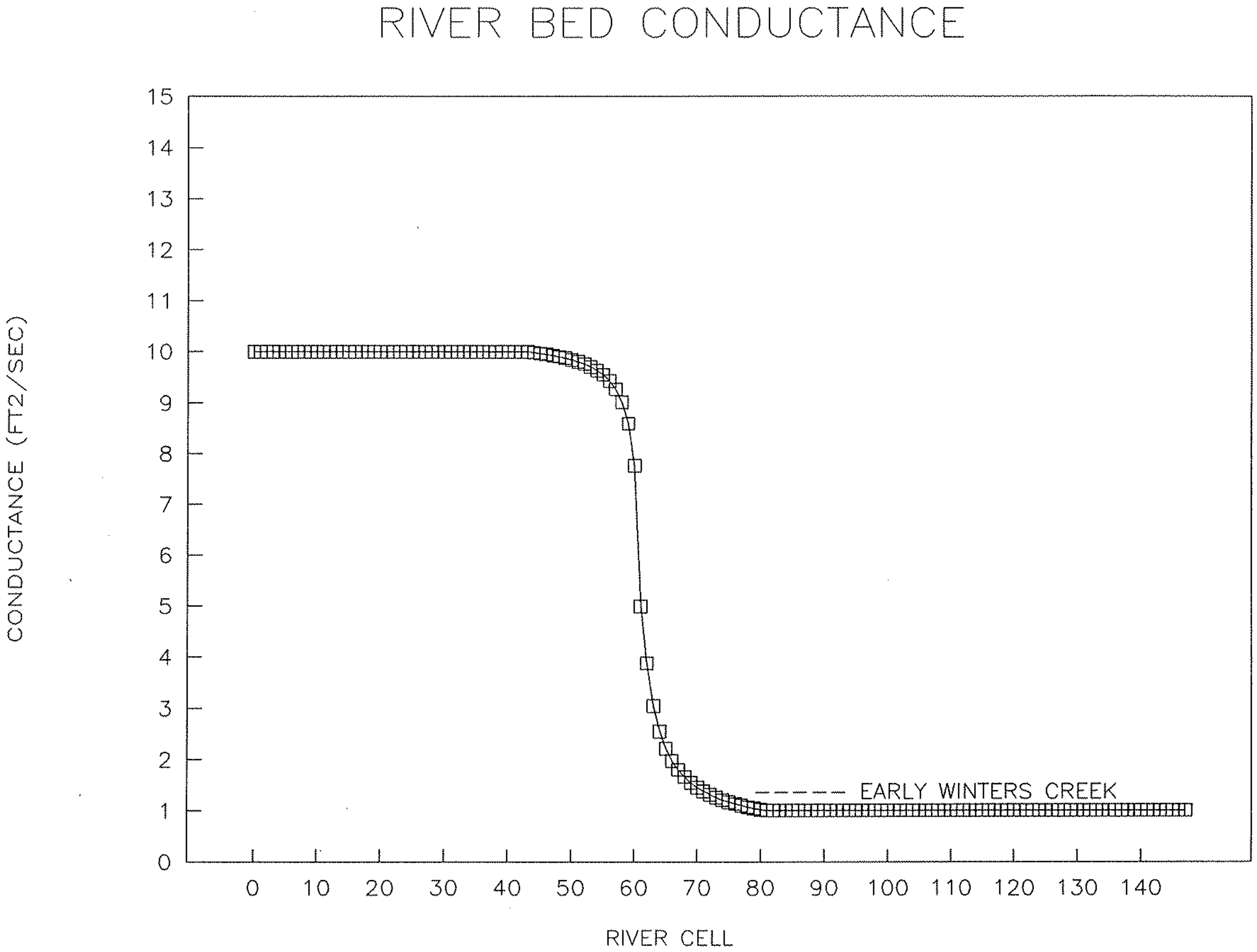

RIVER BED CONDUCTANCE
CONDUCTANCE (FT2/SEC)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
RIVER CELL
EARLY WINTERS CREEK

FIGURE A-6

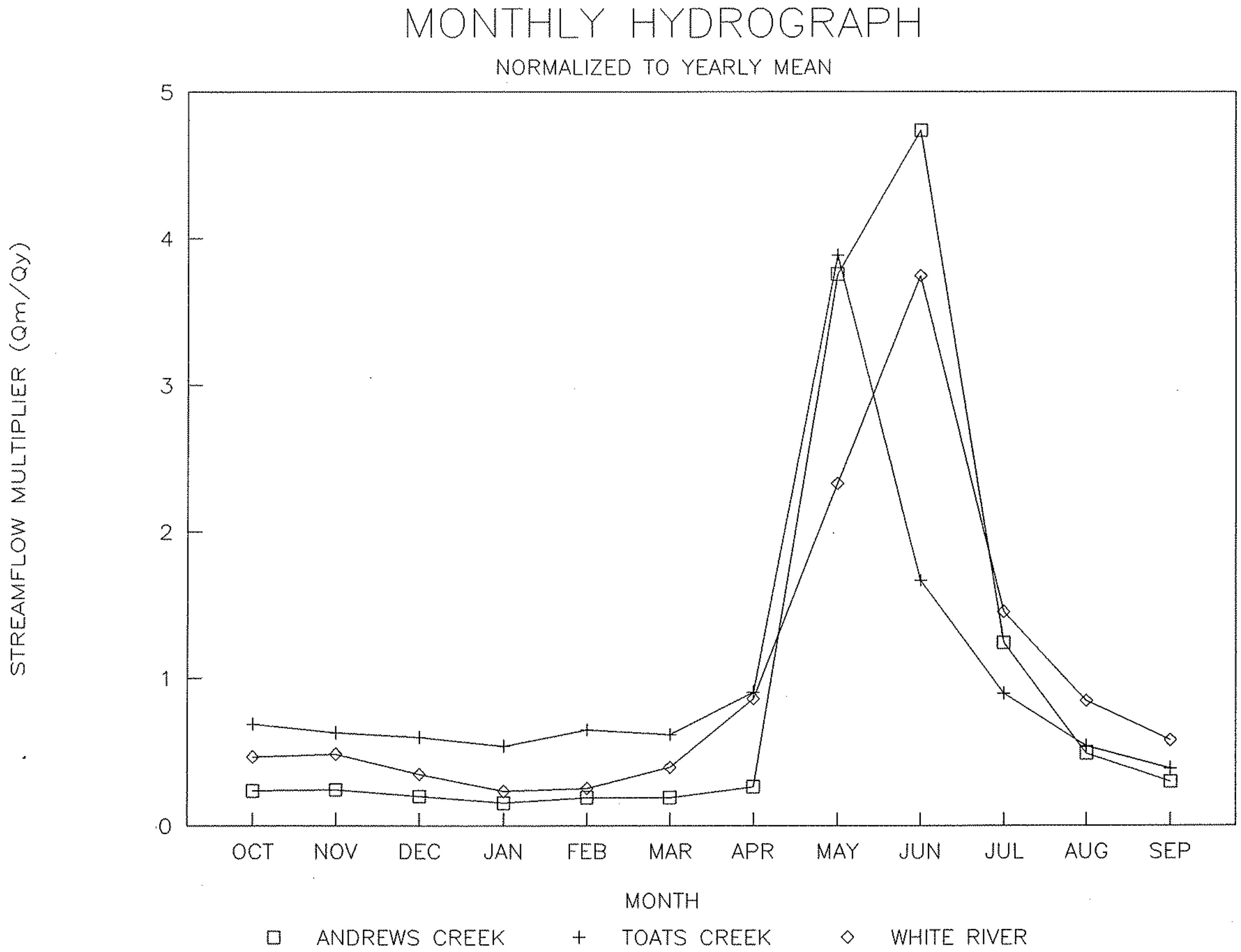

MONTHLY HYDROGRAPH
NORMALIZED TO YEARLY MEAN
STREAMFLOW MULTIPLIER (Qm/Qy)
0
1
2
3
4
5
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
MONTH
□ ANDREWS CREEK
+ TOATS CREEK
◇ WHITE RIVER

FIGURE A-7

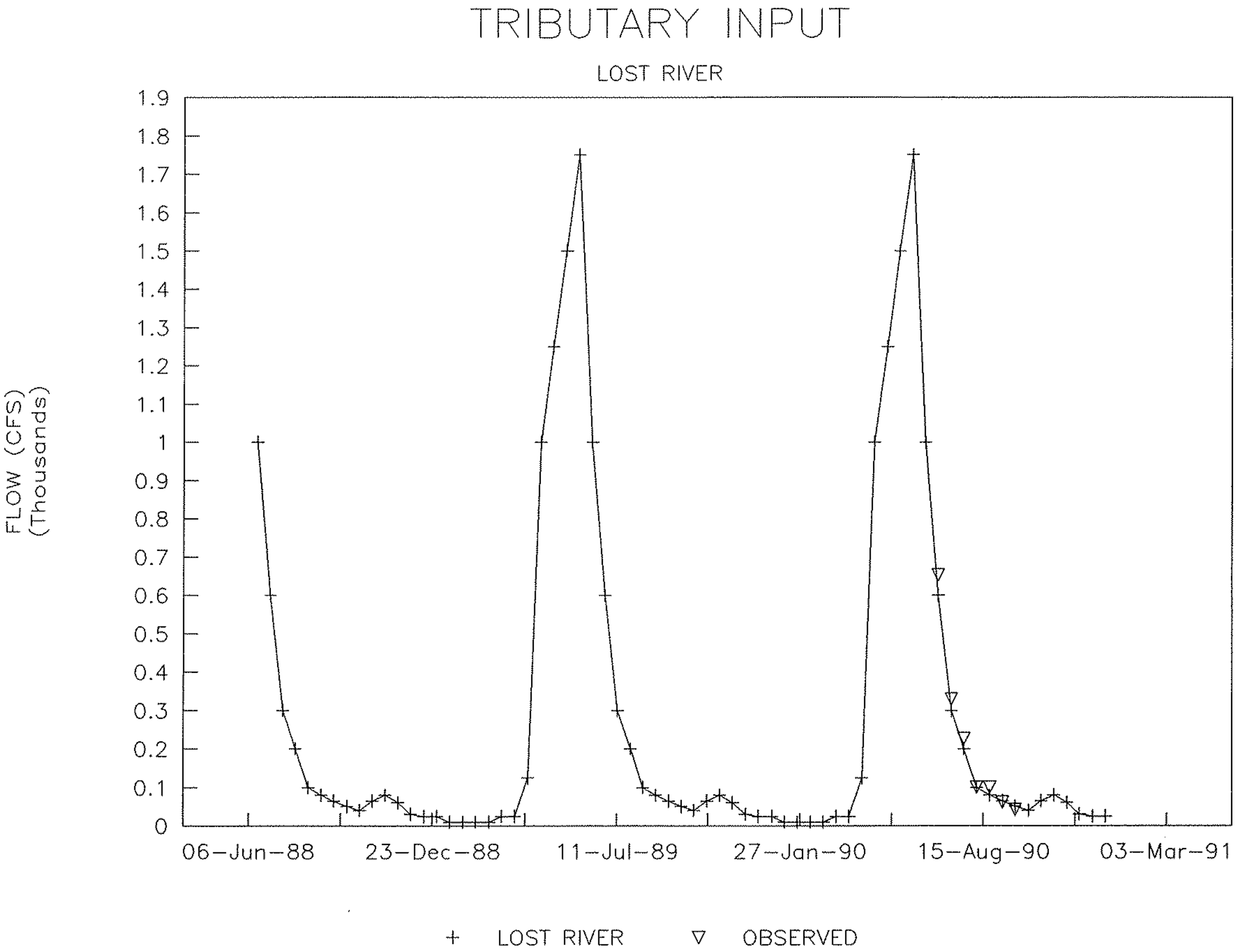
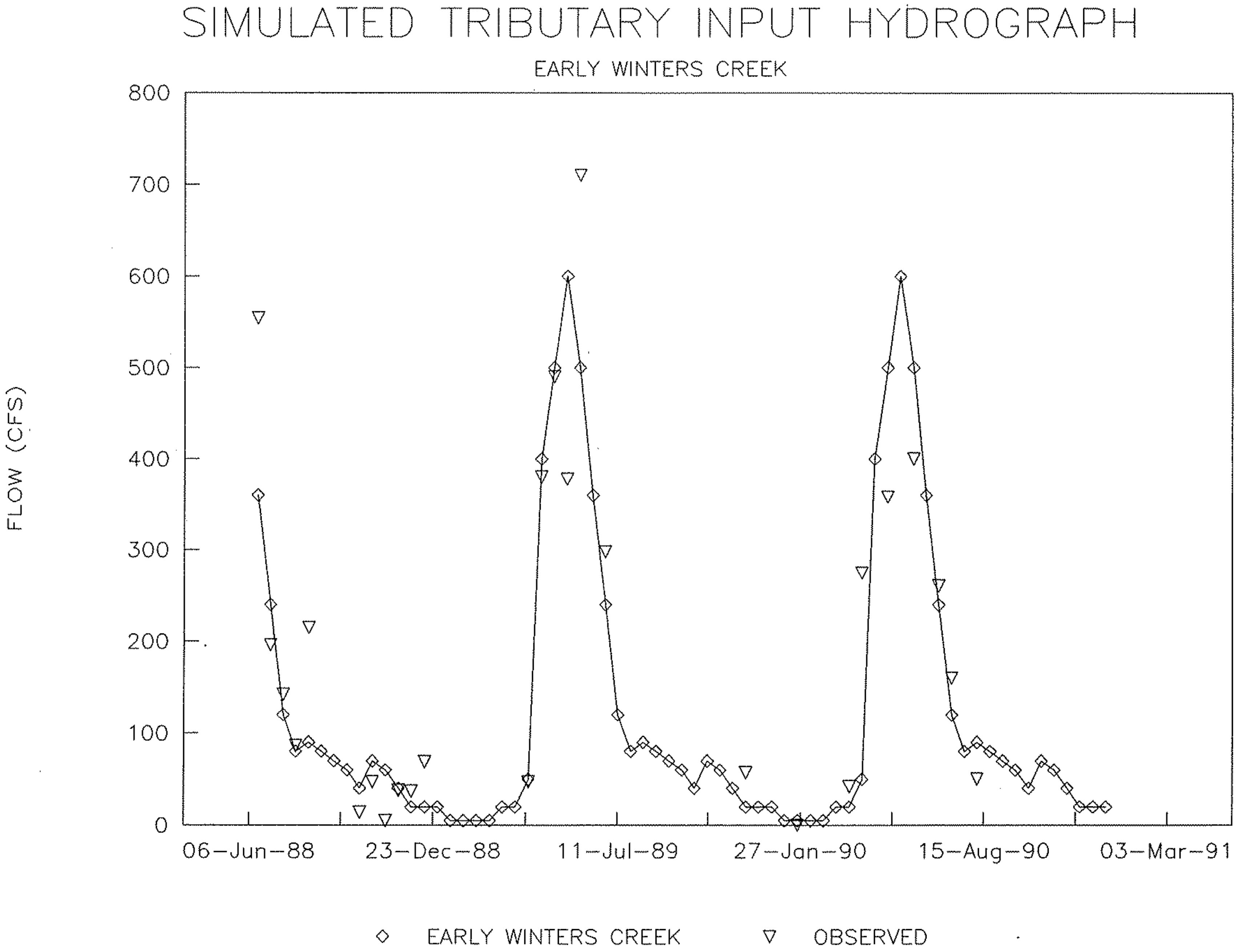

TRIBUTARY INPUT
LOST RIVER
FLOW (CFS)
(Thousands)
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
06-Jun-88
23-Dec-88
11-Jul-89
27-Jan-90
15-Aug-90
03-Mar-91
+ LOST RIVER
▽ OBSERVED

FIGURE A-8



SIMULATED TRIBUTARY INPUT HYDROGRAPH
EARLY WINTERS CREEK
FLOW (CFS)
800
700
600
500
400
300
200
100
0
06-Jun-88
23-Dec-88
11-Jul-89
27-Jan-90
15-Aug-90
03-Mar-91
◇ EARLY WINTERS CREEK
▽ OBSERVED

FIGURE A-9

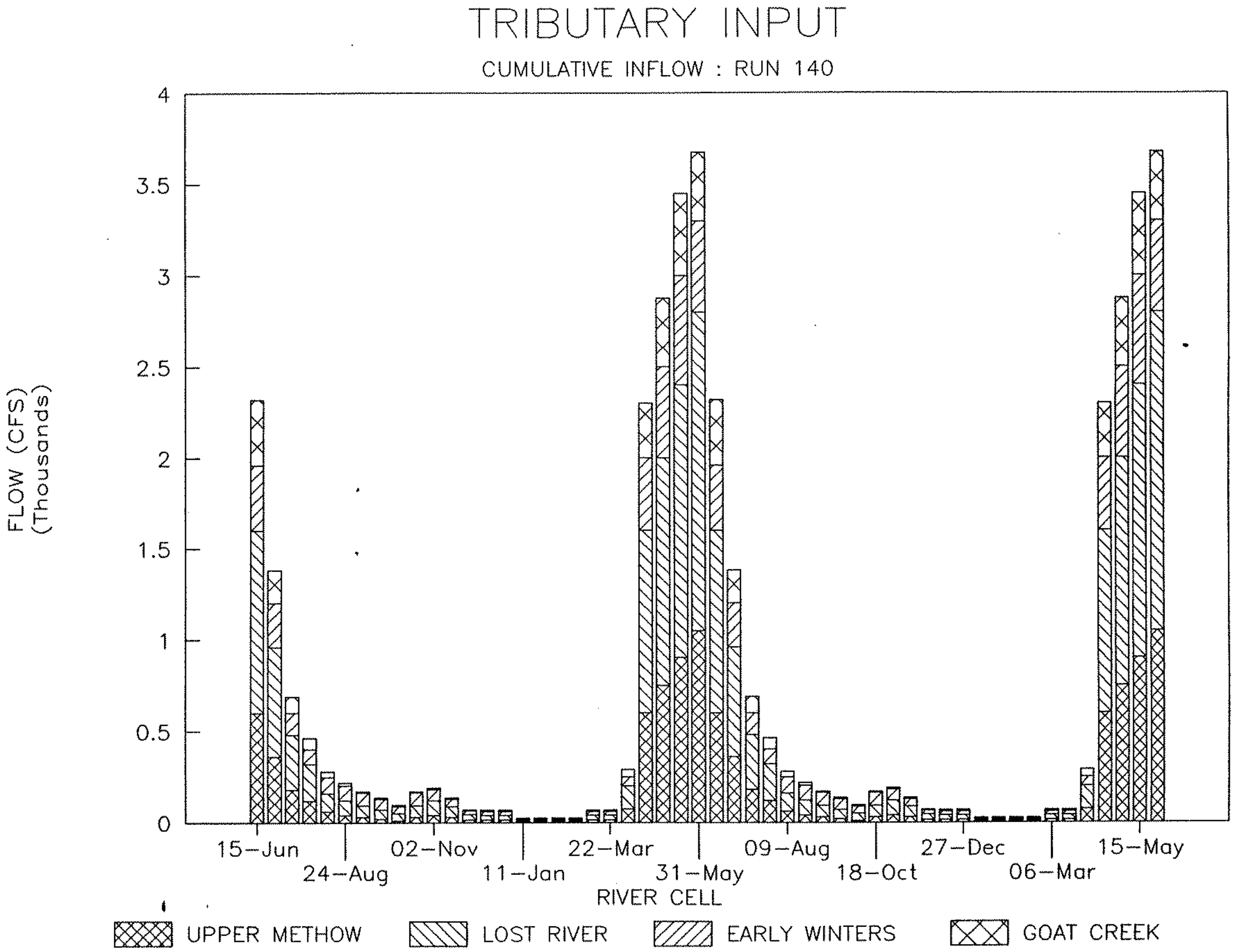

TRIBUTARY INPUT
CUMULATIVE INFLOW : RUN 140
FLOW (CFS)
(Thousands)
4
3.5
3
2.5
2
1.5
1
0.5
0
15-Jun
24-Aug
02-Nov
11-Jan
22-Mar
31-May
09-Aug
18-Oct
27-Dec
06-Mar
15-May
RIVER CELL
UPPER METHOW
LOST RIVER
EARLY WINTERS
GOAT CREEK

