APPENDIX D, Hydrology & Hydraulics

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Additional Water Storage Project, Draft Feasibility Report & EIS

Howard Hanson Dam,
Green River, Washington
April 1998

prepared by
Seattle District

US Army Corps of Engineers®

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Part D1, Hydrology

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APPENDIX D
HYDROLOGY AND HYDRAULICS
PART 1 — HYDROLOGY

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SECTION 1 INTRODUCTION

1.1 PURPOSE AND SCOPE OF PART 1

This portion of the Hydrology and Hydraulics Appendix, Part 1, Hydrology, provides hydrological background for the proposed use of additional conservation storage at Howard A. Hanson Dam. The work is intended as input to study benefits and impacts to the reservoir area and Green River downstream from the dam. A physical description of the Green River basin and operation of Howard Hanson Dam (HHD) can be found in the main report. This hydrology appendix does not repeat the physical description; it primarily documents the water management scheme known as Scenario #7 for refill, water supply, and low flow augmentation of additional storage as overlain on the existing storage of the project. The target demand flows are shown along with the reliability analysis of attaining the targets. Example years are then shown on how the reservoir delivers water to the downstream demands. An introduction to reservoir routing computations shows the simplicity of the two control-point system, but also the complexity of trying to describe the entire seasonal operation within a single model. The expertise of hydrologists, biologists, and water resource planners are all needed to effectively plan and carry out the operation of additional storage.

SECTION 2 CHRONOLOGY OF EVENTS AFFECTING STREAMFLOW

2.1 GENERAL

A chronology of events that affect the quantity and measurement of streamflow in the Green River was compiled in a report titled, "Hydrologic Summary for the Green River Restoration Reconnaissance Report." A pertinent selection of events are compiled into the Table D1-1.

TABLE D1-1. CHRONOLOGY OF EVENTS AFFECTING STREAMFLOW

Date	Streamflow Event
1913	Diversion of 113 cfs by City of Tacoma for water supply.
Oct. 1931	Begin record of streamgage, "Green River near Palmer."
1933	Tacoma registered a water right claim for 400 cfs from Green River.
Aug. 1936	Begin record of streamgage, "Green River near Auburn."
Oct. 1961	Begin record of streamgage, "Green River below Howard A. Hanson Dam."
Dec. 1961	Begin record of streamgage, "Howard A. Hanson Reservoir near Palmer."
Dec. 1961	Begin flood control & conservation storage operation of HHD.
June 1963	End record of streamgage, "Green River near Palmer."
July 1963	Begin record of streamgage, "Green River at Purification Plant near Palmer."
1977	Tacoma completes well field in North Fork valley that can pump 112 cfs.
April 1980	Washington State establishes instream flows at Palmer and Auburn.
July 1995	Establishment of Tacoma and Muckleshoot Agreement for diversion & flows.
March 1996	Environmental Assessment of Sec. 1135 F&W Restoration at HHD

There are some significant points that relate the historical changes and measurement of streamflows on the Green River to the Additional Water Storage (AWS) study.

2.2 EXISTING WATER SUPPLY DIVERSION

The main source of water for the City of Tacoma is the Green River. Diversion of water from this source began in year 1913 at a rate of about 31 cfs. Tacoma Water Division has expanded the diversion according to need so that by 1955, approximately 112 cfs was being diverted. The diversion takes place about 30 miles east of Tacoma near Palmer. The drainage area tributary to the intake point contains 231 square miles. Surface water is diverted from the Green River by means of a concrete dam 17 feet high and 152 feet long.

The intake structure at the north end of the dam carries water through a short tunnel into a settling basin. From the basin, water is conducted by gravity through the transmission line to McMillin Reservoir near Puyallup and then into the City. Two well systems contribute to this system. One of these, the In-City well field in South Tacoma, is principally used for peaking purposes. The other, along the North Fork of the Green River, is used when turbidity conditions in the Green River make its water unacceptable for consumption. The only treatment provided to the Green River water is disinfection. Water filtration is not required due to the availability of high quality water with low turbidity from the protected watershed.

2.3 EXISTING HOWARD HANSON RESERVOIR

Howard Hanson Dam is located on the Green River 35 miles southeast of Seattle, 25 miles east of Tacoma, seven miles upstream from Kanaskat. The dam itself is at river mile 64.5. The project lies entirely within the City of Tacoma municipal water shed and is closed to the public. The embankment is 235 feet high and 500 feet long. The river passes through a 900-foot-long, 19-foot-diameter outlet tunnel. The tunnel is controlled by two 10-foot wide by 12-foot high regulating tainter gates at the bottom of the reservoir pool. Low-flow releases during the summer conservation period are made through a 48-inch bypass intake located about 35-feet above the bottom of the pool. This outlet has capacity of approximately 500 cfs at maximum conservation pool. Construction was complete in 1962. The reservoir extends approximately seven miles eastward form the dam along the main river channel and four miles northerly up the main tributary of the North Fork of the Green River. The reservoir is normally maintained at minimum level (about elevation 1,070 feet) from the end of October to the end of March to provide flood control storage space. The reservoir provides 106,000 ac-ft of flood control storage at elevation 1,206 feet. Beginning around April the reservoir begins to fill to a maximum pool elevation of 1,141 feet to provide summer and early fall low flow augmentation. At full conservation pool level, the summer/fall reservoir impounds 25,400 ac-ft with a surface area of 732 acres. The reservoir operational goals are to store excess storm flows to prevent winter and spring flooding downstream, and provide additional water from storage for low-flow periods in the summer and fall for conservation of fish resources.

2.4 STREAMFLOW MEASUREMENTS

Green River streamflows below the dam are measured at two locations. The first streamgage is 0.7 miles downstream where the drainage area increases from 220 square miles (at the dam) to 221 square miles. This streamgage is used in water management as the outflow from the reservoir. The period of record for stream measurements started in October 1960. The next streamgage is 4.1 miles downstream from the dam where the drainage area is 231 square miles. This gage is significant because it is 0.7 miles downstream of Tacoma's diversion dam and measures the instream flow after diversion. Stream measurements began at this site near Palmer in July 1963. Prior to July 1963, the gage was at a site 1.8 miles upstream where it measured flow above the diversion since

October 1931. The next and last location of streamflow measurement on the main stem is 32.5 miles below the dam near Auburn where the drainage area is 399 square miles (1.8 times the drainage basin size at the dam). The table below provides the locations of the streamgages. The relatively high average discharge per square mile in the vicinity of the damsite makes this a more efficient location for water supply than the other locations.

STREAMGAGE LOCATIONS AND AVERAGE DISCHARGE

Location	River Mile	Square Mile Area	Average Discharge	Avg. Disch. per Sq. Mile
H.A. Hanson Reservoir near Palmer	64.5	220	n/a	
below H.A. Hanson Reservoir	63.8	221	1008	4.6
at Purification Plant, near Palmer (near diversion site)	60.3	231	1067	4.6
Newaukum Creek near Black Diamond	0.8	27.4	60.4	2.2
Big Soos Creek near Auburn	0.9	66.7	126	1.9
Green River near Auburn	32	399	1439	3.6

2.5 TACOMA WELLS

Tacoma completed the installation of a well field along the North Fork of the Green River in 1977. When turbidity levels on the Green River exceed 5 NTU, the surface supply is supplemented by the North Fork well supply. The well field consists of 6 wells spaced between 250 and 300 feet apart. This releases the pressure on Tacoma's first water supply diversion to be in service during a high percentage of the time. The wells (combined with other sources) also allow Tacoma to plan for future water sources that have less than a "firm" (100%) flow reliability. The wells are capable of providing approximately 112 cfs at times when there is no surface flows available from the river. This well field is not capable of supporting a sustained yield at the rates provided by the Green River during the high summer consumption period. Details on well operation are beyond the scope of this report, but can be found in Tacoma's reports on their Water System Plan.

2.6 WASHINGTON STATE INSTREAM FLOWS

In April 1980, the State of Washington Department of Ecology established administrative rules and instream flows at both the Palmer and Auburn gages according to their Instream Resources Protection Program for the Green-Duwamish River Basin. Future water right holders subject to regulation will not be allowed to continue diversion when flows fall below the instream flows. This also applies to diversion of natural flow at HHD reservoir to storage under future water rights.

The instream flows provide varying degrees of protection levels. Instream flow hydrographs have been developed for two locations in the Green River Basin. Normal and critical year curves are supplied for the Palmer station only. They are intended to apply to the proposed future release schedule of HHD to the extent practically and legally possible and an additional water supply diversion proposed by the City of Tacoma. Management of the normal and critical year curves will be the responsibility of the director or his designee, and violation of these flows or levels will only be allowed if overriding public interest will be served.

The presence of HHD on the Green River creates potential opportunity for additional future stored waters and future water rights. The instream flow program recognizes that impoundment of surface waters in Hanson Reservoir is an available means of appropriating additional water resources in the Green River Basin. Though the dam is a federal project, and is exempt from state control, the *use* of stored waters is subject to the state's authority in issuing water rights. A secondary application will be required for parties applying for beneficial use of water stored in a reservoir. Such a secondary application must refer to the reservoir as its source of water supply and show documentary evidence that an agreement has been reached with the owners of the reservoir to impound enough water for the purposes of the application.

INSTREAM FLOW CONTROL LOCATIONS

Control Location	USGS Gage Number	River Mile	Stream Management Reach
Green River near Auburn	12113000	32.0	From influence of mean annual high tide at low instream flow levels (approximately River Mile 11.0) to USGS Gage #12106700
Green River near Palmer	12106700	60.4	From USGS Gage #12106700 to headwaters.

INSTREAM FLOWS FOR FUTURE WATER RIGHTS IN THE GREEN RIVER BASIN

Month	Day	12113000 Normal Year Green River near Auburn	12106700 Normal Year Green River near Palmer	12106700 Critical Year Green River near Palmer
Jan.	1	650	300	300
	15	650	300	300
Feb.	1	650	300	300
	15	650	300	300
Mar.	1	650	300	300
	15	650	300	300
Apr.	1	650	300	300
	15	650	300	300
May	1	650	300	300
	15	650	300	300
June	1	650	300	300
	15	650	300	210
July	1	550	150	150
	15	300	150	150
Aug.	1	300	150	150
	15	300	150	150
Sept.	1	300	150	150
	15	300	150	150
Oct.	1	300	190	150
	15	350	240	150
Nov.	1	550	300	190
	15	550	300	240
Dec.	1	650	300	300
	15	650	300	300

2.7 AGREEMENT BETWEEN MUCKLESHOOT INDIAN TRIBE AND TACOMA

In 1995, a written agreement was reached between the Muckleshoot Indian Tribe and the City of Tacoma regarding the Green/Duwamish river system. The Muckleshoot Indian Tribe is a federally recognized Indian tribe who has rights and responsibilities for the management of fish and wildlife resources and other natural resources of the Green/Duwamish river system. The City of Tacoma is the owner and operator of the municipal water system downstream of HHD through its Department of Public Utilities, Water Division. The agreement settles Muckleshoot claims against Tacoma arising out of Tacoma's municipal water supply operations on the Green River, including Tacoma's First and Second Supply Water Right diversions. The agreement establishes the commitment and framework for a long-term cooperative working relationship between the Muckleshoot Indian Tribe and Tacoma concerning the Green River. The Corps is not a party to the agreement; however, the Corps considers the instream flow requirements and other conditions of the Green River during its water management operations.

By management of its water supply diversions, Tacoma will provide the following minimum continuous instream flows which will vary with weather conditions during the summer months. The determination of wet, average, dry, and drought weather conditions is aided by the use of reference zones within HHD reservoir that show available storage by date. The tabulation of the zones is too detailed for use in this appendix and is available in the Hydraulics and Hydrology Branch of the Corps' Seattle District office. Before a decision is made to drop the instream flows from 250 to 225 cfs, consultation among the Resource Agencies, Muckleshoot Indian Tribe, Corps of Engineers, and Tacoma will explore alternatives to lowering the minimum continuous instream flow.

AUBURN INSTREAM FLOW BY WEATHER CONDITION

Summer Weather Condition	Auburn Instream Flow
Wet Years	350 cfs
Wet to Average Years	300 cfs
Average to Dry Years	250 cfs
Drought Years	250 to 225 cfs depending on the severity of the drought

Tacoma will meet the continuous instream flow requirements at Auburn and Palmer whenever it is withdrawing water from the Green River with its Second Supply Water Right (SSWR) diversion. To the extent that these instream flow requirements are greater than the State Instream Flows, these instream flow requirements control the diversion action.

PALMER INSTREAM FLOW BY SEASON

Season by Dates	Palmer Instream Flow
July 15 to September 15	200 cfs
September 16 to October 31	300 cfs
November 1 to July 14 (all other days of the year)	300 cfs (same as the State Instream Flow)

AUBURN INSTREAM FLOW BY SEASON

Season by Dates	Auburn Instream Flow
July 15 to September 15	400 cfs
for other days of the year	refer to Instream Flow by Weather Condition

The agreement acknowledges that the operation of HHD for fish conservation is designed to protect against a drought that has a probability of occurrence of one in fifty years. While maintaining that standard, the parties agree that the operations should be modified during the summer to provide additional flows in the Green River for fish. Tacoma agrees that if the Corps modifies existing operations of HHD to release more water during the summer months and if fall precipitation does not occur in sufficient quantities to meet the instream flow requirements of the MIT/Tacoma agreement, Tacoma will restrict its withdrawals of water from the Green River by its First Diversion to allow the Corps to recoup water required to maintain its federally mandated minimum instream flows. Tacoma may rely on its well capacity to meet its demand requirements during the period it restricts its Green River withdrawals.

For future diversions, the agreement states that Tacoma will not pursue any further diversion of the Green River from May through October of any year before the completion of the HHD Additional Storage Project. If the additional storage project is approved, Tacoma will apply for a storage right for water stored at HHD as well as a diversion right to make use of that additional stored water.

The "Agreement between the Muckleshoot Indian Tribe and the City of Tacoma Regarding the Green/Duwamish River System (MIT and TPU Agreement)" is one of the last steps before construction starts on Tacoma's SSWR diversion pipeline 5. The SSWR diversion pipeline is not part of the additional storage study; it becomes part of the baseline conditions. The MIT and TPU Agreement provides an elaborate set of rules and conditions that must be met before water can be diverted to the SSWR diversion pipeline. The MIT and TPU Agreement also includes special conditions to use groundwater withdrawal as a trade-off for withdrawal by the first diversion pipeline according to seasonal operating zones defined for Hanson Reservoir. The MIT and TPU Agreement exists outside the realm of the Additional Storage Study, it does not specify any release of stored water at Hanson Reservoir. The Agreement does mention that Tacoma will pursue the sponsorship of approximately 5,000 ac-ft for low-flow augmentation during drought years.

2.8 SECTION 1135 RESTORATION STORAGE

The Environmental Assessment of the Section 1135 Fish and Wildlife Restoration Project was in a preliminary draft form as of September 1997. The selected plan at this time included a modification of Hanson storage operations with the intermittent addition of 5,000 acre-feet (ac-ft) to its conservation storage during years of low snowpack, estimated to occur approximately once every 5 years. Although the restoration project is still under review, there is a very good likelihood that the storage modification will become approved and implemented prior to the implementation of the additional storage project. The potential extra storage is even included in some of the provisions of the Muckleshoot and Tacoma Agreement.

All of the features in the listed above are considered "existing conditions" just prior to the implementation of the additional storage and its operating conditions. Instream flows observed in the past are *not* existing conditions because they do not include diversions to the SSWR pipeline and restoration flows provided by the additional 5,000 ac-ft of storage. A detailed description of the Green River system operation that includes the MIT and TPU Agreement and Section 1135 Restoration Project is to be provided by Tacoma's engineering consultant.

SECTION 3 DATABASE

Streamflow data for the additional storage study was determined in an earlier phase of the study. An engineering consultant took information from the Green River and other stream gages and published an analytical report, "Stochastic Modeling and Generation of the Inflows to Howard Hanson reservoir." This work resulted in a 70-year time sequence of semi-monthly inflows to the reservoir, 1913-1983. Figure 1 shows a time-series graph of the discharges that illustrates the cyclic nature of the runoff that is high in the winter and low in the summer. During the National Drought Study in 1990-1992, the data was updated through 1992 and changed to a weekly time-step. The semi-month data was used during plan formulation. The weekly data was used to illustrate the use of the storage and application of water deliveries downstream of the dam. A summary hydrograph for the average and minimum inflows is shown in Figure 2. This represents natural flow of the Green River at the location of HHD prior to the influence of storage and diversion. The peak flows in the winter are caused by precipitation. The surge in April and May is caused by snowmelt. The minimum flows are a result of little or no rain. There still is a surge in April and May from a minimal snowpack. Low flows occur between mid-July and mid-October on the average. During extremely low flows, the low-flow season is longer, between June and November.

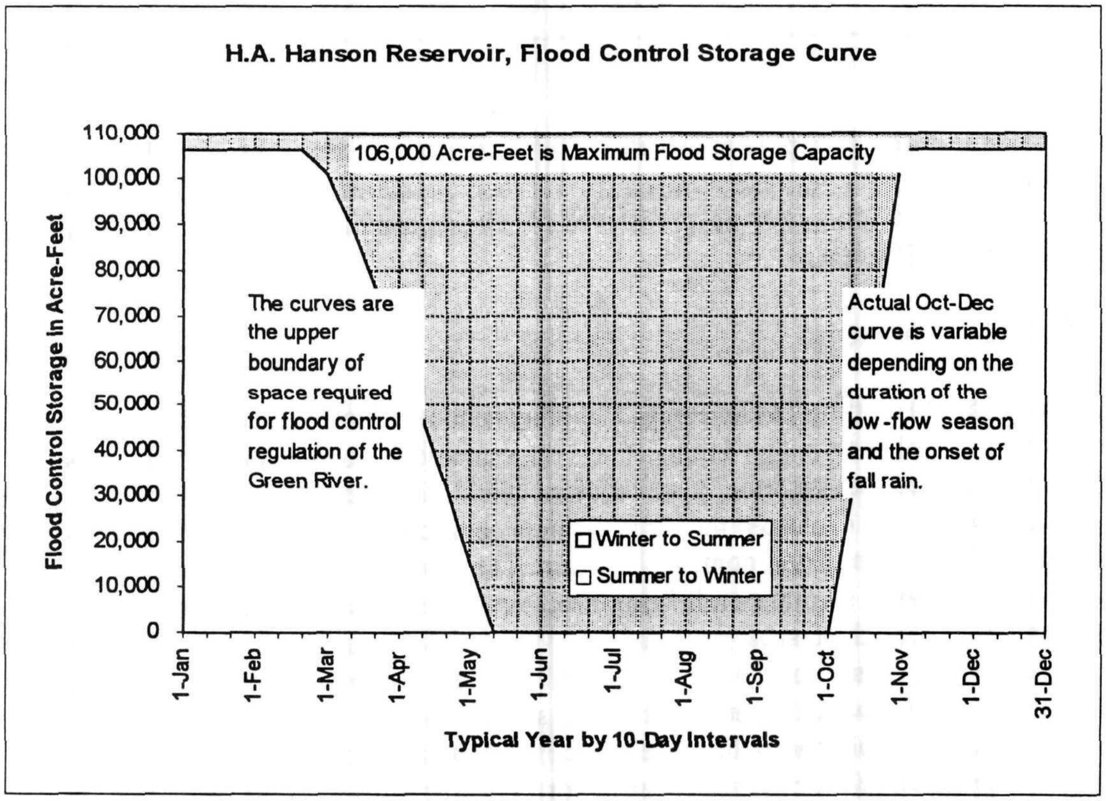
Snowmelt is an important component of the inflow discharge during the spring. Snowmelt comes from the snowpack in the headwaters as the freezing level rises during the spring. The remaining snowpack is observable by climatological gages and predictable in terms of overall quantity. Snowmelt is not separated from the inflow during this study, but the average snowpack accumulation and depletion is shown below for comparison with other hydrologic parameters.

SECTION 4 EXISTING STORAGE

The reservoir is normally kept near elevation 1070 feet during the winter time. This is essentially the zero point for reservoir refill and reservoir drawdown. The total reservoir storage of 106,000 ac-ft at full pool is reserved for flood control operations. The elevation of this storage is 1206 feet.

4.1 FLOOD CONTROL

Storage of 106,000 ac-ft up to elevation 1206 feet is allocated for flood control from approximately October through March. This is the same flood control space as described in the original project description. Space requirements during the transition months, October and March are evaluated during real-time conditions to determine the imperative of providing 100% of the flood control allocation. The reservoir is kept as low as possible during the flood season so that runoff from the Green River watershed above the dam can be impounded to keep the discharge at Auburn within 12,000 cfs. Flood control storage space is not needed outside of the winter period because the river channel is adequate to handle runoff from snowmelt, groundwater, and short-duration rain showers that may occur. The flood control zone is illustrated in the accompanying figure. The curves enclose the upper boundary of space required for flood control on the Green River. The actual slope of the October-through-December curve is variable depending on the duration of the low-flow season and the onset of fall rain.



Flood Control Storage Curve for Howard A. Hanson Reservoir

4.2 CONSERVATION STORAGE

At the end of the flood season, usually in April, water is stored in the reservoir to augment the low natural summer flows for the benefit of fisheries. Flow augmentation in spring benefits spawning of steelhead and incubation of eggs for steelhead and chum salmon, and aids in migration of juvenile salmon. The full conservation pool is at elevation 1141 feet which is approximately 25,400 ac-ft of storage. Details on how the reservoir is filled to its conservation level can be found in the Environmental Impact Statement. The existing project is approximately one-fourth of the available reservoir in terms of storage and approximately three-fifths of the available reservoir in terms of elevation. The storage will supply a minimum flow of 110 cfs in the river channel below the City of Tacoma diversion dam for low flow augmentation to downstream fisheries. Figure 3 shows the average reservoir elevation for the period-of-record on a monthly basis as a bar graph. A line is drawn on the bars for the minimum period-of-record elevation as well as the maximum. The normal minimum elevation is approximately elevation 1070 feet which maintains a small pool to control the turbidity of streamflow.

SECTION 5 RIVER AND RESERVOIR ROUTING COMPUTATIONS

5.1 GENERAL

The proposal of additional storage at Hanson Reservoir was tested by multiple mathematical computations using the data available from the streamgages in Table D1-1 as input and rules for operating the water supply diversions according to instream flows as demands on the river and reservoir. Simulation of the water management of Hanson reservoir was done by computing seasonal water balances between the dam and Tacoma's diversion site downstream. A computer program already generalized for this type of hydrologic problem was customized for the Green River and Howard A. Hanson Reservoir.

5.2 HEC-5 SIMULATION OF CONSERVATION SYSTEMS

River and storage computations were performed by HEC-5, a generalized computer program written by the Hydrologic Engineering Center (HEC) for MS-DOS computers. The program was developed for evaluating conservation storage requirements in a reservoir. The program simulates the sequential operation of a reservoir and river system. System configuration is specified by routing reaches and by required downstream sequential order of input control points. A generic illustration of a reservoir and downstream control point is shown in the Figure 16. The reservoir must have a starting storage and storage values for each target level. Target levels which specify the allocation of storage for conservation purposes can vary monthly. Each control point can have low flow requirements (minimum desired and/or minimum required) which can vary by time period. The program was customized for the Green River between HHD and the location of Tacoma's water supply pipeline diversion by Seattle District engineers in cooperation with the Hydrologic Engineering Center. A semi-month data base was used for the period-of-record simulations.

5.3 INITIAL COMPUTATIONS OF WATER DEMANDS FROM STORAGE

To scope the capability of water supply and instream flow demands on additional storage, multiple scenarios were composed and then tested for success with the HEC-5 computer program. Modeling the water supply delivery was an important aspect. Tacoma's diversion on the Green River is subject to inflows and regulation at HHD. If inflows are above 113 cfs, then 113 cfs is passed through the reservoir and diverted at the Headworks by Tacoma. If inflows are below 113 cfs, then Tacoma has a senior right to the total natural flow. As river flow increases and the date becomes later, regulation of storage is based on the storage rule curve for instream flow augmentation of 110 cfs. If water remains after allocating the water diversions and releasing instream flow, then the reservoir is allowed to rise to some additional storage level. Any additional inflow that would cause the reservoir to rise above its desired level is spilled downstream. Details of the scenario operations are found in the Report.

5.4 SPREADSHEET COMPUTATION OF SAMPLE YEARS

HEC-5 does not perform snowmelt runoff forecasts so some sample years were simulated in more detail with spreadsheet computations. Spreadsheets were useful for their flexibility of user-defined rule changes and were also used to make charts and displays shown at meetings. Spreadsheet computations were used to examine variations in operation caused by decisions such as steelhead fish management that considered snowpack data outside of the HEC-5 model. Operation decisions were made weekly instead of semi-monthly when weekly data became available in the 1990's during a drought study of the Green River basin (not part of this study). The important part of using a spreadsheet is defining the operating targets with computational rules (additional paragraphs follow).

5.5 TARGET INSTREAM FLOW

A typical process used during spreadsheet computations would involve choosing a target instream flow during the spring season based on the snowmelt forecast and expected inflows. In addition to the instream flow, enough water had to be passed through the dam to satisfy Tacoma's first water supply diversion. Inflows in excess of the target outflow were then available for refilling reservoir storage. An ending date of excess flows was established when expected inflows receded below the target flow. Volume computations were then made backwards on the inflow data until a date was reached when the excess volume reached the required reservoir storage times a multiplier. The volume multiplier is variable and subject to judgment by meteorologists and hydrologists who are closely watching the snowmelt and runoff in a particular year. Considering the standard error of snowmelt and runoff forecasts and the intended 98% reliability for reservoir refill, the volume multiplier used in this analysis was 2. In other words, the starting date for a particular operation was selected when expected runoff was enough to fill the reservoir twice. This usually always results in a real-time ending date that is prior to the end of the snowmelt runoff. In other cases, like year 1992, this procedure resulted in just barely filling the reservoir before the end of excess runoff. Once a starting and ending date were predicted, then an expected refill rate was scheduled for the reservoir. Adjustments were made in the target outflow as real-time runoff became known and the reservoir either exceeded or fell behind the expected refill rate.

5.6 COMPUTATIONAL RULES (SAMPLES)

A sample of computational outflow rules are shown below. These are written in a spreadsheet-type format using range names. The operational rules were interpreted in a slightly different manner when used in the Hydrologic Engineering Center computational programs. The purpose of showing a sample of operating rules is to show the reader that one does not necessarily need to be a mathematician or hydraulic engineer to simulate a reservoir and river operation. The expertise of fish biologists was important in developing rules that would be useful for fish while still conserving water.