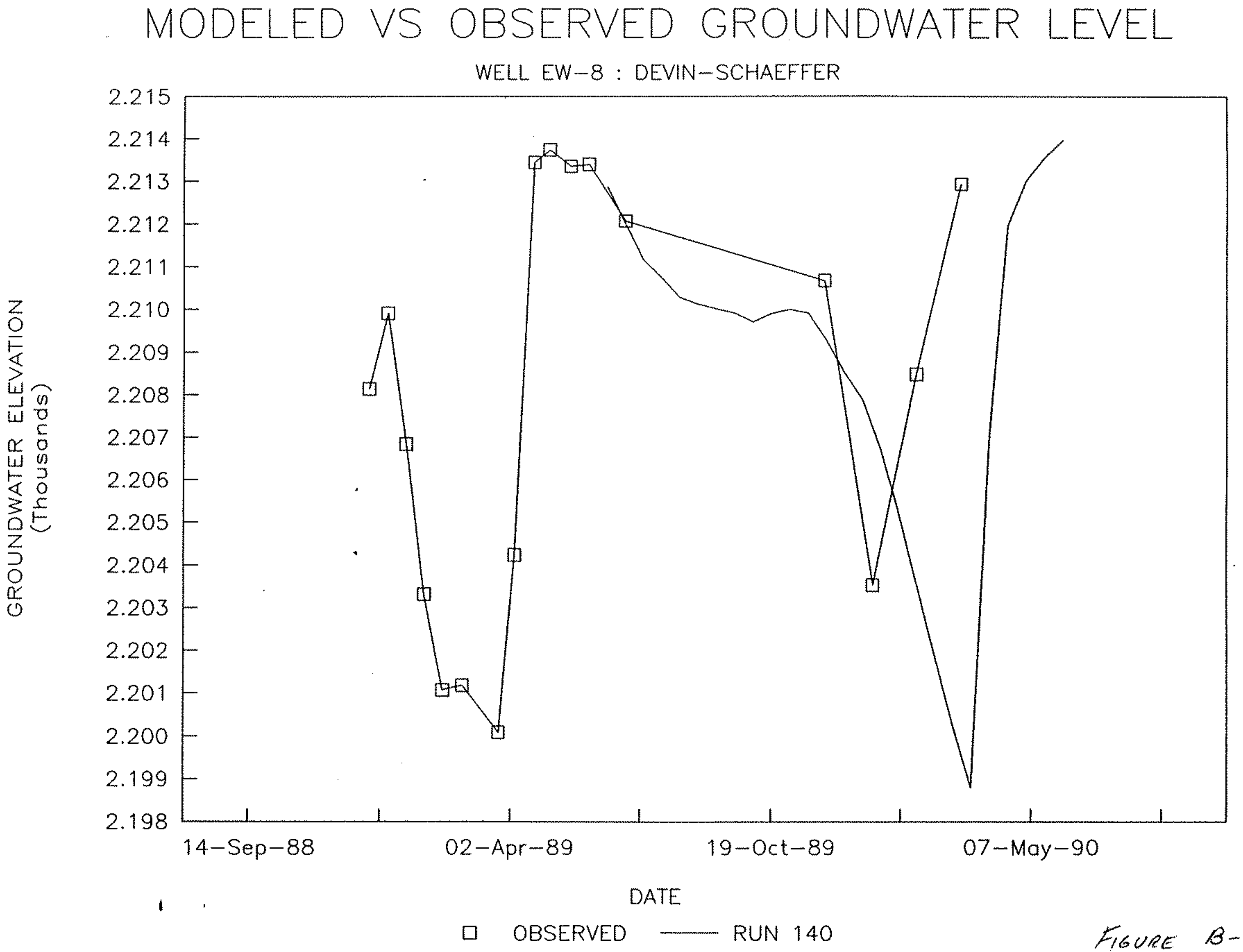
FIGURE A-10

APPENDIX B

CALIBRATION RESULTS

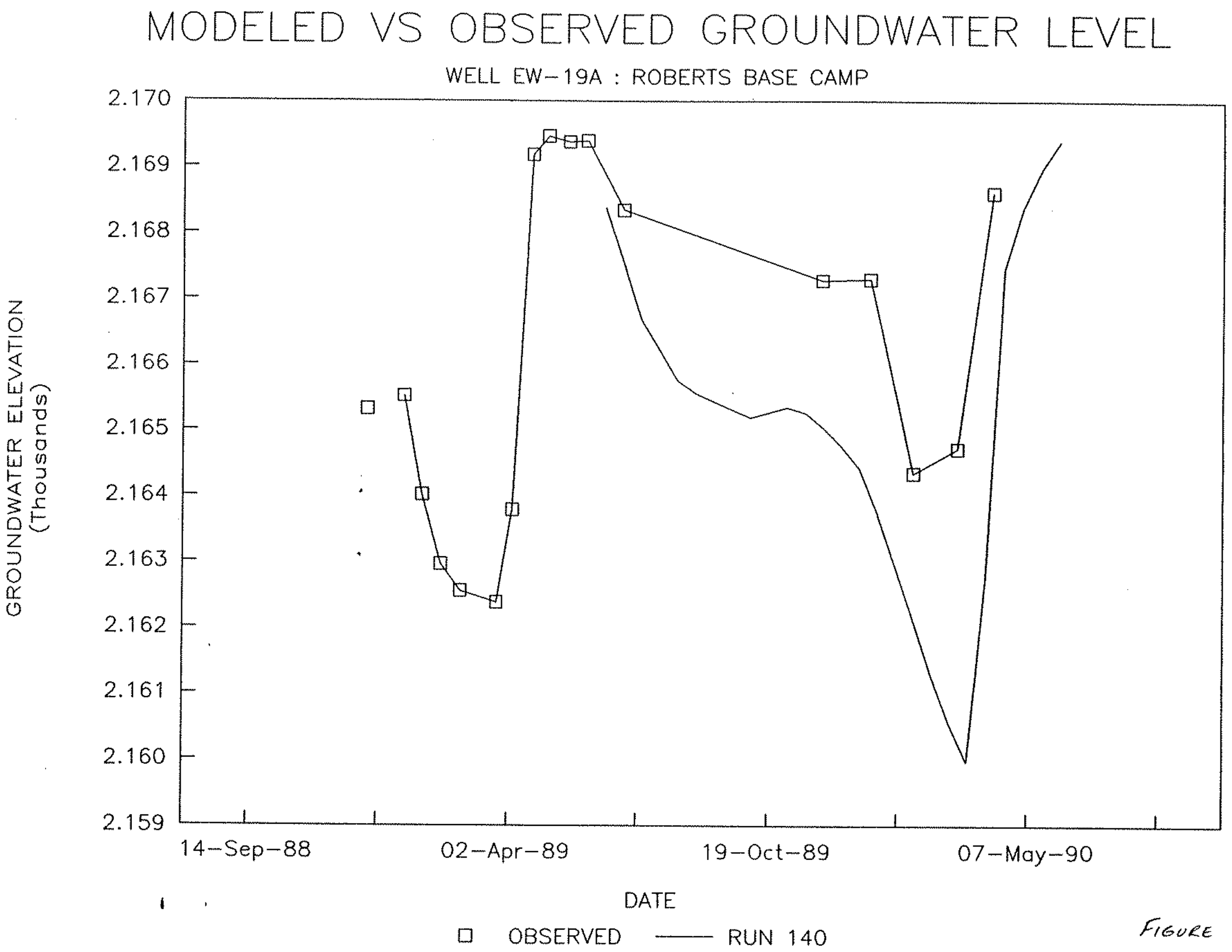
APPENDIX B

Figure	Explanation
B-1 through B-5	Observed groundwater levels between December 1988 and April 1990 versus predicted groundwater levels from 1990 streamflows. The most recent groundwater level data collected by Okanagon County is not yet available.
B-6 through B-9	Observed streamflow profile between July and November 1990 versus predicted streamflow profile.
B-10 through B-14	Observed streamflow at gaged reaches versus predicted streamflow using 1990 tributary inflows.
B-15	Summary of flows entering the aquifer and total tributary input. For example, for the stress period, ending October 19, ~280 cfs were entering from all tributaries, 110 cfs were infiltrated through the riverbed to the aquifer, and ~20 cfs were entering the aquifer through storage (declining water-levels).
B-16	Summary of flows leaving the aquifer. For example stress period ending October 19, ~90 cfs were discharging to the river, 57 cfs were flowing down-valley, and 0 cfs were replenishing aquifer storage (increasing water levels).
B-17	Plot showing progressive decline in streamflow along entire upper Methow River profile. By November 30, reaches above Early Winters are flowing at less than 10 cfs; by December 28, reaches above Early Winters are nearly dry and flows below Early Winters are less than 20 cfs; by February 8, the river is dry between Little Boulder Creek and Lost River. Although the dates reflect mid-winter, this sequence of flows would apply to any four month period of extended low tributary flow.



(1990 streamflow)

FIGURE B-1



(1990 streamflow)

FIGURE 8-2

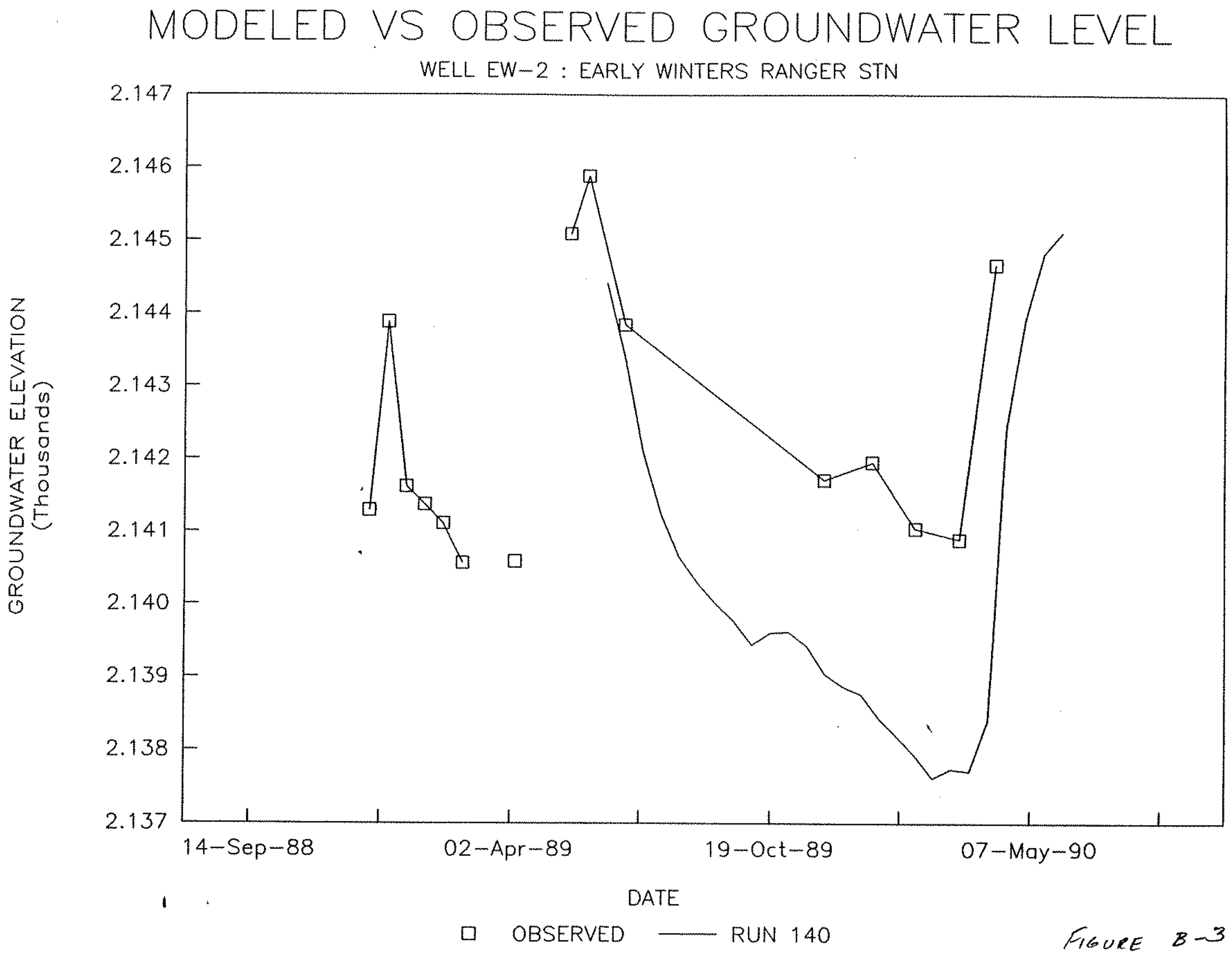
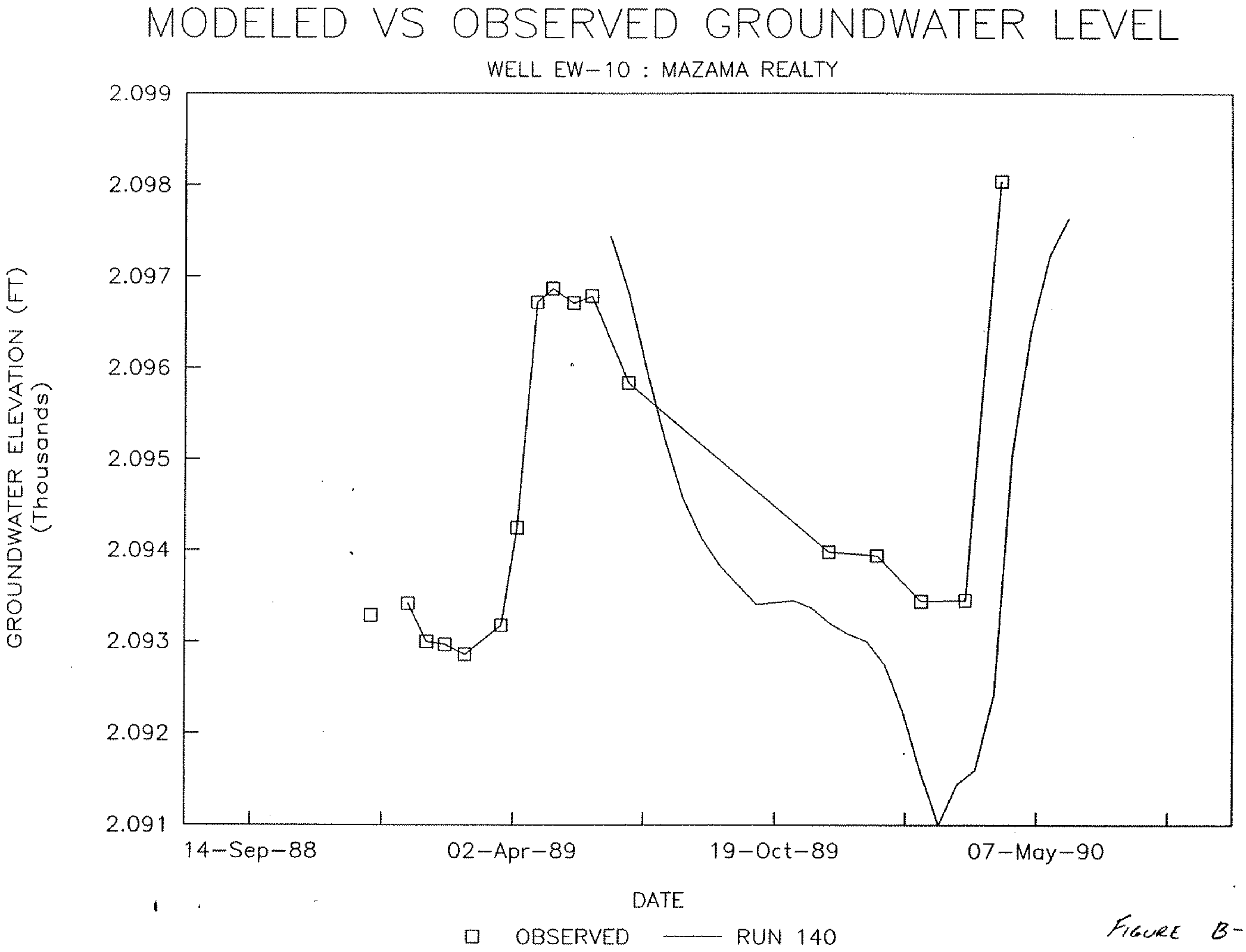


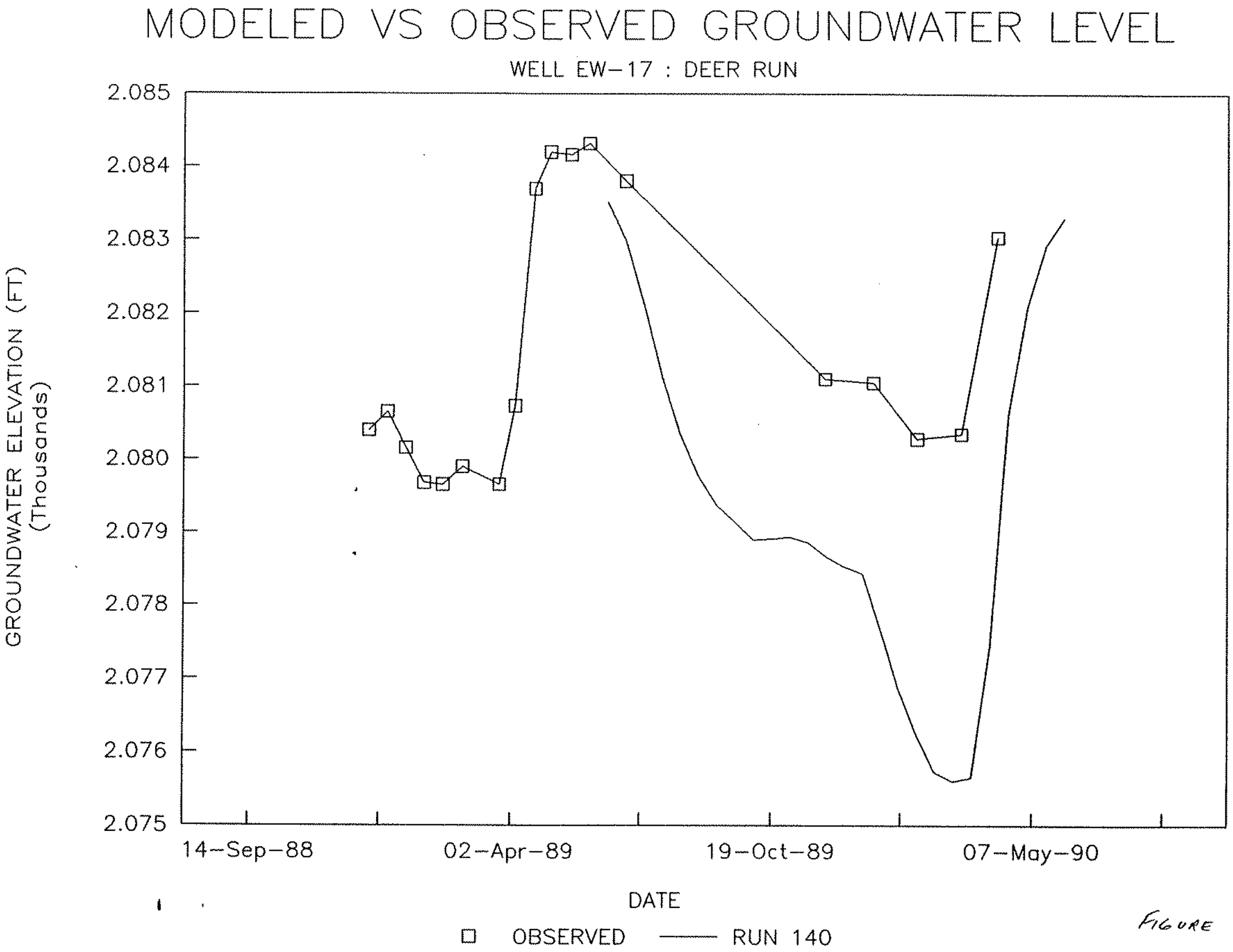
FIGURE B-3

(1990 streamflow)



(1990 stream flow)

FIGURE B-4



MODELED VS OBSERVED GROUNDWATER LEVEL

WELL EW-17 : DEER RUN

(1990 Streamflow)

FIGURE B-5

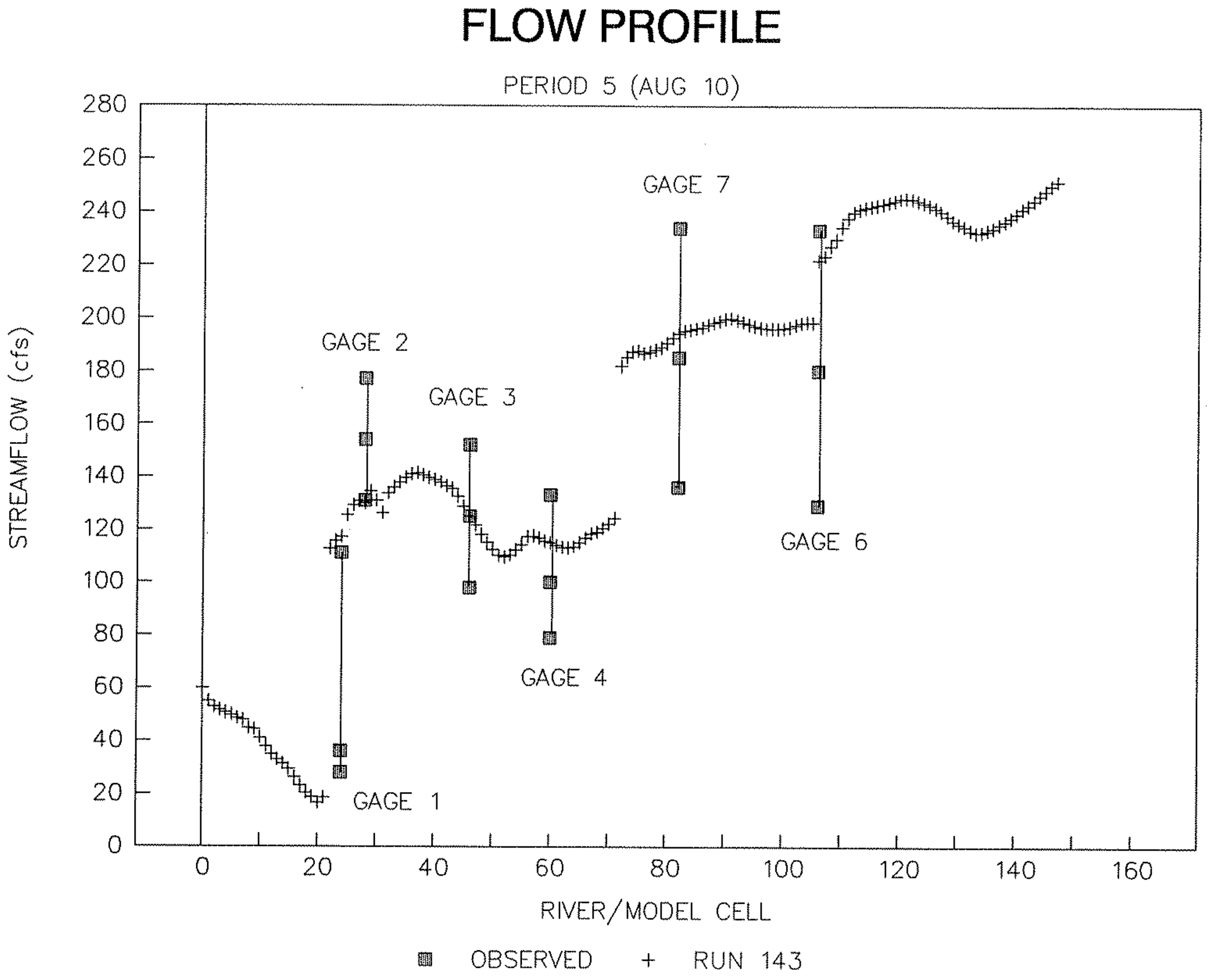

FLOW PROFILE
PERIOD 5 (AUG 10)
STREAMFLOW (cfs)
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
RIVER/MODEL CELL
0
20
40
60
80
100
120
140
160
GAGE 1
GAGE 2
GAGE 3
GAGE 4
GAGE 6
GAGE 7
▨ OBSERVED + RUN 143

FIGURE B-6

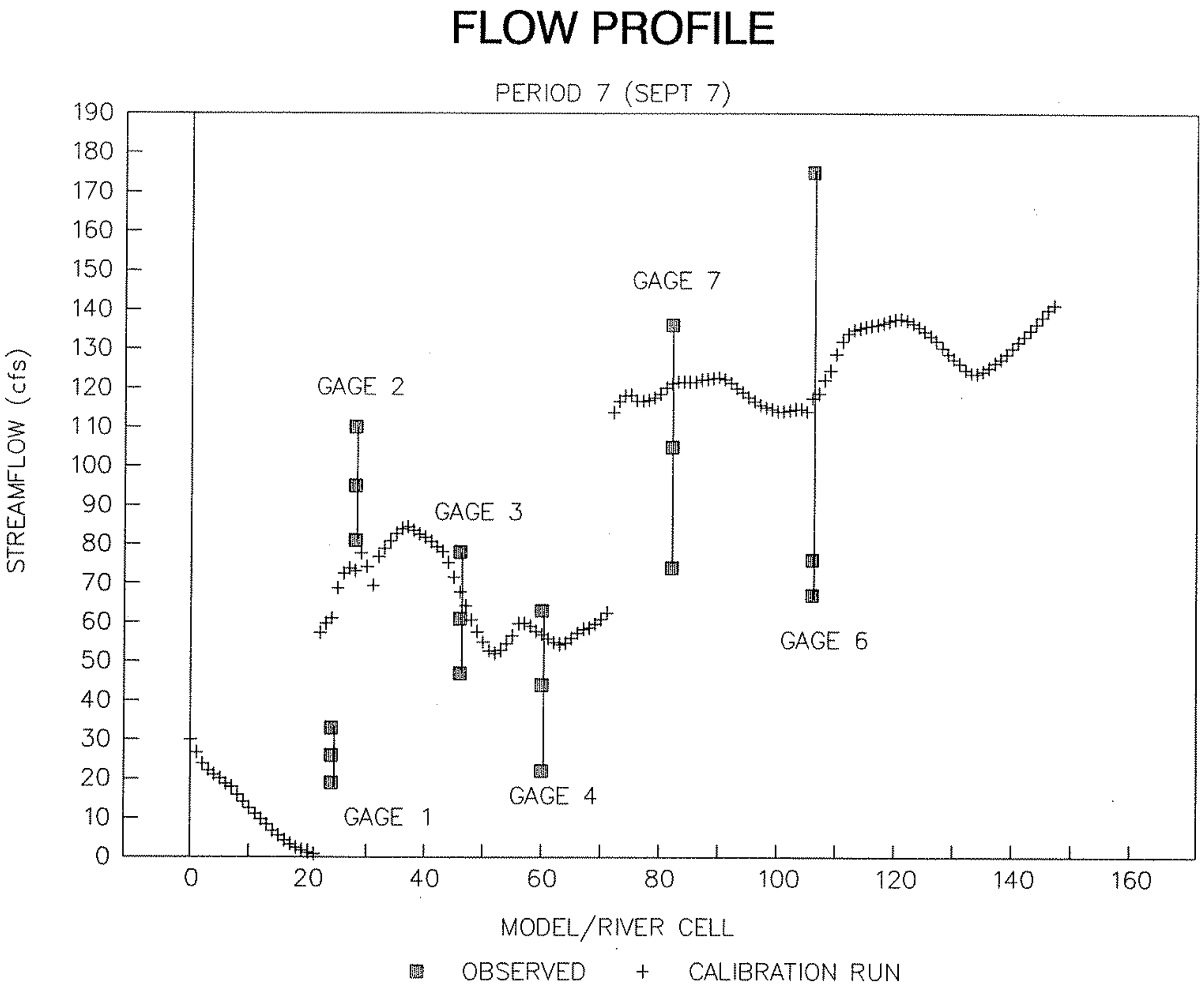

FLOW PROFILE
PERIOD 7 (SEPT 7)
STREAMFLOW (cfs)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
0
20
40
60
80
100
120
140
160
MODEL/RIVER CELL
GAGE 1
GAGE 2
GAGE 3
GAGE 4
GAGE 6
GAGE 7
▨ OBSERVED
+ CALIBRATION RUN

FIGURE B-7

FLOW PROFILE

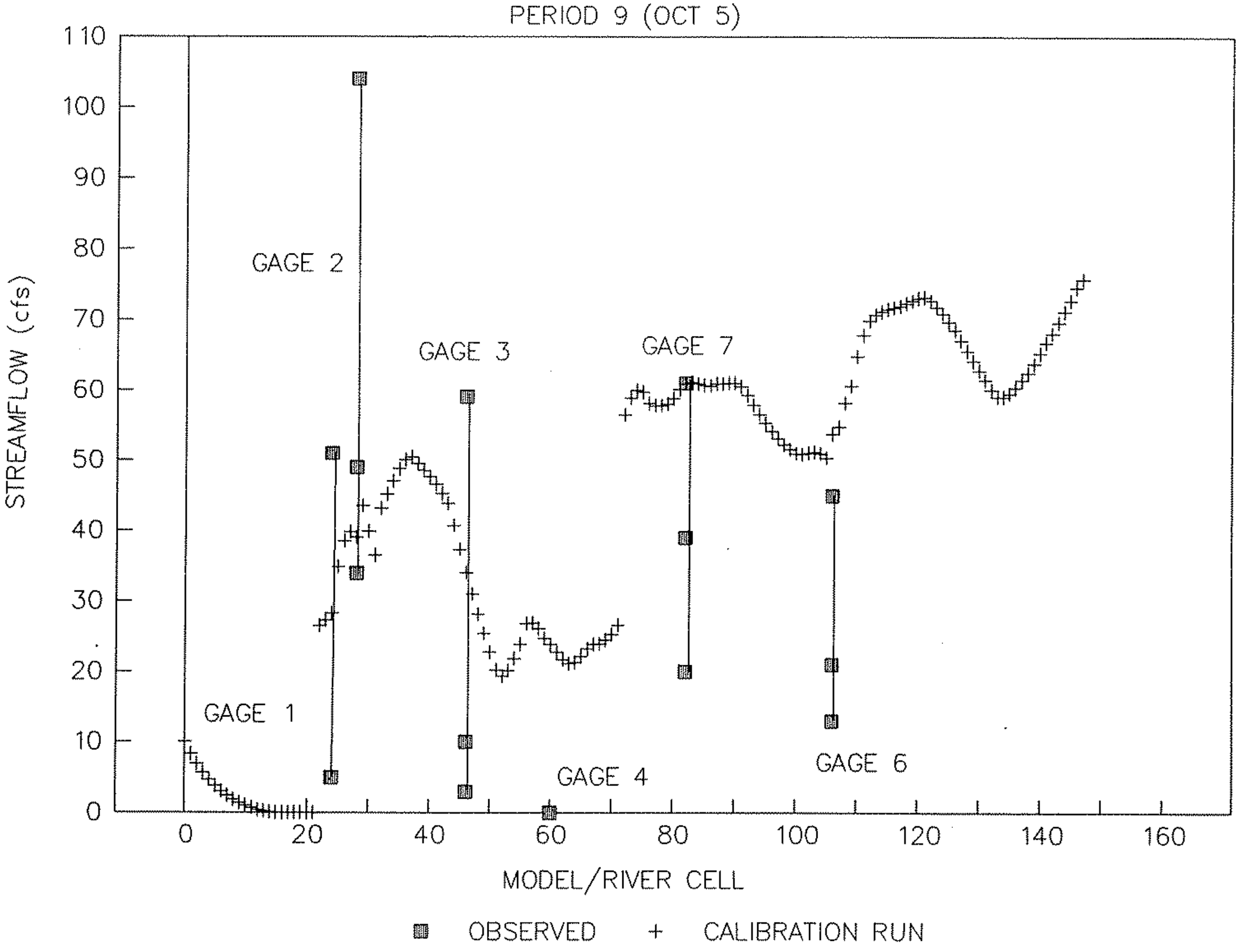


FIGURE B-8

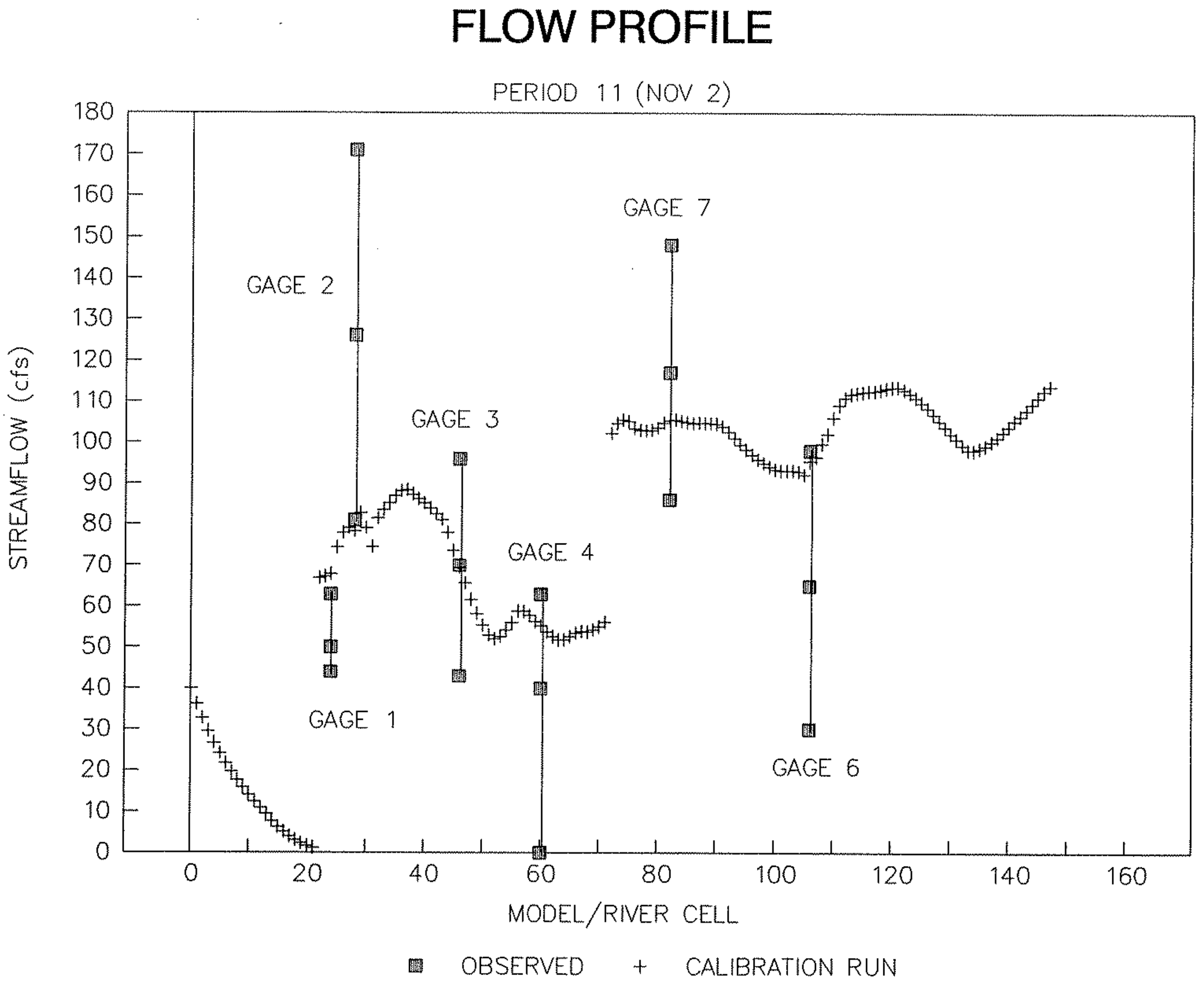

FLOW PROFILE
PERIOD 11 (NOV 2)
STREAMFLOW (cfs)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
MODEL/RIVER CELL
0
20
40
60
80
100
120
140
160
GAGE 1
GAGE 2
GAGE 3
GAGE 4
GAGE 6
GAGE 7
▨ OBSERVED + CALIBRATION RUN

FIGURE B-9

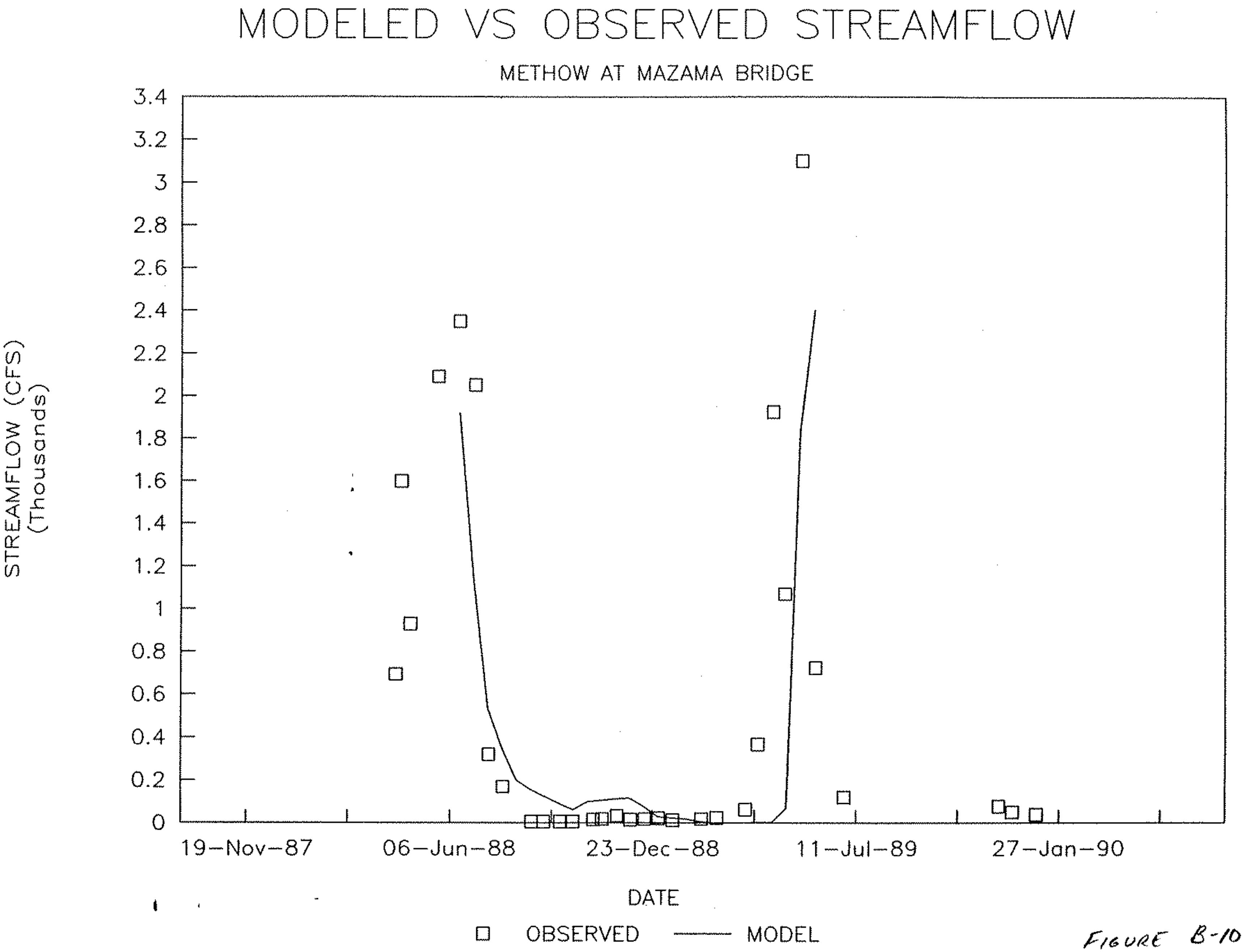

MODELED VS OBSERVED STREAMFLOW
METHOW AT MAZAMA BRIDGE
STREAMFLOW (CFS)
(Thousands)
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
19-Nov-87
06-Jun-88
23-Dec-88
11-Jul-89
27-Jan-90
DATE
□ OBSERVED
—— MODEL

FIGURE B-10

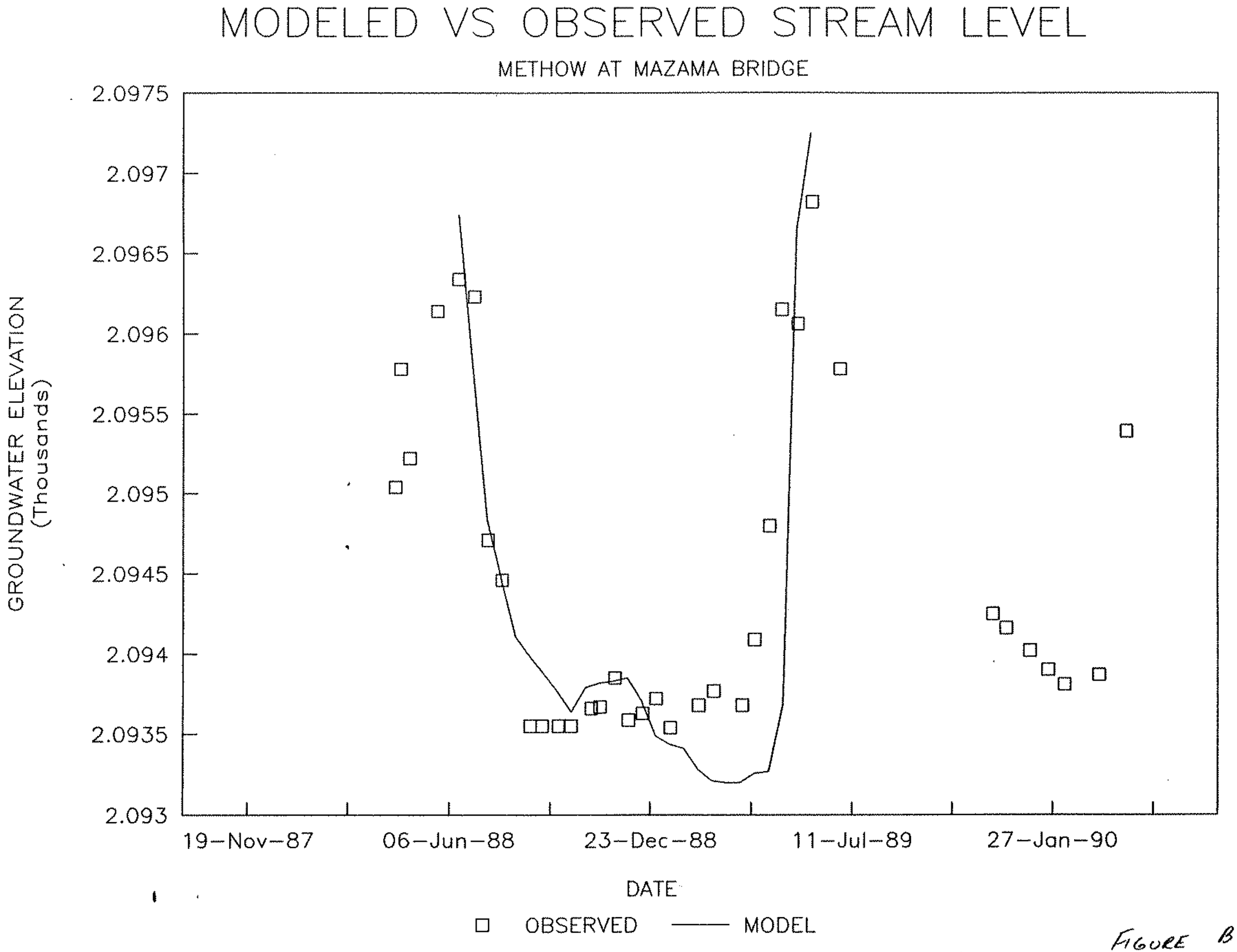

MODELED VS OBSERVED STREAM LEVEL
METHOW AT MAZAMA BRIDGE
GROUNDWATER ELEVATION
(Thousands)
2.0975
2.097
2.0965
2.096
2.0955
2.095
2.0945
2.094
2.0935
2.093
19-Nov-87
06-Jun-88
23-Dec-88
11-Jul-89
27-Jan-90
DATE
OBSERVED
MODEL

FIGURE B-11

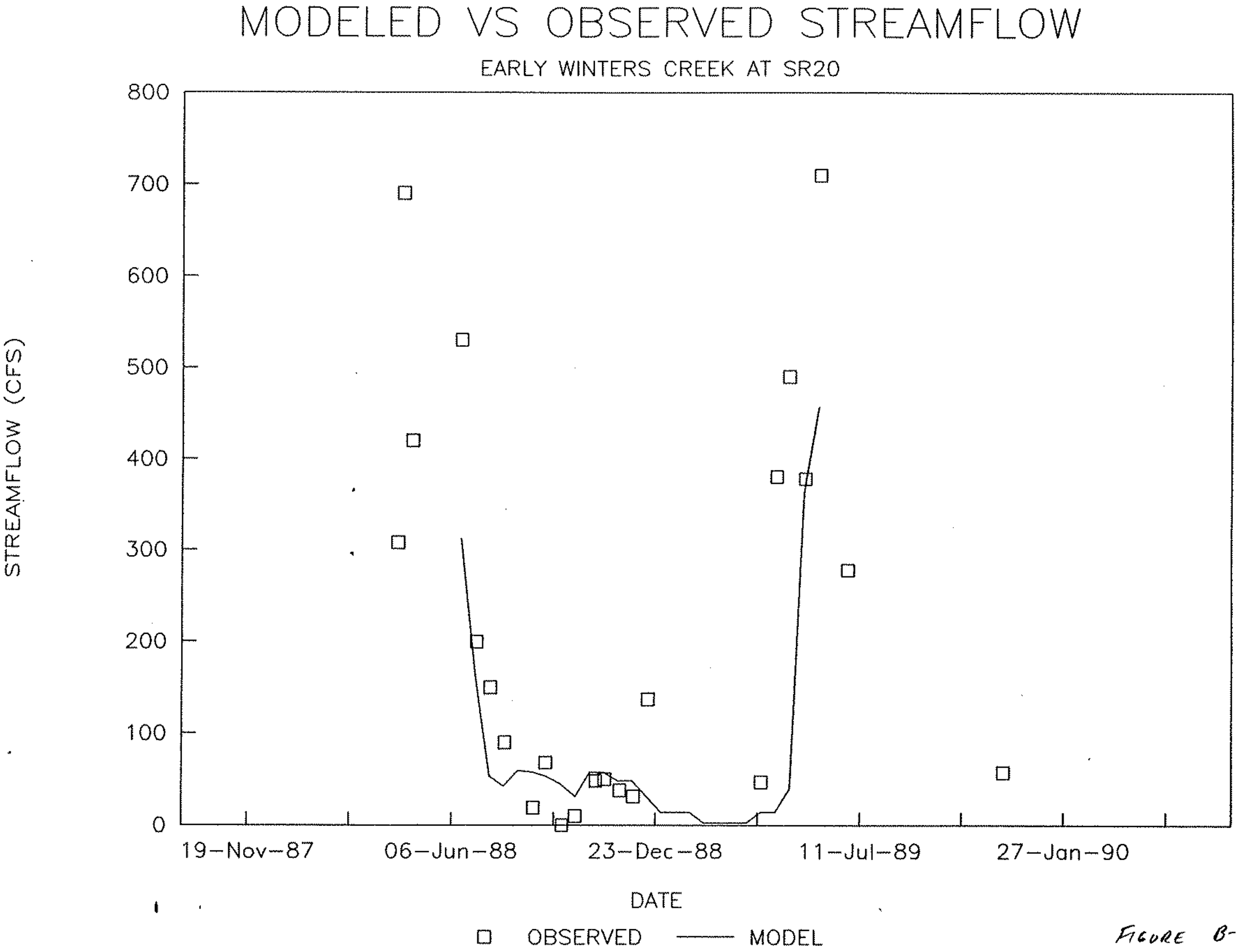
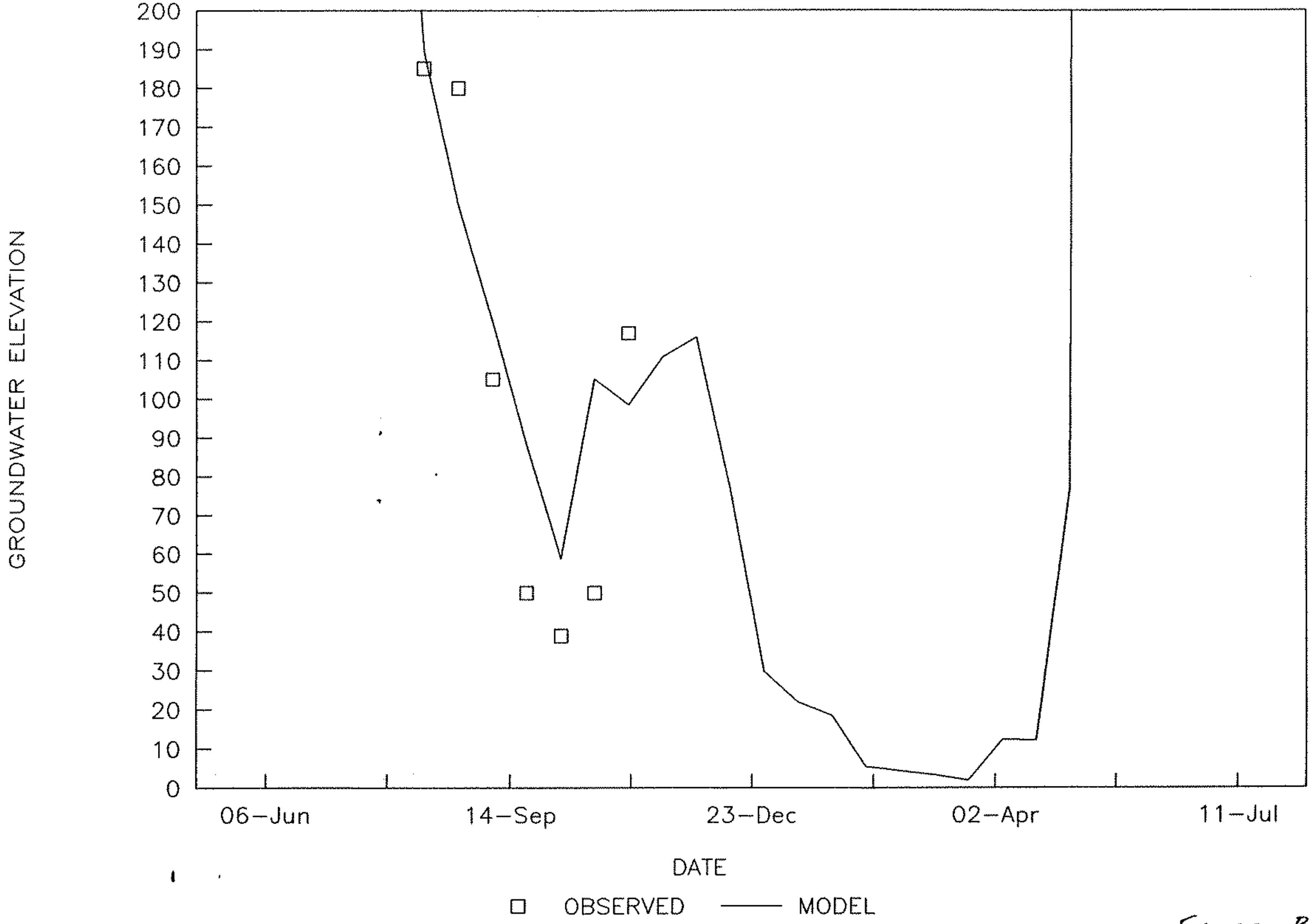

MODELED VS OBSERVED STREAMFLOW
EARLY WINTERS CREEK AT SR20
STREAMFLOW (CFS)
800
700
600
500
400
300
200
100
0
19-Nov-87
06-Jun-88
23-Dec-88
11-Jul-89
27-Jan-90
DATE
☐ OBSERVED
—— MODEL