Runoff Condition	***Outflow equals =***
Before start of refill	= IF(Date<start,Inflow,Out)
After start of refill	= Target+Div_1
During refill check rate	IF(sched_rate<act_rate,
if too fast, raise outflow	AVERAGE(Inflow,(Target+Div_1),
	ELSE,(Target+Div_1))
if too slow and inflow falls	and IF (Inflow<(Target+Div_1)
reduce to factor times InQ	THEN,(Inflow*(act-rate-10%)))
	IF(Inflow>Demand,Inflow,Demand*1.05)
Check if inflow less than 113	IF(Inflow>Div_1,Demand,Inflow+Instrm

Reservoir Operation. When the reservoir is above the conservation pool, releases are made to draw the reservoir back to the conservation pool without exceeding the channel capacity. Releases are made equal to or greater than the minimum *desired* flow when storage is greater than the buffer level. Releases are made equal to the minimum *required* flow when storage is less than the buffer level. No release from storage is made when the reservoir is below the inactive pool (outflow = inflow).

Determine conservation release by,

IF release to satisfy minimum_desired flow < release to bring reservoir to top of buffer,
THEN release = minimum_desired_flow, or
IF release to satisfy minimum_required flow > release to bring reservoir to top of buffer,
THEN release = minimum_required_flow, or
ELSE release = flow required to bring reservoir to top of buffer level. Release should be > required_flow, but < desired_flow.
IF release for minimum_required_flow > release to bring reservoir to its inactive_level,
THEN release = just enough to bring reservoir to its inactive_ level

A sample of a reservoir operating rule:

IF (Total Inflow + Total Storage) is greater than (Demand),
THEN release [(Reservoir + Inflow)/(Total Inflow + Total Storage)] times (Demand)

or

ELSE release (Reservoir + Inflow)

A sample of a rule applied to inflows:

(Green_River_Instream) = IF (Green_Instream_Release) < 110 THEN 1 ELSE 0.

The resulting value of 1 or 0 leads down the appropriate path to more rules.

where, Green_Instream_Release = MINimum of
(Instream_Requirement) or
(Howard_Hanson + Inflow - Water_Right)

Tacoma_Water_right = MINimum of (Primary_Water_Right) or (Green_Inflow)

Diversion = IF (River_Flow) > Demand + Instream,
THEN Diversion = Demand,
ELSE Diversion = River_Flow – Instream

If and when the overall plan is adopted, the next step during design studies would be to develop guide curves and specific operational rules for the storage that consider not only the downstream demand quantities, but also consider the operation of the adopted fish passage facility and water temperature targets.

SECTION 6 TACOMA'S WATER SUPPLY PIPELINE PROJECTS

6.1 FIRST WATER SUPPLY PROJECT

The First Water Supply Project is a pipeline from Tacoma's Green River diversion that heads southwest to Buckley, then west to McMillan Reservoir, and northwest to Tacoma. It has been in operation since 1913 and predates the construction of Howard A. Hanson Dam and regulation by the state's instream flows. This pipeline has the first right to 113 cfs of streamflow as it passes through Hanson Reservoir.

6.2 SECOND SUPPLY WATER RIGHT PROJECT

The Second Supply Water Right project is a 33-mile pipeline (Pipeline No. 5) from Tacoma's Green River diversion dam through South King County that connects with the City's existing water transmission pipeline (Pipeline No. 1) near its Portland Avenue reservoir. This is the pipeline that will use water stored in HHD reservoir. The first pipeline will continue to operate with available run-of-river flows without storage in the reservoir. Instream flows and rules established in the MIT and TPU will be used as criteria that must be met before water supply diversion can take place. After the storage of diversion water is attained, procedures described in this additional storage study will be followed to withdraw water from storage for a short distance in the river to the diversion withdrawal point at Tacoma's Headworks.

For purposes of this study, the amount of water that could be supplied to Tacoma's SSWR was calculated for the observed period of record 1962-1995 based on the past operation of existing storage at HHD. The intent of this calculation was to compare it with the water supply diversion flows that could be supplied with the additional storage. There may be some agreement in place between Tacoma and the Muckleshoot Indian Tribe that calls for diverted water to be returned to the river during certain periods of the year. This water operation is considered outside the scope of this study and therefore not quantified or evaluated. The additional storage project allows the use of water storage space in Hanson reservoir to store diverted water from the Green River for later withdrawal and diversion use by Tacoma. This increases the useable yield of Tacoma's pipeline. A chart of diversion discharges versus dates for a typical year is shown in Figure 6.

6.3 WATER SUPPLY FROM STORAGE

The first water supply diversion is shown from 0 to 113 cfs. This is a firm diversion which was in place prior to the construction of HHD and the establishment of instream flows. A quantity of 113 cfs, or inflow if less, is passed through the project without delay according to Tacoma's water right. The second diversion adds to the first and is shown from 113 cfs to 213 cfs varying to 193 cfs at mid–May. The incremental amount for the pipeline is 100 cfs to 80 cfs. The diversion of 100 cfs is allowed based on instream streamflows. During the winter when there is no conservation storage, instream flows defined by the Washington Department of Ecology constrain the operation of the pipeline. During refill of conservation storage, instream flows are greater than the Ecology flows. During drawdown of conservation storage, enough water is provided for diversion of 80 cfs in conjunction with instream flow which again is greater than the Ecology flows. The quantity of 80 cfs comes from plan formulation studies which determined that this is the greatest practical amount given the requirement of 90% reliability, the instream flows, and physical constraints of elevation 1177 as the maximum pool. Other pool elevations were considered during the formulation studies; however, pools lower than 1177 would provide diversion flows to Tacoma's pipeline that were less than the constructed capacity. Pools greater than 1177 would result in storage in excess of what would be needed for water supply diversion. A likely use of the additional storage would be for low-flow augmentation. Planners were unable to find a willing sponsor for the development of the additional storage and the additional cost beyond what would be needed for the water supply diversion.

SECTION 7 Low Flow Augmentation Target Flows

Instream flows constrain the amount of water that can be diverted by Tacoma. Instream flows are monitored at the Palmer gage, just downstream of Tacoma's diversion site and at a gage near Auburn. Enhanced low flow augmentation is part of the overall project, so reservoir space is allocated for water that supplements the existing reservoir space for low flow augmentation. The amount and use of this storage is quantified in this study. Figure 5 shows a chart of the targeted instream flows. There are four levels of discharge quantity; 110, 200, 300, and 400 cfs; that are satisfied during specific time periods of the year. The instream flow of 110 cfs is applied when the reservoir is operating in the zone of the existing project. The instream flow of 200 cfs is the base amount associated with the use of Tacoma's SSWR diversion when the reservoir is operating in the zone of the additional storage. The instream flow of 300 cfs in the spring is a target associated with spring refill when additional runoff is available in most all of the years. During most of the years, the instream flow would be greater than 300 cfs and last longer than 15 May. Occasionally, when there is a small snowpack, spring runoff is low and the instream flow for refill returns to the base flow of 200 cfs. The instream flow of 400 cfs in the fall is another target to provide additional flow for upstream migrating fish from 15 September through 31 October. This quantity is available in most years and blends with natural weather conditions that cause additional streamflow with rainy weather that ends the low-flow season. Sometimes the wet weather does not return until later in October and November. In these cases, the flow of 400 cfs must be relaxed and return to the base level of 200 cfs. The success of this and other target conditions is shown later in this report. During January and February there are no targets for instream flow because there is no storage – the reservoir is drawn down for flood control operations. There is usually ample water for the river during the rainy wintertime. When the river flow does get low, the Ecology flows would constrain the water supply diversion operations.

SECTION 8 ADDITIONAL STORAGE TO 1177 FT

8.1 TOTAL STORAGE

Additional storage available for development is to elevation 1177 feet. The total storage at this elevation is 62,360 ac-ft. This amount was not determined by traditional supply (inflow) versus demand (outflow) analysis, but rather by geological considerations. The pool is close to the maximum observation of record. During a flood in early December 1975, the pool reached a maximum of 1176 feet on the 5th. An elevation of approximately 1177 feet was considered the highest pool that could be maintained by the geologic strata around the reservoir without reaching a gravely strata that may allow seepage into the Cedar River basin to the north. Existing and potential seepage is discussed in Appendix E, Geotechnical Considerations. The developed storage would be approximately two-thirds of the total project capacity in terms of storage and approximately four-fifths of the total project in terms of elevation. A chart of the storage that shows how it is used during a typical year is shown in Figure 6.

8.2 ADDITIONAL STORAGE ZONE

Figure 6 shows how the additional storage forms a zone on top of the existing storage. The existing storage remains part of the project, water operations revert to the existing project purpose (110 cfs) if the top zone should be depleted during an extreme low inflow event. Both zones diminish in size as time increases towards the end of the year. The drawdown rate is shown as a straight line, but would change during each runoff year. Storage would return to nearly zero by October in most years as the low flow season ends and fall rains begin. The existing storage remains with a 98% reliability and the additional storage is formulated at a 90% reliability. During actual operations, there could be occasions when the reservoir dips into and back out of the "existing" storage; target instream flows would change accordingly. The refill rate shows the reservoir reaching the top during the last half of May. This rate is necessary during years with low spring runoff. During most years there would be ample flows in June, so the refill would likely occur at a slower rate and the remaining available storage could be used to regulate inflow fluctuations to some desirable level downstream. Information on the status of the snowpack would be used to determine the target flow conditions. There is no active storage during the winter period, the space is reserved for flood control operations during high runoff events.

SECTION 9 RELIABILITY OF WATER DELIVERIES

9.1 RELIABILITY AS SUCCESS AND FAILURE

Reliability is based on the probability of obtaining *success* in making water deliveries when operating the storage reservoir for the established targets. The simulation time-step during plan formulation was 2 weeks, so success had to apply over the full 2-week duration. If a demand target was not fully satisfied, even during one time-step, then the operation was considered a *failure* during that season. A 90% success target meant that there should be 90 successes out of every 100 trials on the average. Each trial in the context of additional storage operations is considered a runoff-operating season. The reliability target meant that 90% of the years had to have demands fully satisfied and 10% of the years could have demands partially satisfied. During plan formulation, various demand scenarios were tested by simulating the additional storage operation, adjusting the simulation, and re-simulating until the period-of-record met the 90% / 10% reliability expectation. The end result of the effort was *scenario #7* which was discussed among the water resource agencies and finalized as the proposed plan for water management of the additional storage at HHD. Specific rules used to simulate the reservoir operation are shown later in this appendix.

9.2 RELIABILITY OF WATER SUPPLY (80 CFS)

The success of water supply delivery was checked by looking at the amount of water that was diverted by the SSWR pipeline during a simulated period-of-record. The average amount of water was calculated for each drawdown period, ranked from low to high quantities, and then plotted against the relative success ratio. The resulting plot is shown on Figure 7 in the range of 80 to 100% reliability. Each data point is labeled by the year of occurrence. Eighty cfs was the average diversion amount that coincided with the 90% reliability that was considered successful for surface withdrawal by the sponsor. The data with less than a full diversion amount was labeled again by the duration (in months) of the shortage from the full amount. The longest duration of shortage was 1½ months for years 1952, 1987, and 1941. The average yield was different for each shortage year because the reservoir drawdown periods had different durations. Most of the years would have 100 cfs available for diversion throughout the drawdown season.

9.3 RELIABILITY OF INSTREAM FLOW (200 CFS)

The success of instream flow was tested in the same manner as the test for water supply reliability. The minimum instream flow actually delivered during a season was tabulated and plotted against the relative success ratio. The resulting plot is shown below in the range of 80 to 100% reliability. The individual data points are labeled by the year of occurrence, the semi-month period of the shortage, and the duration of shortage in months. The flow of 200 cfs was the target for the additional storage and 110 cfs was the target for the existing storage. The flow of 150 cfs was an intermediary step so the instream flow wouldn't drop suddenly from 200 to 110 cfs. There were 6 cases when the reservoir stopped receding after the intermediary flow was released, so no further reduction was needed. Four of the cases did not require a reduction in water supply diversion (1917, 1925, 1929, and 1979), and 2 cases did require a reduction in water supply diversion (1934 and 41). Water supply diversion had a slightly higher priority than instream flow by requiring that the instream flow experience a shortage for one time period (half of a month) prior to causing a shortage in water supply diversion. There were 4 occasions when additional storage was depleted and existing storage furnished an instream flow of 110 cfs. The existing storage still has a reliability of up to 98%.

9.4 RELIABILITY OF FALL FLOW (400 CFS)

The target flow in the fall was an increase in the instream flow from 200 cfs to 400 cfs starting in mid-September and lasting through the end of October. When the mid-September storage level was insufficient to provide 400 cfs for the entire 6 weeks, then 400 cfs was provided for a shorter period, or the base flow of 200 cfs was carried through the period. The success of the fall flow was tested in the same manner as the test for the other instream flow. The minimum instream flow actually delivered during the appropriate time period was tabulated and plotted against the relative success ratio. The resulting plot is shown on Figure 9 in the range of 70 to 100% reliability. The individual data points are labeled by the year of occurrence and the duration of shortage in months. The flow of 400 cfs was the target for the additional storage. The reliability obtained for a flow of 400 cfs was approximately 77%. There were 4 occasions when the minimum was less the 400 cfs, but greater than 200 cfs (1925, 86, 57, and 15). In all 4 occasions, the shortage was for only ½ month; the flow was maintained at 400 cfs for at least 1 month. There were 5 occasions when there was no storage available for augmentation, so the instream flow remained at 200 cfs during the full 1½ months (1989, 1938, 1929, 1979, and 1936). Notice the reliability of 200 cfs during the defined time period is greater than 90%. Three of the years have low flow periods that extend beyond October and experience a minimum flow of 110 cfs (1936, 1987, and 1952).

9.5 RELIABILITY OF SPRING FLOW (300 CFS)

The minimum flow in the spring was targeted at 300 cfs from the beginning of March through mid-May. This time period coincides with reservoir refill. When March flow was insufficient to supply 300 cfs, then 200 cfs was applied as the base flow. The minimum instream flow actually delivered during the March through mid-May time period was tabulated and plotted against the relative success ratio. The resulting plot is shown on Figure 10 in the range of 85 to 100% reliability. The individual data points are labeled similarly as the other plots with an additional subscript, the percentage of a full reservoir at the maximum refill. Obtaining a full reservoir had a higher priority than providing 300 cfs. Providing 200 cfs had a higher priority than obtaining a full reservoir. The reliability of a 300 cfs flow turns out approximately 94%. The flow of 300 cfs could be raised by some quantity to obtain a reliability closer to 90%. The refill procedure was refined in later studies using a refill rate that applied to storage instead of a low-flow rate.

Reliability also plays a role in forecasting. River flows during the spring can be forecast knowing the available snowpack which melts and provides streamflow. Forecasting is not an exact science because there is variability and error in estimating the overall snowpack from a few snow gages, predicting future temperatures which cause the snowmelt, and in predicting future rainfall which is random and disturbs the estimate of runoff timing.

Timing is important to initiate water management actions for reservoir refill. Timing decisions were simplified during plan formulation by not using a runoff forecasting procedure and just using a simulation model that initiated refill based on the calendar. Refill was always initiated the first of March which is usually before the date of maximum snowpack. Experience built-in to the period of record showed that refill was required by the first of March in some years in order to have a successful operation throughout the season. During years of ample snowpack, the model simulation would fill quickly and spill any excess runoff that couldn't be stored.

This procedure was sufficient to determine success and failure and therefore arrive at a project formulation. However, it is recognized that an optimum operation would have to include forecasting techniques. The techniques are already in use on a real-time basis in the Seattle Reservoir Control Center and would continued to be used in future operations of additional storage.

Forecasting allows the water manager to save space in the reservoir if high flows are anticipated in the near future. Forecasting also allows the reservoir to fill at a faster rate with lower outflows if low flows are anticipated. The overall effect would be for an observer to see smoother flows downstream than those that would be calculated by a model with calendar-based algorithms. When selecting particular years as simulation examples, the outflow and storage quantities that were output from the planning model were adjusted slightly by comparing them to monthly forecasts for the same years as published by the Soil Conservation Service. The simulation examples in this report should therefore more closely resemble flows and pool levels that would be provided during current water management practices.

SECTION 11 EXAMPLE YEARS OF ADDITIONAL STORAGE OPERATIONS

11.1 HIGH, MEDIUM, AND LOW EXAMPLES

Example years (such as high, medium, and low) were selected from the database to show how the operation of additional storage affects the river flow downstream. A high flow year was not selected for graphical illustration because it would show more than ample water to refill, to allow water supply diversion, to supply water in the lower river above the minimum requirements, and surplus storage would need to be evacuated prior to the onset of winter rains. The examples start in the medium range with sample years that have runoff closer to water demand requirements. Year 1973 has runoff volumes that are right on the margin of 90% performance. Two other years illustrate water management during shortages. Year 1987 has a fall shortage and year 1941 has a spring shortage. The examples are illustrated with a pair of graphs, each with a pair of lines. The first graph shows the Green River discharge as it enters Howard A. Hanson Reservoir. The graph is overlain with a line that shows the contents of the reservoir in terms of percentages of a full reservoir. The second graph shows the Municipal and Industrial (M&I) water supply diversion into the SSWR diversion pipeline 5. The graph also shows the amount of discharge remaining in the river at the Green River near Palmer gage.

11.2 EXAMPLE YEAR 1973 – OPTIMIZED PERFORMANCE

Year 1973 has an amount of runoff when all of the reservoir storage is needed and when the water demands are just met. This example year is shown on Figure 11. Refill of conservation storage was initiated at the beginning of March. No additional flow beyond the target minimum flow of 300 cfs was allowed because the reservoir was behind it's normal refill schedule. A small surge of instream flow occurred near the end of June as the reservoir finally reached full pool. Instream flow was kept at 200 cfs all the way to mid-September when a surge in instream flow to 400 cfs was released as scheduled. A water supply diversion of 80 cfs was allowed throughout the drawdown. At the end of reservoir drawdown, instream flow increased as a result of increasing river flow due to the onset of fall rains. The diversion quantity also switched from 80 cfs to 100 cfs with the additional river flow. The reservoir completed its drawdown and remained down in preparation for flood control operations.

11.3 EXAMPLE YEAR 1987 – FALL SHORTAGE

Year 1987 has ample water in the spring, a normal recession to low flows in the summer, then a late extension of low flows lasting until the end of November. The target flows exceed available supply in the reservoir, so this year illustrates how shortages occur. This example year is shown on Figure 12. Refill of conservation storage was initiated at the beginning of March. Instream flow approached a low in the spring of 400 cfs, so the minimum of 300 cfs was satisfied. The instream flow increased to above 900 cfs as the reservoir filled in mid-May. The instream flow slowly reduced to 200 cfs until a critical point in mid-September. At this point, the natural river flow (inflow) was still low and the reservoir was depleted to approximately 30% of full. There was not enough storage to make the outflow increase to 400 cfs. The storage was approaching the existing operation zone so flow augmentation was cut in half as a transition step towards the existing operation. The instream flow was decreased to 150 cfs and the diversion flow was decreased to 40 cfs. This caused a shortage of 50 cfs in instream flow and 40 cfs in water supply diversion, shown in Figure 12 as a cross-hatched zone. The rate of reservoir depletion slowed and the reservoir level hovered above the existing zone until mid-October. The instream flow was then decreased to 110 cfs for one semi-month, and the water supply diversion was decreased to zero the next semi-month as the reservoir did not emerge from the existing zone. The inflow began to increase during the second half of November, so the diversion was returned to 80 cfs as the instream flow was restored to 200 cfs and the reservoir increased a small amount. The natural river flow made a dramatic increase during December, so the instream flow went way up, the diversion returned to 100 cfs, and the reservoir was brought to its flood control level.

11.4 EXAMPLE YEAR 1941 – SPRING SHORTAGE

Year 1941 is unusual because of its low runoff during the spring. This year has the lowest 3-month flow (March through May) of the entire period-of-record. This year is a severe test of an operating plan that requires additional storage as a key element. . This example year is shown on Figure 13. Refill of conservation storage was initiated at the beginning of March; however, the actual inflow and forecast for future flows was so low that instream flow was set at the required minimum of 200 cfs rather than the desired minimum of 300 cfs. During the second half of March, inflow was less than the first half, so the water supply diversion was reduced from 100 cfs to 80 cfs. The water supply reduction does not usually occur until *after* full pool is reached; however, runoff conditions indicated that full pool might not be reached this season, so augmentation was treated as if the reservoir was in a drawdown mode. Operation decisions such as those for this year are somewhat subjective in this example. More general rules were developed in later studies using daily flows and are discussed later in this report.

The maximum pool was reached in June, approximately 60% of the normal full pool. By mid-July, the pool was already below 50% so the augmentation quantities were reduced by half. The instream flow was reduced to 150 cfs and the water supply diversion was reduced to 40 cfs. The rate of reservoir draft was reduced enough to keep it just above the existing reservoir zone, so water deliveries were kept at the ½ rate without requiring a full reduction. By the first half of September, natural runoff increased enough to allow the augmentation to be restored to 80 cfs diversion and 200 cfs instream flow. By mid-September, runoff from fall rains arrived in time to increase storage in the reservoir and allow the instream flow to increase to the scheduled 400 cfs. Even though the reservoir only reached 60% of full pool, there was enough water to make normal water deliveries for approximately half of the low–flow season and to make 50% deliveries during the lowest half of the season.

SECTION 12 ALLOCATION OF ADDITIONAL STORAGE

The paragraphs that discussed example years of additional storage operations showed that different patterns and amounts of water are delivered to the two downstream purposes for each sample year. The storage actually used for each purpose therefore is slightly different each year. In order to separate storage for a specific purpose from the total storage, year 1973 was used for analysis because supply and demand are right at the optimum for this year. The specific storage quantities were determined by summing the volume of water delivered for each purpose during the low-flow season. Figure 14 illustrates the stored water just after refill ready to serve its appointed purposes. The existing conservation storage is 25,400 ac-ft. The additional storage is the total at 1177 feet less existing, 62,400 – 25,400 = 37,000 ac-ft. The additional storage is separated into quantities of 22,400 ac-ft for water supply diversion and 14,600 ac-ft for instream flow. The water supply storage does not include water supplied by natural flows that is diverted into the first water supply diversion. The water supply storage is also *not* used to augment instream flows in order to allow some diversion quantity.

SECTION 13 OPERATION OF FISH PASSAGE FACILITY

13.1 FISH FLOWS ARE SECONDARY TO INSTREAM AND DIVERSION DEMANDS

The fish passage structure needs to operate through a range of conditions while the reservoir is filling. The active refill period is March through June. The outflow discharges from the project became the basis for development of preliminary design concepts for fish passage. The fish passage facility was intended to have a selective withdrawal system in order to have control of passing water at desired temperatures. The specific operation of the fish passage facility is assumed to be secondary to the requirements for flow downstream. The total outflow from the reservoir would first be determined by downstream demands. The flow through the fish passage facility would then be adjusted to match the outflow demand. If the fish passage facility can not pass 100% of the flow required for water yield, it will back off to the next practical increment of discharge. The remainder of the required discharge will be made up by the existing bypass or the sluice gate if the pool is low. This might result in say 90% of the required discharge passing through the fish passage facility and 10% of the required discharge passing through the bypass in order to just meet the downstream demand (and not spill beyond the demand). The chart shown in Figure 15 was used to aid in hydraulic design to help size the fish screen.

13.2 FLOWS DURING RESERVOIR REFILL

Figure 17 illustrates the average time-varying outflow from March through mid-June, which is the reservoir refill period. This season could have a high discharge in March due to rain and another high in May due to melting snowpack. The discharge could range from low to high in the span of one or so weeks. The double horizontal line shows the average discharge of about 900 cfs. A single line shows the upper quartile where 25% of the discharges were greater than 1,300 cfs. Another line shows the quartile where 25% of the discharges were less than about 700 cfs.

13.3 FLOWS DURING CONSTRUCTION PERIOD OF FISH BYPASS FACILITY

An early concept to construct the fish bypass facility was to use a cofferdam that tied into the existing intake tower. Due to the presence of a summer conservation pool to elevation 1141 feet and the prohibitive cost of a cofferdam to that elevation, the construction season would have to be in the wintertime. There is 6 months available between mid-October (after drawdown) and mid-April (before refill) when construction could take place when there is no conservation pool. A hydrologic analysis of inflows was done to investigate how often a cofferdam would be overtopped at proposed elevations of 1080 feet, 1090 feet, and 1100 feet. A discharge capacity that would pass 1-in-5-year flow conditions was assumed desirable for construction. A 4-week period was assumed necessary as a drying-out period between the time of cofferdam overtopping and the resumption of construction activity. Some typical conditions were selected from observed annual hydrographs on file in the Reservoir Control Center. In typical years, there is a high-water event at 1 to 1½ month intervals. There is about 3 months of "dry" gaps within the 6 months of available construction time. There is not enough difference in the outlet capacities for elevations 1080, 1090, and 1100 feet to make a difference in the allowable construction time. This means that winter construction periods are approximately 50% effective in allowing the progress of construction work.

Another test of allowable construction periods was done by looking at the possibility of having no storage refill to elevation 1141 feet. This would allow an additional 6 months per year of construction between the time periods of mid-April to mid-October. The minimum required outflow from the dam is 223 cfs; 113 cfs for Tacoma's water supply diversion and 110 cfs for instream flow. If the inflow receded below 223 cfs, then the difference would have to be made up by pumping from Tacoma's underground aquifer. A cursory analysis of inflows showed that the average pumping requirement for inflow years 1962-1994 was 7,400 ac-ft. The sponsor, who would have to perform the pumping, was interested in a 10% level of exceedance. A 10% exceedance level of pumping requirements was approximately 15,000 ac-ft. Considering potential construction costs (estimated by others) for pumping, for a high cofferdam, and for time delays due to overtopping, a new construction scheme was proposed that involved moving the fish-bypass tower slightly away from the existing tower and its associated construction problems.

SECTION 14 ENVIRONMENTAL IMPACTS AND 2-PHASED IMPLEMENTATION

14.1 DROUGHT STORAGE OF 5,000 ACRE-FEET

Near the completion of the additional storage study, a separate study was initiated under the Section 1135 Authority to provide restoration projects on the Green River. One of the outcomes of the Section 1135 study was authorization of 5,000 ac-ft of storage for low flow augmentation during the summer. Initially the storage would be implemented during drought conditions. Drought conditions were assumed to occur approximately 1 out of 5 years. However, through adaptive management the water authorized in the Section 1135 project may be stored as frequently as every year. A separate report describes the restoration projects and 5,000 ac-ft of storage. It is assumed that the 5,000 ac-ft of storage will be stored every year at the time of implementation of Phase I of the additional storage project. Therefore, the storage of the 5,000 ac-ft of water for low flow augmentation becomes part of the baseline conditions.