Figure B-12

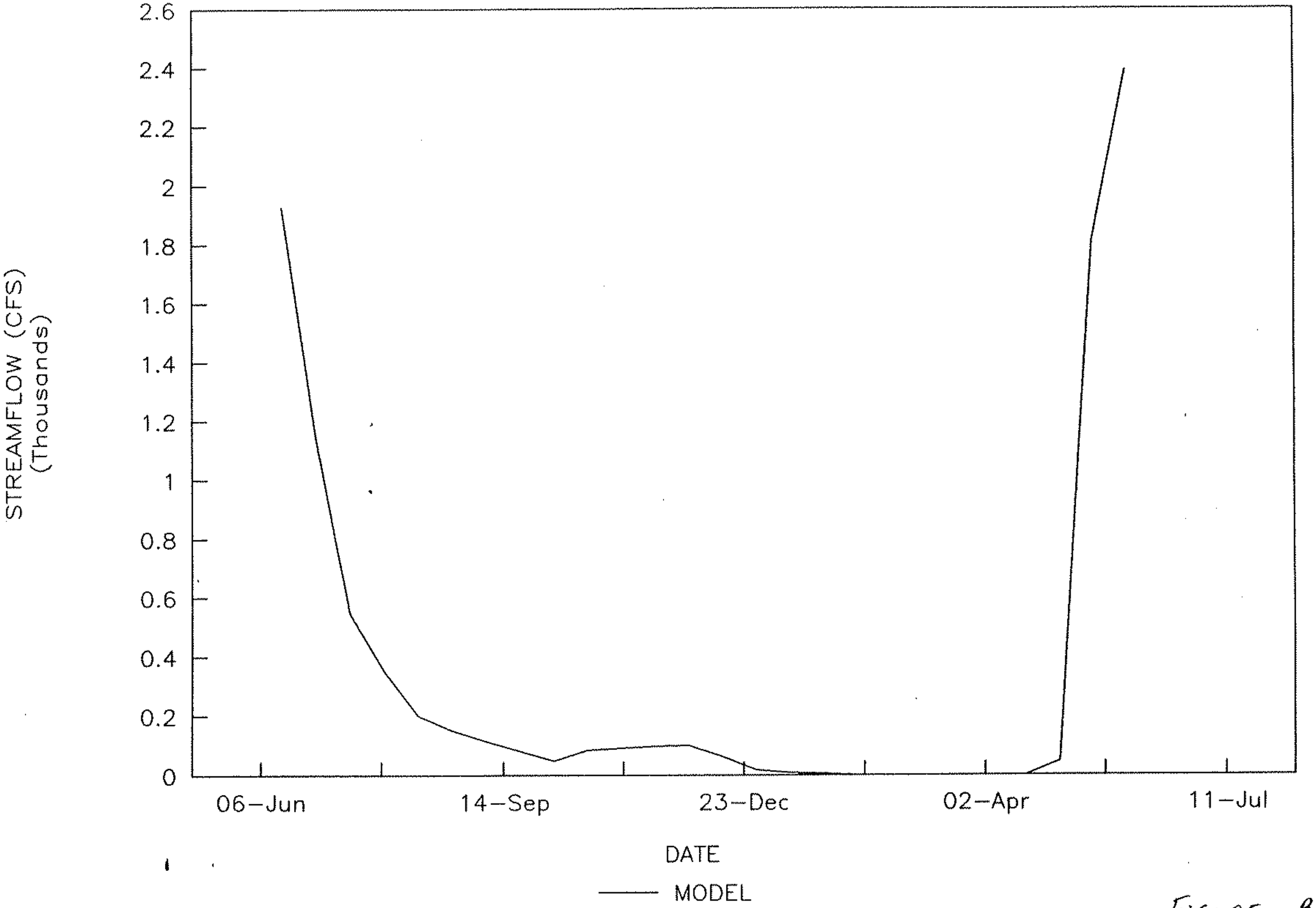


MODELED VS OBSERVED STREAM LEVEL

METHOW AT GAGE 7 (1990)

(1990)

FIGURE B-13

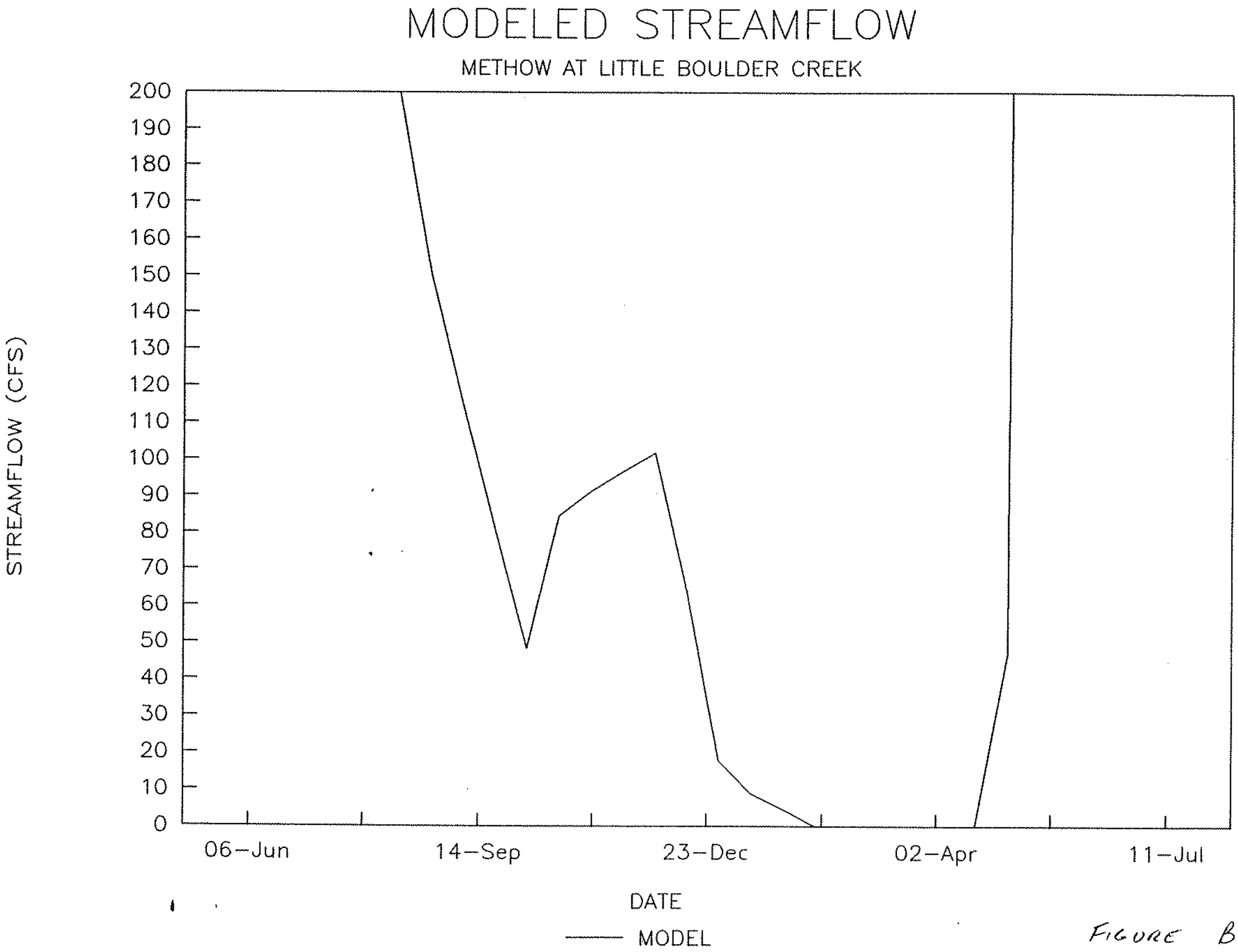


MODELED STREAMFLOW

METHOW AT LITTLE BOULDER CREEK

(1990 streamflow)

FIGURE B-14



1990 Streamflow

FIGURE B-14 A

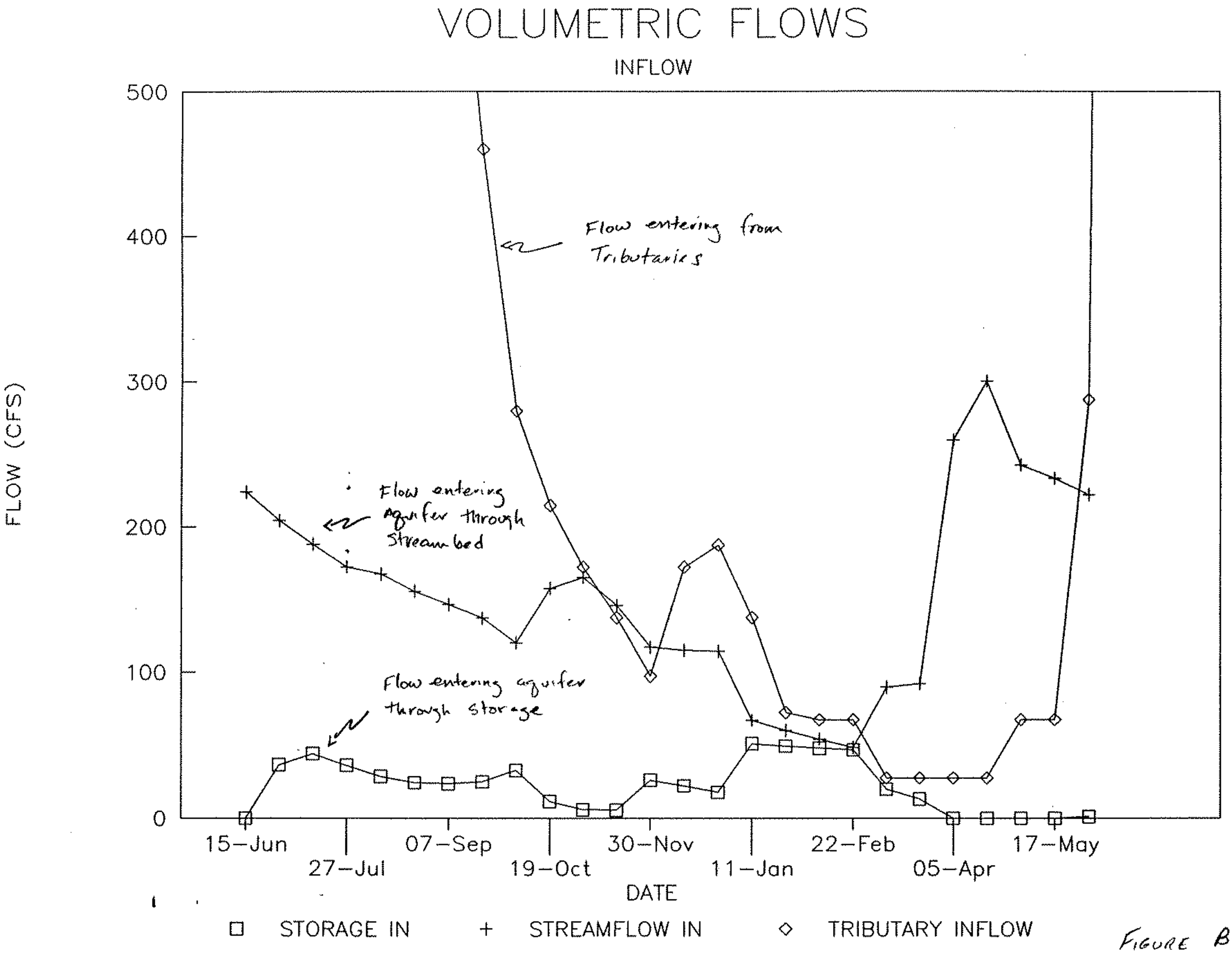

VOLUMETRIC FLOWS
INFLOW
FLOW (CFS)
500
400
300
200
100
0
15-Jun
27-Jul
07-Sep
19-Oct
30-Nov
11-Jan
22-Feb
05-Apr
17-May
DATE
Flow entering from Tributaries
Flow entering aquifer through Streambed
Flow entering aquifer through storage
□ STORAGE IN
+ STREAMFLOW IN
◇ TRIBUTARY INFLOW

FIGURE B-15

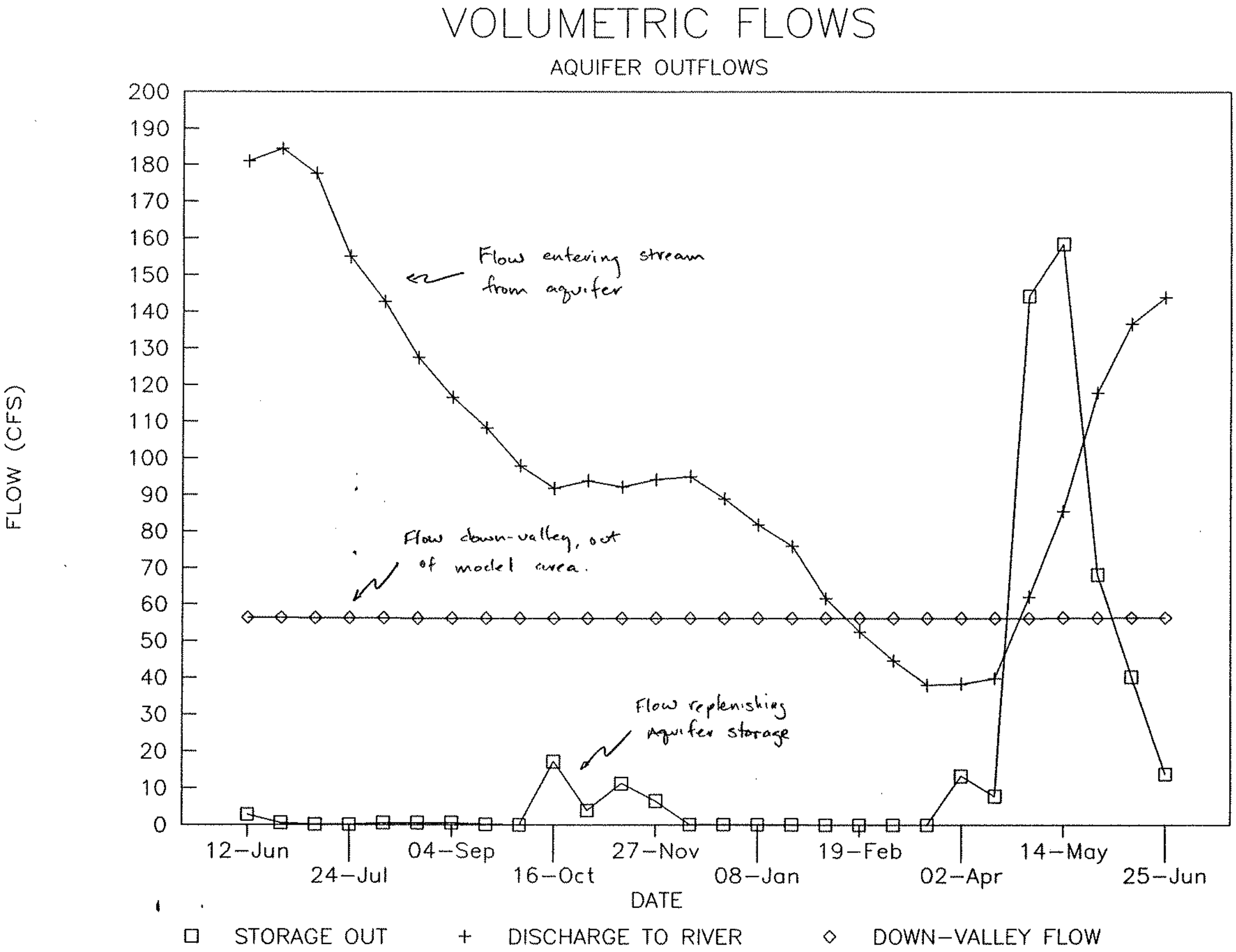

VOLUMETRIC FLOWS
AQUIFER OUTFLOWS
FLOW (CFS)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
12–Jun
24–Jul
04–Sep
16–Oct
27–Nov
08–Jan
19–Feb
02–Apr
14–May
25–Jun
DATE
□ STORAGE OUT
+ DISCHARGE TO RIVER
◇ DOWN–VALLEY FLOW
Flow entering stream from aquifer
Flow down-valley, out of model area.
Flow replenishing aquifer storage

FIGURE B-16

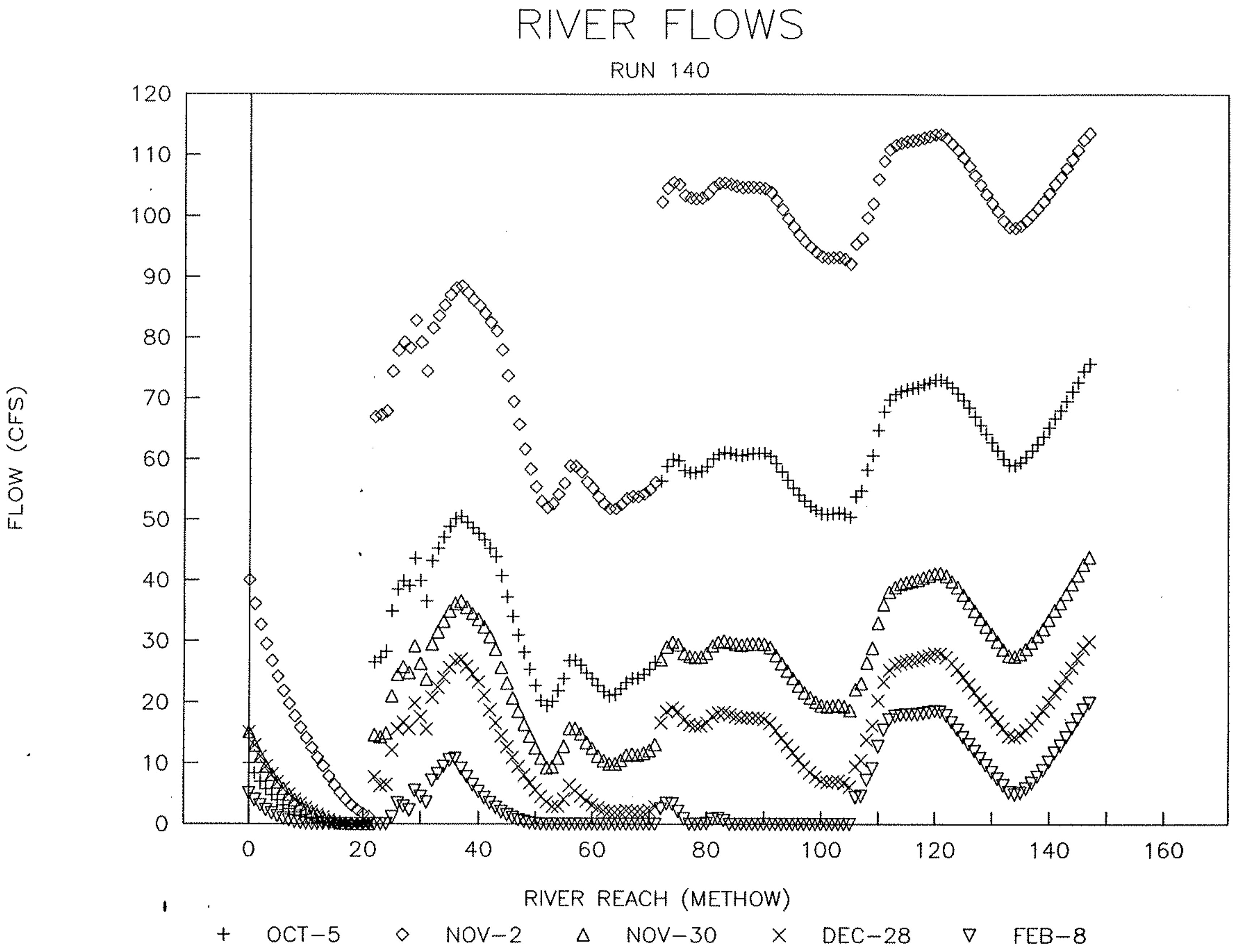
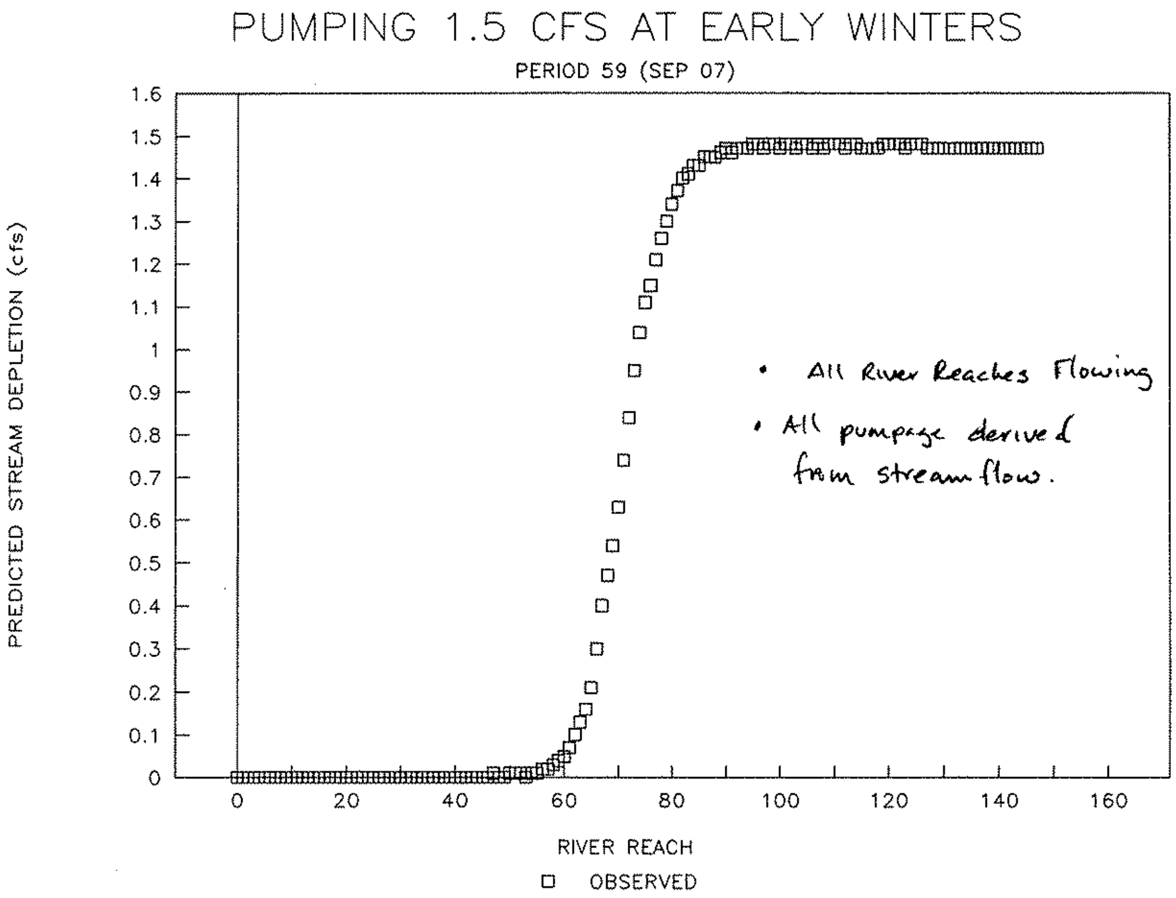

RIVER FLOWS
RUN 140
FLOW (CFS)
120
110
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
RIVER REACH (METHOW)
+ OCT-5
◇ NOV-2
△ NOV-30
× DEC-28
▽ FEB-8