14.2 STORAGE REFILL RATE

After the hydrologic study was completed, additional studies were undertaken by biologists to define the environmental impacts of the operation of the additional reservoir storage. An important outcome of these studies was that the refill operation should have less impact on reducing flows on the river. Additional guidelines were suggested during refill in the form of refill rates on the amount of storage accumulation that would be allowed per day during specific months. Another outcome was that the total accumulation of storage should be reduced (from pool elevation 1177 feet). Planners came up with the concept of a 2-phased project implementation. The first phase would be at a partial storage implementation. Environmental impacts would be observed in the field prior to the implementation of the second and final phase. The first phase would implement 20,000 ac-ft (out of 22,400 ac-ft) of the water-supply storage.

14.3 2-PHASED IMPLEMENTATION

In order to evaluate the effects of proposed flow conditions under the 2 phases of the additional water storage project, modeling studies were undertaken to simulate reservoir operations that provide water for diversions and instream flows. Detailed results are reported in a separate report by CH2M Hill, Howard Hanson Dam Additional Water Storage Project Modeling Results for Baseline, Phase I, and Phase II Reservoir Operations, March 4, 1997. Some of the results are reported in this appendix. Three separate conditions were modeled; Baseline, Phase I, and Phase II.

Baseline is defined as the operation of HHD utilizing the existing rule curve and the operation of Tacoma's SSWR diversion pipeline. The pipeline operates without augmentation from reservoir storage. Storage of 5,000 ac-ft is assumed as active for drought years (1 in 5 years).

Phase I adds to Baseline the fish passage facility at the dam and 20,000 ac-ft of additional active M&I water storage collected by storing Tacoma's SSWR diversion. Also implemented is 5,000 ac-ft of storage in 4 out of 5 years (the non-drought years), which makes this storage an annual operation.

Phase II adds to Phase I the storage of an additional 9,600 ac-ft of water for fisheries use and an additional 2,400 ac-ft for M&I use.

The Green River watershed was modeled from the USGS gage at Auburn upstream to the USGS gage at Palmer and finally upstream to Howard Hanson Dam. The model ran on a daily time step. Flow information was averaged on a semi-month basis to mimic information available in the additional water storage study. Outflow from the dam is determined by the inflows to the dam, downstream instream flow requirements established at Palmer and Auburn gages, water supply diversions and maximum levels and rates of change allowed behind the dam and in the lower river. In order to apply rules to different conditions, the storage behind the dam was hypothetically split into 3 storage allocations.

Fish Dam 1 is the existing storage which strictly follows the 98% rule curve and meets a 110 cfs base flow at Palmer.

Fish Dam 2 represents the storage volume available to protect and improve instream flow conditions. The amount of this storage changes with Phase I and 2.

Diversion Dam is the storage volume available to Tacoma for M&I water uses.

14.4 MODELING COMPUTATIONS

Modeling rules were developed during a succession of meetings among a team of water managers, fish biologists, and other engineers-planners experienced with the regulated hydrologic cycle and biological resources of the Green River. The purpose of the meetings was to update the water resource development proposed in the additional water storage study into a more detailed simulation that matched biological need with increments of water storage as they became available in the future phases. Modeling computations were performed using an Excel spreadsheet in Windows 95 operating environment. Operating rules were input to the model as a series of macros that are methodically applied to the daily inflow data stream. Evaluators were also interested in seeing river conditions without any storage operations or water supply diversions. This section follows with detailed tabulations of the inflows at Hanson Dam, natural flows at the Palmer gage site, and natural flows at the Auburn gage site. Each of the tabulations is followed by a separate tabulation that shows the percentile flows at 5%, 10%, 20%, 25%, 50%, 75%, 80%, 90%, and 95% for each of the semi-month period for the period-of-record.

The following exhibits follow this page of text:

- Hanson Reservoir Inflows by Half-Months from 1964 through 1995.
- Percent Exceedances of Hanson Reservoir Inflows by Half-Months.
- Palmer Natural Flows by Half-Months from 1964 through 1995.
- Percent Exceedances of Palmer Natural Flows by Half-Months.
- Auburn Natural Flows by Half-Months from 1964 through 1995.
- Percent Exceedances of Auburn Natural Flows by Half-Months.

Half Monthly Average for InflowToHanson in CFS
Inflow To Hanson

CFS	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Jan 1-15	1,857	654	1,062	2,925	1,042	2,253	585	1,472	1,391	1,649	1,275	1,202	2,194	568	741	469
Jan 16-31	1,480	4,645	758	2,619	2,739	575	2,839	3,871	2,684	1,171	4,385	4,042	3,117	1,218	678	465
Feb 1-15	1,095	2,487	596	2,017	1,238	439	1,262	2,704	1,562	507	1,656	970	1,263	584	782	1,925
Feb 16-28	1,200	2,275	736	1,430	3,498	415	1,549	1,660	3,932	576	1,110	1,029	1,196	592	712	1,018
Mar 1-15	1,030	1,278	904	803	1,010	487	870	871	4,243	744	1,069	1,577	665	712	619	2,255
Mar 16-31	1,252	883	1,301	1,003	1,106	1,533	1,043	1,029	2,657	591	1,706	763	1,001	912	1,087	1,233
Apr 1-15	1,765	807	2,434	782	1,219	1,808	1,586	1,411	1,739	585	1,827	728	1,724	1,520	785	1,325
Apr 16-30	1,612	2,191	1,320	719	1,014	2,109	952	1,269	1,327	929	2,010	1,101	1,396	1,236	1,050	1,436
May 1-15	1,673	1,202	2,044	1,218	1,099	2,353	1,477	2,945	2,665	961	2,309	2,494	2,489	929	1,031	1,659
May 16-31	2,697	1,289	1,052	1,977	877	2,106	1,514	2,142	2,621	795	2,071	2,357	1,273	776	1,023	1,154
June 1-15	2,947	936	832	1,104	1,130	1,213	1,107	1,564	1,783	452	3,746	1,923	800	796	623	564
June 16-30	2,093	456	615	816	485	765	495	1,357	1,286	610	1,909	920	901	380	402	314
July 1-15	1,077	283	640	343	349	546	264	866	933	372	888	629	521	268	266	269
July 16-31	554	201	321	235	261	313	187	536	584	238	563	302	311	206	214	191
Aug 1-15	402	172	224	169	210	231	147	260	306	187	297	216	266	167	177	156
Aug 16-31	365	175	180	146	458	181	118	196	254	157	218	328	404	290	214	154
Sept 1-15	433	163	155	150	362	151	214	282	211	141	179	285	327	357	259	177
Sept 16-30	610	188	150	119	1,262	332	202	189	646	171	153	180	230	473	554	118
Oct 1-15	996	199	184	250	715	574	337	186	322	209	140	218	224	367	296	104
Oct 16-31	529	365	749	1,160	1,034	305	433	646	245	286	126	1,189	320	416	236	295
Nov 1-15	518	451	560	1,124	1,425	459	398	1,728	549	725	243	1,701	451	2,023	844	236
Nov 16-30	1,395	451	1,292	635	1,635	510	1,462	1,040	675	979	802	2,202	738	2,959	972	180
Dec 1-15	2,648	858	1,844	1,122	1,908	509	1,029	1,739	800	1,350	818	6,518	610	7,210	1,693	1,932
Dec 16-31	1,527	395	2,095	2,831	774	939	573	1,326	3,805	2,179	2,598	2,147	1,034	1,367	1,081	2,423

CFS	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan 1-15	650	1,000	789	3,312	3,058	484	548	678	377	1,636	2,997	1,735	603	520	1,883	870
Jan 16-31	619	465	3,108	910	3,183	579	1,269	530	710	1,987	1,012	1,520	2,042	1,434	1,009	974
Feb 1-15	1,044	1,145	2,463	610	1,249	381	717	1,371	1,887	978	2,484	2,066	1,240	909	478	1,848
Feb 16-28	1,215	3,294	4,102	1,323	887	893	3,074	908	1,105	550	1,450	3,412	1,143	529	730	3,520
Mar 1-15	1,414	633	1,695	1,325	910	684	1,691	1,978	1,325	886	1,502	1,042	853	1,058	1,638	996
Mar 16-31	1,035	463	950	989	1,738	949	1,378	1,085	1,829	1,230	1,626	757	679	1,858	1,224	987
Apr 1-15	1,296	910	738	974	1,242	2,688	991	1,306	2,782	2,753	1,897	2,151	494	1,465	1,417	810
Apr 16-30	2,069	1,987	1,043	820	1,127	1,638	955	1,641	1,720	1,920	1,892	1,369	1,021	1,429	1,339	721
May 1-15	1,208	1,238	1,432	910	1,552	1,464	1,344	1,433	1,602	1,522	1,504	1,320	667	1,963	811	1,090
May 16-31	664	938	1,674	754	1,818	1,631	1,256	626	1,330	881	950	1,060	345	901	507	676
June 1-15	500	1,036	1,033	421	1,265	1,280	561	503	785	683	1,844	701	229	931	465	388
June 16-30	418	1,229	640	449	984	499	325	288	463	368	876	687	206	758	613	333
July 1-15	344	521	366	574	546	273	261	225	329	247	406	374	244	528	349	245
July 16-31	227	311	265	629	296	185	261	176	224	184	255	238	182	648	220	167
Aug 1-15	166	211	193	312	214	183	172	149	169	156	189	175	172	393	172	159
Aug 16-31	184	172	155	221	169	138	152	124	151	165	221	153	134	241	149	181
Sept 1-15	423	193	270	365	179	199	145	112	128	133	183	137	188	171	176	133
Sept 16-30	274	183	234	320	152	212	331	121	255	124	149	112	490	149	145	126
Oct 1-15	210	560	344	226	191	190	276	100	195	125	407	91	313	163	120	970
Oct 16-31	166	266	459	251	355	1,640	239	108	1,051	163	1,599	123	319	210	695	995
Nov 1-15	1,266	257	790	1,527	947	2,604	666	148	1,777	1,913	3,317	416	1,070	260	1,097	2,609
Nov 16-30	1,191	476	809	1,830	724	638	3,999	221	1,683	1,180	4,800	1,432	1,228	303	1,267	4,747
Dec 1-15	1,562	1,529	1,521	1,005	633	439	881	1,135	1,809	2,235	1,737	3,029	844	1,324	1,450	2,653
Dec 16-31	3,332	827	733	698	1,047	445	737	346	1,044	680	1,071	909	1,063	466	2,575	1,264

Percent Exceedance at InflowToHanson (1964 to 1995)
Inflow To Hanson

CFS	5%	10%	20%	25%	50%	75%	80%	90%	95%
01/01 to 01/15	4,375	2,596	1,750	1,561	808	537	501	430	385
01/16 to 01/31	5,975	4,090	2,667	2,172	1,043	675	599	484	428
02/01 to 02/15	3,535	2,545	1,811	1,591	976	630	562	440	397
02/16 to 02/28	5,914	3,441	1,824	1,647	1,065	697	634	529	456
03/01 to 03/15	2,900	2,058	1,479	1,345	973	725	680	605	527
03/16 to 03/31	2,500	1,915	1,448	1,379	1,024	773	731	641	563
04/01 to 04/15	2,798	2,533	1,936	1,768	1,294	849	793	674	559
04/16 to 04/30	2,443	2,185	1,841	1,720	1,282	970	910	776	713
05/01 to 05/15	3,128	2,640	2,071	1,894	1,316	1,061	1,002	844	754
05/16 to 05/31	2,786	2,292	1,846	1,718	1,137	789	739	573	486
06/01 to 06/15	2,929	1,992	1,446	1,327	827	550	486	406	352
06/16 to 06/30	1,681	1,350	974	871	555	393	366	305	266
07/01 to 07/15	973	849	626	533	365	274	255	231	213
07/16 to 07/31	686	538	385	338	248	196	188	175	163
08/01 to 08/15	374	309	257	237	192	164	158	145	137
08/16 to 08/31	399	301	242	223	176	149	144	131	121
09/01 to 09/15	451	375	288	261	177	145	138	125	115
09/16 to 09/30	808	578	343	287	178	144	133	116	107
10/01 to 10/15	849	579	395	351	218	151	139	113	99
10/16 to 10/31	1,668	1,174	746	631	302	199	181	134	116
11/01 to 11/15	3,559	2,503	1,523	1,338	682	359	322	240	178
11/16 to 11/30	4,067	2,727	1,683	1,455	909	557	502	325	228
12/01 to 12/15	4,828	3,560	2,160	1,918	1,185	700	640	503	435
12/16 to 12/31	4,222	3,037	1,836	1,542	891	631	569	444	384

Half Monthly Average for Palmer in CFS
Natural

CFS	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Jan 1-15	1,913	673	1,094	3,013	1,073	2,321	603	1,516	1,433	1,699	1,314	1,238	2,260	585	764	484
Jan 16-31	1,524	4,785	781	2,697	2,821	593	2,924	3,987	2,764	1,206	4,517	4,164	3,211	1,254	699	479
Feb 1-15	1,127	2,561	614	2,077	1,275	453	1,300	2,785	1,609	522	1,706	999	1,301	601	806	1,983
Feb 16-28	1,236	2,343	758	1,473	3,603	427	1,595	1,710	4,050	593	1,144	1,060	1,232	610	733	1,049
Mar 1-15	1,061	1,317	931	828	1,040	501	897	897	4,371	766	1,101	1,624	685	734	638	2,323
Mar 16-31	1,289	910	1,340	1,034	1,139	1,579	1,074	1,060	2,737	609	1,757	786	1,031	940	1,119	1,270
Apr 1-15	1,818	831	2,507	806	1,255	1,862	1,633	1,453	1,791	603	1,882	750	1,776	1,566	809	1,365
Apr 16-30	1,660	2,256	1,359	741	1,044	2,172	981	1,307	1,367	957	2,070	1,134	1,438	1,273	1,082	1,479
May 1-15	1,723	1,238	2,105	1,254	1,132	2,423	1,521	3,033	2,745	990	2,378	2,569	2,564	957	1,062	1,708
May 16-31	2,778	1,328	1,084	2,036	903	2,169	1,559	2,207	2,699	819	2,133	2,428	1,312	799	1,054	1,189
June 1-15	3,035	964	857	1,137	1,164	1,249	1,140	1,611	1,836	466	3,858	1,981	824	820	642	581
June 16-30	2,156	470	633	840	499	788	510	1,398	1,325	629	1,966	948	929	392	414	324
July 1-15	1,109	291	660	353	359	563	271	892	961	383	915	648	536	276	274	277
July 16-31	571	207	330	242	269	322	192	552	602	245	579	311	320	212	220	196
Aug 1-15	414	177	231	174	216	238	151	268	315	193	306	222	274	172	183	161
Aug 16-31	375	180	186	150	472	186	121	202	262	162	225	338	417	299	221	159
Sept 1-15	446	168	160	155	373	156	221	290	217	145	184	293	336	368	266	182
Sept 16-30	629	194	155	123	1,300	342	208	194	665	177	158	186	237	487	571	122
Oct 1-15	1,025	205	189	257	736	591	347	191	332	215	144	225	231	378	304	107
Oct 16-31	545	376	772	1,195	1,065	314	446	666	252	294	130	1,225	330	428	243	304
Nov 1-15	534	464	577	1,157	1,467	473	409	1,780	566	747	251	1,752	465	2,084	869	244
Nov 16-30	1,437	465	1,330	654	1,684	525	1,506	1,071	695	1,008	827	2,268	761	3,047	1,001	186
Dec 1-15	2,727	884	1,899	1,156	1,966	524	1,060	1,791	824	1,391	843	6,713	628	7,426	1,744	1,990
Dec 16-31	1,572	407	2,158	2,916	797	967	590	1,366	3,919	2,244	2,676	2,211	1,065	1,408	1,114	2,495

CFS	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan 1-15	669	1,030	812	3,412	3,150	499	564	698	388	1,685	3,087	1,787	621	536	1,939	896
Jan 16-31	638	479	3,201	937	3,278	596	1,307	546	731	2,046	1,043	1,566	2,103	1,477	1,039	1,004
Feb 1-15	1,075	1,179	2,536	628	1,286	393	739	1,412	1,943	1,008	2,558	2,128	1,278	937	492	1,903
Feb 16-28	1,251	3,392	4,225	1,362	913	920	3,167	935	1,138	566	1,494	3,515	1,178	544	752	3,626
Mar 1-15	1,456	652	1,746	1,364	937	704	1,742	2,037	1,365	913	1,547	1,073	878	1,090	1,687	1,026
Mar 16-31	1,066	477	978	1,019	1,790	977	1,419	1,117	1,884	1,267	1,675	779	700	1,913	1,261	1,016
Apr 1-15	1,335	937	760	1,004	1,280	2,769	1,020	1,345	2,865	2,835	1,954	2,216	509	1,509	1,459	834
Apr 16-30	2,131	2,047	1,074	844	1,161	1,687	984	1,690	1,772	1,978	1,948	1,410	1,052	1,472	1,379	743
May 1-15	1,245	1,275	1,475	938	1,598	1,508	1,385	1,476	1,650	1,567	1,549	1,359	687	2,022	836	1,123
May 16-31	684	966	1,725	777	1,873	1,680	1,293	644	1,370	907	979	1,091	355	928	522	696
June 1-15	515	1,067	1,064	434	1,303	1,319	578	518	808	704	1,899	722	235	959	479	399
June 16-30	431	1,266	659	462	1,014	514	335	297	477	379	902	708	213	780	631	343
July 1-15	355	536	377	591	563	281	269	232	339	254	418	385	251	544	360	252
July 16-31	233	321	273	648	305	191	269	181	231	189	263	245	188	667	227	172
Aug 1-15	171	218	199	321	221	188	178	153	174	160	194	181	178	405	177	164
Aug 16-31	189	177	160	228	174	142	157	127	156	170	228	157	138	248	154	187
Sept 1-15	435	199	278	376	184	205	149	116	132	137	188	141	194	176	181	137
Sept 16-30	282	189	241	329	157	219	341	125	262	127	153	115	504	153	149	130
Oct 1-15	216	577	354	233	197	195	285	103	201	129	420	94	322	168	124	999
Oct 16-31	171	274	473	259	366	1,689	246	111	1,083	168	1,647	126	328	216	716	1,024
Nov 1-15	1,304	265	814	1,573	976	2,682	686	152	1,831	1,971	3,416	429	1,102	267	1,129	2,687
Nov 16-30	1,227	491	833	1,885	745	658	4,119	228	1,733	1,216	4,944	1,475	1,265	312	1,305	4,889
Dec 1-15	1,609	1,575	1,567	1,035	652	452	907	1,169	1,863	2,302	1,789	3,120	869	1,364	1,493	2,732
Dec 16-31	3,432	852	755	719	1,078	459	759	356	1,076	700	1,104	936	1,095	480	2,653	1,302

Percent Exceedance at Palmer (1964 to 1995)
Natural

CFS	5%	10%	20%	25%	50%	75%	80%	90%	95%
01/01 to 01/15	4,506	2,674	1,803	1,608	832	553	516	443	397
01/16 to 01/31	6,154	4,213	2,747	2,237	1,074	695	617	499	441
02/01 to 02/15	3,641	2,621	1,865	1,639	1,005	649	579	453	409
02/16 to 02/28	6,091	3,544	1,878	1,696	1,097	718	653	545	469
03/01 to 03/15	2,987	2,120	1,523	1,386	1,002	747	700	623	543
03/16 to 03/31	2,575	1,972	1,491	1,420	1,055	796	753	660	580
04/01 to 04/15	2,882	2,609	1,994	1,821	1,333	874	817	694	576
04/16 to 04/30	2,516	2,251	1,896	1,772	1,320	999	937	799	734
05/01 to 05/15	3,222	2,719	2,133	1,951	1,355	1,093	1,032	869	777
05/16 to 05/31	2,870	2,361	1,901	1,770	1,171	813	761	590	501
06/01 to 06/15	3,017	2,052	1,489	1,367	852	566	501	418	362
06/16 to 06/30	1,731	1,391	1,003	897	571	405	377	314	274
07/01 to 07/15	1,002	874	645	549	376	282	263	238	219
07/16 to 07/31	707	554	397	348	255	202	194	180	168
08/01 to 08/15	385	318	265	244	198	169	163	149	141
08/16 to 08/31	411	310	249	230	181	153	148	135	125
09/01 to 09/15	465	386	297	269	182	149	142	129	118
09/16 to 09/30	832	595	353	296	183	148	137	119	110
10/01 to 10/15	874	596	407	362	225	156	144	116	102
10/16 to 10/31	1,718	1,209	768	650	311	205	186	138	119
11/01 to 11/15	3,666	2,578	1,569	1,378	702	370	332	247	183
11/16 to 11/30	4,189	2,809	1,733	1,499	936	574	517	335	235
12/01 to 12/15	4,973	3,667	2,225	1,976	1,221	721	659	518	448
12/16 to 12/31	4,349	3,128	1,891	1,588	918	650	586	457	396

Half Monthly Average for Auburn in CFS
Natural

CFS	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Jan 1-15	2,822	1,347	1,762	3,769	1,502	3,570	1,015	2,206	2,126	2,454	1,816	2,246	3,263	805	1,323	841
Jan 16-31	2,755	5,742	1,333	3,849	3,263	1,303	3,849	4,842	3,872	1,995	5,383	5,302	4,391	1,534	1,165	909
Feb 1-15	2,007	4,004	995	2,839	1,847	1,227	1,904	3,496	2,313	979	2,904	1,791	1,938	818	1,319	2,753
Feb 16-28	1,835	3,276	1,103	2,156	4,304	995	2,185	2,439	5,079	976	2,126	2,155	2,006	818	1,105	1,810
Mar 1-15	1,571	2,034	1,369	1,364	1,557	938	1,380	1,788	5,925	1,194	2,036	2,620	1,256	1,172	994	3,005
Mar 16-31	1,884	1,427	1,758	1,597	1,640	1,918	1,493	1,787	3,592	1,012	2,641	1,487	1,518	1,282	1,451	1,761
Apr 1-15	2,260	1,219	2,889	1,272	1,744	2,318	2,063	2,103	2,464	887	2,697	1,230	2,223	1,889	1,092	1,810
Apr 16-30	2,113	2,765	1,748	1,212	1,444	2,586	1,430	1,755	1,896	1,167	2,658	1,595	1,885	1,570	1,570	1,890
May 1-15	2,100	1,677	2,350	1,612	1,457	2,685	1,895	3,243	3,048	1,243	2,840	2,933	2,945	1,155	1,481	2,090
May 16-31	3,104	1,680	1,348	2,356	1,173	2,419	1,906	2,472	3,052	1,093	2,567	2,926	1,630	1,009	1,410	1,455
June 1-15	3,448	1,271	1,074	1,444	1,645	1,588	1,426	1,944	2,167	664	4,158	2,309	1,028	1,127	926	772
June 16-30	2,726	692	851	1,051	781	1,103	759	1,695	1,584	838	2,402	1,162	1,161	600	637	475
July 1-15	1,407	476	923	535	564	856	466	1,173	1,233	556	1,222	879	699	425	474	431
July 16-31	817	352	537	390	432	541	352	801	855	357	887	475	469	335	431	341
Aug 1-15	618	314	396	295	354	408	293	454	510	304	541	361	431	274	366	317
Aug 16-31	554	320	333	276	645	343	248	366	443	282	409	539	576	438	368	317
Sept 1-15	616	291	299	278	561	292	351	502	392	251	350	491	506	464	428	350
Sept 16-30	808	310	292	234	1,558	519	354	364	877	293	307	340	365	580	817	249
Oct 1-15	1,226	325	333	385	978	787	487	362	510	388	312	381	405	431	508	227
Oct 16-31	702	526	937	1,363	1,431	450	619	845	404	437	373	1,427	463	486	424	474
Nov 1-15	791	620	734	1,420	1,834	700	593	2,186	778	999	465	2,257	647	2,230	1,143	409
Nov 16-30	1,900	633	1,589	836	2,148	741	1,710	1,521	915	1,495	1,148	2,813	937	3,208	1,304	334
Dec 1-15	3,626	1,124	2,464	1,390	2,882	895	1,585	2,449	1,067	1,935	1,104	7,877	825	7,931	2,463	2,243
Dec 16-31	2,534	784	2,802	3,241	1,447	1,650	1,103	2,211	5,184	3,116	3,308	3,230	1,327	2,285	1,615	3,394

CFS	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan 1-15	1,341	1,716	1,244	4,120	3,920	959	928	1,221	571	2,454	4,081	2,460	927	817	2,382	1,541
Jan 16-31	1,432	972	4,321	1,646	4,078	936	2,011	1,059	1,041	2,747	1,909	2,437	2,590	1,910	1,510	1,477
Feb 1-15	1,703	1,657	3,499	1,152	2,041	769	1,219	1,987	2,254	1,549	3,604	2,885	1,950	1,354	820	2,616
Feb 16-28	1,803	4,182	6,088	2,045	1,732	1,280	3,751	1,302	1,477	1,148	2,373	4,825	1,767	849	1,305	4,653
Mar 1-15	2,179	1,217	2,686	2,027	1,574	1,093	2,228	2,649	1,742	1,617	2,271	2,091	1,319	1,328	2,262	1,717
Mar 16-31	1,765	863	1,677	1,511	2,457	1,294	1,829	1,682	2,259	2,101	2,257	1,420	1,100	2,462	1,731	1,674
Apr 1-15	1,921	1,380	1,277	1,541	1,947	2,929	1,417	1,771	3,360	3,677	2,358	3,376	788	2,152	1,902	1,293
Apr 16-30	2,811	2,450	1,494	1,165	1,727	1,925	1,310	2,133	2,260	2,566	2,258	2,051	1,402	2,077	1,719	1,130
May 1-15	1,677	1,669	1,851	1,225	2,136	1,737	1,813	1,889	2,110	1,943	1,933	1,822	920	2,521	1,100	1,474
May 16-31	991	1,375	2,071	1,021	2,399	1,831	1,614	945	1,762	1,263	1,336	1,510	538	1,359	704	971
June 1-15	763	1,582	1,333	639	1,811	1,612	820	743	1,180	973	2,478	1,010	393	1,458	632	612
June 16-30	650	1,759	860	693	1,445	760	545	475	728	569	1,357	994	360	1,214	836	535
July 1-15	561	882	558	808	930	444	443	387	558	395	755	637	406	898	513	404
July 16-31	403	588	440	892	547	320	427	314	396	299	476	429	309	993	341	275
Aug 1-15	315	424	343	483	443	327	311	274	319	251	349	310	295	663	284	256
Aug 16-31	329	354	285	385	438	258	267	238	293	262	386	270	246	429	258	293
Sept 1-15	602	373	413	566	469	327	267	220	265	217	337	254	303	311	298	223
Sept 16-30	427	359	376	490	411	331	474	233	390	207	291	209	598	284	263	217
Oct 1-15	340	883	505	351	371	302	410	201	366	219	532	181	436	296	240	1,188
Oct 16-31	299	516	638	374	514	1,963	398	211	1,419	276	1,915	226	435	348	859	1,266
Nov 1-15	1,610	626	1,007	1,875	1,226	3,040	830	262	2,297	2,283	4,117	588	1:248	386	1,541	3,070
Nov 16-30	1,681	851	1,094	2,481	1,102	1,019	4,616	341	2,396	1,625	6,311	1,838	1,546	437	1,601	5,578
Dec 1-15	2,272	2,175	2,056	1,676	1,122	945	1,455	1,382	2,402	3,056	2,959	3,613	1,173	1,702	2,191	4,373
Dec 16-31	4,150	1,482	1,259	1,276	1,561	758	1,221	594	1,589	1,114	1,766	1,334	1,504	733	3,604	2,069

Percent Exceedance at Auburn (1964 to 1995)
Natural

CFS	5%	10%	20%	25%	50%	75%	80%	90%	95%
01/01 to 01/15	5,609	3,550	2,739	2,423	1,452	1,009	939	786	704
01/16 to 01/31	6,733	5,400	3,765	3,153	1,773	1,196	1,093	915	816
02/01 to 02/15	4,358	3,724	2,803	2,466	1,622	1,141	1,043	850	725
02/16 to 02/28	7,591	4,732	2,846	2,517	1,770	1,178	1,108	946	859
03/01 to 03/15	3,956	2,927	2,226	2,115	1,651	1,257	1,185	1,021	956
03/16 to 03/31	3,135	2,649	2,176	2,014	1,616	1,299	1,214	1,068	956
04/01 to 04/15	3,465	3,055	2,578	2,418	1,854	1,318	1,258	1,091	884
04/16 to 04/30	2,978	2,749	2,412	2,202	1,778	1,380	1,306	1,179	1,094
05/01 to 05/15	3,452	3,086	2,525	2,372	1,781	1,433	1,351	1,162	1,030
05/16 to 05/31	3,152	2,682	2,304	2,129	1,513	1,125	1,045	872	726
06/01 to 06/15	3,338	2,647	1,905	1,731	1,134	836	722	609	557
06/16 to 06/30	2,258	1,741	1,346	1,217	816	612	574	500	439
07/01 to 07/15	1,282	1,167	925	844	581	450	433	392	371
07/16 to 07/31	1,002	815	639	566	422	344	328	302	286
08/01 to 08/15	606	524	458	428	338	290	283	265	256
08/16 to 08/31	641	491	422	408	327	268	262	244	239
09/01 to 09/15	638	562	482	453	336	266	253	229	214
09/16 to 09/30	1,128	751	508	454	328	263	254	222	200
10/01 to 10/15	1,149	804	572	520	363	296	267	226	196
10/16 to 10/31	2,030	1,530	989	838	459	347	329	281	228
11/01 to 11/15	4,251	3,113	1,985	1,708	931	562	512	390	339
11/16 to 11/30	4,733	3,320	2,224	2,013	1,260	802	740	496	370
12/01 to 12/15	6,157	4,338	3,045	2,714	1,756	1,176	1,046	792	688
12/16 to 12/31	5,680	4,074	2,702	2,344	1,528	1,077	996	786	669

SECTION 15 SUMMARY OF BASELINE OPERATIONS

Baseline is the operation of HHD utilizing the existing rule curve and the operation of Tacoma's SSWR diversion pipeline. Storage of 5,000 ac-ft is assumed as active for drought years. This was modeled by refilling the reservoir with the extra 5,000 ac-ft every year (to elevation 1147 feet). In non-drought years, the reservoir is returned to elevation 1141 feet by the end of June, which mimics the additional pool height used every year to manipulate floating debris around the reservoir. During drought years the extra 5,000 ac-ft is maintained as long as possible to help with low-flow augmentation.

This section provides reservoir elevation and downstream flows in a format similar to the natural conditions. The tabulations are preceded by a detailed listing of operating rules as excerpted from the "Modeling" report.

The following exhibits follow this page of text:

- Baseline Operating Rules (10).
- Hanson Reservoir Baseline Elevations by Half-Months from 1964 through 1995.
- Hanson Reservoir Baseline Outflows by Half-Months from 1964 through 1995.
- Percent Exceedances of Hanson Reservoir Baseline Outflows by Half-Months.
- Palmer Baseline Flows by Half-Months from 1964 through 1995.
- Percent Exceedances of Palmer Baseline Flows by Half-Months.
- Auburn Baseline Flows by Half-Months from 1964 through 1995.
- Percent Exceedances of Auburn Baseline Flows by Half-Months.

Baseline

1. The start of refill of Howard Hanson Dam is 15 March;
2. The refill rates for Fish Dam 2 are:
   * From 15 March to 15 April: 200 cfs or 400 acre-feet/day (rounded to nearest 100)
   * From 15 April to 31 May: 400 cfs or 800 acre-feet/day.

   Fish Dam 1 is refilled following the 98 percent rule curve and on some days will exceed the refill targets stated above.
3. The priorities for use of water that flows into Howard Hanson Reservoir are as follows:
   1) Pipeline 1 water right of 72 mgd (111 cfs) from natural Green River flows
   2) 110 cfs base flow at Palmer
   3) Fish Dam 1 storage following the 98 percent rule curve
   4) Palmer and Auburn instream flows as approved in the Agreement
   5) Pipeline 5 water right of 65 mgd (100 cfs)
   6) Fish Dam 2 instream flow requirement of 900 cfs from 15 March to 1 May, and 900 cfs to 400 cfs ramp from 1 May to 1 July
   7) Fish Dam 2 storage requirements following refill level and rate limitations; and
   8) Instream release
4. The refill targets for active storage, as shown in Figures 1 and 2, are:

TABLE 1

Date	Fish Dam 1 Average (Acre-Feet)	Fish Dam 2 Average (Acre-Feet)	Fish Dam 1 Dry (Acre-Feet)	Fish Dam 2 Dry (Acre-Feet)
15 March	0	0	0	0
1 April	0	5,100	8,100	0
15 April	0	5,100	20,300	0
1 May	8,100	5,910	23,800	0
15 May	20,300	5,910	26,700	2,500
1 June	23,800	5,400	26,700	2,500
15 June	29,200	0	26,700	2,500[(1)]
30 June	24,200	0	26,700	0

[(1)] 2,500 acre-feet are in Fish Dam 2 for use in fisheries protection.

5. The maximum volume of water stored in Fish Dam 2 (Fish Dam 2 being the facility that stores water to augment flows at Auburn when the natural inflows drop below the instream flow levels) is equal to the difference between the refill rates shown above and the existing 98 percent Corps refill rule curve as shown in Table 1 under Fish Dam 1.

All water stored in Fish Dam 2 is outside the storage required to meet the flood responsibilities of the dam. In addition, the water stored in Fish Dam 2 is limited to 5,100 acre-feet or elevation 1100 feet until April 15 to allow downstream migrating fish to pass the dam. Until Phase 1 is complete, there is no fish passage facility at the dam and fish must dive down in the reservoir to pass through the existing valves.

6. The instream flow level for refill of Fish Dam 2 is 900 cfs from 15 March to 1 May. Water will be stored in the dam when flow exceeds 900 cfs at Auburn; up to a maximum equal to the storage levels and fill rates discussed in 2, 3, and 4 above. Water will be released from storage in Fish Dam 2 when flows begin to dip below 900 cfs at Auburn; up to the volume stored in Fish Dam 2. The instream flow levels linearly decrease from 900 cfs on 1 May to 400 cfs on 1 July.

7. There are no induced freshets or shaving of peaks.

8. For filling of Fish Dam 1, the existing Corps' 98 percent rule curve is followed, with the base flow of 110 cfs at Palmer. The dam meets the 350, 300, 250, and 225 cfs requirements at Auburn in an average year and 250 cfs and 225 cfs in a dry year, in accordance with the Agreement. In dry springs, the refill period for Fish Dam 1 begins 15 days earlier on 1 April.

9. All water diverted for Pipeline 5 is in accordance with the instantaneous rate and volume restrictions of the state water right and the Agreement.

10. From 1 July through the end of reservoir operation (generally 8 December), Fish Dam 1 meets the baseflow levels at Auburn in accordance with the Agreement. The summer months conditions as stated in the Agreement are, "*For Wet Years the minimum continuous instream flow shall be 350 cfs. For Wet to Average Years the minimum continuous instream flow shall be 300 cfs. For Average to Dry Years the minimum continuous instream flow shall be 250 cfs. For Drought Years, the minimum continuous instream flow shall range from 250 to 225 cfs, depending on the severity of the drought.*"

Half Monthly Average Elevation for Total Dam
Baseline

Feet	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Jan 1-15	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070
Jan 16-31	1,070	1,086	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,072	1,070	1,070	1,070	1,070
Feb 1-15	1,070	1,077	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070
Feb 16-28	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070
Mar 1-15	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070
Mar 16-31	1,091	1,090	1,089	1,090	1,083	1,090	1,091	1,091	1,091	1,071	1,091	1,091	1,090	1,080	1,084	1,091
Apr 1-15	1,100	1,100	1,100	1,100	1,102	1,100	1,100	1,100	1,100	1,091	1,100	1,100	1,100	1,102	1,095	1,100
Apr 16-30	1,114	1,114	1,114	1,107	1,123	1,114	1,113	1,114	1,114	1,123	1,114	1,113	1,114	1,123	1,099	1,114
May 1-15	1,136	1,135	1,135	1,125	1,140	1,136	1,134	1,136	1,136	1,140	1,136	1,135	1,136	1,140	1,126	1,135
May 16-31	1,147	1,146	1,146	1,141	1,146	1,147	1,146	1,147	1,147	1,146	1,147	1,146	1,147	1,146	1,140	1,146
June 1-15	1,147	1,147	1,147	1,147	1,147	1,147	1,147	1,147	1,147	1,147	1,147	1,147	1,147	1,147	1,146	1,147
June 16-30	1,144	1,144	1,144	1,144	1,144	1,144	1,144	1,144	1,144	1,144	1,144	1,144	1,144	1,146	1,147	1,144
July 1-15	1,141	1,141	1,141	1,141	1,141	1,141	1,141	1,141	1,141	1,141	1,141	1,141	1,141	1,145	1,146	1,140
July 16-31	1,141	1,139	1,141	1,139	1,141	1,141	1,139	1,141	1,141	1,139	1,141	1,141	1,141	1,144	1,145	1,138
Aug 1-15	1,139	1,135	1,139	1,136	1,138	1,139	1,135	1,139	1,139	1,135	1,139	1,138	1,139	1,142	1,143	1,134
Aug 16-31	1,136	1,130	1,135	1,129	1,136	1,135	1,128	1,136	1,136	1,129	1,136	1,135	1,136	1,139	1,139	1,129
Sept 1-15	1,131	1,123	1,128	1,122	1,131	1,128	1,123	1,131	1,131	1,122	1,131	1,131	1,131	1,135	1,135	1,125
Sept 16-30	1,125	1,119	1,121	1,116	1,125	1,124	1,120	1,124	1,125	1,116	1,123	1,124	1,125	1,130	1,130	1,118
Oct 1-15	1,119	1,112	1,114	1,109	1,119	1,119	1,116	1,118	1,119	1,111	1,115	1,118	1,119	1,124	1,124	1,108
Oct 16-31	1,112	1,111	1,110	1,111	1,112	1,112	1,112	1,111	1,111	1,110	1,106	1,112	1,111	1,118	1,118	1,105
Nov 1-15	1,102	1,102	1,102	1,102	1,102	1,102	1,102	1,102	1,102	1,102	1,099	1,102	1,102	1,110	1,110	1,102
Nov 16-30	1,085	1,085	1,085	1,085	1,085	1,085	1,085	1,085	1,085	1,085	1,085	1,085	1,085	1,098	1,098	1,084
Dec 1-15	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,096	1,073	1,096	1,079	1,073
Dec 16-31	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070

Feet	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan 1-15	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,073	1,070	1,070	1,070	1,070	1,070
Jan 16-31	1,070	1,070	1,071	1,070	1,072	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070
Feb 1-15	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070
Feb 16-28	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070
Mar 1-15	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070
Mar 16-31	1,091	1,070	1,091	1,087	1,091	1,080	1,090	1,091	1,089	1,091	1,091	1,091	1,077	1,091	1,091	1,091
Apr 1-15	1,100	1,092	1,099	1,100	1,100	1,100	1,102	1,100	1,100	1,100	1,100	1,102	1,091	1,100	1,100	1,100
Apr 16-30	1,114	1,123	1,111	1,104	1,114	1,114	1,123	1,114	1,114	1,114	1,114	1,123	1,123	1,114	1,114	1,104
May 1-15	1,135	1,140	1,133	1,125	1,133	1,135	1,140	1,135	1,136	1,135	1,136	1,140	1,140	1,136	1,128	1,125
May 16-31	1,143	1,146	1,146	1,140	1,146	1,146	1,146	1,145	1,147	1,146	1,146	1,146	1,146	1,147	1,140	1,140
June 1-15	1,147	1,147	1,147	1,146	1,147	1,147	1,147	1,146	1,147	1,147	1,147	1,147	1,147	1,147	1,146	1,146
June 16-30	1,144	1,147	1,144	1,144	1,144	1,144	1,144	1,144	1,145	1,147	1,144	1,144	1,144	1,146	1,144	1,144
July 1-15	1,141	1,146	1,141	1,141	1,141	1,141	1,141	1,144	1,144	1,146	1,143	1,141	1,144	1,145	1,141	1,140
July 16-31	1,140	1,145	1,140	1,141	1,141	1,138	1,140	1,143	1,142	1,144	1,141	1,141	1,143	1,144	1,139	1,137
Aug 1-15	1,137	1,143	1,138	1,139	1,139	1,134	1,137	1,140	1,137	1,140	1,138	1,137	1,141	1,141	1,134	1,131
Aug 16-31	1,132	1,139	1,133	1,135	1,136	1,128	1,130	1,136	1,131	1,136	1,135	1,131	1,137	1,136	1,127	1,127
Sept 1-15	1,131	1,135	1,127	1,131	1,131	1,123	1,122	1,129	1,124	1,130	1,130	1,123	1,132	1,130	1,122	1,120
Sept 16-30	1,125	1,130	1,125	1,125	1,125	1,119	1,119	1,121	1,120	1,121	1,122	1,114	1,129	1,122	1,117	1,113
Oct 1-15	1,119	1,124	1,119	1,119	1,118	1,111	1,119	1,111	1,117	1,109	1,117	1,105	1,124	1,113	1,108	1,117
Oct 16-31	1,108	1,118	1,111	1,111	1,111	1,111	1,109	1,099	1,112	1,102	1,112	1,094	1,118	1,107	1,105	1,112
Nov 1-15	1,101	1,110	1,102	1,102	1,102	1,102	1,102	1,089	1,102	1,106	1,102	1,095	1,110	1,101	1,102	1,102
Nov 16-30	1,085	1,098	1,085	1,085	1,085	1,085	1,086	1,084	1,085	1,098	1,098	1,085	1,098	1,084	1,085	1,096
Dec 1-15	1,073	1,079	1,073	1,073	1,073	1,073	1,073	1,079	1,073	1,079	1,073	1,073	1,079	1,073	1,073	1,084
Dec 16-31	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070

Half Monthly Average for HH Outflow in CFS
Baseline

CFS	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Jan 1-15	1,857	654	1,062	2,925	1,042	2,253	585	1,472	1,391	1,649	1,275	1,202	2,194	568	741	469
Jan 16-31	1,480	3,648	758	2,619	2,739	575	2,839	3,871	2,684	1,171	4,385	4,042	3,117	1,218	678	465
Feb 1-15	1,095	3,550	596	2,017	1,238	439	1,262	2,704	1,562	507	1,656	970	1,263	584	782	1,925
Feb 16-28	1,200	2,275	736	1,430	3,498	415	1,549	1,660	3,932	576	1,110	1,029	1,196	592	712	1,018
Mar 1-15	1,017	1,265	890	803	1,007	487	857	857	4,230	741	1,056	1,563	663	712	619	2,242
Mar 16-31	1,104	743	1,152	843	948	1,373	895	881	2,509	594	1,558	615	842	752	926	1,085
Apr 1-15	1,765	799	2,434	782	1,136	1,808	1,586	1,411	1,739	331	1,827	728	1,724	1,437	884	1,325
Apr 16-30	1,312	1,891	1,020	574	613	1,809	681	969	1,027	528	1,710	814	1,096	835	809	1,141
May 1-15	1,253	804	1,644	842	883	1,933	1,061	2,525	2,245	746	1,889	2,074	2,070	723	662	1,239
May 16-31	2,613	1,184	949	1,777	774	2,022	1,399	2,058	2,536	690	1,987	2,261	1,189	663	824	1,065
June 1-15	2,947	936	832	1,028	1,130	1,213	1,107	1,564	1,783	459	3,746	1,923	800	799	536	575
June 16-30	2,261	624	783	984	653	933	663	1,525	1,454	772	2,077	1,088	1,069	419	402	472
July 1-15	1,077	295	640	363	349	546	296	866	933	380	888	629	521	282	307	323
July 16-31	554	282	324	279	300	313	235	536	584	321	563	321	331	249	256	238
Aug 1-15	483	269	304	290	274	316	265	341	387	294	378	316	326	254	255	255
Aug 16-31	443	266	309	274	513	299	253	295	333	268	302	369	483	345	293	249
Sept 1-15	551	257	271	237	480	280	254	378	328	251	294	403	444	475	376	244
Sept 16-30	694	283	270	238	1,346	359	260	286	730	242	293	305	356	557	638	246
Oct 1-15	1,106	243	263	236	826	685	370	286	433	230	241	289	294	478	407	206
Oct 16-31	611	402	776	1,205	1,116	387	515	725	329	325	218	1,271	401	498	318	260
Nov 1-15	626	558	668	1,231	1,532	566	505	1,835	655	833	292	1,808	559	2,131	951	347
Nov 16-30	1,504	560	1,401	744	1,744	619	1,571	1,149	784	1,088	912	2,311	848	3,068	1,081	286
Dec 1-15	2,680	890	1,876	1,154	1,940	541	1,061	1,771	832	1,382	850	6,549	642	7,326	1,809	1,964
Dec 16-31	1,527	395	2,095	2,831	774	939	573	1,326	3,805	2,179	2,598	2,147	1,034	1,367	1,081	2,423

CFS	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan 1-15	650	1,000	789	3,312	3,058	484	548	678	377	1,636	2,997	1,735	603	520	1,883	870
Jan 16-31	619	465	3,108	910	3,183	579	1,269	530	710	1,987	1,012	1,520	2,042	1,434	1,009	974
Feb 1-15	1,044	1,145	2,463	610	1,249	381	717	1,371	1,887	978	2,484	2,066	1,240	909	478	1,848
Feb 16-28	1,215	3,294	4,102	1,323	887	893	3,074	908	1,105	550	1,450	3,412	1,143	529	730	3,520
Mar 1-15	1,400	633	1,682	1,311	896	684	1,678	1,964	1,312	873	1,488	1,028	839	1,045	1,625	983
Mar 16-31	887	463	801	841	1,590	788	1,230	937	1,681	1,082	1,478	608	692	1,710	1,076	838
Apr 1-15	1,296	656	738	979	1,242	2,688	908	1,306	2,782	2,753	1,897	2,069	244	1,465	1,417	810
Apr 16-30	1,769	1,586	796	714	873	1,354	555	1,341	1,420	1,620	1,592	968	616	1,129	1,081	620
May 1-15	850	1,018	1,012	490	1,132	1,076	1,128	1,035	1,182	1,137	1,088	1,105	461	1,543	561	670
May 16-31	578	838	1,540	573	1,691	1,502	1,152	585	1,246	763	863	955	232	816	317	495
June 1-15	449	1,036	1,033	333	1,265	1,280	570	484	785	683	1,844	701	239	931	365	302
June 16-30	579	1,229	808	608	1,152	667	484	323	537	391	989	855	296	805	781	491
July 1-15	344	562	366	574	546	305	280	229	358	272	435	374	230	557	358	295
July 16-31	281	351	305	629	296	257	293	224	313	260	292	278	235	679	312	269
Aug 1-15	263	292	268	393	295	268	274	236	292	266	301	278	240	505	299	265
Aug 16-31	266	251	285	300	247	268	296	246	271	265	271	293	249	351	253	253
Sept 1-15	463	311	296	483	296	260	270	247	249	277	307	268	246	316	239	265
Sept 16-30	358	267	327	404	255	293	265	249	266	273	283	230	550	277	243	188
Oct 1-15	339	671	446	349	284	256	397	247	261	243	448	182	424	269	211	911
Oct 16-31	278	347	541	323	437	1,661	312	184	1,132	201	1,681	184	401	258	663	1,077
Nov 1-15	1,323	364	897	1,635	1,055	2,711	774	189	1,885	1,871	3,424	388	1,177	336	1,204	2,716
Nov 16-30	1,300	586	918	1,939	833	748	4,108	242	1,792	1,289	4,909	1,542	1,337	408	1,376	3,945
Dec 1-15	1,594	1,645	1,553	1,036	665	471	913	1,206	1,841	2,351	1,769	3,061	,960	1,356	1,481	3,596
Dec 16-31	3,332	827	733	698	1,047	445	737	346	1,044	680	1,071	909	1,063	466	2,575	1,264

Percent Exceedance at HH Outflow (1964 to 1995)
Baseline

CFS	5%	10%	20%	25%	50%	75%	80%	90%	95%
01/01 to 01/15	4,375	2,596	1,750	1,561	808	537	501	430	385
01/16 to 01/31	5,975	4,090	2,667	2,172	1,043	675	599	484	428
02/01 to 02/15	3,566	2,545	1,811	1,591	976	630	562	440	397
02/16 to 02/28	5,914	3,441	1,824	1,647	1,065	697	634	529	456
03/01 to 03/15	2,900	2,058	1,470	1,324	970	716	678	605	527
03/16 to 03/31	2,207	1,808	1,337	1,225	854	671	642	568	509
04/01 to 04/15	2,798	2,533	1,936	1,768	1,274	833	786	625	422
04/16 to 04/30	2,101	1,846	1,519	1,407	965	690	642	560	454
05/01 to 05/15	2,718	2,242	1,661	1,484	966	719	669	559	443
05/16 to 05/31	2,715	2,189	1,743	1,527	1,037	675	596	518	321
06/01 to 06/15	2,929	1,992	1,439	1,325	812	530	484	358	268
06/16 to 06/30	1,864	1,540	1,123	1,029	695	515	477	391	343
07/01 to 07/15	973	849	633	546	368	295	288	260	233
07/16 to 07/31	693	547	386	343	298	260	256	231	221
08/01 to 08/15	455	403	330	318	285	266	261	245	235
08/16 to 08/31	461	379	316	307	282	256	251	242	233
09/01 to 09/15	547	470	389	364	286	256	251	237	225
09/16 to 09/30	838	629	395	353	281	251	243	225	216
10/01 to 10/15	954	663	475	426	297	246	238	215	184
10/16 to 10/31	1,750	1,233	817	667	367	278	255	210	184
11/01 to 11/15	3,667	2,611	1,631	1,445	783	446	397	318	215
11/16 to 11/30	4,176	2,861	1,798	1,569	1,023	667	612	433	295
12/01 to 12/15	6,098	3,745	2,205	1,952	1,228	757	682	542	467
12/16 to 12/31	4,222	3,037	1,836	1,542	891	631	569	444	384

Half Monthly Average for Palmer in CFS
Baseline

CFS	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Jan 1-15	1,701	462	915	2,801	861	2,109	436	1,307	1,221	1,487	1,102	1,026	2,048	385	553	323
Jan 16-31	1,312	3,575	569	2,485	2,609	387	2,712	3,775	2,552	994	4,305	3,952	2,999	1,042	487	323
Feb 1-15	915	3,413	402	1,865	1,063	300	1,088	2,573	1,397	331	1,494	787	1,089	422	594	1,797
Feb 16-28	1,024	2,132	546	1,261	3,391	295	1,383	1,498	3,838	387	932	848	1,020	398	521	837
Mar 1-15	836	1,091	706	615	825	327	671	672	4,145	551	876	1,399	471	522	426	2,097
Mar 16-31	929	557	979	661	769	1,207	714	699	2,377	400	1,397	426	660	567	747	910
Apr 1-15	1,606	611	2,295	594	961	1,651	1,421	1,241	1,579	209	1,670	538	1,564	1,271	695	1,153
Apr 16-30	1,148	1,744	847	428	443	1,661	498	795	855	367	1,558	635	926	673	634	972
May 1-15	1,091	628	1,493	690	704	1,792	895	2,401	2,113	571	1,746	1,937	1,932	539	511	1,077
May 16-31	2,482	1,010	769	1,624	588	1,873	1,233	1,910	2,403	502	1,837	2,120	1,015	474	643	888
June 1-15	2,823	752	645	849	952	1,037	928	1,399	1,624	305	3,646	1,769	612	611	346	393
June 16-30	2,112	428	589	796	456	744	466	1,354	1,281	578	1,922	904	885	272	280	306
July 1-15	897	192	448	238	238	351	190	680	749	246	703	436	334	178	203	213
July 16-31	359	177	191	174	195	188	130	349	391	216	368	206	219	144	150	133
Aug 1-15	288	163	197	185	169	207	158	204	221	189	210	211	209	148	145	149
Aug 16-31	283	160	203	167	365	193	145	190	206	162	193	226	310	212	186	142
Sept 1-15	354	150	164	130	291	173	152	221	207	144	188	236	269	324	241	138
Sept 16-30	505	177	163	138	1,172	237	155	181	564	135	186	199	252	391	450	140
Oct 1-15	924	138	157	132	635	490	246	181	296	125	133	184	190	312	281	120
Oct 16-31	417	271	625	1,069	935	277	360	553	225	208	110	1,110	267	355	214	150
Nov 1-15	429	385	476	1,053	1,363	399	356	1,675	461	669	183	1,647	388	1,979	778	237
Nov 16-30	1,336	381	1,228	551	1,581	438	1,403	969	638	906	735	2,165	658	2,945	898	180
Dec 1-15	2,547	705	1,719	977	1,786	394	880	1,611	645	1,211	675	6,533	456	7,330	1,648	1,817
Dec 16-31	1,360	279	1,946	2,705	588	755	407	1,154	3,707	2,032	2,465	1,999	853	1,196	902	2,283