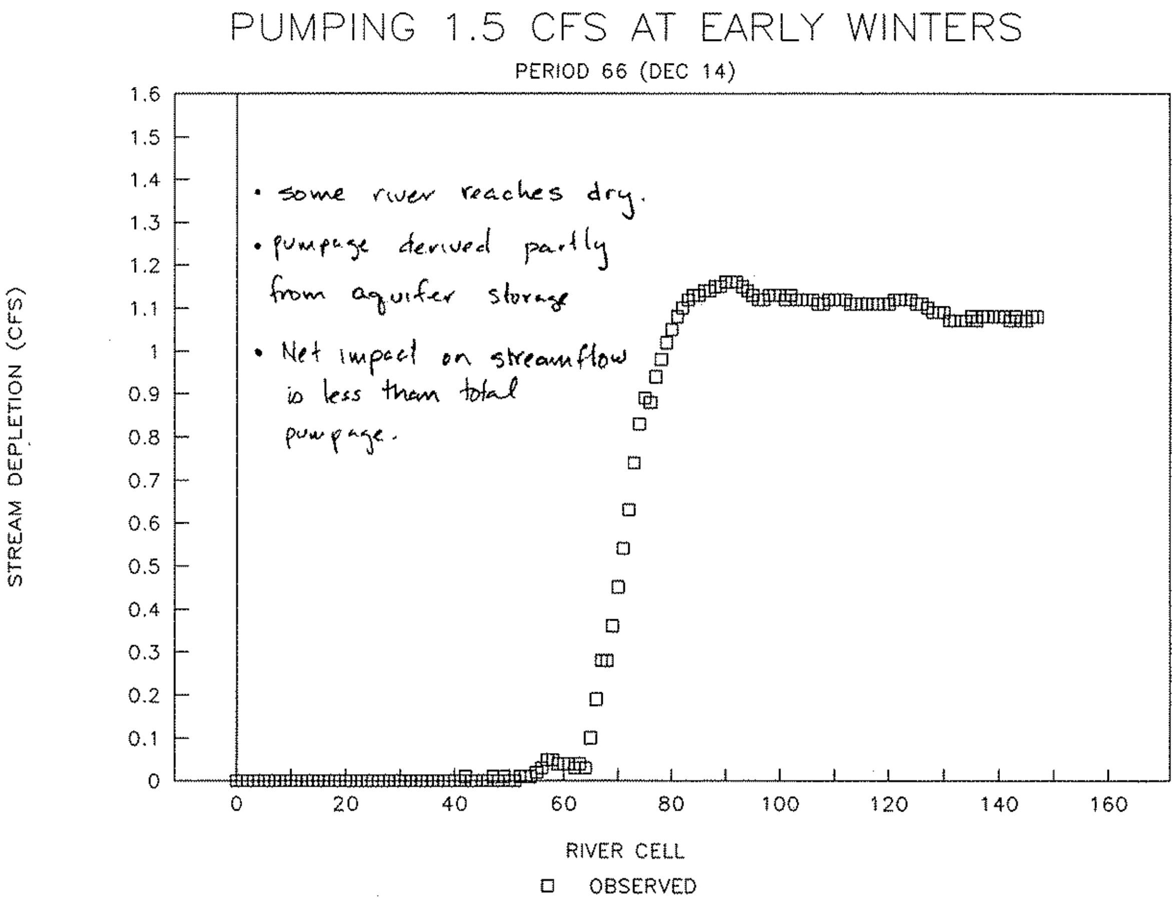
FIGURE B-17

APPENDIX C

Figure	Explanation
C-1, C-2	Predicted stream depletion from pumping 1.5 cfs at Early Winters. Stress Periods 59 and 66: Figure C-1 68 and 69: Figure C-2 Illustrates progressive decrease in streamflow impacts caused by increased withdrawal from aquifer storage.
C-3	Detailed flow profile between Early Winters Fan (Cell 70) and Deer Run (Cell 100). At period 68 (C-3A), one additional dry reach is caused by pumping. At period 69 (C-3B), 5 additional reaches are dry. All pumping is at Early Winters.
C-4	Predicted stream depletion from pumping 1.5 cfs at Cassel Ranch stress period 68 and 69. Impacts are reduced compared to pumping at Early Winters, because of additional storage withdrawals above Early Winters Fan.
C-5	Detailed flow profile between Early Winters Fan (Cell 70) and Deer Run. At period 69, five additional dry reaches are caused by pumping when all pumping is at Early Winters (C-5A). By shifting pumpage to Cassel Field (C-3B), only one additional dry reach is predicted.
C-6	Artificial recharge scenarios for the flowing river conditions (period 59). Up to 1.25 cfs withdrawn from reaches above gage 7 for injection site near Mazama. Downstream impacts are less than 0.3 cfs depending on the amount of recharge (80% vs. 100%). Injection near wells reduces maximum impact to about 0.5 cfs. Injection at Early Winters Fan produces increased streamflows compared to base case, in the Early Winters fan region and no downstream impact for 100% recharge.
C-7	Artifical recharge scenarios for low-flow/dry river conditions (period 69). All impacts reduced due to increased storage withdrawl. Flowing reaches downstream of Mazama have higher predicted streamflows than the base case for an injection site near Mazama. These reaches are impacted slighty for other recharge sites. All scenarios impact reaches near Early Winters fan to some extent. Recharge sites adjacent to wells produce the smallest impacts but without an increase in downstream flows.
C-8	Detailed flow profile. Injection near wells (or at Early Winters Fan) results in no additional dry reaches during pumping. Injection near Mazama results in some acceleration of dry reaches up stream of the injection site.
C-9 - C-11	Predicted drawdowns for each pumping scenario at well locations.



- All River Reaches Flowing
- All pumpage derived from streamflow.

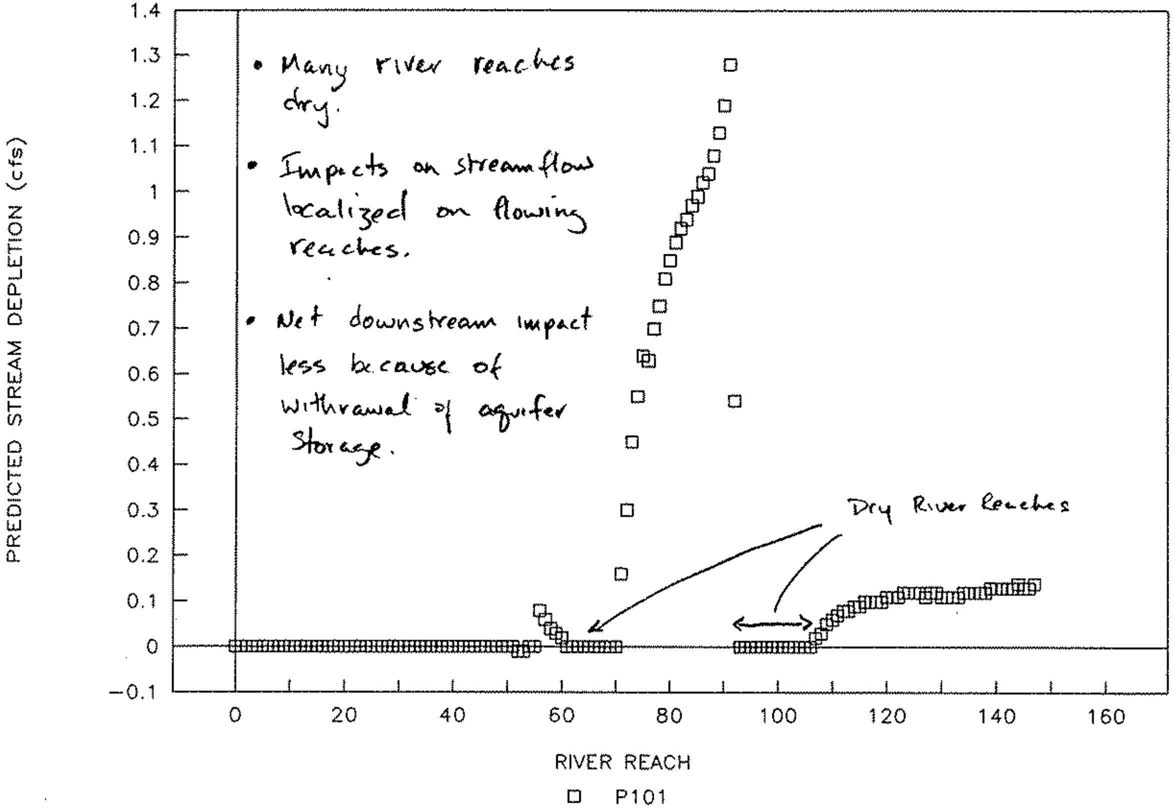


- some river reaches dry.
- pumpage derived partly from aquifer storage
- Net impact on streamflow is less than total pumpage.

FIGURE C-1

PUMPING 1.5 CFS AT EARLY WINTERS

PERIOD 68 (JAN 11)

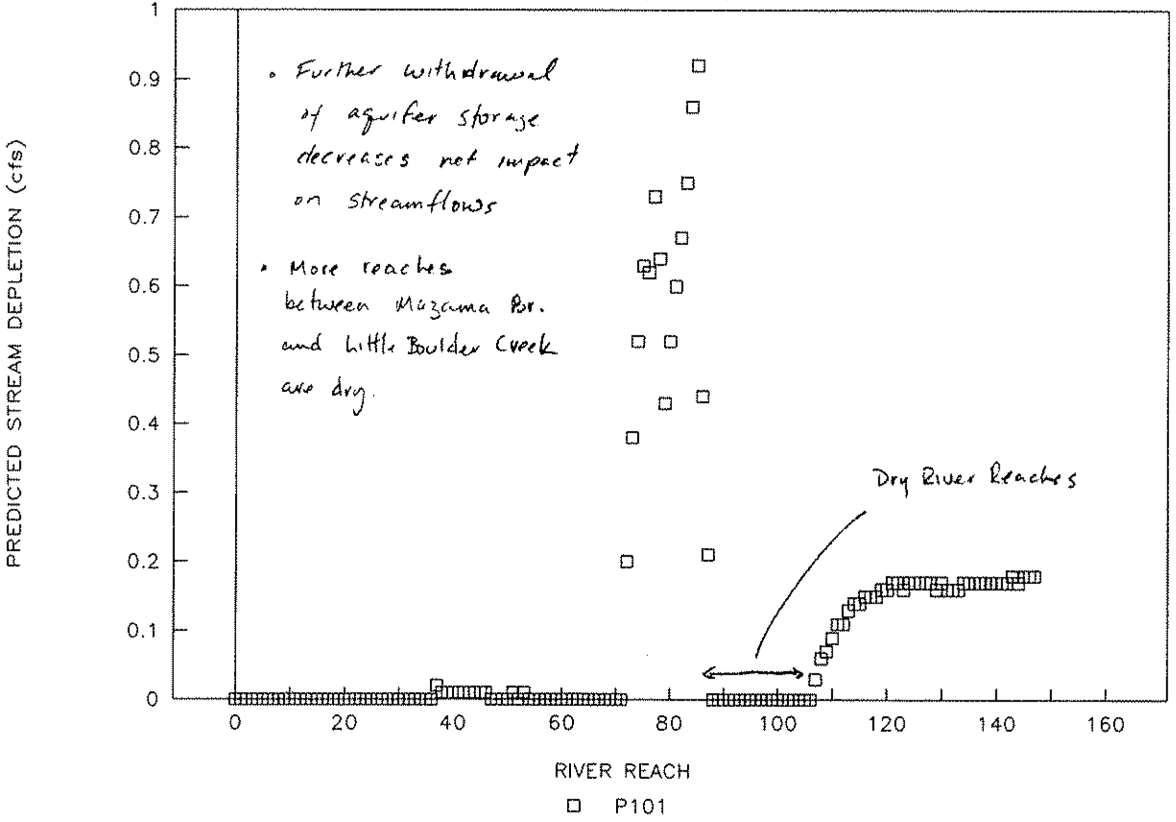


- Many river reaches dry.
- Impacts on streamflow localized on flowing reaches.
- Net downstream impact less because of withrawal of aquifer storage.

Dry River Reaches

PUMPING 1.5 CFS AT EARLY WINTERS

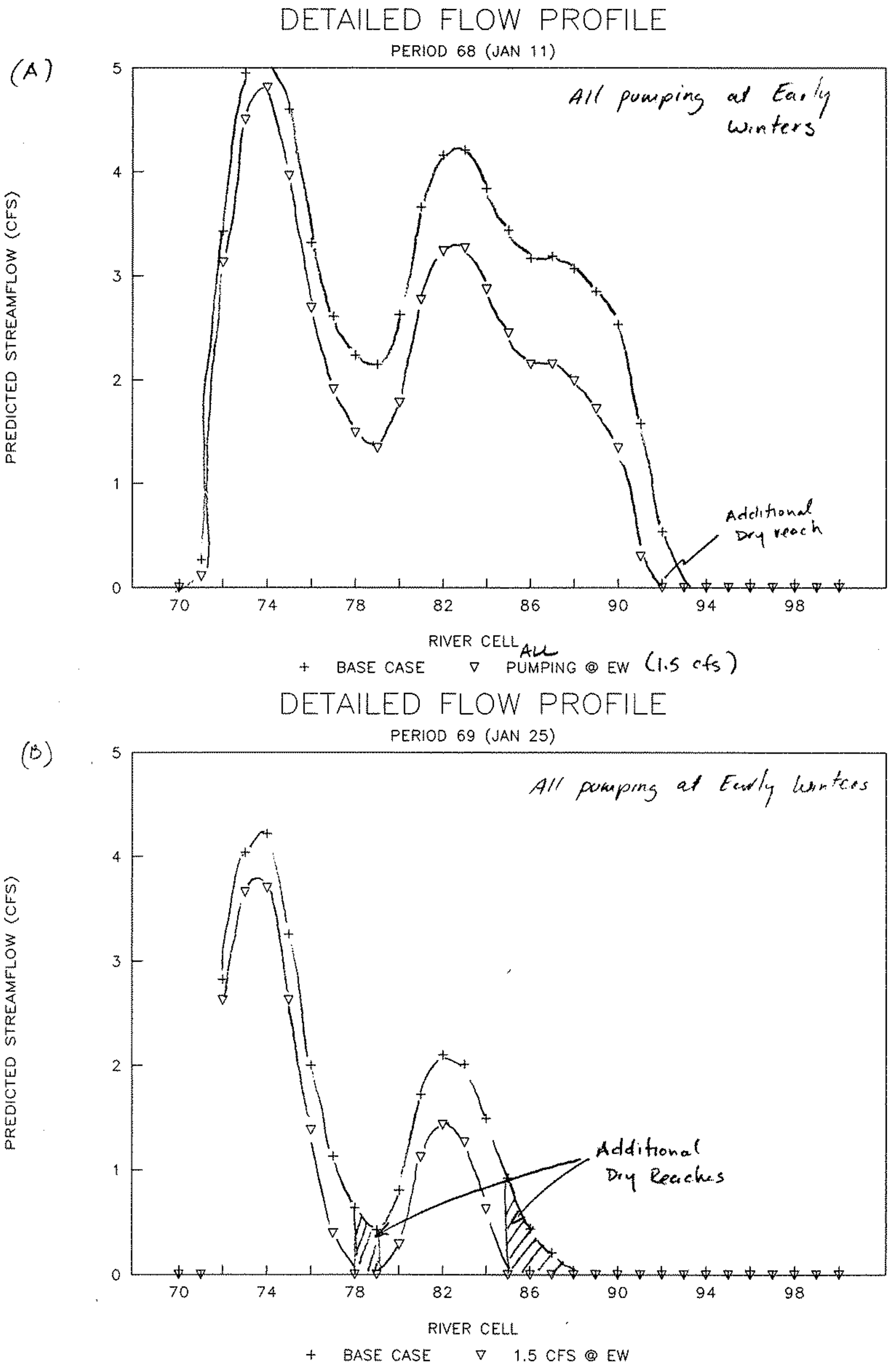
PERIOD 69 (JAN 25)



- Further withdrawal of aquifer storage decreases net impact on streamflows
- More reaches between Mazama Br. and Little Boulder Creek are dry.

Dry River Reaches

FIGURE C-2



DETAILED FLOW PROFILE

PERIOD 68 (JAN 11)

All pumping at Early Winters

Additional Dry reach

DETAILED FLOW PROFILE

PERIOD 69 (JAN 25)

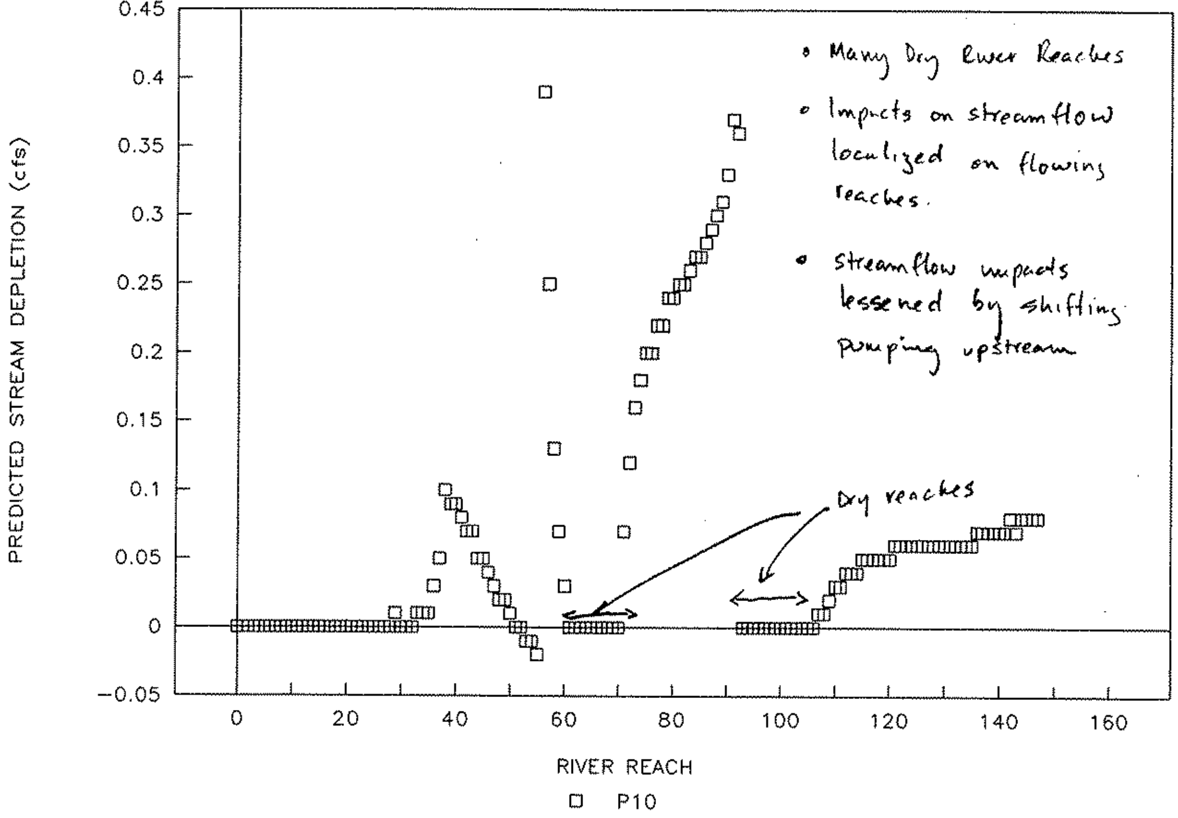
All pumping at Early Winters

Additional Dry Reaches

FIGURE C-3

PUMPING 1.5 CFS AT CASSEL RANCH

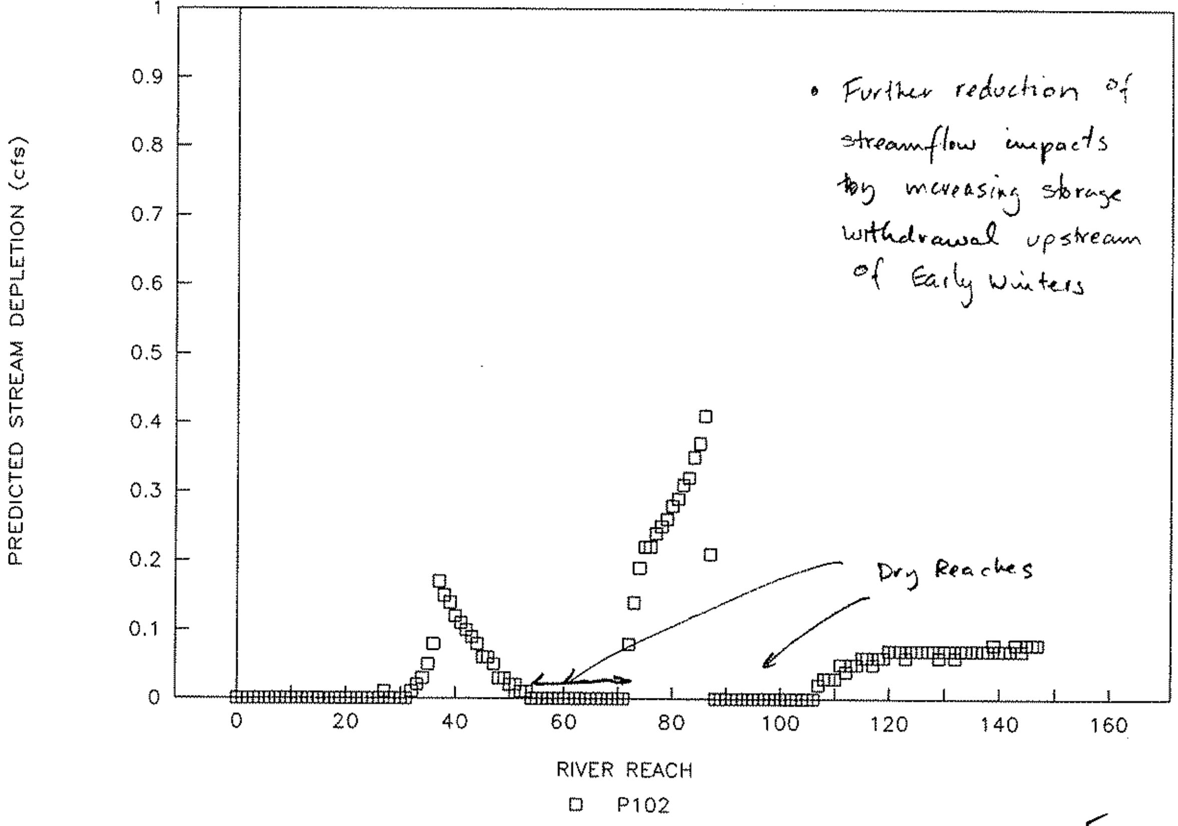
PERIOD 68 (JAN 11)



- Many Dry River Reaches
- Impacts on streamflow localized on flowing reaches.
- streamflow impacts lessened by shifting pumping upstream

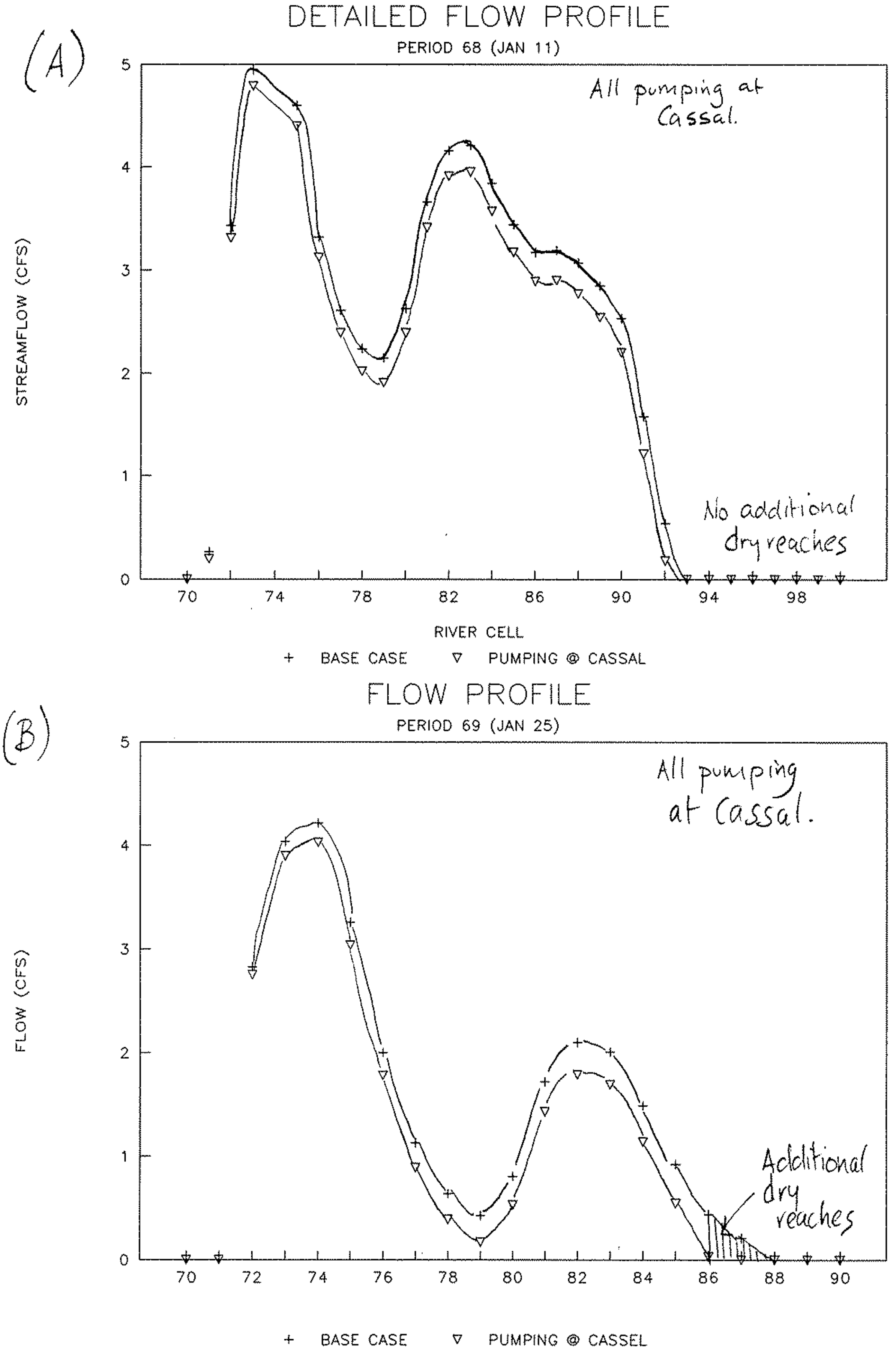
PUMPING 1.5 CFS AT CASSEL RANCH

PERIOD 69 (JAN 25)