CFS	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan 1-15	464	818	621	3,218	2,938	335	383	488	263	1,473	2,875	1,577	422	358	1,727	684
Jan 16-31	454	302	2,989	726	3,066	395	1,095	384	522	1,834	831	1,354	1,891	1,316	827	792
Feb 1-15	868	1,040	2,325	417	1,075	271	527	1,200	1,731	798	2,346	1,916	1,066	725	321	1,691
Feb 16-28	1,039	3,180	4,013	1,150	701	731	2,961	723	926	354	1,282	3,303	966	362	540	3,414
Mar 1-15	1,231	449	1,521	1,139	712	492	1,517	1,812	1,139	693	1,322	848	653	882	1,462	801
Mar 16-31	706	318	618	659	1,430	605	1,059	757	1,524	907	1,315	419	502	1,553	900	656
Apr 1-15	1,123	480	548	797	1,068	2,557	728	1,133	2,653	2,623	1,742	1,921	144	1,297	1,247	622
Apr 16-30	1,619	1,434	620	557	695	1,191	417	1,178	1,260	1,466	1,436	797	479	960	910	487
May 1-15	688	843	843	343	970	908	957	867	1,019	971	921	935	306	1,390	424	498
May 16-31	441	654	1,378	388	1,533	1,339	978	438	1,074	578	684	781	130	631	219	348
June 1-15	321	856	852	227	1,091	1,107	398	355	596	499	1,687	510	135	747	255	196
June 16-30	382	1,054	615	410	970	470	314	220	382	280	803	664	191	615	587	316
July 1-15	229	366	240	424	351	202	176	124	218	168	240	234	126	332	240	191
July 16-31	177	209	200	438	179	152	189	117	178	154	163	172	129	455	207	163
Aug 1-15	156	181	163	240	185	162	168	129	155	160	195	174	133	281	193	158
Aug 16-31	160	145	179	195	141	162	190	140	163	158	167	187	142	205	146	147
Sept 1-15	296	191	187	308	188	154	164	145	147	170	201	161	140	212	133	162
Sept 16-30	251	162	223	282	148	188	157	142	162	171	176	146	406	170	136	130
Oct 1-15	234	496	302	244	175	150	271	151	155	153	337	131	286	162	122	768
Oct 16-31	172	241	402	219	300	1,527	201	126	953	126	1,517	125	279	153	555	894
Nov 1-15	1,169	260	709	1,479	871	2,577	592	121	1,726	1,760	3,312	277	997	232	1,025	2,583
Nov 16-30	1,124	399	730	1,782	643	555	4,016	137	1,630	1,113	4,846	1,373	1,162	276	1,202	3,875
Dec 1-15	1,429	1,479	1,387	855	476	312	727	1,042	1,683	2,206	1,609	2,940	773	1,184	1,313	3,464
Dec 16-31	3,220	640	552	521	872	299	549	233	864	488	901	724	883	324	2,441	1,090

Percent Exceedance at Palmer (1964 to 1995)
Baseline

CFS	5%	10%	20%	25%	50%	75%	80%	90%	95%
01/01 to 01/15	4,294	2,462	1,591	1,396	620	341	304	300	285
01/16 to 01/31	5,942	4,001	2,535	2,025	862	483	405	300	300
02/01 to 02/15	3,461	2,409	1,653	1,427	793	437	367	300	298
02/16 to 02/28	5,879	3,332	1,666	1,484	885	506	441	333	300
03/01 to 03/15	2,775	1,908	1,302	1,152	787	527	486	411	331
03/16 to 03/31	2,064	1,656	1,168	1,056	673	481	454	380	316
04/01 to 04/15	2,670	2,397	1,782	1,609	1,100	646	598	435	300
04/16 to 04/30	1,961	1,698	1,364	1,246	793	520	480	393	300
05/01 to 05/15	2,600	2,110	1,511	1,329	789	550	490	385	300
05/16 to 05/31	2,591	2,049	1,584	1,361	859	489	442	345	225
06/01 to 06/15	2,805	1,840	1,270	1,153	626	346	310	263	168
06/16 to 06/30	1,703	1,369	940	841	504	315	300	286	241
07/01 to 07/15	790	663	436	349	232	191	184	156	128
07/16 to 07/31	495	342	229	214	192	153	148	125	115
08/01 to 08/15	259	224	210	202	174	157	152	138	128
08/16 to 08/31	287	224	205	200	175	149	144	136	125
09/01 to 09/15	348	300	234	220	179	149	145	132	122
09/16 to 09/30	649	433	293	248	176	145	138	129	116
10/01 to 10/15	767	468	300	300	192	141	133	115	110
10/16 to 10/31	1,588	1,056	627	473	264	172	152	122	110
11/01 to 11/15	3,561	2,474	1,464	1,273	591	300	296	216	128
11/16 to 11/30	4,086	2,732	1,637	1,401	838	472	415	300	189
12/01 to 12/15	6,065	3,644	2,058	1,798	1,052	566	489	345	300
12/16 to 12/31	4,137	2,916	1,679	1,376	706	438	374	300	284

Half Monthly Average for Auburn in CFS
Baseline

CFS	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Jan 1-15	2,610	1,135	1,584	3,557	1,290	3,358	848	1,997	1,914	2,242	1,605	2,034	3,051	605	1,113	680
Jan 16-31	2,544	4,533	1,121	3,637	3,051	1,097	3,637	4,630	3,660	1,783	5,171	5,090	4,179	1,323	953	754
Feb 1-15	1,795	4,856	783	2,627	1,635	1,075	1,692	3,284	2,101	789	2,692	1,579	1,726	639	1,107	2,568
Feb 16-28	1,623	3,064	891	1,944	4,092	863	1,974	2,227	4,867	769	1,914	1,943	1,795	607	893	1,598
Mar 1-15	1,346	1,808	1,144	1,152	1,343	763	1,155	1,562	5,699	979	1,811	2,395	1,042	960	782	2,779
Mar 16-31	1,524	1,074	1,398	1,225	1,270	1,546	1,133	1,427	3,232	803	2,281	1,126	1,148	909	1,078	1,401
Apr 1-15	2,048	998	2,677	1,060	1,450	2,106	1,852	1,891	2,252	493	2,485	1,018	2,011	1,594	979	1,598
Apr 16-30	1,601	2,253	1,236	900	842	2,075	948	1,243	1,384	578	2,146	1,095	1,373	970	1,123	1,383
May 1-15	1,468	1,068	1,738	1,048	1,029	2,054	1,268	2,611	2,416	824	2,208	2,301	2,314	737	931	1,459
May 16-31	2,808	1,363	1,033	1,944	858	2,123	1,579	2,175	2,756	777	2,270	2,618	1,334	684	999	1,154
June 1-15	3,236	1,059	862	1,156	1,433	1,376	1,214	1,732	1,955	503	3,946	2,097	816	917	631	584
June 16-30	2,682	651	807	1,007	737	1,059	715	1,651	1,540	788	2,358	1,118	1,117	481	502	457
July 1-15	1,195	377	711	420	443	644	384	961	1,021	418	1,010	667	497	327	403	367
July 16-31	605	322	399	322	359	407	290	598	644	328	676	371	368	268	361	278
Aug 1-15	491	300	363	305	308	377	300	391	415	300	445	350	366	250	329	305
Aug 16-31	461	300	350	294	539	350	272	354	387	281	377	426	469	351	334	300
Sept 1-15	524	274	303	253	479	310	282	433	382	250	354	434	438	420	402	305
Sept 16-30	685	293	300	250	1,430	415	301	350	776	251	335	353	380	484	696	267
Oct 1-15	1,125	259	302	260	877	686	386	351	475	297	301	340	364	366	484	240
Oct 16-31	574	421	790	1,237	1,301	412	533	732	377	351	353	1,312	400	412	395	320
Nov 1-15	687	541	633	1,315	1,729	626	539	2,082	673	920	397	2,152	570	2,125	1,052	403
Nov 16-30	1,799	550	1,487	733	2,045	654	1,607	1,419	858	1,393	1,056	2,711	834	3,105	1,201	328
Dec 1-15	3,446	945	2,284	1,211	2,702	765	1,405	2,269	888	1,755	936	7,697	653	7,835	2,367	2,069
Dec 16-31	2,322	655	2,590	3,029	1,237	1,438	919	1,999	4,972	2,904	3,096	3,018	1,115	2,073	1,403	3,182

CFS	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan 1-15	1,135	1,504	1,053	3,927	3,709	796	747	1,011	447	2,242	3,869	2,250	728	639	2,170	1,329
Jan 16-31	1,249	795	4,109	1,435	3,866	734	1,799	897	832	2,536	1,697	2,225	2,378	1,748	1,298	1,265
Feb 1-15	1,496	1,518	3,287	941	1,829	647	1,007	1,775	2,042	1,340	3,393	2,673	1,739	1,142	649	2,404
Feb 16-28	1,591	3,970	5,876	1,834	1,520	1,091	3,545	1,090	1,265	936	2,161	4,613	1,555	667	1,093	4,441
Mar 1-15	1,954	1,013	2,460	1,801	1,349	882	2,003	2,424	1,517	1,397	2,046	1,866	1,094	1,119	2,037	1,491
Mar 16-31	1,405	704	1,317	1,151	2,097	922	1,469	1,322	1,898	1,741	1,897	1,060	903	2,102	1,371	1,314
Apr 1-15	1,710	923	1,065	1,333	1,735	2,718	1,125	1,559	3,148	3,465	2,146	3,081	423	1,940	1,690	1,081
Apr 16-30	2,299	1,838	1,040	878	1,261	1,429	742	1,621	1,748	2,054	1,746	1,439	829	1,565	1,250	874
May 1-15	1,121	1,237	1,220	630	1,508	1,137	1,385	1,279	1,478	1,346	1,305	1,398	540	1,889	688	850
May 16-31	749	1,063	1,725	633	2,060	1,490	1,299	738	1,466	934	1,041	1,200	314	1,062	401	623
June 1-15	569	1,371	1,121	431	1,599	1,400	639	580	968	768	2,266	798	292	1,246	408	408
June 16-30	601	1,547	816	640	1,402	717	525	399	633	470	1,258	950	339	1,049	792	508
July 1-15	435	712	421	640	719	365	350	279	438	308	577	486	281	687	394	343
July 16-31	346	476	366	682	421	281	347	250	343	264	376	356	250	781	322	266
Aug 1-15	300	387	307	403	407	302	301	250	300	250	350	303	250	539	300	250
Aug 16-31	300	321	303	353	405	278	300	250	300	250	325	300	250	386	250	253
Sept 1-15	463	365	321	498	473	277	282	250	280	250	350	273	250	347	250	248
Sept 16-30	396	332	358	442	402	300	290	250	290	250	313	239	500	300	250	217
Oct 1-15	358	801	452	362	349	257	397	248	321	243	449	218	400	291	239	957
Oct 16-31	300	483	567	334	448	1,800	353	225	1,289	234	1,785	225	386	285	699	1,136
Nov 1-15	1,475	621	902	1,781	1,122	2,936	735	231	2,192	2,073	4,013	436	1,144	352	1,437	2,965
Nov 16-30	1,578	759	991	2,378	1,000	917	4,513	251	2,293	1,522	6,213	1,736	1,443	402	1,498	4,564
Dec 1-15	2,092	2,079	1,876	1,496	946	805	1,275	1,255	2,222	2,960	2,779	3,433	1,077	1,522	2,011	5,104
Dec 16-31	3,938	1,270	1,057	1,078	1,355	598	1,010	471	1,377	902	1,564	1,122	1,292	576	3,392	1,857

Percent Exceedance at Auburn (1964 to 1995)
Baseline

CFS	5%	10%	20%	25%	50%	75%	80%	90%	95%
01/01 to 01/15	5,397	3,338	2,527	2,211	1,240	810	751	640	530
01/16 to 01/31	6,612	5,188	3,553	2,941	1,561	991	890	741	634
02/01 to 02/15	4,146	3,512	2,591	2,254	1,410	934	851	701	591
02/16 to 02/28	7,379	4,520	2,634	2,305	1,558	972	910	753	680
03/01 to 03/15	3,744	2,715	2,007	1,889	1,409	1,039	970	816	746
03/16 to 03/31	2,800	2,302	1,779	1,656	1,231	900	900	900	758
04/01 to 04/15	3,253	2,843	2,366	2,206	1,638	1,070	999	900	520
04/16 to 04/30	2,461	2,237	1,877	1,681	1,256	900	900	754	605
05/01 to 05/15	2,890	2,464	1,876	1,743	1,215	892	843	678	570
05/16 to 05/31	2,899	2,406	1,944	1,745	1,204	782	729	590	430
06/01 to 06/15	3,126	2,435	1,680	1,519	921	605	544	460	350
06/16 to 06/30	2,079	1,714	1,274	1,145	757	531	509	452	416
07/01 to 07/15	1,070	973	719	639	442	350	350	343	282
07/16 to 07/31	790	603	462	426	350	300	300	251	250
08/01 to 08/15	474	421	400	391	300	300	300	250	250
08/16 to 08/31	469	400	376	350	300	300	250	250	250
09/01 to 09/15	528	486	402	400	300	250	250	250	250
09/16 to 09/30	972	605	444	397	300	250	250	250	250
10/01 to 10/15	1,029	670	475	440	350	263	250	250	226
10/16 to 10/31	1,900	1,368	844	668	396	300	300	250	225
11/01 to 11/15	4,146	3,008	1,881	1,604	827	476	452	350	264
11/16 to 11/30	4,688	3,300	2,134	1,911	1,157	699	637	452	350
12/01 to 12/15	7,648	4,197	2,878	2,586	1,583	996	879	621	536
12/16 to 12/31	5,468	3,862	2,490	2,132	1,316	873	785	615	531

SECTION 16 SUMMARY OF PHASE I OPERATIONS

Phase I adds to Baseline an additional 20,000 ac-ft of storage by storing Tacoma's SSWR diversion. Also implemented is 5,000 ac-ft of storage for fisheries use in 4-out-of-5 years (the non-drought years), which makes this storage an annual operation. The total full pool is at elevation 1167 feet.

This section provides reservoir elevation and downstream flows in a format similar to the baseline conditions. The tabulations are preceded by a detailed listing of operating rules as excerpted from the "Modeling" report. The modeled rules do not entirely match the current plan formulation. The rules modeled the 5,000 ac-ft of fisheries storage as if it were still a 1-in-5 year operation. So 4-out-of-5 years operate from a maximum pool of 1162 feet which is 5 feet too low. The drought years operate from a maximum pool of 1167 feet which is the correct formulation. Instream flows are therefore slightly lower for most of the years towards the end of the low-flow season due to less storage. Inspection of this data may cause some confusion for the reader; however, it was considered more worthwhile to include this data rather than leave it out.

The following exhibits follow this page of text:

- Phase I Operating Rules (11).
- Hanson Reservoir Phase I Elevations by Half-Months from 1964 through 1995.
- Hanson Reservoir Phase I Outflows by Half-Months from 1964 through 1995.
- Percent Exceedances of Hanson Reservoir Phase I Outflows by Half-Months.
- Palmer Phase I Flows by Half-Months from 1964 through 1995.
- Percent Exceedances of Palmer Phase I Flows by Half-Months.
- Auburn Phase I Flows by Half-Months from 1964 through 1995.
- Percent Exceedances of Auburn Phase I Flows by Half-Months.

Phase I

1. The start of refill is 15 February. Prior to 1 March, a maximum of 3000 acre-feet is stored in the Diversion Dam for water supply diversion within the Pipeline 5 water right.

2. The maximum refill rates for the Diversion Dam and Fish Dam 2 are:

   * From 15 February to 28 February: 100 cfs or 200 acre-feet/day (Pipeline 5 water only)
   * From 1 March to 30 March: 400 cfs or 800 acre-feet/day
   * From 1 April to 30 April: 300 cfs or 600 acre-feet/day
   * From 1 May to 30 June: 200 cfs or 400 acre-feet/day.

   Fish Dam 2 is refilled following the 98 percent rule curve and on some days will exceed the refill targets stated above. For any day or group of days where the reservoir fill targets are not met, the reservoir is allowed to make up any shortfall in one day if water is available.

   To provide protection for the fish passing through the reservoir, the refill rates between 15 April and 30 June limit the refill to the point that no additional water is available for storage above the needs of Fish Dam 1. To allow for storage of the Pipeline 5 water, 200 acre-feet of water per day is moved from Fish Dam 2 to the Diversion Dam during this period. Without this reallocation of previously stored water, the water from the Pipeline 5 water right could not be stored in many years from 15 April to 30 June, decreasing the normal storage volume by approximately 42 percent.

3. The priorities for use of water that flows into Howard Hanson Reservoir are as follows:

   1) Pipeline 1 water right of 72 mgd (111 cfs) from natural Green River flows
   2) 110 cfs base flow at Palmer
   3) Fish Dam 1 storage following the 98 percent rule curve
   4) Palmer and Auburn instream flows as approved in the Agreement
   5) Pipeline 5 water right of 65 mgd (100 cfs); this water is stored behind the dam from 15 February to 30 June
   6) Fish Dam 2 instream flow requirement of 900 cfs from 15 February to 28 February, and from 1 March to 1 May flows of 900 cfs, 750 cfs, and 575 cfs for a wet, average, and dry spring, respectively, and 900 cfs to 400 cfs ramp from 1 May to 1 July
   7) Fish Dam 2 storage requirements following refill level and rate limitations
   8) Instream release

4. The refill targets for active storage, as shown in Figures 3 and 4, are:

TABLE 2

Date	Fish Dam 1 Wet & Average (Acre-Feet)	Fish Dam 1 Dry (Acre-Feet)	Diversion Dam Wet, Average, & Dry (Acre-Feet)	Fish Dam 2 Wet & Average (Acre-Feet)	Fish Dam 2 Dry (Acre-Feet)
February 15	0	0	0	0	0
March 1	0	0	3,000	0	0
March 15	0	0	6,000	9,000	9,000
April 1	0	0	9,000	18,800	18,800
April 15	0	8,100	12,000	24,800	16,700
May 1	8,100	20,300	15,000	21,100	13,700
May 15	20,300	23,800	18,000	5,900	7,400
June 1	23,800	26,700	20,000	400	2,500
June 15	24,200	26,700(1)	20,000	0	2,500(1)
June 30	24,200	26,700	20,000	0	0

(1) 2,500 acre-feet are in Fish Dam 2 for use in fisheries protection.

5. The maximum volume of water stored in Fish Dam 2 is equal to the difference between the refill rates stated above and the existing 98 percent Corps refill rule curve, as shown in Table 2 under Fish Dam 1. All water stored in Fish Dam 2 is outside the storage required to meet the flood responsibilities of the dam.

6. The conditions in the spring are evaluated to determine whether or not the spring is considered wet, average, or dry. The snow water equivalent is measured at Stampede Pass on 1 March and if it is greater than or equal to 50 inches, it is considered a wet spring, between 24 and 50 inches an average spring, and less than or equal to 24 inches a dry spring. In addition, the snow water equivalent is measured again on 1 May. If it exceeds 12 inches, the summer is average or better and if it is 12 inches or less, then drought conditions are implemented in accordance with the Agreement.

7. The instream flow levels for refill of Fish Dam 2 are 900 cfs in February for all conditions, and in March and April, 900 cfs, 750 cfs, and 575 cfs for wet, average, and dry conditions, respectively. The instream flow levels linearly decrease from 900 and 750 cfs on 1 May to 400 cfs on 1 July and in dry conditions from 575 cfs on 1 May to 250 cfs on 1 July.

8. Freshets, at a duration of 38 hours and a level of 2,500 cfs, as measured at the Auburn gage, are delivered on 1 May and 15 May under wet and average conditions, and at a level of 1,250 cfs on only one day, 1 May, under dry conditions.

9. For filling of Fish Dam 1, the existing Corps' 98 percent rule curve is followed, with the base flow of 110 cfs at Palmer. The dam meets the 350, 300, 250, and 225 cfs requirements at Auburn in an average year and 250 cfs and 225 cfs in a dry year, in accordance with the Agreement. In dry springs, the refill period for Fish Dam 1 begins 15 days earlier on 1 April.

10. All water diverted for Pipeline 5 is in accordance with the state water right and the Agreement. All water stored for diversion in the Diversion Dam is deducted from the Pipeline 5 water right and is within the instantaneous rate and volume restrictions of that right.

11. From July 1 through the end of reservoir operation (generally December 8), Fish Dam 1 meets the baseflow levels at Auburn in accordance with the Agreement. The summer months conditions as stated in the agreement are, *"For Wet Years the minimum continuous instream flow shall be 350 cfs. For Wet to Average Years the minimum continuous instream flow shall be 300 cfs. For Average to Dry Years the minimum continuous instream flow shall be 250 cfs. For Drought Years, the minimum continuous instream flow shall range from 250 to 225 cfs, depending on the severity of the drought."*

Half Monthly Average for Total Dam (Elevation)
Phase1

Feet	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Jan 1-15	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070
Jan 16-31	1,070	1,086	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,072	1,070	1,070	1,070	1,070
Feb 1-15	1,070	1,077	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070
Feb 16-28	1,079	1,079	1,079	1,079	1,079	1,072	1,079	1,079	1,079	1,078	1,079	1,079	1,079	1,079	1,079	1,079
Mar 1-15	1,112	1,112	1,107	1,112	1,111	1,078	1,111	1,112	1,112	1,107	1,112	1,112	1,106	1,108	1,098	1,112
Mar 16-31	1,137	1,137	1,137	1,137	1,132	1,120	1,137	1,137	1,137	1,129	1,137	1,137	1,134	1,130	1,121	1,137
Apr 1-15	1,151	1,150	1,151	1,151	1,146	1,151	1,151	1,151	1,151	1,137	1,151	1,146	1,151	1,145	1,149	1,151
Apr 16-30	1,160	1,159	1,160	1,159	1,157	1,160	1,160	1,160	1,160	1,148	1,160	1,154	1,160	1,156	1,155	1,160
May 1-15	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,156	1,162	1,160	1,162	1,165	1,163	1,162
May 16-31	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,167	1,166	1,162
June 1-15	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,167	1,167	1,162
June 16-30	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,162	1,167	1,167	1,162
July 1-15	1,161	1,161	1,161	1,161	1,161	1,161	1,161	1,161	1,161	1,161	1,161	1,161	1,161	1,165	1,165	1,160
July 16-31	1,159	1,157	1,159	1,157	1,158	1,159	1,157	1,159	1,159	1,157	1,159	1,159	1,159	1,162	1,162	1,157
Aug 1-15	1,155	1,152	1,155	1,152	1,154	1,155	1,152	1,155	1,155	1,152	1,155	1,154	1,155	1,157	1,158	1,151
Aug 16-31	1,150	1,146	1,149	1,145	1,150	1,149	1,144	1,150	1,150	1,145	1,150	1,149	1,150	1,152	1,152	1,145
Sept 1-15	1,143	1,138	1,141	1,137	1,143	1,141	1,138	1,143	1,143	1,137	1,143	1,143	1,143	1,146	1,146	1,139
Sept 16-30	1,136	1,131	1,133	1,129	1,136	1,135	1,132	1,135	1,136	1,129	1,134	1,135	1,135	1,140	1,140	1,130
Oct 1-15	1,127	1,121	1,122	1,119	1,127	1,127	1,124	1,126	1,127	1,121	1,124	1,126	1,127	1,131	1,131	1,118
Oct 16-31	1,115	1,114	1,113	1,114	1,115	1,115	1,115	1,115	1,115	1,113	1,110	1,115	1,114	1,121	1,121	1,109
Nov 1-15	1,102	1,102	1,102	1,102	1,102	1,102	1,102	1,102	1,102	1,102	1,099	1,102	1,102	1,110	1,110	1,102
Nov 16-30	1,085	1,085	1,085	1,085	1,085	1,085	1,085	1,085	1,085	1,085	1,085	1,085	1,085	1,098	1,098	1,084
Dec 1-15	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,096	1,073	1,096	1,079	1,073
Dec 16-31	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070

Feet	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan 1-15	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,073	1,070	1,070	1,070	1,070	1,070
Jan 16-31	1,070	1,070	1,071	1,070	1,072	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070
Feb 1-15	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070
Feb 16-28	1,079	1,079	1,079	1,079	1,079	1,076	1,079	1,079	1,079	1,079	1,079	1,079	1,079	1,078	1,079	1,079
Mar 1-15	1,112	1,107	1,112	1,112	1,110	1,106	1,111	1,112	1,112	1,104	1,112	1,112	1,111	1,098	1,112	1,112
Mar 16-31	1,137	1,115	1,137	1,137	1,137	1,125	1,137	1,137	1,136	1,137	1,137	1,136	1,133	1,130	1,137	1,137
Apr 1-15	1,151	1,128	1,150	1,151	1,151	1,151	1,150	1,151	1,150	1,151	1,150	1,149	1,140	1,145	1,151	1,151
Apr 16-30	1,160	1,143	1,160	1,158	1,160	1,160	1,160	1,160	1,159	1,160	1,159	1,159	1,148	1,155	1,160	1,159
May 1-15	1,162	1,154	1,162	1,161	1,162	1,162	1,162	1,166	1,163	1,166	1,163	1,162	1,156	1,163	1,162	1,161
May 16-31	1,161	1,160	1,162	1,161	1,162	1,162	1,162	1,164	1,164	1,166	1,163	1,162	1,158	1,164	1,160	1,160
June 1-15	1,162	1,166	1,162	1,162	1,162	1,162	1,162	1,166	1,165	1,167	1,164	1,162	1,158	1,166	1,161	1,161
June 16-30	1,162	1,167	1,162	1,162	1,162	1,162	1,162	1,165	1,165	1,167	1,164	1,162	1,158	1,166	1,162	1,161
July 1-15	1,161	1,165	1,161	1,161	1,161	1,161	1,161	1,164	1,163	1,165	1,162	1,161	1,158	1,164	1,161	1,160
July 16-31	1,158	1,162	1,158	1,159	1,159	1,157	1,158	1,160	1,159	1,161	1,159	1,159	1,157	1,161	1,157	1,156
Aug 1-15	1,153	1,158	1,154	1,155	1,155	1,151	1,153	1,156	1,154	1,156	1,154	1,153	1,155	1,156	1,151	1,150
Aug 16-31	1,147	1,152	1,148	1,150	1,150	1,145	1,146	1,150	1,147	1,150	1,149	1,146	1,150	1,150	1,144	1,144
Sept 1-15	1,143	1,146	1,141	1,143	1,143	1,138	1,137	1,142	1,138	1,143	1,143	1,138	1,144	1,143	1,137	1,136
Sept 16-30	1,136	1,140	1,136	1,136	1,136	1,131	1,131	1,133	1,132	1,133	1,134	1,127	1,139	1,133	1,130	1,127
Oct 1-15	1,126	1,131	1,127	1,127	1,126	1,121	1,127	1,120	1,125	1,120	1,125	1,116	1,131	1,122	1,118	1,125
Oct 16-31	1,112	1,121	1,115	1,114	1,114	1,114	1,113	1,104	1,115	1,106	1,115	1,100	1,121	1,111	1,109	1,115
Nov 1-15	1,101	1,110	1,102	1,102	1,102	1,102	1,102	1,089	1,102	1,105	1,102	1,095	1,110	1,101	1,102	1,102
Nov 16-30	1,085	1,098	1,085	1,085	1,085	1,085	1,086	1,084	1,085	1,098	1,098	1,085	1,098	1,084	1,085	1,096
Dec 1-15	1,073	1,079	1,073	1,073	1,073	1,073	1,073	1,079	1,073	1,079	1,073	1,073	1,079	1,073	1,073	1,084
Dec 16-31	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070

Half Monthly Average for HH Outflow in CFS
Phase1

CFS	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Jan 1-15	1,857	654	1,062	2,925	1,042	2,253	585	1,472	1,391	1,649	1,275	1,202	2,194	568	741	469
Jan 16-31	1,480	3,648	758	2,619	2,739	575	2,839	3,871	2,684	1,171	4,385	4,042	3,117	1,218	678	465
Feb 1-15	1,088	3,544	589	2,010	1,231	438	1,255	2,697	1,556	504	1,649	963	1,257	577	776	1,918
Feb 16-28	1,100	2,175	635	1,330	3,398	394	1,448	1,560	3,832	481	1,010	928	1,095	491	611	917
Mar 1-15	620	868	493	429	645	423	460	460	3,833	415	659	1,166	391	396	486	1,844
Mar 16-31	848	530	897	567	803	735	639	625	2,254	394	1,303	442	469	582	504	829
Apr 1-15	1,462	465	2,132	480	919	1,506	1,284	1,109	1,436	399	1,524	523	1,422	1,220	555	1,023
Apr 16-30	1,363	1,929	1,077	506	611	1,868	704	1,020	1,085	528	1,762	872	1,148	833	762	1,187
May 1-15	1,673	1,202	2,038	1,183	1,098	2,346	1,477	2,945	2,659	809	2,309	2,291	2,489	740	744	1,659
May 16-31	2,697	1,289	1,052	1,977	877	2,106	1,514	2,142	2,621	681	2,071	2,357	1,273	776	1,023	1,154
June 1-15	2,947	936	832	1,104	1,130	1,213	1,107	1,564	1,783	452	3,746	1,923	800	796	623	564
June 16-30	2,093	456	615	816	485	765	495	1,357	1,286	610	1,909	920	901	380	402	330
July 1-15	1,159	377	722	445	431	628	378	948	1,015	462	970	711	603	391	388	389
July 16-31	636	364	406	361	382	395	317	618	666	403	644	403	413	340	337	320
Aug 1-15	565	351	386	372	356	397	347	423	469	376	460	398	408	336	340	337
Aug 16-31	525	348	391	356	595	381	335	377	415	350	384	451	565	432	375	331
Sept 1-15	633	339	353	319	562	362	336	460	410	333	376	485	526	557	458	326
Sept 16-30	776	365	352	320	1,428	441	342	368	812	324	375	387	438	639	720	328
Oct 1-15	1,188	325	345	318	908	767	452	368	515	312	323	371	376	560	488	288
Oct 16-31	693	484	858	1,287	1,198	469	597	807	411	407	300	1,353	482	580	400	342
Nov 1-15	626	558	668	1,231	1,532	566	505	1,835	655	833	292	1,808	559	2,131	951	347
Nov 16-30	1,504	560	1,401	744	1,744	619	1,571	1,149	784	1,088	912	2,311	848	3,068	1,081	286
Dec 1-15	2,680	890	1,876	1,154	1,940	541	1,061	1,771	832	1,382	850	6,549	642	7,326	1,809	1,964
Dec 16-31	1,527	395	2,095	2,831	774	939	573	1,326	3,805	2,179	2,598	2,147	1,034	1,367	1,081	2,423

CFS	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan 1-15	650	1,000	789	3,312	3,058	484	548	678	377	1,636	2,997	1,735	603	520	1,883	870
Jan 16-31	619	465	3,108	910	3,183	579	1,269	530	710	1,987	1,012	1,520	2,042	1,434	1,009	974
Feb 1-15	1,037	1,138	2,456	603	1,242	375	711	1,364	1,880	972	2,477	2,059	1,234	903	475	1,841
Feb 16-28	1,114	3,193	4,002	1,222	786	815	2,980	807	1,004	449	1,349	3,312	1,043	457	629	3,420
Mar 1-15	1,003	413	1,285	914	499	458	1,291	1,567	925	476	1,102	642	483	778	1,224	585
Mar 16-31	632	402	550	586	1,335	522	978	704	1,449	826	1,226	402	426	1,458	821	608
Apr 1-15	993	619	432	685	940	2,207	691	980	2,482	2,450	1,597	1,851	394	1,165	1,114	481
Apr 16-30	1,821	1,584	794	649	909	1,390	685	1,392	1,435	1,672	1,627	1,056	676	1,129	1,119	535
May 1-15	1,208	1,024	1,432	819	1,522	1,464	1,344	1,265	1,552	1,354	1,451	1,320	519	1,807	782	1,028
May 16-31	664	738	1,674	764	1,818	1,631	1,256	731	1,289	881	949	1,060	349	851	559	736
June 1-15	500	883	1,033	410	1,265	1,280	561	423	785	683	1,844	701	215	909	409	364
June 16-30	418	1,229	640	449	984	499	325	340	463	387	876	687	222	758	613	335
July 1-15	426	644	448	656	628	387	362	311	440	352	517	456	229	639	440	338
July 16-31	363	433	387	711	378	339	375	306	395	334	374	360	235	761	394	342
Aug 1-15	345	374	350	474	377	350	356	318	374	348	382	360	259	587	381	347
Aug 16-31	348	333	367	382	329	350	378	327	353	347	353	375	331	433	335	335
Sept 1-15	544	393	378	565	378	342	352	329	331	359	389	350	328	398	321	353
Sept 16-30	440	349	409	486	337	375	347	331	348	355	365	312	632	359	325	270
Oct 1-15	421	753	528	431	366	338	479	329	343	345	530	264	506	351	293	993
Oct 16-31	360	429	623	405	519	1,743	394	266	1,214	296	1,763	266	483	340	745	1,159
Nov 1-15	1,323	364	897	1,635	1,055	2,711	774	189	1,885	1,852	3,424	388	1,177	336	1,204	2,716
Nov 16-30	1,300	586	918	1,939	833	748	4,108	242	1,792	1,289	4,909	1,542	1,337	408	1,376	3,945
Dec 1-15	1,594	1,645	1,553	1,036	665	471	913	1,206	1,841	2,351	1,769	3,061	960	1,356	1,481	3,596
Dec 16-31	3,332	827	733	698	1,047	445	737	346	1,044	680	1,071	909	1,063	466	2,575	1,264

Percent Exceedance at HH Outflow (1964 to 1995)
Phase1

CFS	5%	10%	20%	25%	50%	75%	80%	90%	95%
01/01 to 01/15	4,375	2,596	1,750	1,561	808	537	501	430	385
01/16 to 01/31	5,975	4,090	2,667	2,172	1,043	675	599	484	428
02/01 to 02/15	3,490	2,545	1,811	1,574	976	629	556	437	397
02/16 to 02/28	5,813	3,340	1,723	1,546	964	597	533	428	399
03/01 to 03/15	2,497	1,591	1,067	920	552	398	393	390	388
03/16 to 03/31	1,981	1,472	1,022	936	582	399	395	390	389
04/01 to 04/15	2,485	2,228	1,621	1,457	989	552	498	416	392
04/16 to 04/30	2,187	1,941	1,635	1,482	1,009	673	609	479	421
05/01 to 05/15	3,126	2,627	2,098	1,970	1,238	957	895	636	538
05/16 to 05/31	2,786	2,325	1,980	1,789	1,136	733	663	486	395
06/01 to 06/15	2,929	1,992	1,439	1,317	807	535	473	398	338
06/16 to 06/30	1,681	1,350	972	871	555	393	369	325	286
07/01 to 07/15	1,055	931	715	628	450	376	369	334	298
07/16 to 07/31	775	629	468	425	380	340	336	308	298
08/01 to 08/15	537	485	412	400	367	348	343	323	311
08/16 to 08/31	543	461	398	389	364	338	333	324	315
09/01 to 09/15	629	552	471	446	368	338	333	320	307
09/16 to 09/30	920	711	477	435	363	333	324	307	298
10/01 to 10/15	1,036	745	557	508	379	330	322	298	266
10/16 to 10/31	1,832	1,315	899	749	449	359	338	296	266
11/01 to 11/15	3,667	2,611	1,631	1,444	783	446	397	318	217
11/16 to 11/30	4,176	2,861	1,798	1,569	1,023	667	612	433	295
12/01 to 12/15	6,098	3,745	2,205	1,952	1,228	757	682	542	467
12/16 to 12/31	4,222	3,037	1,836	1,542	891	631	569	444	384

Half Monthly Average for Palmer in CFS
Phase1

CFS	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Jan 1-15	1,701	462	915	2,801	861	2,109	436	1,307	1,221	1,487	1,102	1,026	2,048	385	553	323
Jan 16-31	1,312	3,575	569	2,485	2,609	387	2,712	3,775	2,552	994	4,305	3,952	2,999	1,042	487	323
Feb 1-15	915	3,413	402	1,865	1,063	300	1,088	2,573	1,397	331	1,494	787	1,089	422	594	1,797
Feb 16-28	1,024	2,132	546	1,261	3,391	295	1,383	1,498	3,838	387	932	848	1,020	398	521	837
Mar 1-15	539	795	409	341	564	327	375	375	3,849	325	579	1,102	300	306	393	1,801
Mar 16-31	775	445	825	485	725	669	559	545	2,222	300	1,243	353	388	498	425	755
Apr 1-15	1,404	378	2,094	392	844	1,449	1,220	1,040	1,377	305	1,468	433	1,362	1,154	467	951
Apr 16-30	1,300	1,883	1,005	416	530	1,820	621	947	1,013	445	1,710	794	1,078	759	682	1,119
May 1-15	1,612	1,126	1,988	1,108	1,019	2,305	1,410	2,921	2,627	726	2,266	2,255	2,453	657	664	1,597
May 16-31	2,631	1,180	937	1,925	767	2,058	1,412	2,059	2,552	594	1,986	2,281	1,164	664	940	1,042
June 1-15	2,823	752	645	949	952	1,111	928	1,399	1,624	354	3,646	1,769	612	611	430	393
June 16-30	1,944	301	421	646	314	580	339	1,186	1,113	442	1,754	736	717	263	280	228
July 1-15	897	192	448	238	238	351	190	680	749	246	703	436	334	206	201	203
July 16-31	359	177	191	174	195	188	130	349	391	216	368	206	219	152	147	133
Aug 1-15	288	163	197	185	169	207	158	204	221	189	210	211	209	148	148	149
Aug 16-31	283	160	203	167	365	193	145	190	206	162	193	226	310	216	186	142
Sept 1-15	354	150	164	130	291	173	152	221	207	144	188	236	269	324	241	138
Sept 16-30	505	177	163	138	1,172	237	155	181	564	135	186	199	252	391	450	140
Oct 1-15	924	138	157	132	635	490	246	181	296	125	133	184	190	312	281	120
Oct 16-31	417	271	625	1,069	935	277	360	553	225	208	110	1,110	267	355	214	150
Nov 1-15	429	385	476	1,053	1,363	399	356	1,675	461	669	183	1,647	388	1,979	778	237
Nov 16-30	1,336	381	1,228	551	1,581	438	1,403	969	638	906	735	2,165	658	2,945	898	180
Dec 1-15	2,547	705	1,719	977	1,786	394	880	1,611	645	1,211	675	6,533	456	7,330	1,648	1,817
Dec 16-31	1,360	279	1,946	2,705	588	755	407	1,154	3,707	2,032	2,465	1,999	853	1,196	902	2,283

CFS	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan 1-15	464	818	621	3,218	2,938	335	383	488	263	1,473	2,875	1,577	422	358	1,727	684
Jan 16-31	454	302	2,989	726	3,066	395	1,095	384	522	1,834	831	1,354	1,891	1,316	827	792
Feb 1-15	868	1,040	2,325	417	1,075	271	527	1,200	1,731	798	2,346	1,916	1,066	725	321	1,691
Feb 16-28	1,039	3,180	4,013	1,150	701	731	2,961	723	926	354	1,282	3,303	966	362	540	3,414
Mar 1-15	934	321	1,224	842	415	367	1,230	1,515	853	391	1,035	562	398	698	1,161	504
Mar 16-31	552	305	467	504	1,275	439	908	625	1,392	752	1,164	313	335	1,402	746	526
Apr 1-15	921	535	342	603	866	2,176	609	908	2,454	2,422	1,543	1,804	297	1,098	1,045	394
Apr 16-30	1,771	1,521	714	563	831	1,327	603	1,330	1,375	1,618	1,572	985	595	1,060	1,048	445
May 1-15	1,133	933	1,364	735	1,457	1,396	1,273	1,197	1,489	1,288	1,385	1,248	428	1,755	695	949
May 16-31	546	653	1,581	675	1,729	1,551	1,175	638	1,181	764	830	949	248	766	463	645
June 1-15	335	767	852	300	1,091	1,107	395	305	596	496	1,687	510	110	729	311	264
June 16-30	283	1,054	459	312	802	348	221	238	313	275	690	496	116	568	468	234
July 1-15	229	366	240	424	351	202	176	124	218	166	240	234	125	332	240	191
July 16-31	177	209	200	438	179	152	189	117	178	146	163	172	129	455	207	153
Aug 1-15	156	181	163	240	185	162	168	129	155	160	195	174	133	281	193	158
Aug 16-31	160	145	179	195	141	162	190	140	163	158	167	187	142	205	146	147
Sept 1-15	296	191	187	308	188	154	164	145	147	170	201	161	140	212	133	164
Sept 16-30	251	162	223	282	148	188	157	142	162	171	176	146	406	170	136	130
Oct 1-15	234	496	302	244	175	150	271	151	155	160	337	131	286	162	122	768
Oct 16-31	172	241	402	219	300	1,527	201	126	953	130	1,517	125	279	153	555	894
Nov 1-15	1,169	260	709	1,479	871	2,577	592	121	1,726	1,738	3,312	277	997	232	1,025	2,583
Nov 16-30	1,124	399	730	1,782	643	555	4,016	137	1,630	1,113	4,846	1,373	1,162	276	1,202	3,875
Dec 1-15	1,429	1,479	1,387	855	476	312	727	1,042	1,683	2,206	1,609	2,940	773	1,184	1,313	3,464
Dec 16-31	3,220	640	552	521	872	299	549	233	864	488	901	724	883	324	2,441	1,090

Percent Exceedance at Palmer (1964 to 1995)
Phase1

CFS	5%	10%	20%	25%	50%	75%	80%	90%	95%
01/01 to 01/15	4,294	2,462	1,591	1,396	620	341	304	300	285
01/16 to 01/31	5,942	4,001	2,535	2,025	862	483	405	300	300
02/01 to 02/15	3,461	2,409	1,653	1,427	793	437	367	300	298
02/16 to 02/28	5,879	3,332	1,666	1,484	885	506	441	333	300
03/01 to 03/15	2,472	1,539	999	848	469	300	300	300	300
03/16 to 03/31	1,941	1,417	953	865	499	310	300	300	300
04/01 to 04/15	2,457	2,192	1,567	1,404	916	466	411	327	300
04/16 to 04/30	2,141	1,897	1,578	1,424	935	590	525	388	331
05/01 to 05/15	3,108	2,594	2,050	1,918	1,176	884	810	552	450
05/16 to 05/31	2,724	2,254	1,908	1,708	1,032	615	535	374	300
06/01 to 06/15	2,805	1,868	1,280	1,145	632	356	314	299	237
06/16 to 06/30	1,519	1,179	793	694	360	293	269	223	183
07/01 to 07/15	790	663	436	349	231	191	184	158	128
07/16 to 07/31	495	342	229	214	191	153	147	127	114
08/01 to 08/15	259	224	210	202	174	157	153	140	129
08/16 to 08/31	287	224	205	200	175	149	144	136	125
09/01 to 09/15	348	300	234	220	179	149	145	132	122
09/16 to 09/30	649	433	293	248	176	145	138	129	116
10/01 to 10/15	767	468	300	300	192	143	134	115	110
10/16 to 10/31	1,588	1,056	627	473	264	172	152	123	110
11/01 to 11/15	3,561	2,474	1,464	1,272	591	300	296	216	128
11/16 to 11/30	4,086	2,732	1,637	1,401	838	472	415	300	189
12/01 to 12/15	6,065	3,644	2,058	1,798	1,052	566	489	345	300
12/16 to 12/31	4,137	2,916	1,679	1,376	706	438	374	300	284

Half Monthly Average for Auburn in CFS
Phase1

CFS	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Jan 1-15	2,610	1,135	1,584	3,557	1,290	3,358	848	1,997	1,914	2,242	1,605	2,034	3,051	605	1,113	680
Jan 16-31	2,544	4,533	1,121	3,637	3,051	1,097	3,637	4,630	3,660	1,783	5,171	5,090	4,179	1,323	953	754
Feb 1-15	1,795	4,856	783	2,627	1,635	1,075	1,692	3,284	2,101	789	2,692	1,579	1,726	639	1,107	2,568
Feb 16-28	1,623	3,064	891	1,944	4,092	863	1,974	2,227	4,867	769	1,914	1,943	1,795	607	893	1,598
Mar 1-15	1,049	1,512	847	878	1,081	763	858	1,266	5,403	753	1,515	2,098	871	745	750	2,483
Mar 16-31	1,370	962	1,243	1,049	1,226	1,008	978	1,272	3,078	703	2,127	1,054	875	841	757	1,246
Apr 1-15	1,846	765	2,475	859	1,333	1,904	1,650	1,690	2,050	589	2,283	913	1,810	1,477	751	1,396
Apr 16-30	1,753	2,392	1,394	888	930	2,234	1,071	1,395	1,542	655	2,298	1,254	1,525	1,056	1,170	1,530
May 1-15	1,989	1,566	2,233	1,466	1,345	2,567	1,783	3,131	2,930	980	2,728	2,619	2,834	855	1,083	1,979
May 16-31	2,957	1,533	1,201	2,244	1,036	2,308	1,758	2,324	2,904	868	2,419	2,779	1,483	874	1,296	1,308
June 1-15	3,236	1,059	862	1,256	1,433	1,449	1,214	1,732	1,955	553	3,946	2,097	816	917	715	584
June 16-30	2,514	524	639	857	595	895	589	1,483	1,372	652	2,190	950	949	471	502	379
July 1-15	1,195	377	711	420	443	644	384	961	1,021	418	1,010	667	497	355	401	357
July 16-31	605	322	399	322	359	407	290	598	644	328	676	371	368	276	357	278
Aug 1-15	491	300	363	305	308	377	300	391	415	300	445	350	366	250	331	305
Aug 16-31	461	300	350	294	539	350	272	354	387	281	377	426	469	356	334	300
Sept 1-15	524	274	303	253	479	310	282	433	382	250	354	434	438	420	402	305
Sept 16-30	685	293	300	250	1,430	415	301	350	776	251	335	353	380	484	696	267
Oct 1-15	1,125	259	302	260	877	686	386	351	475	297	301	340	364	366	484	240
Oct 16-31	574	421	790	1,237	1,301	412	533	732	377	351	353	1,312	400	412	395	320
Nov 1-15	687	541	633	1,315	1,729	626	539	2,082	673	920	397	2,152	570	2,125	1,052	403
Nov 16-30	1,799	550	1,487	733	2,045	654	1,607	1,419	858	1,393	1,056	2,711	834	3,105	1,201	328
Dec 1-15	3,446	945	2,284	1,211	2,702	765	1,405	2,269	888	1,755	936	7,697	653	7,835	2,367	2,069
Dec 16-31	2,322	655	2,590	3,029	1,237	1,438	919	1,999	4,972	2,904	3,096	3,018	1,115	2,073	1,403	3,182

CFS	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan 1-15	1,135	1,504	1,053	3,927	3,709	796	747	1,011	447	2,242	3,869	2,250	728	639	2,170	1,329
Jan 16-31	1,249	795	4,109	1,435	3,866	734	1,799	897	832	2,536	1,697	2,225	2,378	1,748	1,298	1,265
Feb 1-15	1,496	1,518	3,287	941	1,829	647	1,007	1,775	2,042	1,340	3,393	2,673	1,739	1,142	649	2,404
Feb 16-28	1,591	3,970	5,876	1,834	1,520	1,091	3,545	1,090	1,265	936	2,161	4,613	1,555	667	1,093	4,441
Mar 1-15	1,657	885	2,164	1,505	1,052	756	1,717	2,127	1,231	1,095	1,759	1,580	838	936	1,736	1,195
Mar 16-31	1,250	691	1,166	996	1,942	756	1,317	1,190	1,767	1,586	1,746	954	736	1,951	1,216	1,184
Apr 1-15	1,508	978	860	1,140	1,533	2,337	1,006	1,334	2,948	3,264	1,947	2,964	577	1,740	1,488	854
Apr 16-30	2,451	1,925	1,134	884	1,397	1,565	928	1,773	1,863	2,206	1,882	1,627	945	1,666	1,389	833
May 1-15	1,566	1,327	1,740	1,022	1,995	1,625	1,702	1,610	1,948	1,664	1,769	1,711	661	2,254	959	1,300
May 16-31	853	1,062	1,928	920	2,255	1,702	1,496	938	1,573	1,120	1,187	1,368	432	1,197	645	920
June 1-15	583	1,282	1,121	504	1,599	1,400	637	530	968	765	2,266	798	268	1,228	465	477
June 16-30	503	1,547	659	542	1,234	594	432	416	565	465	1,145	782	264	1,002	672	426
July 1-15	435	712	421	640	719	365	350	279	438	306	577	486	'279	687	394	343
July 16-31	346	476	366	682	421	281	347	250	343	256	376	356	250	781	322	256
Aug 1-15	300	387	307	403	407	302	301	250	300	250	350	303	250	539	300	250
Aug 16-31	300	321	303	353	405	278	300	250	300	250	325	300	250	386	250	253
Sept 1-15	463	365	321	498	473	277	282	250	280	250	350	273	250	347	250	250
Sept 16-30	396	332	358	442	402	300	290	250	290	250	313	239	500	300	250	217
Oct 1-15	358	801	452	362	349	257	397	248	321	250	449	218	400	291	239	957
Oct 16-31	300	483	567	334	448	1,800	353	225	1,289	238	1,785	225	386	285	699	1,136
Nov 1-15	1,475	621	902	1,781	1,122	2,936	735	231	2,192	2,050	4,013	436	1,144	352	1,437	2,965
Nov 16-30	1,578	759	991	2,378	1,000	917	4,513	251	2,293	1,522	6,213	1,736	1,443	402	1,498	4,564
Dec 1-15	2,092	2,079	1,876	1,496	946	805	1,275	1,255	2,222	2,960	2,779	3,433	1,077	1,522	2,011	5,104
Dec 16-31	3,938	1,270	1,057	1,078	1,355	598	1,010	471	1,377	902	1,564	1,122	1,292	576	3,392	1,857

Percent Exceedance at Auburn (1964 to 1995)
Phase1

CFS	5%	10%	20%	25%	50%	75%	80%	90%	95%
01/01 to 01/15	5,397	3,338	2,527	2,211	1,240	810	751	640	530
01/16 to 01/31	6,612	5,188	3,553	2,941	1,561	991	890	741	634
02/01 to 02/15	4,146	3,512	2,591	2,254	1,410	934	851	701	591
02/16 to 02/28	7,379	4,520	2,634	2,305	1,558	972	910	753	680
03/01 to 03/15	3,441	2,410	1,704	1,586	1,098	805	769	750	710
03/16 to 03/31	2,620	2,128	1,609	1,478	1,035	785	750	750	675
04/01 to 04/15	3,053	2,642	2,159	2,004	1,436	900	836	750	575
04/16 to 04/30	2,621	2,403	2,040	1,877	1,408	977	896	750	692
05/01 to 05/15	3,335	2,905	2,500	2,312	1,601	1,227	1,124	851	721
05/16 to 05/31	3,038	2,570	2,287	2,089	1,361	900	844	647	532
06/01 to 06/15	3,126	2,435	1,726	1,519	921	607	549	484	432
06/16 to 06/30	2,046	1,529	1,134	1,012	610	493	465	403	350
07/01 to 07/15	1,070	973	719	639	442	350	350	346	283
07/16 to 07/31	790	603	461	426	350	300	300	250	250
08/01 to 08/15	474	421	400	391	300	300	300	250	250
08/16 to 08/31	469	400	377	350	300	300	250	250	250
09/01 to 09/15	528	486	402	400	300	250	250	250	250
09/16 to 09/30	972	605	444	397	300	250	250	250	250
10/01 to 10/15	1,029	670	475	440	350	263	250	250	229
10/16 to 10/31	1,900	1,368	844	668	396	300	300	250	225
11/01 to 11/15	4,146	3,008	1,881	1,604	827	476	452	350	264
11/16 to 11/30	4,688	3,300	2,134	1,911	1,157	699	637	452	350
12/01 to 12/15	7,648	4,197	2,878	2,586	1,583	996	879	621	536
12/16 to 12/31	5,468	3,862	2,490	2,132	1,316	873	785	615	531

SECTION 17 SUMMARY OF PHASE II OPERATIONS

Phase II adds to Phase I the storage of an additional 9,600 ac-ft of water for fisheries use and an additional 2,400 ac-ft for M&I use. The total full pool is at elevation 1177 feet. There are some differences in the operation of this storage from the operation described earlier in the text. The operation of storage in this section includes some beneficial uses of water as discovered in an adaptive management exercise done by the modelers. The operation is more sophisticated than the modeling used during earlier project formulation studies. The reservoir operates for 2 instream control points, Palmer and Auburn, instead of just one at Palmer. The operation has rules for 3 different seasons, wet, average, and dry. The operation also has rates imposed on reservoir refill. The operation assumes that the pattern of outflow should somewhat match the natural runoff pattern. This is different than an earlier concept of water management that favored more steady reservoir releases that used the reservoir to buffer freshets.