- Further reduction of streamflow impacts by increasing storage withdrawal upstream of Early Winters

FIGURE C-4



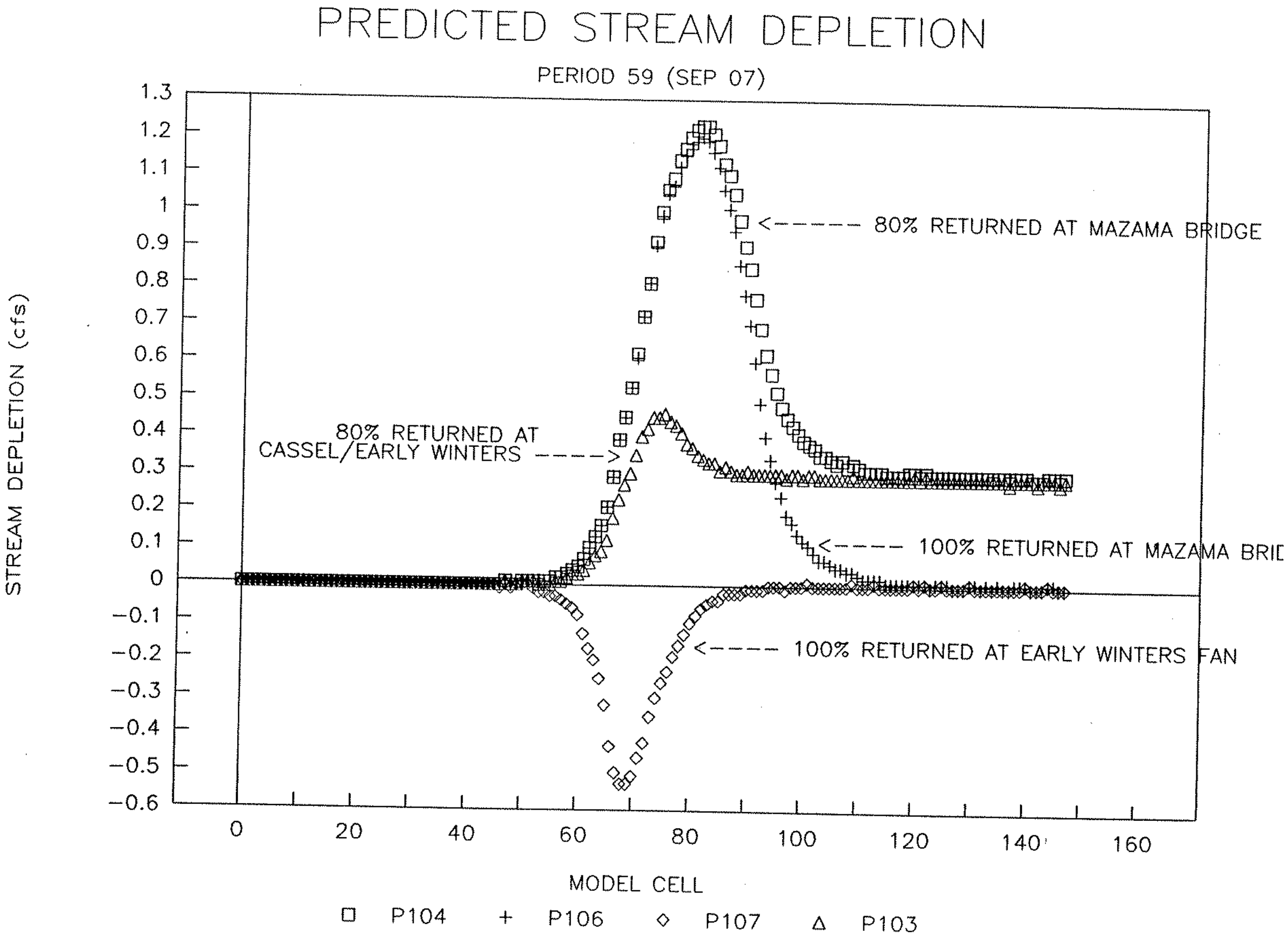
All pumping at Cassal.

No additional dry reaches

All pumping at Cassal.

Additional dry reaches

FIGURE C-5



80% Return Mazama

100% return Mazama

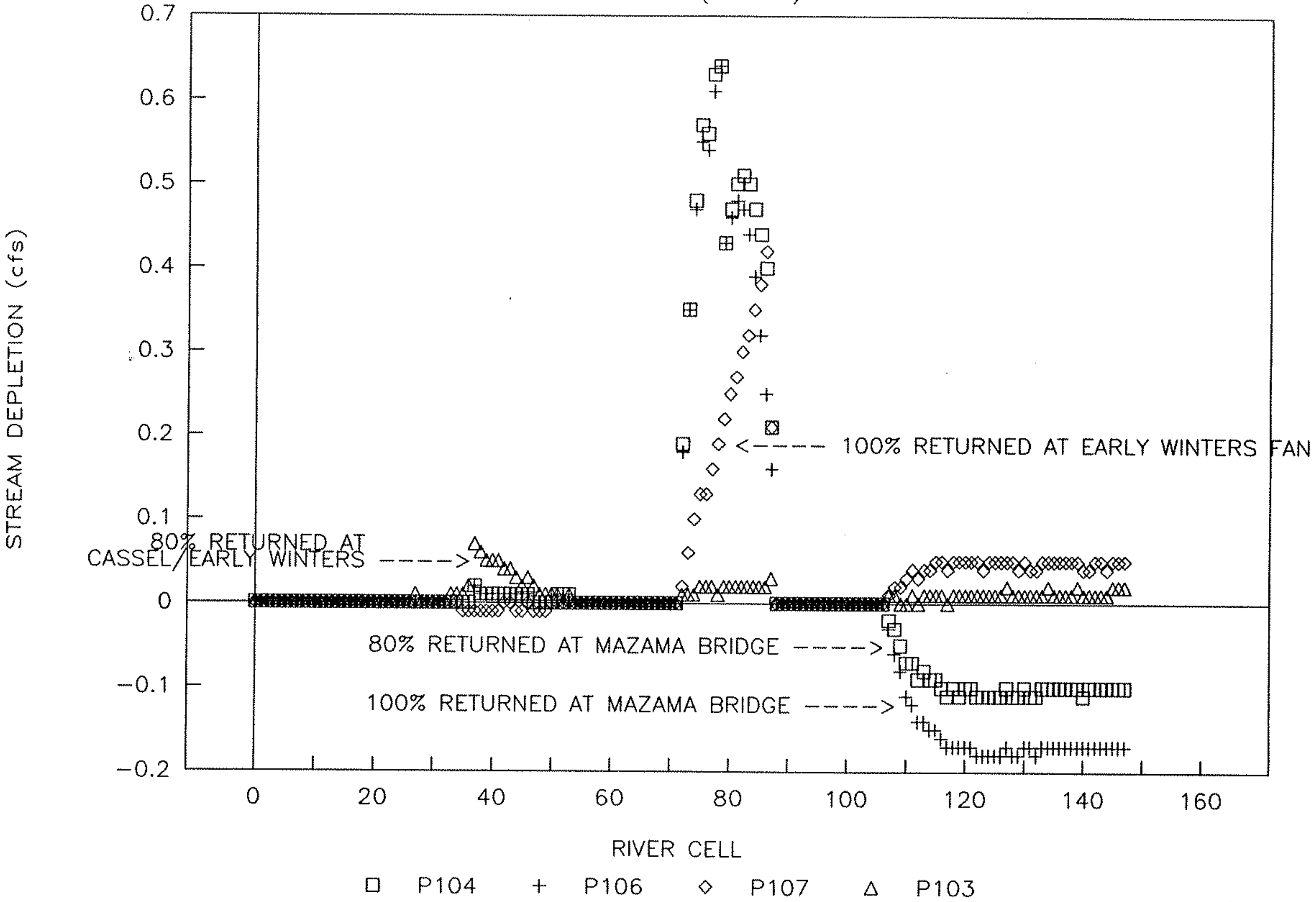
100% return EW. Fan

80% return wells.

FIGURE C-6

PREDICTED STREAM DEPLETION

PERIOD 69 (JAN 25)



80% Return @ Mazama

100% Return @ Mazama

100% return @ EW Fan

80% return @ wells.

FIGURE C-7

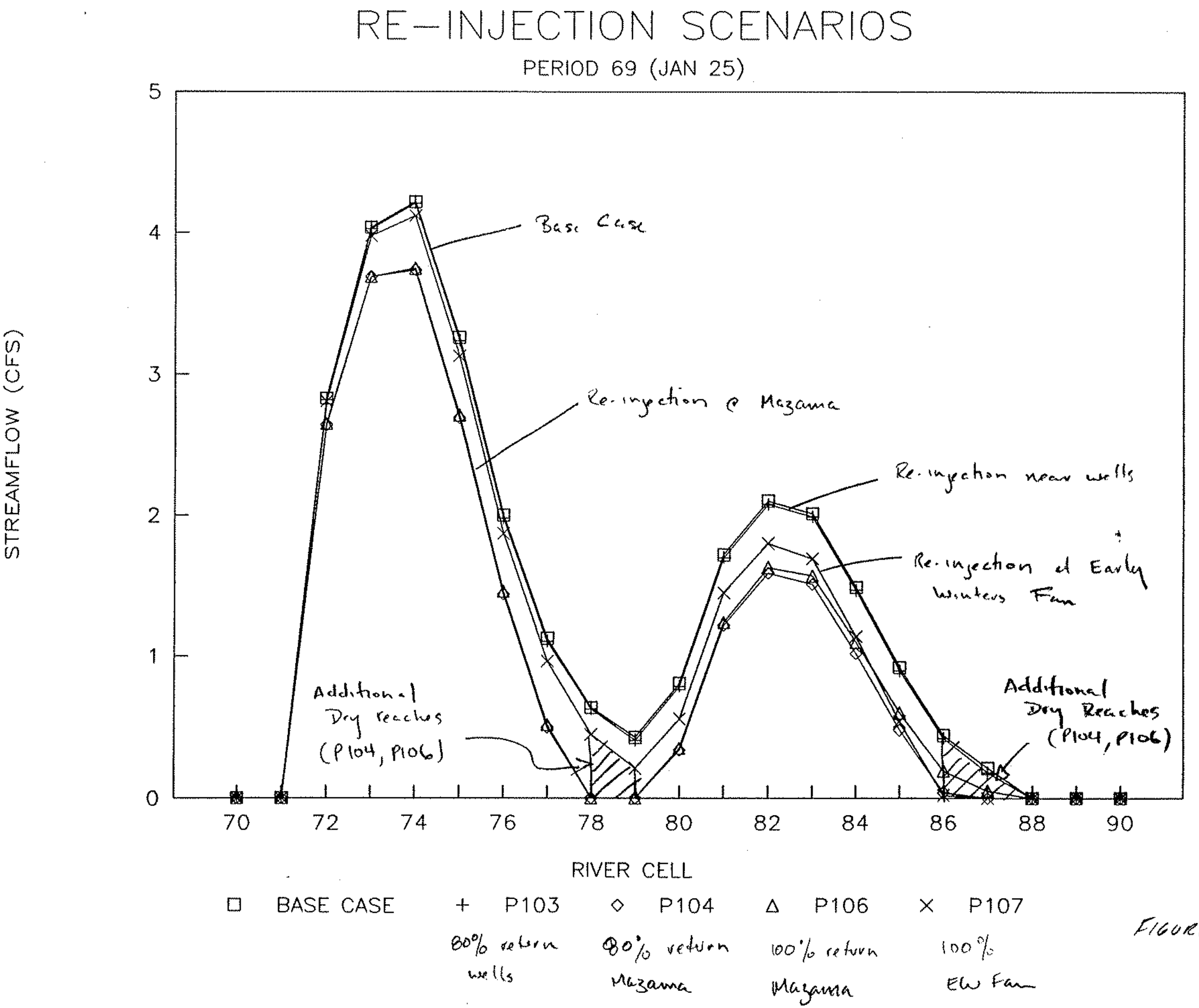
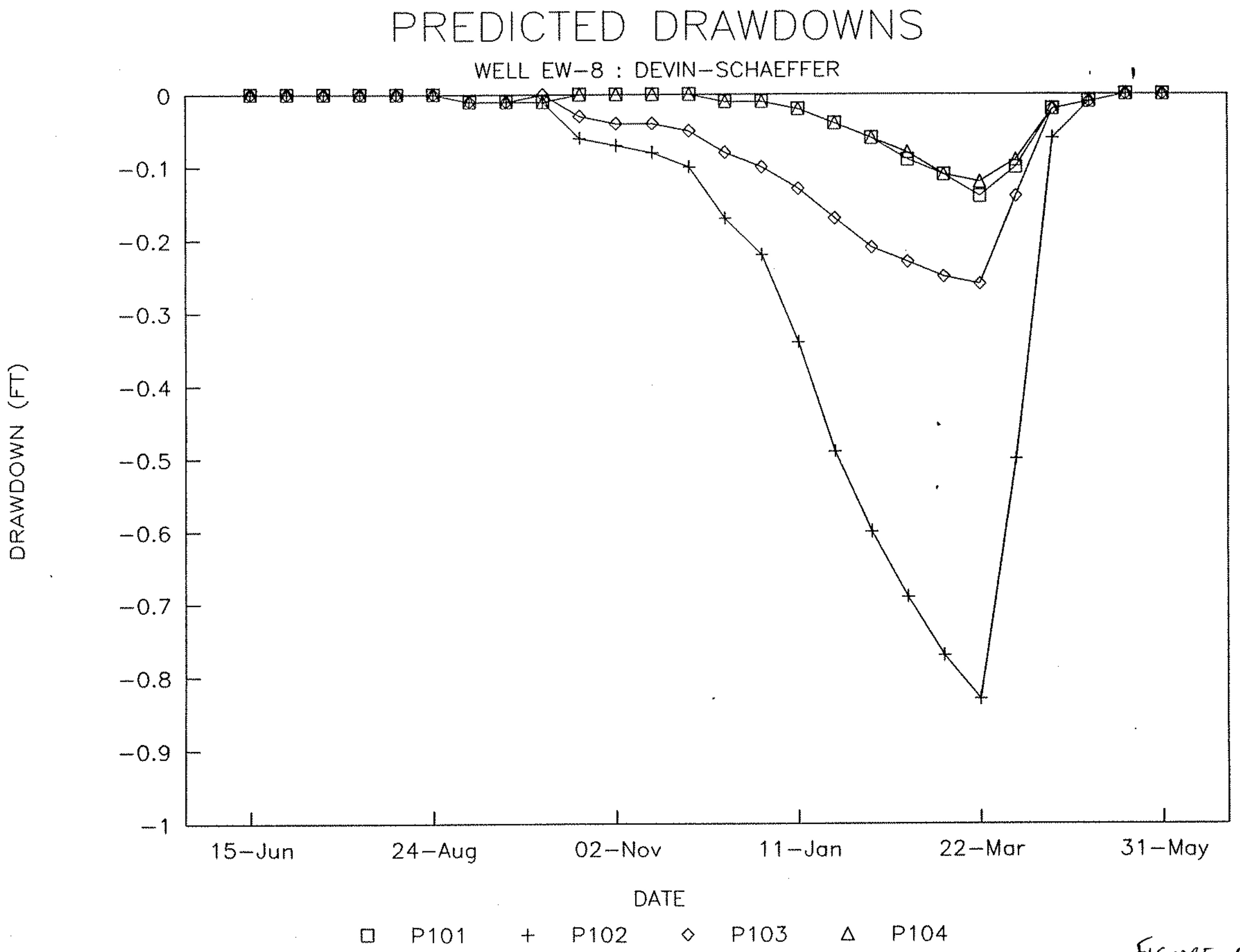

RE-INJECTION SCENARIOS
PERIOD 69 (JAN 25)
STREAMFLOW (CFS)
5
4
3
2
1
0
70
72
74
76
78
80
82
84
86
88
90
RIVER CELL
□ BASE CASE
+ P103
◇ P104
△ P106
× P107
80% return wells
80% return Mazama
100% return Mazama
100% EW Fan
Base Case
Re-injection @ Mazama
Re-injection near wells
Re-injection at Early Winters Fan
Additional Dry reaches (P104, P106)
Additional Dry Reaches (P104, P106)