This section continues with exhibits that provide reservoir elevation and downstream flows in a format similar to the Phase I section. The tabulations are preceded by a detailed listing of operating rules as excerpted from the "Modeling" report.

The following exhibits follow this page of text:

- Phase II Operating Rules (11).
- Hanson Reservoir Phase II Elevations by Half-Months from 1964 through 1995.
- Hanson Reservoir Phase II Outflows by Half-Months from 1964 through 1995.
- Percent Exceedances of Hanson Reservoir Phase II Outflows by Half-Months.
- Palmer Phase II Flows by Half-Months from 1964 through 1995.
- Percent Exceedances of Palmer Phase II Flows by Half-Months.
- Auburn Phase II Flows by Half-Months from 1964 through 1995.
- Percent Exceedances of Auburn Phase II Flows by Half-Months.

Phase II

1. The start of refill is 15 February. Between 15 February and 1 March, a maximum of 5,000 acre-feet is stored in Fish Dam 2 for use by the Corps for fisheries protection.

2. The maximum refill rates for the Diversion Dam and Fish Dam 2 are:

   * From 15 February to 15 April: 750 cfs or 1,500 acre-feet/day
   * From 16 April to 30 April: 300 cfs or 600 acre-feet/day
   * From 1 May to 31 May: 200 cfs or 400 acre-feet/day.

   Fish Dam 1 is refilled following the 98 percent rule curve and on some days will exceed the refill targets stated above. For any day or group of days where the reservoir fill targets are not met, the reservoir is allowed to make up any shortfall in one day, if water is available.

   To provide protection for the fish passing through the reservoir, the refill rates between 15 April and 31 May limit the refill to the point that no additional water is available for storage above the needs of Fish Dam 1.

3. The priorities for use of water that flows into Howard Hanson Reservoir are as follows:

   1) Pipeline 1 water right of 72 mgd (111 cfs) from natural Green River flows
   2) 110 cfs base flow at Palmer
   3) Fish Dam 1 storage following the 98 percent rule curve
   4) Palmer and Auburn instream flows as approved in the Agreement
   5) Pipeline 5 water right of 65 mgd (100 cfs)
   6) Fish Dam 2 and Diversion Dam instream flow requirement of 900 cfs from 15 February to 28 February, and from 1 March to 1 May flows of 900 cfs, 750 cfs, and 575 cfs for a wet, average, and dry spring, respectively, and 900 cfs of 750 cfs to 400 cfs ramp from 1 May to 1 July for a wet and average spring and 575 cfs to 250 cfs for a dry spring
   7) Fish Dam 2 and Diversion Dam storage requirements following refill level and rate limitations, with the water allocated to Fish Dam 2 and Diversion Dam equal to the percentage of required storage; approximately 60 percent to Diversion Dam and 40 percent to Fish Dam 2. This allocation will provide the opportunity for both Fish Dam 2 and Diversion Dam to fill to the same percentage of full in any given year.
   8) Spill.

4. The refill targets for active storage, as shown in Figures 5 and 6, are:

TABLE 3

Date	Fish Dam 1 Wet & Average (Acre-Feet)	Fish Dam 1 Dry (Acre-Feet)	Diversion Dam Wet & Average (Acre-Feet)	Diversion Dam Dry (Acre-Feet)	Fish Dam 2 Wet & Average (Acre-Feet)	Fish Dam 2 Dry (Acre-Feet)
Feb 15	0	0	0	0	0	0
March 1	0	0	0	0	5,000	5,000
March 15	0	0	13,500	13,500	14,000	14,000
April 1	0	0	22,400	22,400	29,100	29,100
April 15	0	8,100	22,400	22,400	38,800	30,700
May 1	8,100	20,300	22,400	22,400	30,700	18,500
May 15	20,300	23,800	22,400	22,400	18,500	15,000
June 1	23,800	24,200	22,400	22,400	15,000	14,600
June 15	24,200	24,200	22,400	22,400	14,600	14,600
June 30	24,200	24,200	22,400	22,400	14,600	14,600
July 1	24,200	26,700	22,400	21,150	14,600	13,350

5. The maximum volume of water stored in Fish Dam 2 is equal to the difference between the refill rates stated above and the existing 98 percent Corps refill rule curve, as shown in Table 2 under Fish Dam 1.

6. In Phase 2, the level of snow in the watershed and the level of water stored in the Fish Dams are evaluated four times between March and September (four decision points) to set the condition for that particular season, for example, wet, average, or dry, in accordance with the following criteria:

   * The snow water equivalent levels in the spring are evaluated to determine whether or not the spring is considered wet, average, or dry. The snow water equivalent is measured at Stampede Pass on 1 March. If it is greater than or equal to 50 inches, it is considered a wet spring, between 24 and 50 inches an average spring, and less than or equal to 24 inches a dry spring. The conditions are reevaluated on 1 July, 15 September, and 30 September.

   * If the total storage in Fish Dam 1 and 2 exceeds 37,000 acre-feet, then the summer is considered average; less than 37,000 acre-feet and it is considered dry. This requirement designates a condition which sets the requirements for Fish Dam 2 but it also is proposed to be used instead of 1 May to set the summertime condition under the Agreement.

   * The conditions are examined again on 15 September and if Fish Dam 1 is in Zone 1, storage exceeding 15,740 acre-feet, and the summer condition was average, then the condition is reset to wet for the fall. If Fish Dam 1 is outside Zone 1 or the summer condition was dry, then no change to the condition is made on 15 September and the summer condition remains in effect until 30 September.

- The amount of water in storage on 30 September in Fish Dam 1 sets the fall condition. If Fish Dam 1 is in Zone 1, then the condition is set as wet, if it is in Zone 2 or 3 then it is average, if it is in Zone 4 , below 8,261 acre-feet, then it is set as a dry fall.

7. The instream flow levels are set in accordance with the conditions set on the four decision points. The various flow levels are:

   - For refill of Fish Dam 2 and Diversion Dam, the instream flow requirements are 900 cfs in February for all conditions, and in March and April, 900 cfs, 750 cfs, and 575 cfs for wet, average, and dry conditions, respectively. The instream flow levels linearly decrease from 900 and 750 cfs on 1 May to 400 cfs on 1 July and in dry conditions from 575 cfs on 1 May to 250 cfs on 1 July.

   - For the summer, Fish Dam 1 supports 350, 300, 250, and 225 cfs in an average summer and 250 and 225 cfs for a dry summer. Fish Dam 2 supports 300 cfs in an average summer and 250 cfs in a dry summer. In Phase 2, no condition anticipates having the flow at Auburn drop below 250 cfs.

   - A wet condition set on 15 September increases the flow provided by Fish Dam 2 to 400 cfs for the period 16 September to 30 September.

   - On 30 September, the flow in the river at Auburn is supported by Fish Dam 2 at a level of 450 cfs for the month of October in a wet condition, 400 cfs in an average condition, and 350 cfs in a dry condition. The levels set in September are supported by the water stored in Fish Dam 2 through the remainder of the year, until Fish Dam 2 is empty or until the rains return and the water is spilled to provide the needed flood control storage.

8. Freshets, at a duration of 38 hours and a level of 2,500 cfs as measured at the Auburn gage, are delivered on April 1, April 15, May 1, and May 15 under wet and average conditions, and at a level of 1,250 cfs on the same four days under dry conditions. Whenever Fish Dam 2 is below 65 percent of full on any of the four days where freshets are to be sent, then the freshet for that day is skipped. On September 1 in all years, a summertime freshet 700 cfs, as measured at Auburn, is delivered.

9. For filling of Fish Dam 1, the existing Corps' 98 percent rule curve is followed, with the base flow of 110 cfs at Palmer. The dam meets the 350, 300, 250, and 225 cfs requirements at Auburn in an average year and 250 cfs and 225 cfs in a dry year, in accordance with the Agreement. In dry springs, the refill period for Fish Dam 1 begins 15 days earlier on 1 April.

10. All water diverted for Pipeline 5 is in accordance with the instantaneous rate and volume restrictions of the state water right and the Agreement. All water stored for diversion is done so through the rights held by the Corps of Engineers for this project.

11. From 1 July through the end of reservoir operation (generally 8 December), Fish Dam 1 meets the baseflow levels at Auburn in accordance with the Agreement. The summer months conditions as stated in the agreement are, "*For Wet Years the minimum continuous instream flow shall be 350 cfs. For Wet to Average Years the minimum continuous instream flow shall be 300 cfs. For Average to Dry Years the minimum continuous instream flow shall be 250 cfs. For Drought Years, the minimum continuous instream flow shall range from 250 to 225 cfs, depending on the severity of the drought.*" In addition, Fish Dam 2 in Phase 2 has the ability to increase flows during the summer and fall.

Half Monthly Average for Total Dam (Elevation)

Phase2Alt2

Feet	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Jan 1-15	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070
Jan 16-31	1,070	1,086	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,072	1,070	1,070	1,070	1,070
Feb 1-15	1,070	1,077	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070
Feb 16-28	1,087	1,087	1,073	1,087	1,086	1,070	1,087	1,087	1,087	1,070	1,087	1,087	1,087	1,070	1,072	1,087
Mar 1-15	1,122	1,128	1,097	1,117	1,125	1,071	1,116	1,117	1,128	1,093	1,123	1,127	1,108	1,090	1,081	1,127
Mar 16-31	1,153	1,153	1,137	1,138	1,141	1,110	1,143	1,139	1,158	1,116	1,158	1,147	1,131	1,117	1,103	1,158
Apr 1-15	1,173	1,158	1,174	1,154	1,168	1,163	1,164	1,166	1,175	1,123	1,176	1,151	1,159	1,154	1,137	1,171
Apr 16-30	1,177	1,165	1,177	1,162	1,177	1,177	1,177	1,177	1,177	1,138	1,177	1,158	1,177	1,174	1,143	1,177
May 1-15	1,177	1,173	1,177	1,170	1,177	1,177	1,177	1,177	1,177	1,152	1,177	1,168	1,177	1,177	1,154	1,177
May 16-31	1,177	1,177	1,176	1,177	1,177	1,177	1,177	1,177	1,177	1,167	1,177	1,175	1,177	1,177	1,163	1,177
June 1-15	1,177	1,177	1,177	1,177	1,177	1,177	1,177	1,177	1,177	1,169	1,177	1,177	1,177	1,177	1,168	1,177
June 16-30	1,177	1,177	1,177	1,177	1,177	1,177	1,177	1,177	1,177	1,171	1,177	1,177	1,177	1,177	1,169	1,176
July 1-15	1,176	1,176	1,176	1,176	1,176	1,176	1,175	1,176	1,176	1,172	1,176	1,176	1,176	1,175	1,169	1,174
July 16-31	1,174	1,172	1,174	1,172	1,173	1,174	1,171	1,174	1,174	1,171	1,174	1,173	1,173	1,171	1,169	1,172
Aug 1-15	1,171	1,167	1,170	1,168	1,169	1,171	1,167	1,171	1,171	1,168	1,171	1,169	1,170	1,166	1,168	1,168
Aug 16-31	1,166	1,162	1,165	1,162	1,165	1,166	1,160	1,166	1,166	1,163	1,166	1,165	1,166	1,160	1,165	1,164
Sept 1-15	1,159	1,155	1,158	1,154	1,159	1,158	1,153	1,159	1,159	1,157	1,159	1,159	1,159	1,159	1,159	1,159
Sept 16-30	1,151	1,149	1,150	1,146	1,151	1,151	1,148	1,151	1,151	1,151	1,151	1,151	1,151	1,151	1,151	1,151
Oct 1-15	1,143	1,140	1,141	1,135	1,143	1,143	1,141	1,142	1,143	1,142	1,140	1,141	1,142	1,142	1,143	1,140
Oct 16-31	1,131	1,131	1,130	1,129	1,131	1,131	1,131	1,131	1,131	1,131	1,128	1,131	1,129	1,130	1,131	1,126
Nov 1-15	1,118	1,118	1,118	1,118	1,118	1,118	1,118	1,118	1,118	1,118	1,117	1,118	1,118	1,118	1,118	1,118
Nov 16-30	1,104	1,104	1,104	1,104	1,104	1,104	1,104	1,104	1,104	1,104	1,104	1,104	1,104	1,104	1,104	1,103
Dec 1-15	1,087	1,087	1,087	1,087	1,087	1,087	1,087	1,087	1,087	1,087	1,087	1,106	1,087	1,102	1,087	1,086
Dec 16-31	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075

Feet	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan 1-15	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,073	1,070	1,070	1,070	1,070	1,070
Jan 16-31	1,070	1,070	1,071	1,070	1,072	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070
Feb 1-15	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070	1,070
Feb 16-28	1,083	1,087	1,087	1,087	1,087	1,080	1,082	1,083	1,087	1,073	1,087	1,087	1,086	1,070	1,079	1,087
Mar 1-15	1,128	1,111	1,127	1,124	1,113	1,110	1,128	1,125	1,127	1,091	1,128	1,125	1,119	1,091	1,128	1,120
Mar 16-31	1,154	1,114	1,154	1,151	1,153	1,121	1,158	1,155	1,155	1,140	1,158	1,144	1,136	1,151	1,156	1,149
Apr 1-15	1,167	1,128	1,160	1,167	1,174	1,165	1,175	1,167	1,176	1,172	1,175	1,169	1,140	1,175	1,172	1,159
Apr 16-30	1,177	1,161	1,167	1,170	1,177	1,177	1,177	1,177	1,177	1,177	1,177	1,177	1,154	1,177	1,177	1,166
May 1-15	1,177	1,177	1,174	1,174	1,177	1,177	1,177	1,177	1,177	1,177	1,177	1,177	1,164	1,177	1,177	1,172
May 16-31	1,175	1,177	1,177	1,176	1,177	1,177	1,177	1,175	1,177	1,176	1,176	1,177	1,165	1,177	1,174	1,176
June 1-15	1,177	1,177	1,177	1,176	1,177	1,177	1,177	1,177	1,177	1,177	1,177	1,177	1,163	1,177	1,171	1,175
June 16-30	1,177	1,177	1,177	1,177	1,177	1,177	1,177	1,176	1,177	1,177	1,177	1,177	1,161	1,177	1,174	1,175
July 1-15	1,176	1,176	1,176	1,176	1,176	1,175	1,175	1,174	1,176	1,174	1,176	1,176	1,161	1,176	1,175	1,174
July 16-31	1,173	1,174	1,173	1,174	1,174	1,171	1,173	1,171	1,173	1,169	1,173	1,173	1,161	1,174	1,172	1,170
Aug 1-15	1,168	1,171	1,169	1,171	1,171	1,166	1,168	1,167	1,168	1,163	1,170	1,169	1,159	1,171	1,168	1,165
Aug 16-31	1,163	1,166	1,164	1,166	1,166	1,160	1,162	1,161	1,163	1,155	1,165	1,163	1,155	1,166	1,163	1,160
Sept 1-15	1,159	1,159	1,157	1,159	1,159	1,152	1,154	1,153	1,155	1,147	1,159	1,155	1,149	1,159	1,157	1,153
Sept 16-30	1,151	1,151	1,151	1,151	1,151	1,148	1,148	1,146	1,150	1,138	1,151	1,146	1,146	1,150	1,151	1,145
Oct 1-15	1,142	1,143	1,143	1,142	1,141	1,137	1,143	1,133	1,143	1,124	1,142	1,132	1,143	1,139	1,140	1,141
Oct 16-31	1,125	1,131	1,131	1,127	1,130	1,129	1,130	1,108	1,131	1,107	1,131	1,108	1,131	1,124	1,126	1,131
Nov 1-15	1,115	1,118	1,118	1,118	1,118	1,118	1,118	1,090	1,118	1,110	1,118	1,097	1,118	1,111	1,118	1,118
Nov 16-30	1,104	1,104	1,104	1,104	1,104	1,104	1,105	1,085	1,104	1,104	1,114	1,103	1,104	1,099	1,104	1,113
Dec 1-15	1,087	1,087	1,087	1,087	1,087	1,087	1,087	1,085	1,087	1,087	1,087	1,087	1,087	1,087	1,087	1,096
Dec 16-31	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075	1,075

Half Monthly Average for HH Outflow in CFS
Phase2Alt2

CFS	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Jan 1-15	1,857	654	1,062	2,925	1,042	2,253	585	1,472	1,391	1,649	1,275	1,202	2,194	568	741	469
Jan 16-31	1,480	3,648	758	2,619	2,739	575	2,839	3,871	2,684	1,171	4,385	4,042	3,117	1,218	678	465
Feb 1-15	1,083	3,538	596	2,005	1,236	439	1,250	2,692	1,550	507	1,644	958	1,251	584	782	1,913
Feb 16-28	1,020	2,095	668	1,250	3,307	415	1,369	1,480	3,752	561	930	849	1,016	592	656	838
Mar 1-15	494	526	512	491	528	479	488	486	3,487	490	480	951	492	491	587	1,499
Mar 16-31	607	638	554	484	496	717	533	481	2,008	494	799	509	494	493	605	687
Apr 1-15	1,100	559	1,664	497	502	711	700	586	1,340	420	1,504	617	628	522	656	818
Apr 16-30	1,648	1,927	1,351	455	974	2,068	940	1,223	1,324	530	2,001	814	1,336	846	773	1,397
May 1-15	1,637	849	1,973	833	1,099	2,313	1,412	2,896	2,626	485	2,309	2,109	2,471	929	643	1,653
May 16-31	2,697	1,280	1,052	1,894	877	2,106	1,514	2,142	2,621	488	2,071	2,162	1,273	776	823	1,154
June 1-15	2,947	936	832	1,104	1,130	1,213	1,107	1,564	1,783	448	3,746	1,923	800	796	493	577
June 16-30	2,093	457	615	816	485	765	496	1,357	1,286	489	1,909	920	901	380	401	391
July 1-15	1,169	398	732	462	441	638	402	958	1,025	366	980	721	612	410	268	324
July 16-31	646	374	416	370	391	404	344	628	676	338	654	413	422	380	227	309
Aug 1-15	494	361	381	381	366	377	357	377	399	336	392	408	404	396	273	313
Aug 16-31	619	358	401	373	613	391	373	427	508	329	470	469	597	365	326	309
Sept 1-15	688	401	406	402	617	439	396	537	466	372	435	540	581	529	513	393
Sept 16-30	865	381	412	380	1,517	548	352	444	900	376	444	459	517	727	809	373
Oct 1-15	1,250	477	454	468	970	829	533	477	577	463	431	490	482	639	550	475
Oct 16-31	784	549	956	1,291	1,288	560	688	866	504	540	356	1,405	544	654	491	477
Nov 1-15	681	614	723	1,287	1,588	622	560	1,891	707	888	357	1,864	612	2,186	1,007	363
Nov 16-30	1,558	614	1,454	798	1,798	673	1,625	1,203	838	1,142	965	2,365	901	3,122	1,135	358
Dec 1-15	2,730	940	1,927	1,205	1,991	591	1,111	1,822	883	1,433	901	6,600	692	7,293	1,776	1,998
Dec 16-31	1,582	451	2,150	2,887	830	994	629	1,382	3,860	2,234	2,654	2,202	1,089	1,422	1,137	2,478

CFS	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan 1-15	650	1,000	789	3,312	3,058	484	548	678	377	1,636	2,997	1,735	603	520	1,883	870
Jan 16-31	619	465	3,108	910	3,183	579	1,269	530	710	1,987	1,012	1,520	2,042	1,434	1,009	974
Feb 1-15	1,038	1,133	2,451	598	1,237	381	717	1,359	1,875	978	2,472	2,054	1,228	909	478	1,836
Feb 16-28	1,028	3,114	3,922	1,143	724	699	2,881	829	931	517	1,270	3,232	963	529	562	3,340
Mar 1-15	710	484	939	572	485	558	947	1,134	604	480	746	481	486	636	935	482
Mar 16-31	585	449	595	608	734	622	610	716	1,036	475	966	489	489	748	638	482
Apr 1-15	602	469	518	613	887	1,273	682	644	2,456	1,935	1,469	1,109	398	1,063	885	500
Apr 16-30	2,079	703	834	748	1,170	1,692	938	1,572	1,762	1,954	1,924	1,369	439	1,381	1,381	626
May 1-15	1,188	1,238	1,107	614	1,457	1,410	1,344	1,426	1,561	1,488	1,472	1,320	485	1,963	721	687
May 16-31	706	938	1,674	754	1,818	1,631	1,256	692	1,330	881	950	1,060	373	901	691	695
June 1-15	461	1,036	1,033	456	1,265	1,280	561	454	785	683	1,844	701	314	931	489	425
June 16-30	418	1,229	640	429	984	499	325	364	465	387	876	687	258	758	471	362
July 1-15	434	613	459	651	638	417	386	298	421	434	498	466	219	620	396	311
July 16-31	373	403	396	721	387	374	384	315	374	390	359	370	235	740	340	345
Aug 1-15	355	345	360	409	326	360	366	328	353	408	392	369	240	485	341	356
Aug 16-31	358	388	377	470	405	382	388	337	361	406	363	385	335	495	345	344
Sept 1-15	605	451	442	620	433	402	421	369	388	396	434	413	338	437	363	393
Sept 16-30	529	435	489	574	413	385	417	345	395	363	455	400	463	462	385	363
Oct 1-15	524	815	600	529	474	491	540	493	450	404	610	455	570	470	483	1,044
Oct 16-31	520	520	712	530	578	1,761	485	404	1,306	311	1,853	436	571	464	848	1,249
Nov 1-15	1,264	420	953	1,616	1,110	2,767	829	193	1,940	1,791	3,480	317	1,233	384	1,260	2,772
Nov 16-30	1,354	639	971	1,993	887	801	4,162	242	1,845	1,343	4,963	1,509	1,391	388	1,430	3,988
Dec 1-15	1,645	1,611	1,604	1,087	715	521	964	1,150	1,891	2,317	1,819	3,112	927	1,400	1,532	3,657
Dec 16-31	3,387	883	789	754	1,102	501	793	401	1,100	735	1,127	964	1,119	522	2,631	1,319

Percent Exceedance at HH Outflow (1964 to 1995)
Phase2Alt2

CFS	5%	10%	20%	25%	50%	75%	80%	90%	95%
01/01 to 01/15	4,375	2,596	1,750	1,561	808	537	501	430	385
01/16 to 01/31	5,975	4,090	2,667	2,172	1,043	675	599	484	428
02/01 to 02/15	3,490	2,545	1,789	1,553	972	626	558	440	397
02/16 to 02/28	5,734	3,192	1,644	1,387	885	621	577	495	456
03/01 to 03/15	2,058	1,121	676	601	491	483	480	476	468
03/16 to 03/31	1,846	951	661	596	491	482	479	472	460
04/01 to 04/15	2,607	2,076	1,383	943	521	477	474	464	425
04/16 to 04/30	2,352	2,203	1,869	1,711	1,188	753	611	475	439
05/01 to 05/15	3,108	2,608	2,058	1,880	1,207	878	779	548	489
05/16 to 05/31	2,740	2,377	1,968	1,747	1,081	729	621	509	465
06/01 to 06/15	2,929	1,992	1,446	1,327	819	502	491	428	392
06/16 to 06/30	1,681	1,350	965	865	517	399	384	350	305
07/01 to 07/15	1,065	941	718	625	442	386	371	307	269
07/16 to 07/31	778	630	475	428	383	348	340	310	248
08/01 to 08/15	471	417	401	396	366	342	335	319	307
08/16 to 08/31	592	511	451	423	380	352	344	329	309
09/01 to 09/15	760	678	545	512	411	367	361	342	329
09/16 to 09/30	989	792	567	516	429	380	368	350	339
10/01 to 10/15	1,098	787	614	575	494	466	457	440	415
10/16 to 10/31	1,923	1,372	960	778	539	484	467	435	358
11/01 to 11/15	3,722	2,646	1,680	1,492	827	496	449	371	261
11/16 to 11/30	4,230	2,915	1,852	1,623	1,072	719	660	464	365
12/01 to 12/15	6,059	3,790	2,237	1,997	1,264	777	717	580	513
12/16 to 12/31	4,278	3,093	1,892	1,598	947	687	625	500	440

Half Monthly Average for Palmer in CFS
Phase2Alt2

CFS	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Jan 1-15	1,701	462	915	2,801	861	2,109	436	1,307	1,221	1,487	1,102	1,026	2,048	385	553	323
Jan 16-31	1,312	3,575	569	2,485	2,609	387	2,712	3,775	2,552	994	4,305	3,952	2,999	1,042	487	323
Feb 1-15	903	3,401	402	1,853	1,061	300	1,076	2,561	1,385	331	1,482	775	1,077	422	594	1,785
Feb 16-28	844	1,952	478	1,081	3,200	295	1,203	1,318	3,658	372	752	668	840	398	465	657
Mar 1-15	313	352	327	303	346	318	302	300	3,403	300	300	787	300	300	393	1,355
Mar 16-31	433	453	381	302	317	551	353	300	1,875	300	639	320	312	309	425	512
Apr 1-15	941	371	1,525	309	327	553	536	416	1,180	297	1,346	426	468	356	467	646
Apr 16-30	1,484	1,781	1,179	309	793	1,919	756	1,049	1,152	369	1,849	635	1,166	684	598	1,229
May 1-15	1,475	673	1,822	681	920	2,172	1,245	2,772	2,494	309	2,166	1,972	2,334	745	492	1,491
May 16-31	2,566	1,106	872	1,742	691	1,957	1,347	1,995	2,487	300	1,922	2,021	1,100	587	642	977
June 1-15	2,823	752	645	925	952	1,037	928	1,399	1,624	298	3,646	1,769	612	611	300	407
June 16-30	1,944	302	421	646	314	580	341	1,186	1,113	303	1,754	736	717	263	278	289
July 1-15	897	203	448	245	238	351	204	680	749	232	703	436	334	215	165	167
July 16-31	359	177	191	174	195	188	147	349	391	152	368	206	219	183	122	112
Aug 1-15	234	163	185	185	169	180	158	179	189	139	183	211	204	198	116	114
Aug 16-31	328	160	203	174	375	193	173	217	236	130	218	236	336	171	129	110
Sept 1-15	397	203	208	203	324	240	202	264	238	174	229	262	303	302	251	192
Sept 16-30	580	184	213	188	1,251	309	155	245	639	178	246	261	310	471	522	174
Oct 1-15	976	279	256	272	687	542	300	280	317	257	232	294	285	408	308	280
Oct 16-31	496	300	711	1,066	1,016	323	412	601	300	314	157	1,156	331	442	283	263
Nov 1-15	485	430	528	1,108	1,418	444	380	1,731	512	707	232	1,703	419	2,035	831	259
Nov 16-30	1,388	417	1,281	605	1,635	477	1,457	1,022	663	959	784	2,219	712	2,998	952	252
Dec 1-15	2,598	754	1,770	1,026	1,836	416	930	1,662	695	1,261	715	6,584	499	7,297	1,615	1,851
Dec 16-31	1,416	303	2,001	2,760	641	810	441	1,210	3,762	2,088	2,520	2,055	908	1,251	957	2,339