FIGURE C-8



All Pumping at Early Winters

shift pumping to Cassel Ranch

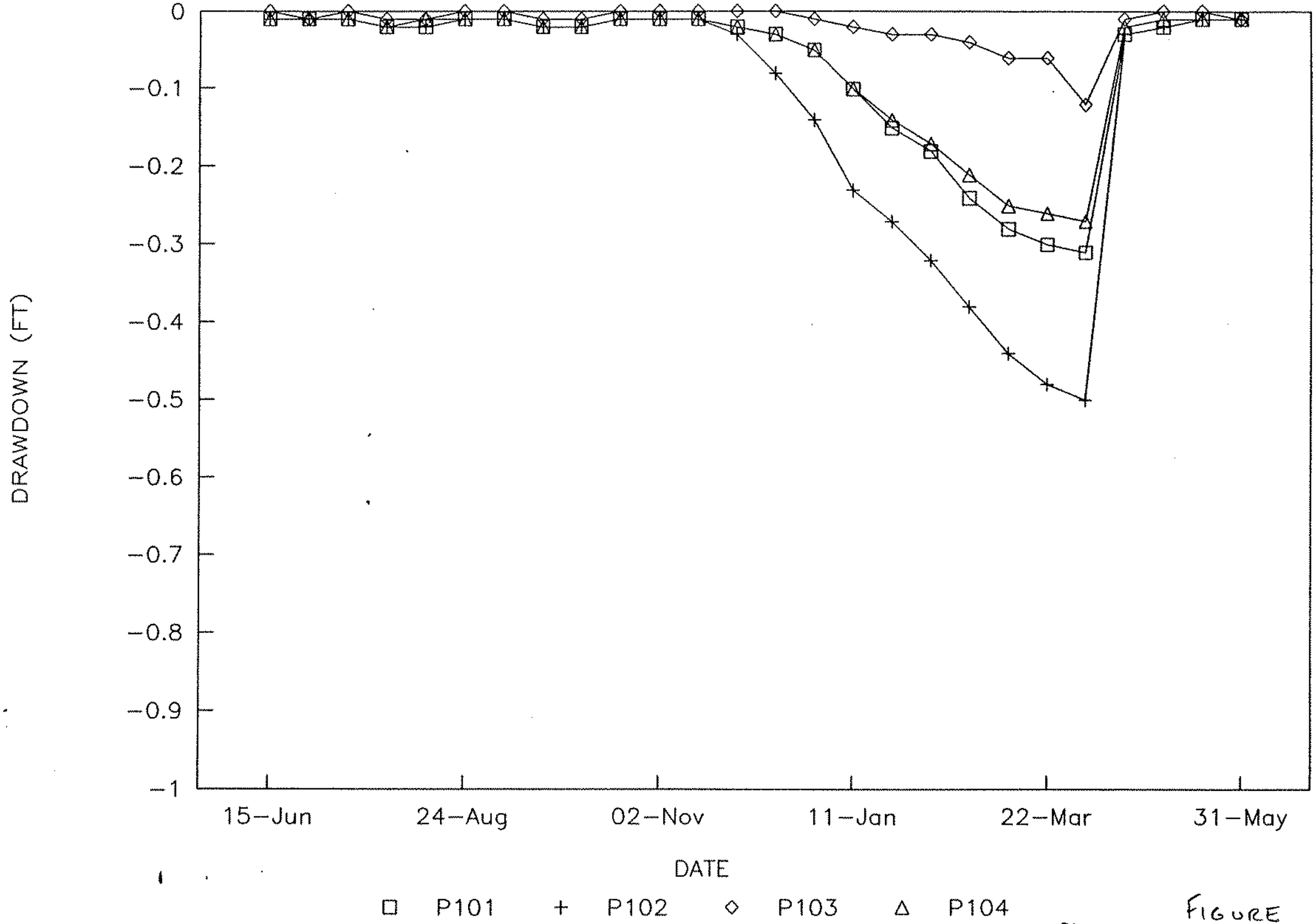
Re-inject 80% near Mazama

Re-inject 80% near wells

FIGURE C-9

PREDICTED DRAWDOWNS

WELL EW-19 : ROBERTS BASE CAMP



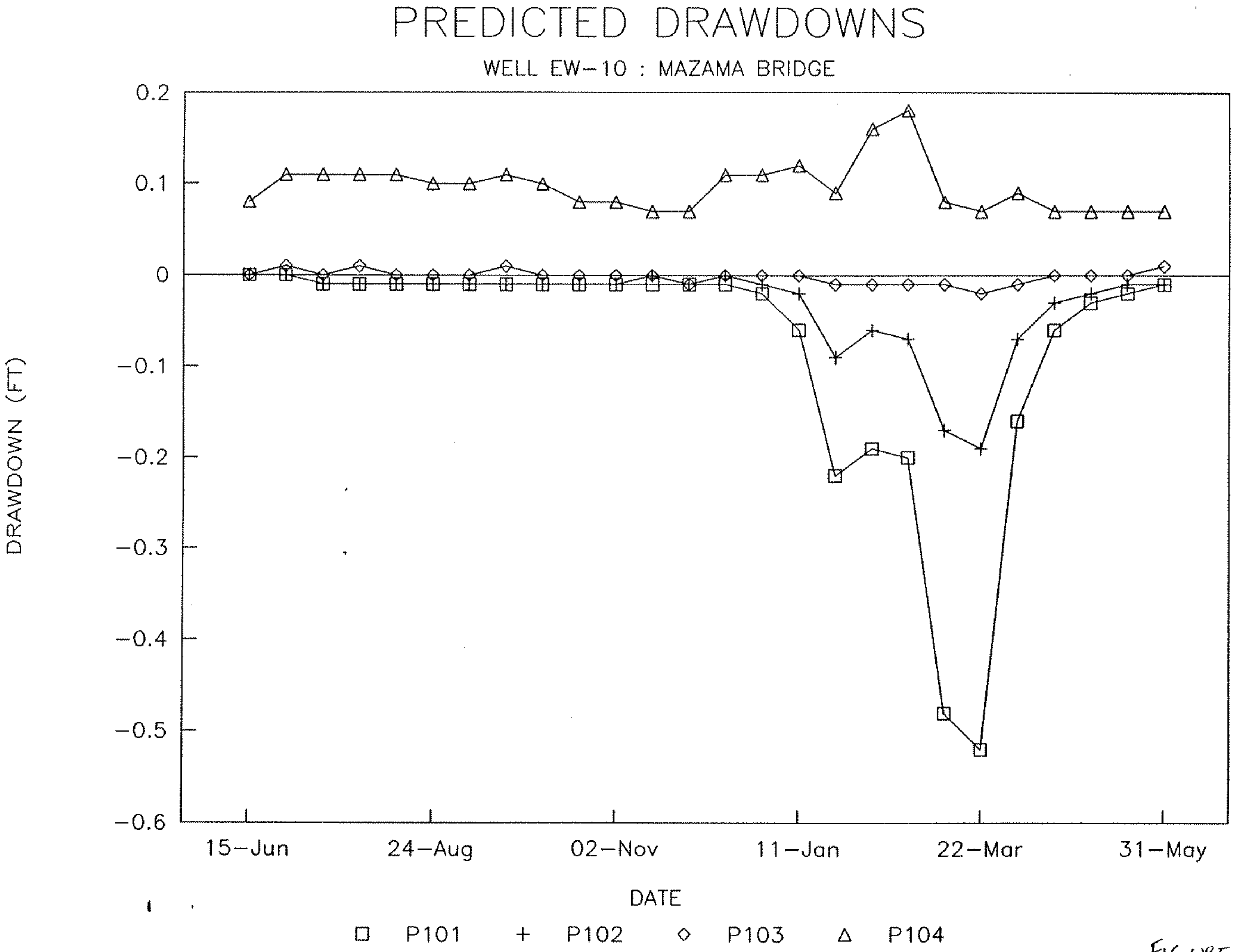
All Pumping at Early Winters

shift pumping to Cassel Ranch

Re-inject 80% near wells

Re-inject 80% near mazama

FIGURE C-10



P101: All Pumping At Early Winters

P102: Shift pumping to Cassel Ranch

P103: Re-inject 80% Near wells

P104: Re-inject 80% near Mazama

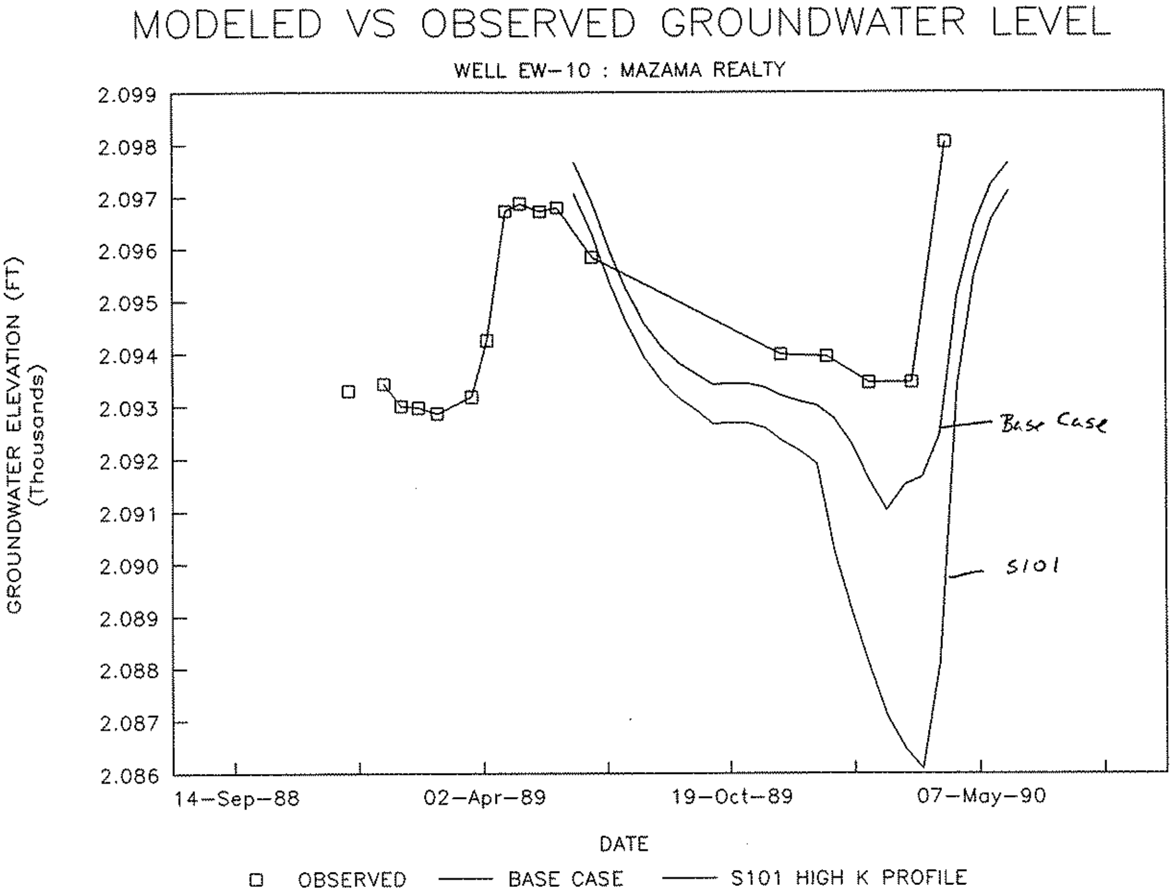
FIGURE C-11

APPENDIX C

PUMPING SCENARIO RESULTS

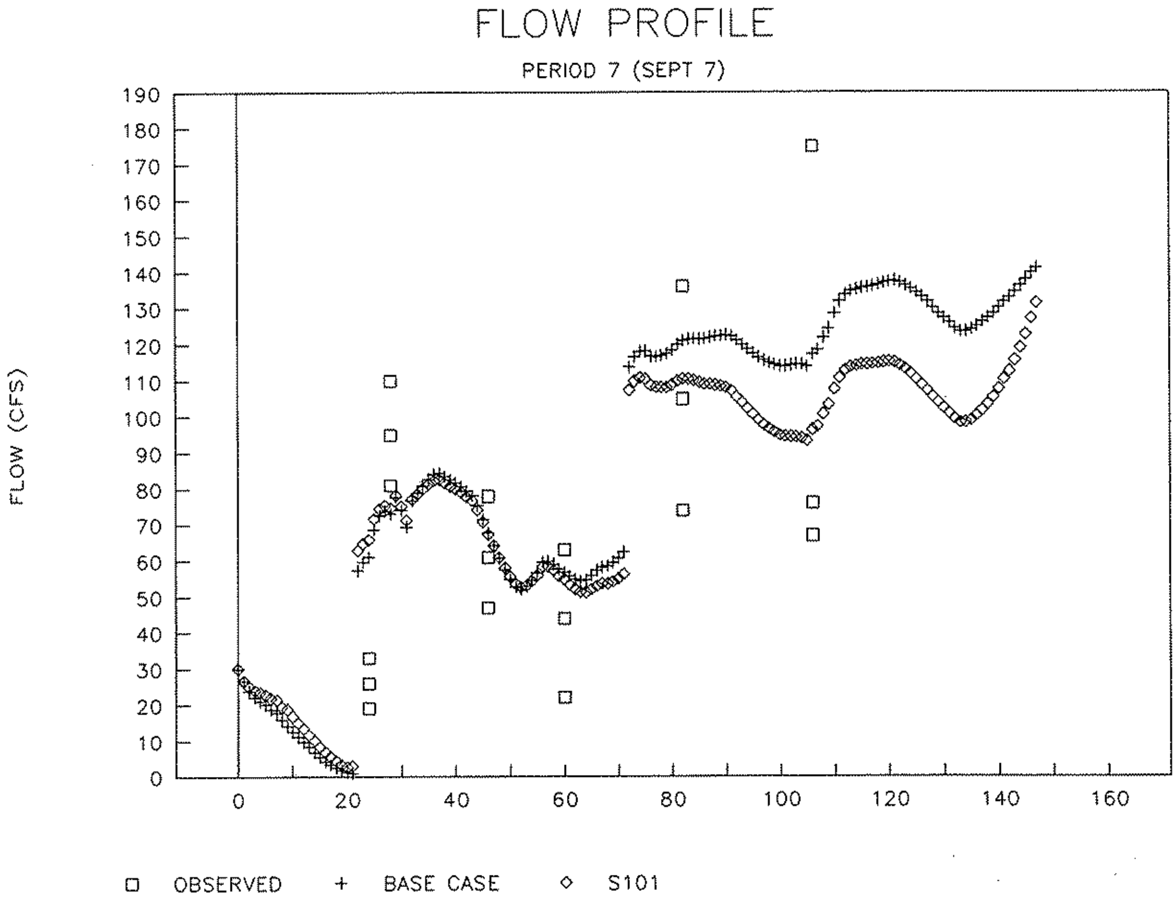
APPENDIX D

SENSITIVITY RESULTS



MODELED VS OBSERVED GROUNDWATER LEVEL

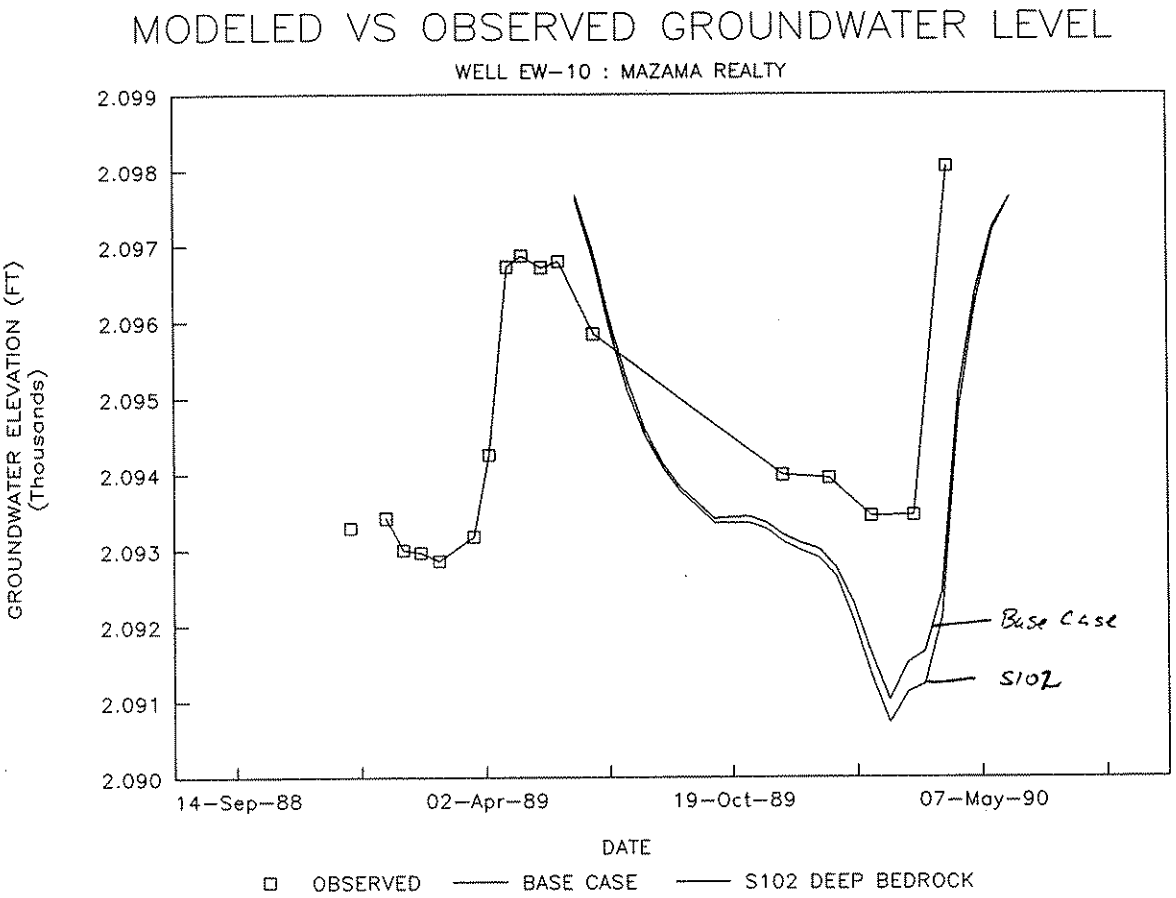
WELL EW-10 : MAZAMA REALTY



FLOW PROFILE

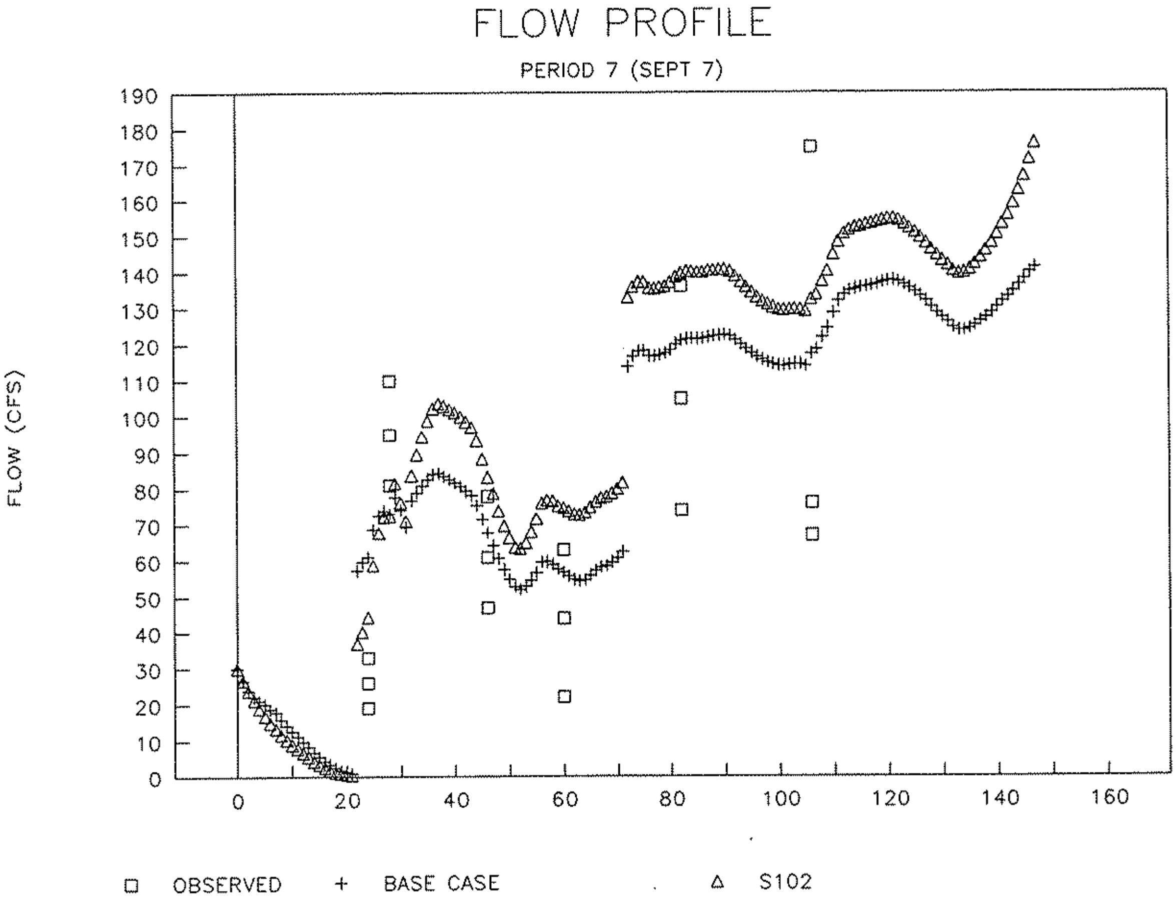
PERIOD 7 (SEPT 7)

Figure D-1



MODELED VS OBSERVED GROUNDWATER LEVEL

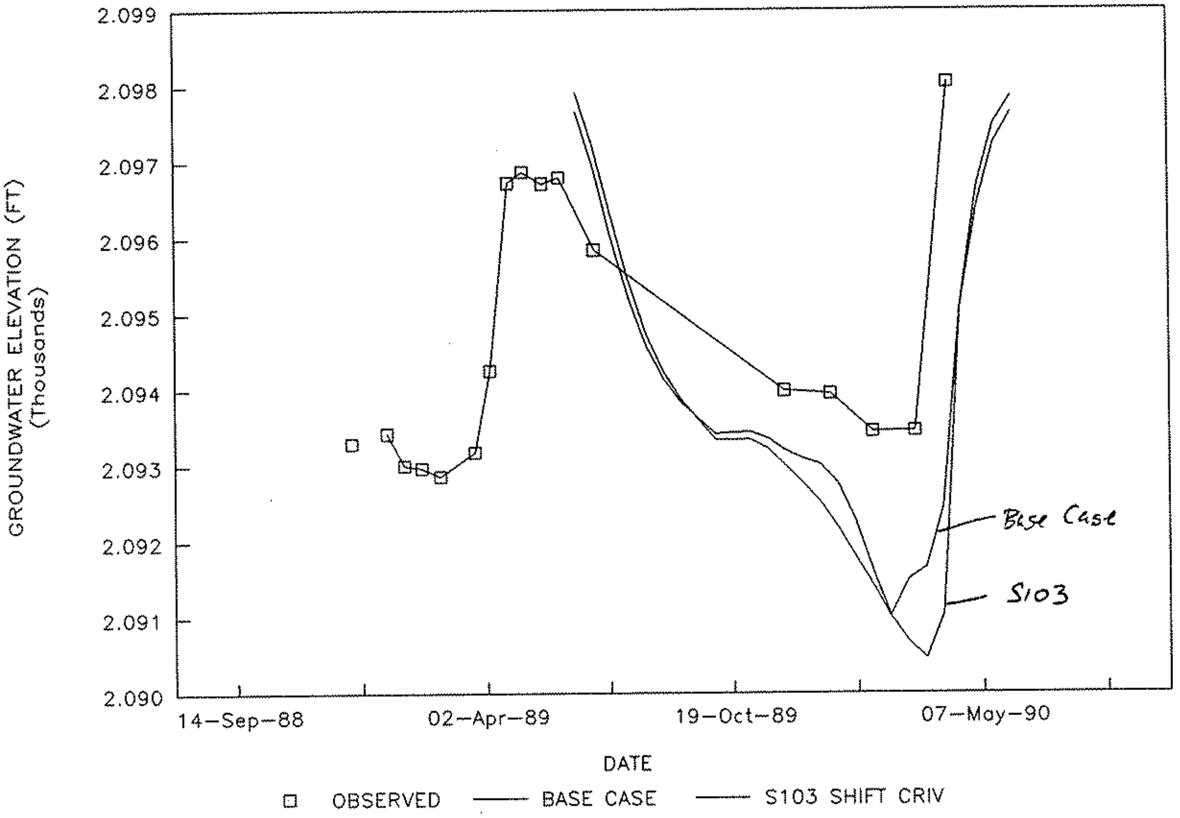
WELL EW-10 : MAZAMA REALTY



FLOW PROFILE

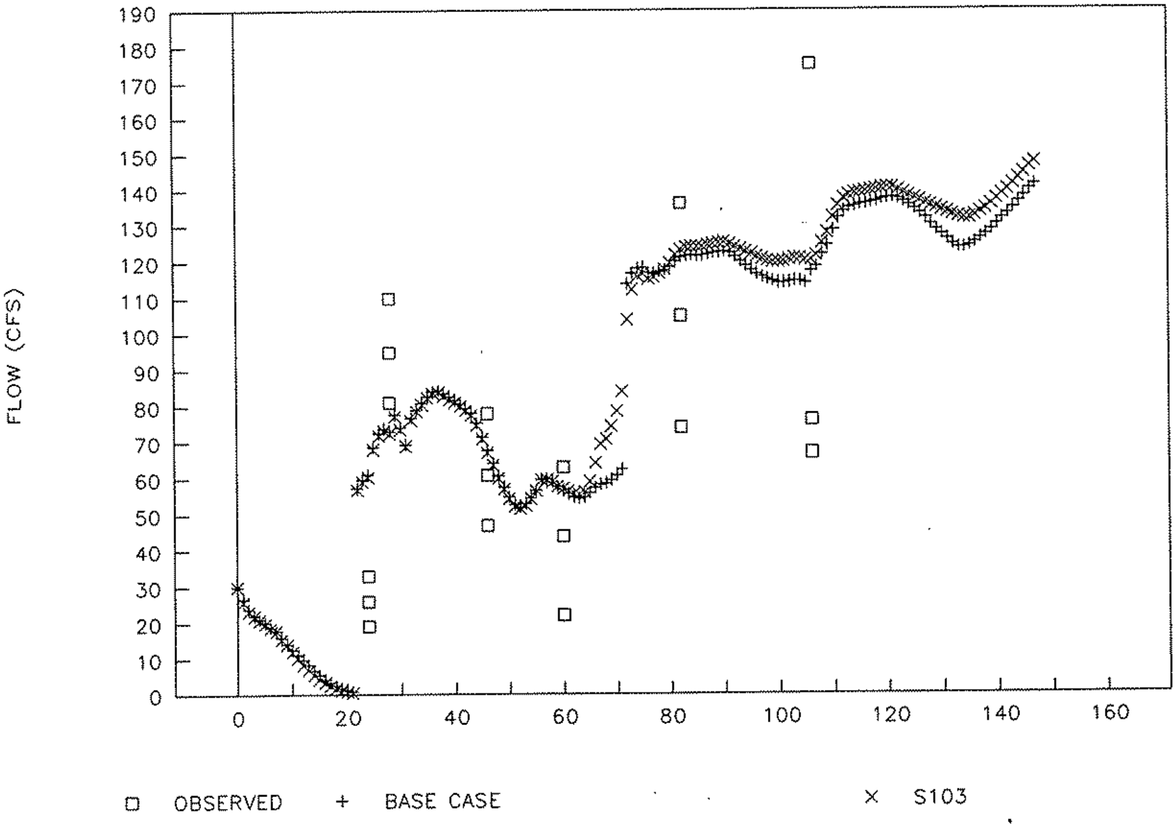
PERIOD 7 (SEPT 7)

FIGURE D.2



MODELED VS OBSERVED GROUNDWATER LEVEL

WELL EW-10 : MAZAMA REALTY



FLOW PROFILE

PERIOD 7 (SEPT 7)

FIGURE D-3

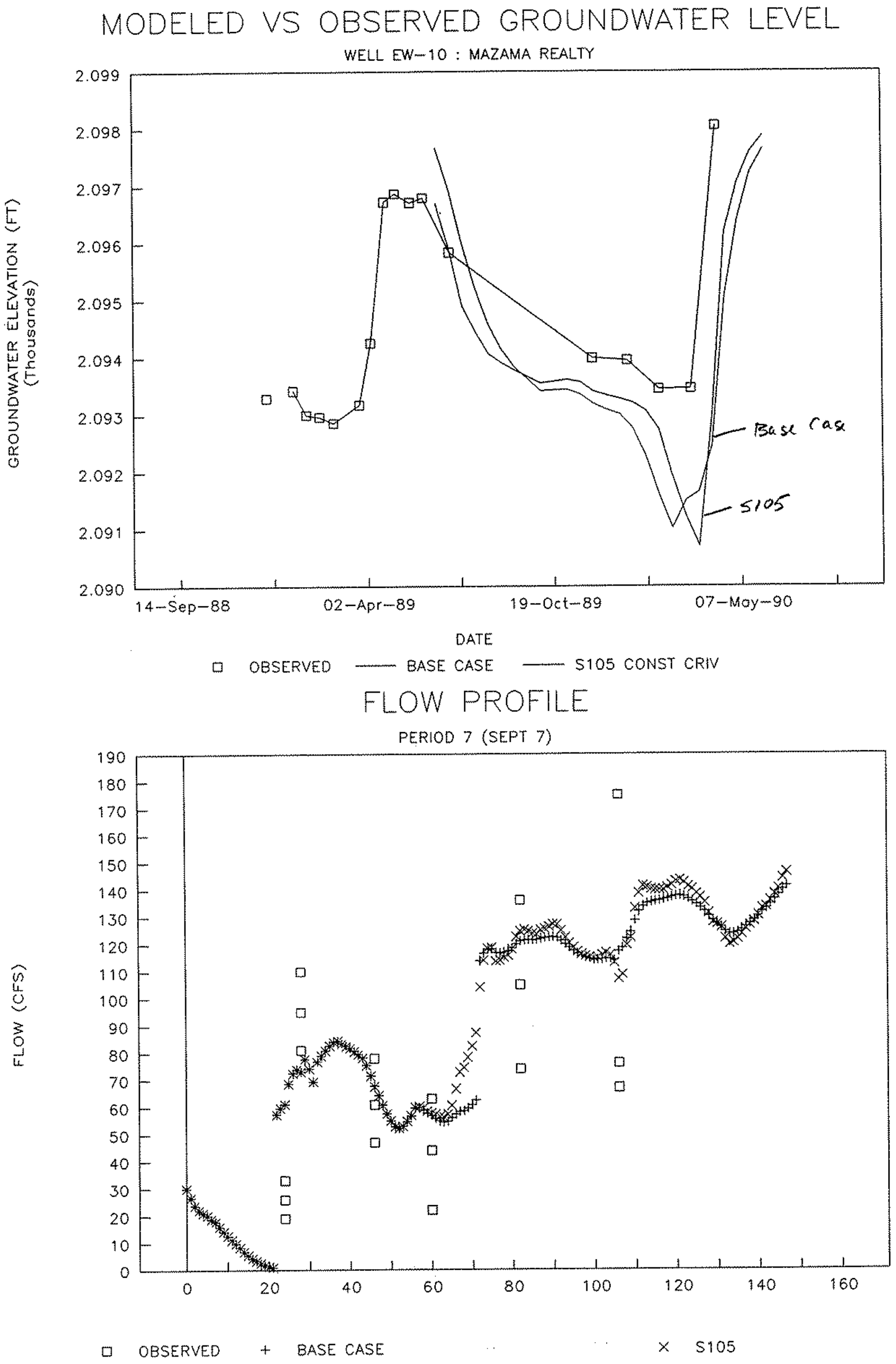
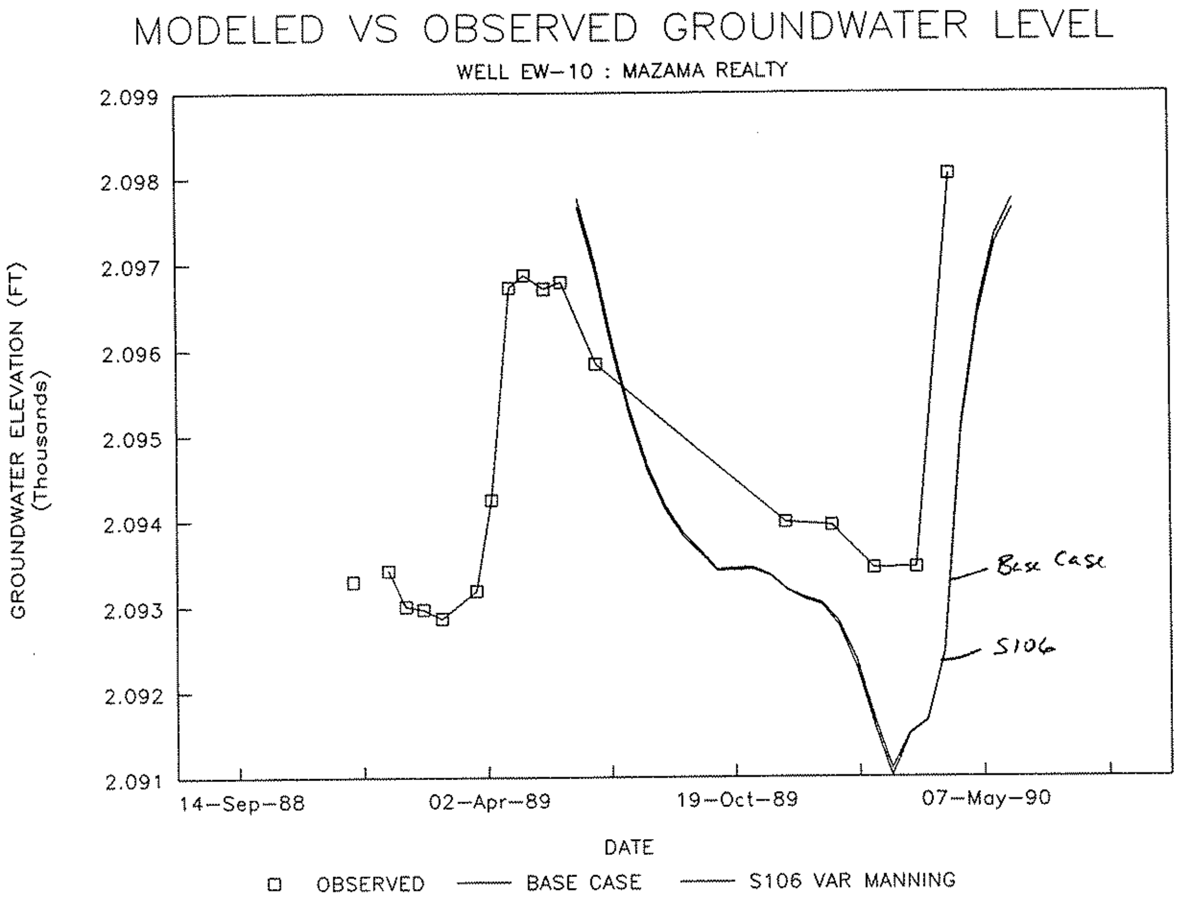
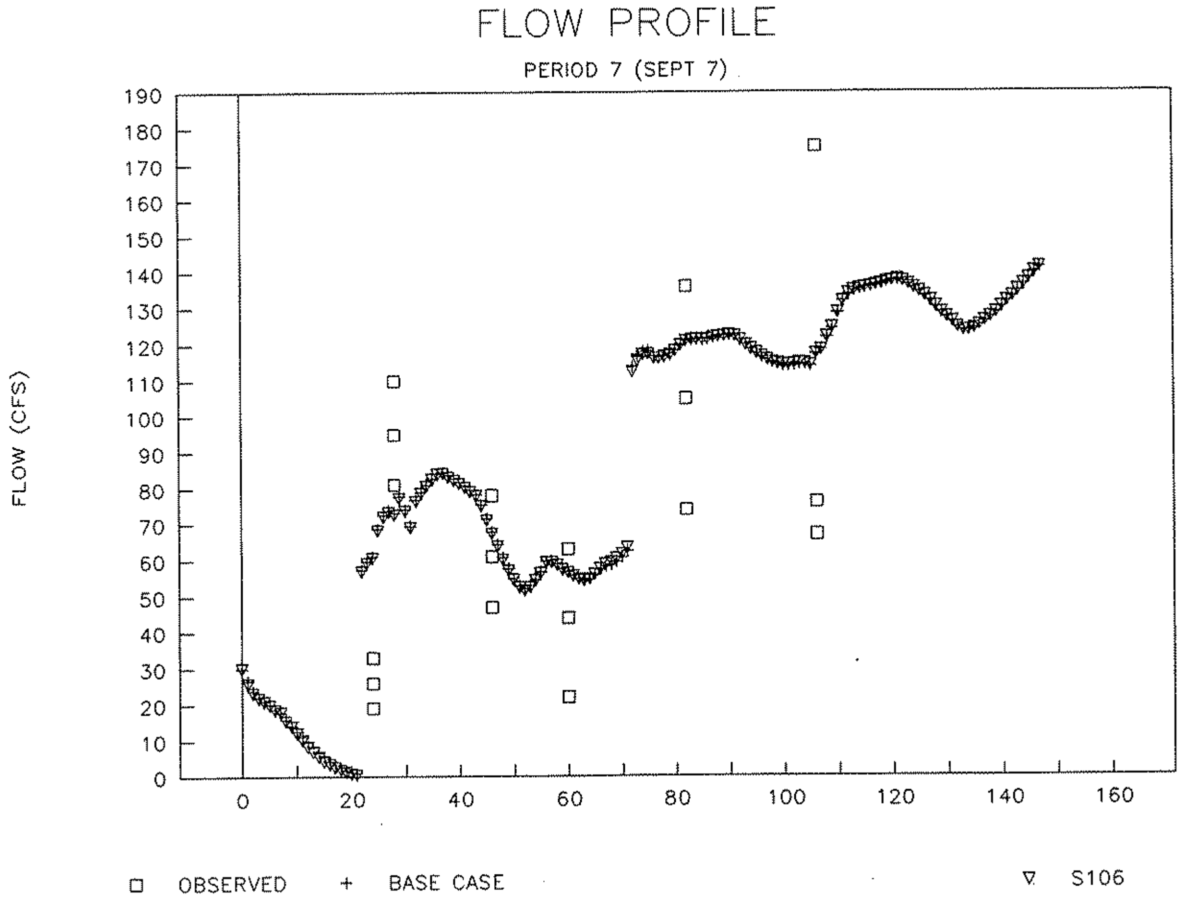

MODELED VS OBSERVED GROUNDWATER LEVEL
WELL EW-10 : MAZAMA REALTY
GROUNDWATER ELEVATION (FT)
(Thousands)
2.099
2.098
2.097
2.096
2.095
2.094
2.093
2.092
2.091
2.090
14-Sep-88
02-Apr-89
19-Oct-89
07-May-90
DATE
Base Case
S105
□ OBSERVED
—— BASE CASE
—— S105 CONST CRIV
FLOW PROFILE
PERIOD 7 (SEPT 7)
FLOW (CFS)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
□ OBSERVED
+ BASE CASE
× S105

Figure D.4

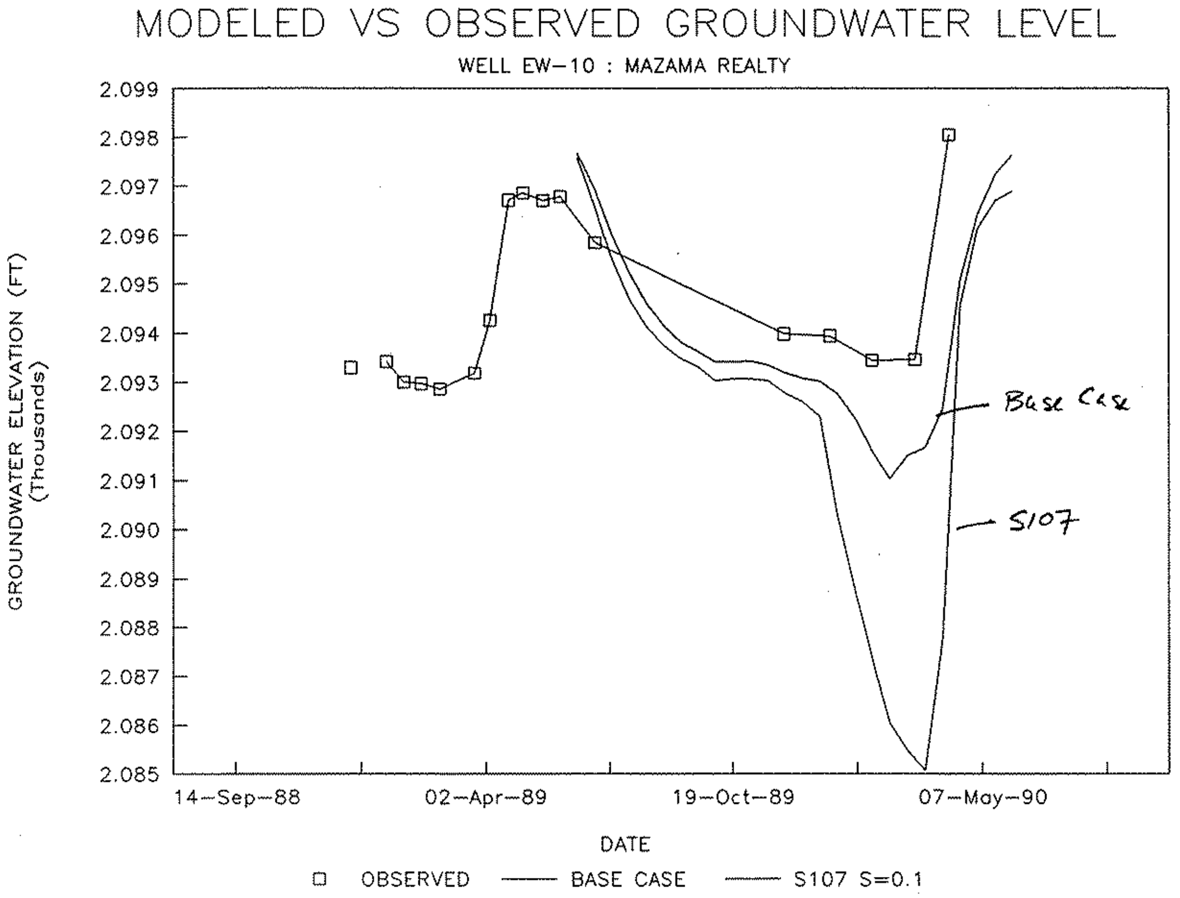

MODELED VS OBSERVED GROUNDWATER LEVEL

WELL EW-10 : MAZAMA REALTY


FLOW PROFILE

PERIOD 7 (SEPT 7)

FIGURE D-5


MODELED VS OBSERVED GROUNDWATER LEVEL
WELL EW-10 : MAZAMA REALTY
GROUNDWATER ELEVATION (FT)
(Thousands)
2.099
2.098
2.097
2.096
2.095
2.094
2.093
2.092
2.091
2.090
2.089
2.088
2.087
2.086
2.085
14-Sep-88
02-Apr-89
19-Oct-89
07-May-90
DATE
Base Case
S107
□ OBSERVED
—— BASE CASE
—— S107 S=0.1

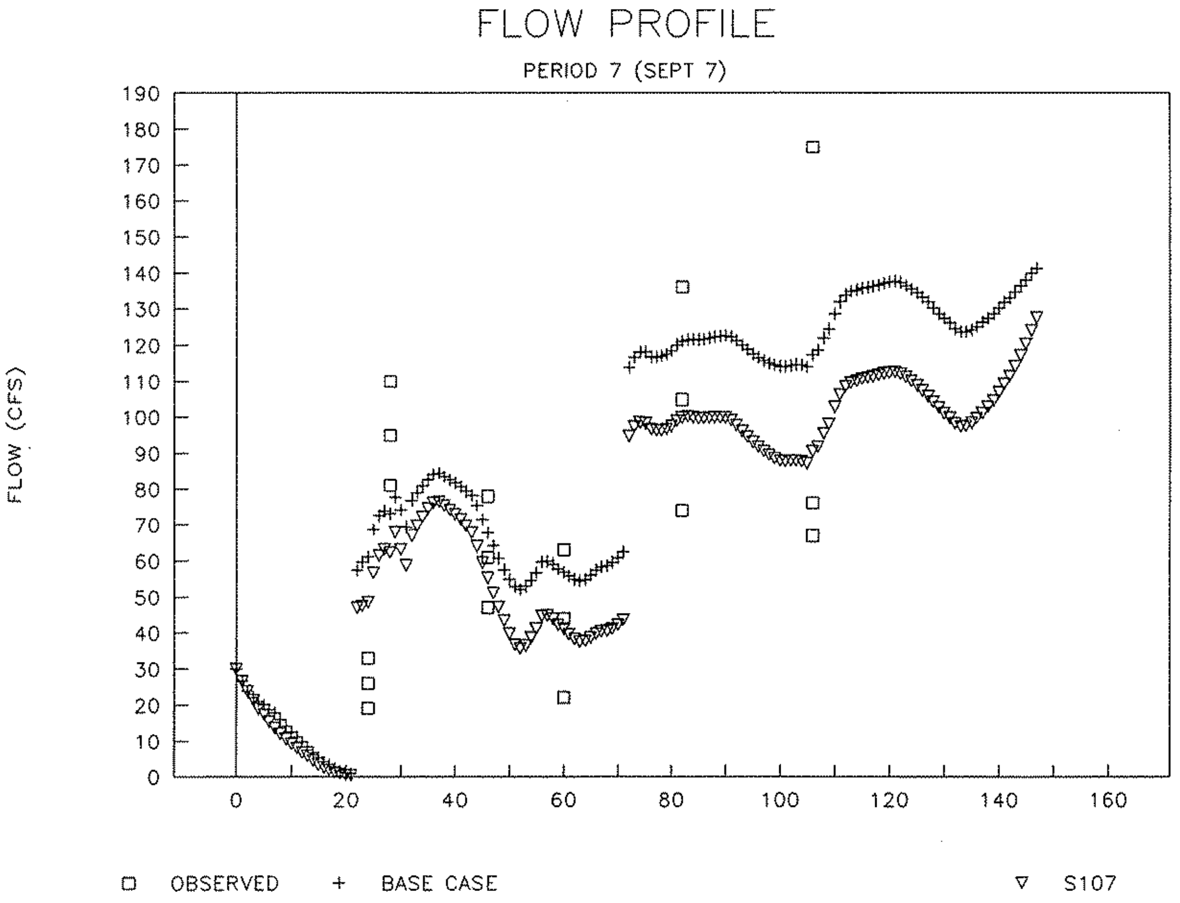
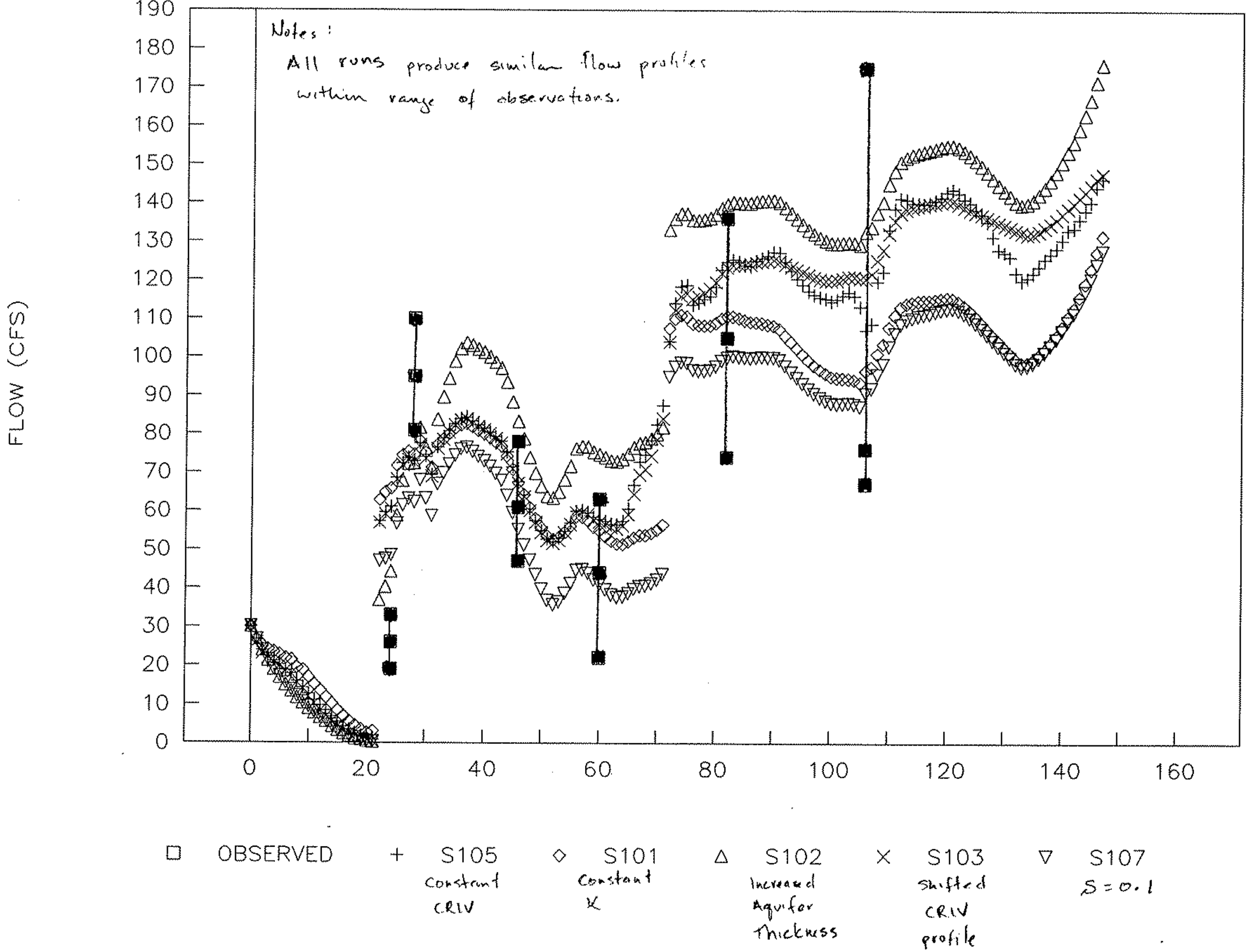

FLOW PROFILE
PERIOD 7 (SEPT 7)
FLOW (CFS)
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
□ OBSERVED
+ BASE CASE
▽ S107

FIGURE D-6

FIGURE D-7

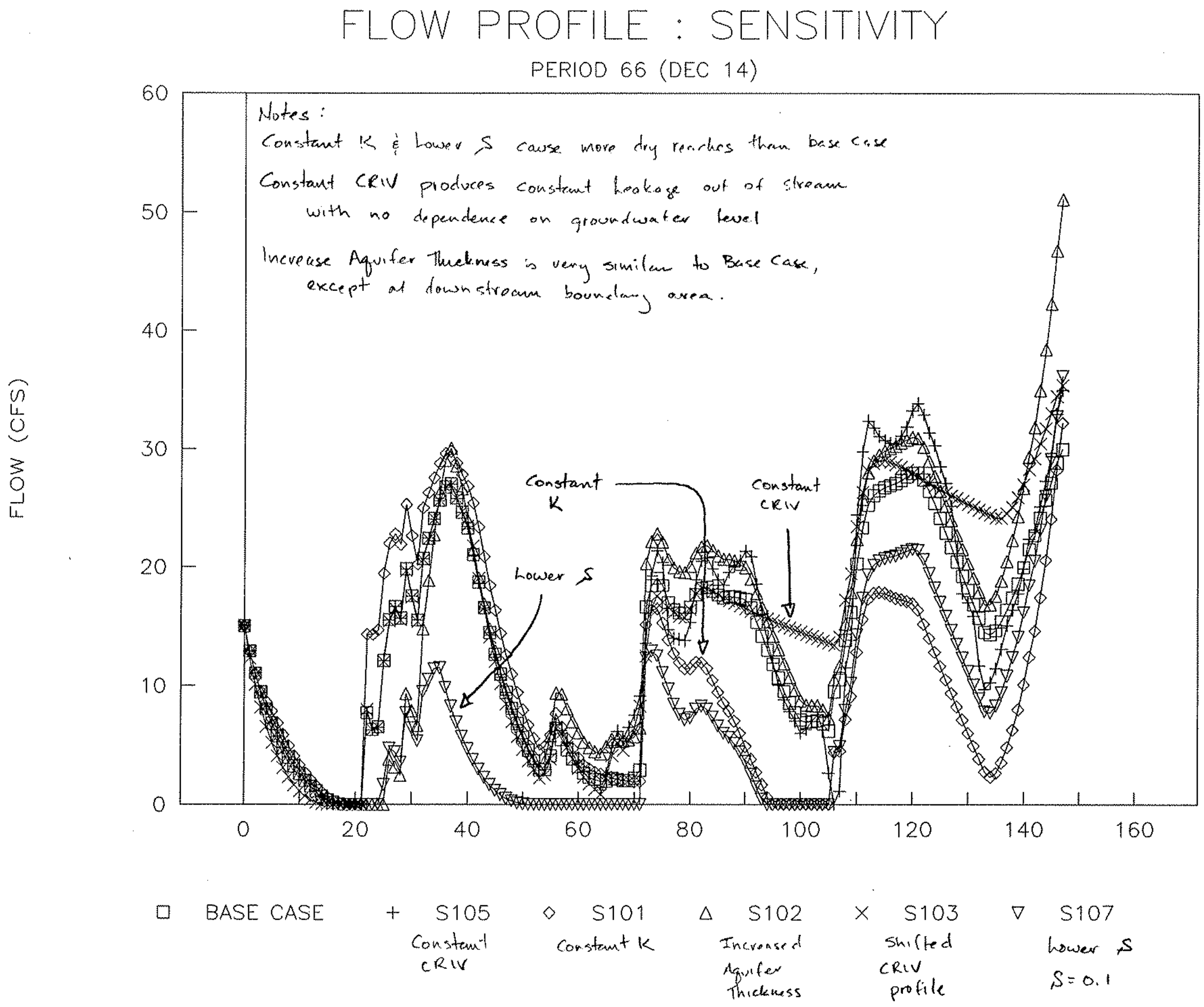
FLOW PROFILE SENSITIVITY

PERIOD 59 (SEPT 7)



Notes:
All runs produce similar flow profiles within range of observations.

FIGURE D-8



Notes:

Constant K & Lower S cause more dry reaches than base case

Constant CRIV produces constant leakage out of stream
with no dependence on groundwater level

Increase Aquifer Thickness is very similar to Base Case,
except at downstream boundary area.