CFS	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan 1-15	464	818	621	3,218	2,938	335	383	488	263	1,473	2,875	1,577	422	358	1,727	684
Jan 16-31	454	302	2,989	726	3,066	395	1,095	384	522	1,834	831	1,354	1,891	1,316	827	792
Feb 1-15	862	1,028	2,313	405	1,063	271	527	1,188	1,719	798	2,334	1,904	1,054	725	321	1,679
Feb 16-28	852	3,000	3,833	970	538	537	2,767	645	752	322	1,102	3,123	786	362	372	3,234
Mar 1-15	540	300	778	399	300	367	786	981	432	300	579	300	300	473	772	300
Mar 16-31	404	305	411	426	574	439	440	536	878	300	803	300	300	592	462	300
Apr 1-15	429	292	328	431	712	1,142	500	471	2,327	1,806	1,314	961	297	895	715	313
Apr 16-30	1,929	551	658	591	992	1,529	755	1,409	1,601	1,800	1,769	1,198	302	1,212	1,210	493
May 1-15	1,013	1,063	938	460	1,295	1,242	1,173	1,257	1,397	1,321	1,305	1,147	313	1,810	542	511
May 16-31	526	754	1,513	565	1,661	1,468	1,081	545	1,158	695	767	884	270	716	568	531
June 1-15	303	856	852	329	1,091	1,107	395	305	596	496	1,687	510	209	747	373	315
June 16-30	283	1,054	459	292	802	348	221	262	315	275	690	[illegible]	153	568	303	259
July 1-15	227	324	242	409	351	222	190	144	219	238	240	234	115	332	228	158
July 16-31	177	187	199	438	179	177	189	117	178	192	163	172	129	455	143	147
Aug 1-15	156	148	163	207	129	162	168	129	155	210	195	174	133	232	143	158
Aug 16-31	160	183	179	242	187	184	190	140	163	208	167	187	142	232	146	147
Sept 1-15	335	237	227	338	204	204	223	175	194	220	236	214	140	242	165	194
Sept 16-30	291	238	282	321	210	188	215	145	198	217	256	206	234	263	186	166
Oct 1-15	326	542	348	333	276	293	312	302	249	260	401	313	324	272	284	824
Oct 16-31	322	294	455	335	348	1,539	273	244	1,034	150	1,598	285	315	267	634	975
Nov 1-15	1,111	295	765	1,464	927	2,633	639	123	1,782	1,674	3,367	206	1,053	281	1,080	2,638
Nov 16-30	1,178	445	784	1,836	696	609	4,070	137	1,684	1,167	4,896	1,342	1,216	279	1,256	3,918
Dec 1-15	1,480	1,445	1,437	905	523	335	778	985	1,734	2,172	1,659	2,991	740	1,227	1,364	3,525
Dec 16-31	3,275	696	600	566	928	319	603	273	919	544	953	780	939	359	2,496	1,145

Percent Exceedance at Palmer (1964 to 1995)
Phase2Alt2

CFS	5%	10%	20%	25%	50%	75%	80%	90%	95%
01/01 to 01/15	4,294	2,462	1,591	1,396	620	341	304	300	285
01/16 to 01/31	5,942	4,001	2,535	2,025	862	483	405	300	300
02/01 to 02/15	3,383	2,409	1,636	1,388	789	433	363	300	298
02/16 to 02/28	5,699	3,081	1,486	1,222	705	429	382	300	300
03/01 to 03/15	1,930	965	500	421	300	300	300	300	300
03/16 to 03/31	1,690	780	480	424	300	300	300	300	300
04/01 to 04/15	2,473	1,910	1,213	781	345	300	300	300	300
04/16 to 04/30	2,180	2,049	1,713	1,553	1,018	569	439	306	300
05/01 to 05/15	3,002	2,474	1,908	1,724	1,031	700	593	389	304
05/16 to 05/31	2,610	2,211	1,815	1,587	906	542	449	349	300
06/01 to 06/15	2,805	1,840	1,277	1,155	632	343	314	300	291
06/16 to 06/30	1,519	1,179	782	679	322	299	284	248	203
07/01 to 07/15	790	663	433	341	233	200	191	156	117
07/16 to 07/31	495	342	217	204	188	152	145	129	110
08/01 to 08/15	221	210	200	199	169	145	139	128	110
08/16 to 08/31	303	247	219	213	182	155	145	131	112
09/01 to 09/15	546	387	274	248	207	169	163	145	134
09/16 to 09/30	707	504	306	300	232	185	179	153	142
10/01 to 10/15	819	499	364	330	300	275	268	248	238
10/16 to 10/31	1,669	1,101	677	490	313	293	282	243	165
11/01 to 11/15	3,617	2,508	1,513	1,320	636	309	300	266	160
11/16 to 11/30	4,140	2,786	1,691	1,455	887	524	463	300	259
12/01 to 12/15	6,026	3,689	2,090	1,842	1,087	586	524	383	314
12/16 to 12/31	4,192	2,972	1,735	1,432	761	494	430	301	300

Half Monthly Average for Auburn in CFS
Phase2Alt2

CFS	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Jan 1-15	2,610	1,135	1,584	3,557	1,290	3,358	848	1,997	1,914	2,242	1,605	2,034	3,051	605	1,113	680
Jan 16-31	2,544	4,533	1,121	3,637	3,051	1,097	3,637	4,630	3,660	1,783	5,171	5,090	4,179	1,323	953	754
Feb 1-15	1,783	4,844	783	2,615	1,633	1,075	1,680	3,272	2,089	789	2,680	1,567	1,714	639	1,107	2,556
Feb 16-28	1,443	2,884	823	1,764	3,901	863	1,793	2,047	4,687	755	1,734	1,763	1,615	607	838	1,418
Mar 1-15	823	1,069	765	839	864	754	785	1,191	4,957	727	1,235	1,783	871	739	750	2,037
Mar 16-31	1,028	970	800	866	818	890	772	1,027	2,731	703	1,522	1,021	800	651	757	1,004
Apr 1-15	1,383	758	1,907	775	816	1,009	966	1,066	1,853	581	2,162	906	915	679	751	1,091
Apr 16-30	1,937	2,289	1,567	781	1,192	2,333	1,206	1,497	1,681	579	2,437	1,095	1,612	981	1,086	1,640
May 1-15	1,852	1,113	2,067	1,039	1,245	2,434	1,618	2,982	2,797	562	2,628	2,336	2,715	943	911	1,873
May 16-31	2,892	1,459	1,136	2,062	961	2,207	1,694	2,260	2,840	574	2,355	2,519	1,419	797	998	1,244
June 1-15	3,236	1,059	862	1,232	1,433	1,376	1,214	1,732	1,955	496	3,946	2,097	816	917	585	598
June 16-30	2,514	524	639	857	595	895	590	1,483	1,372	513	2,190	950	949	471	501	440
July 1-15	1,195	388	711	428	443	644	399	961	1,021	405	1,010	667	497	364	365	321
July 16-31	605	322	399	322	359	407	307	598	644	263	676	371	368	307	332	257
Aug 1-15	438	300	350	305	308	350	300	365	384	250	418	350	360	300	299	270
Aug 16-31	506	300	350	300	548	350	300	381	417	250	403	437	495	310	277	268
Sept 1-15	567	327	347	327	512	377	332	476	413	280	395	460	473	398	413	360
Sept 16-30	759	300	350	300	1,509	486	301	415	852	294	395	415	438	564	768	301
Oct 1-15	1,177	400	400	400	929	738	441	450	496	430	400	450	459	461	511	400
Oct 16-31	653	450	876	1,234	1,382	458	585	780	452	457	400	1,358	464	500	464	434
Nov 1-15	742	586	685	1,371	1,785	671	563	2,137	724	958	446	2,208	601	2,181	1,105	425
Nov 16-30	1,851	586	1,540	787	2,099	692	1,661	1,472	882	1,446	1,105	2,764	888	3,159	1,255	400
Dec 1-15	3,497	994	2,335	1,260	2,752	787	1,456	2,320	938	1,805	976	7,748	695	7,802	2,334	2,103
Dec 16-31	2,378	679	2,646	3,084	1,290	1,493	954	2,054	5,027	2,960	3,151	3,074	1,170	2,128	1,459	3,238

CFS	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Jan 1-15	1,135	1,504	1,053	3,927	3,709	796	747	1,011	447	2,242	3,869	2,250	728	639	2,170	1,329
Jan 16-31	1,249	795	4,109	1,435	3,866	734	1,799	897	832	2,536	1,697	2,225	2,378	1,748	1,298	1,265
Feb 1-15	1,489	1,506	3,275	929	1,817	647	1,007	1,763	2,030	1,340	3,381	2,661	1,727	1,142	649	2,392
Feb 16-28	1,404	3,790	5,696	1,653	1,358	897	3,351	1,011	1,091	903	1,981	4,433	1,375	667	925	4,261
Mar 1-15	1,263	864	1,718	1,062	937	756	1,273	1,593	809	1,004	1,303	1,318	741	711	1,347	991
Mar 16-31	1,103	691	1,110	918	1,241	756	849	1,101	1,253	1,134	1,384	941	700	1,140	933	958
Apr 1-15	1,016	735	845	967	1,379	1,302	897	897	2,822	2,648	1,718	2,121	577	1,537	1,158	772
Apr 16-30	2,608	954	1,078	912	1,558	1,767	1,080	1,853	2,089	2,388	2,079	1,839	652	1,817	1,550	880
May 1-15	1,445	1,457	1,314	747	1,833	1,471	1,601	1,669	1,857	1,697	1,689	1,610	547	2,309	806	863
May 16-31	834	1,163	1,859	810	2,187	1,619	1,402	845	1,550	1,051	1,124	1,303	454	1,147	750	806
June 1-15	551	1,371	1,121	534	1,599	1,400	637	530	968	765	2,266	798	367	1,246	526	528
June 16-30	503	1,547	659	523	1,234	594	432	440	567	465	1,145	782	301	1,002	507	451
July 1-15	433	670	423	625	719	385	364	299	439	378	577	486	269	687	382	310
July 16-31	346	454	366	682	421	307	347	250	343	302	376	356	250	781	258	250
Aug 1-15	300	354	307	370	351	302	301	250	300	300	350	303	250	490	250	250
Aug 16-31	300	359	303	399	451	300	300	250	300	300	325	300	250	414	250	253
Sept 1-15	501	410	361	528	489	327	341	280	327	300	385	327	250	377	282	280
Sept 16-30	435	408	418	481	464	300	348	253	326	297	393	300	328	393	300	253
Oct 1-15	450	847	499	450	450	400	438	400	414	350	513	400	439	400	400	1,014
Oct 16-31	450	536	620	450	496	1,812	425	344	1,370	258	1,866	385	422	400	777	1,217
Nov 1-15	1,417	656	958	1,765	1,177	2,991	783	233	2,248	1,986	4,068	365	1,199	400	1,492	3,021
Nov 16-30	1,632	806	1,045	2,432	1,053	970	4,567	251	2,347	1,576	6,263	1,705	1,497	404	1,552	4,607
Dec 1-15	2,143	2,046	1,926	1,546	993	828	1,326	1,198	2,272	2,927	2,830	3,484	1,044	1,566	2,061	5,166
Dec 16-31	3,993	1,325	1,105	1,122	1,410	618	1,064	511	1,433	958	1,616	1,177	1,347	611	3,447	1,913

Percent Exceedance at Auburn (1964 to 1995)
Phase2Alt2

CFS	5%	10%	20%	25%	50%	75%	80%	90%	95%
01/01 to 01/15	5,397	3,338	2,527	2,211	1,240	810	751	640	530
01/16 to 01/31	6,612	5,188	3,553	2,941	1,561	991	890	741	634
02/01 to 02/15	4,143	3,512	2,577	2,235	1,410	931	851	701	591
02/16 to 02/28	7,199	3,963	2,454	2,125	1,363	900	900	758	680
03/01 to 03/15	2,969	1,740	1,270	1,190	896	750	750	750	704
03/16 to 03/31	2,443	1,467	1,098	1,030	875	750	750	710	652
04/01 to 04/15	2,887	2,500	1,875	1,456	850	750	750	693	575
04/16 to 04/30	2,660	2,500	2,222	1,997	1,486	966	836	750	580
05/01 to 05/15	3,235	2,834	2,284	2,145	1,460	1,028	918	723	570
05/16 to 05/31	2,937	2,500	2,166	1,982	1,264	833	756	601	568
06/01 to 06/15	3,126	2,435	1,693	1,519	922	562	546	509	492
06/16 to 06/30	2,046	1,529	1,134	1,000	586	488	474	417	400
07/01 to 07/15	1,070	955	713	623	440	368	350	325	280
07/16 to 07/31	790	603	457	420	350	300	300	250	250
08/01 to 08/15	440	400	350	350	300	300	298	250	250
08/16 to 08/31	477	433	400	399	300	300	280	250	250
09/01 to 09/15	700	560	455	426	350	300	300	250	250
09/16 to 09/30	915	670	469	445	400	300	300	290	250
10/01 to 10/15	1,081	720	492	466	450	400	400	400	400
10/16 to 10/31	1,981	1,422	902	681	450	400	400	400	400
11/01 to 11/15	4,202	2,878	1,920	1,654	855	491	461	400	308
11/16 to 11/30	4,742	3,354	2,188	1,965	1,211	752	688	450	400
12/01 to 12/15	7,657	4,203	2,910	2,579	1,627	1,039	911	673	569
12/16 to 12/31	5,524	3,918	2,545	2,188	1,372	929	841	661	551

FIGURES

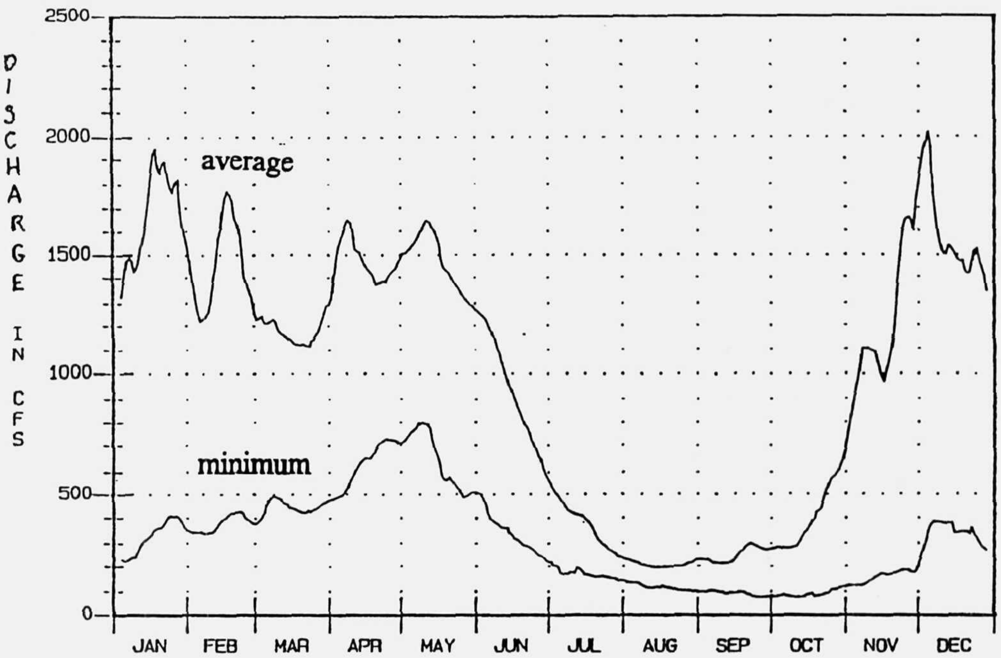


Figure 1. Green River Inflow to H.A.Hanson Dam, Summary Hydrograph

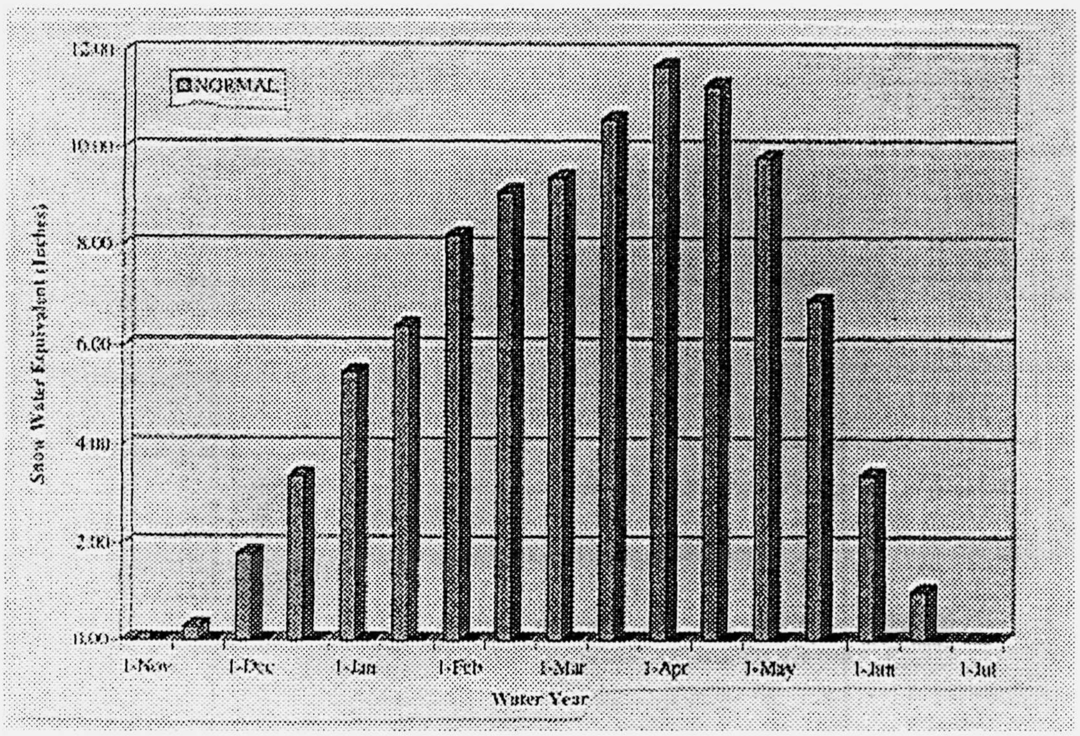


Figure 2. Green River Basin Snowpack, Typical Normal Conditions

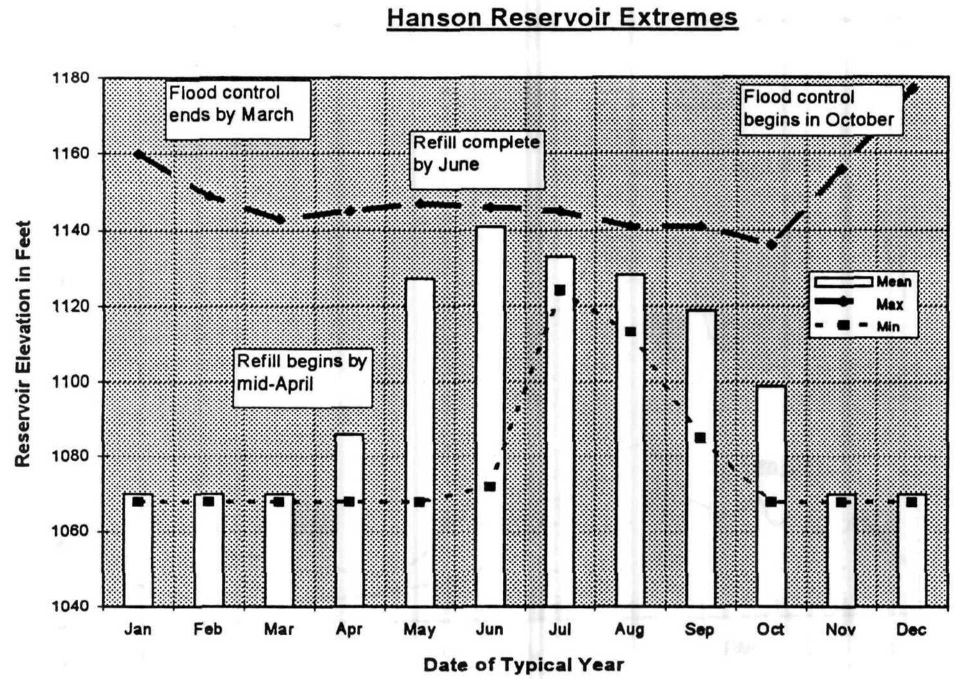


Figure 3. Hanson Reservoir - Means by Month with Maximum and Minimum Extremes.

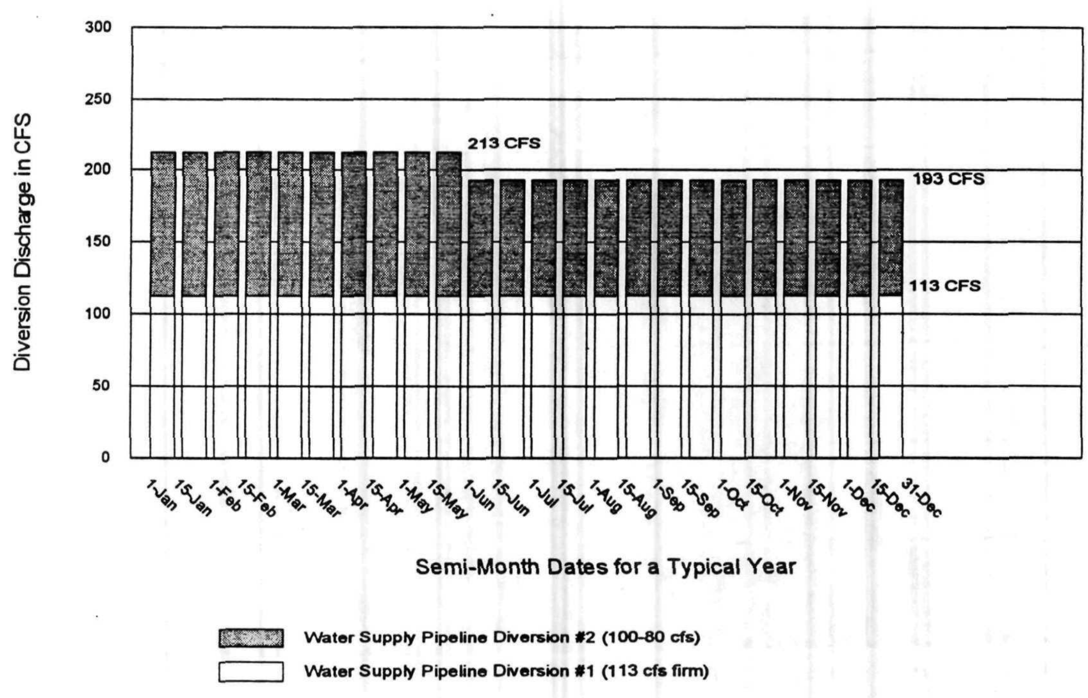


Figure 4. Target Diversion Flows from the Green River below Howard Hanson Dam

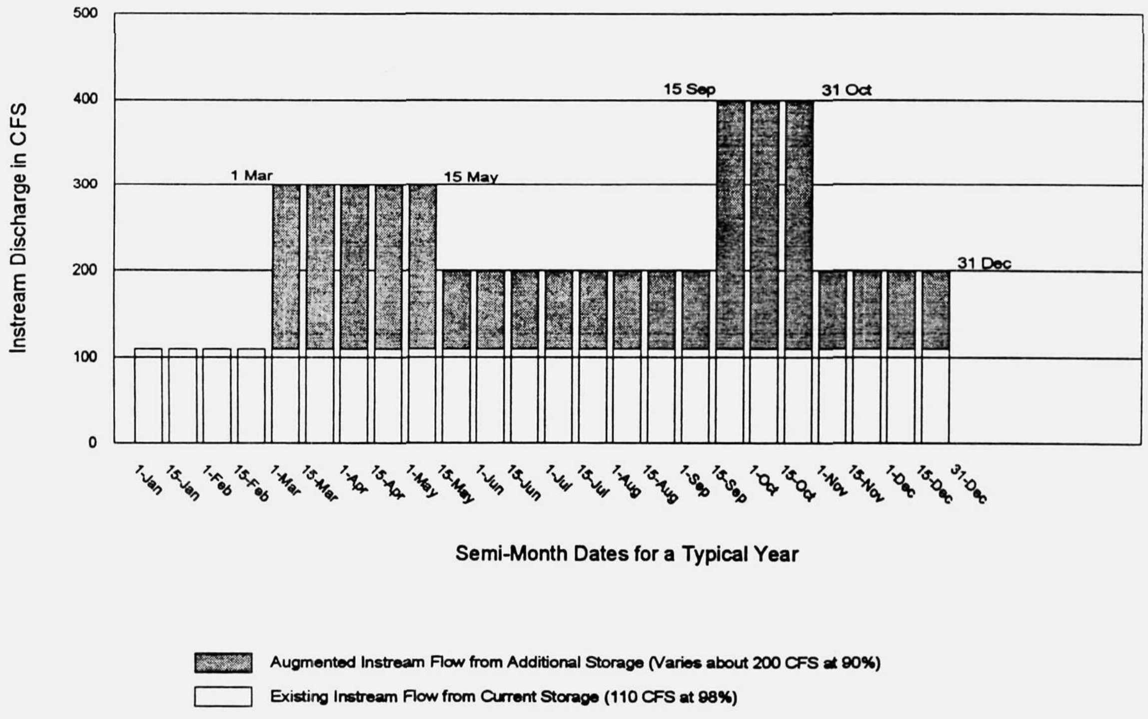


Figure 5. Target Instream Flows on the Green River below the Diversion Site

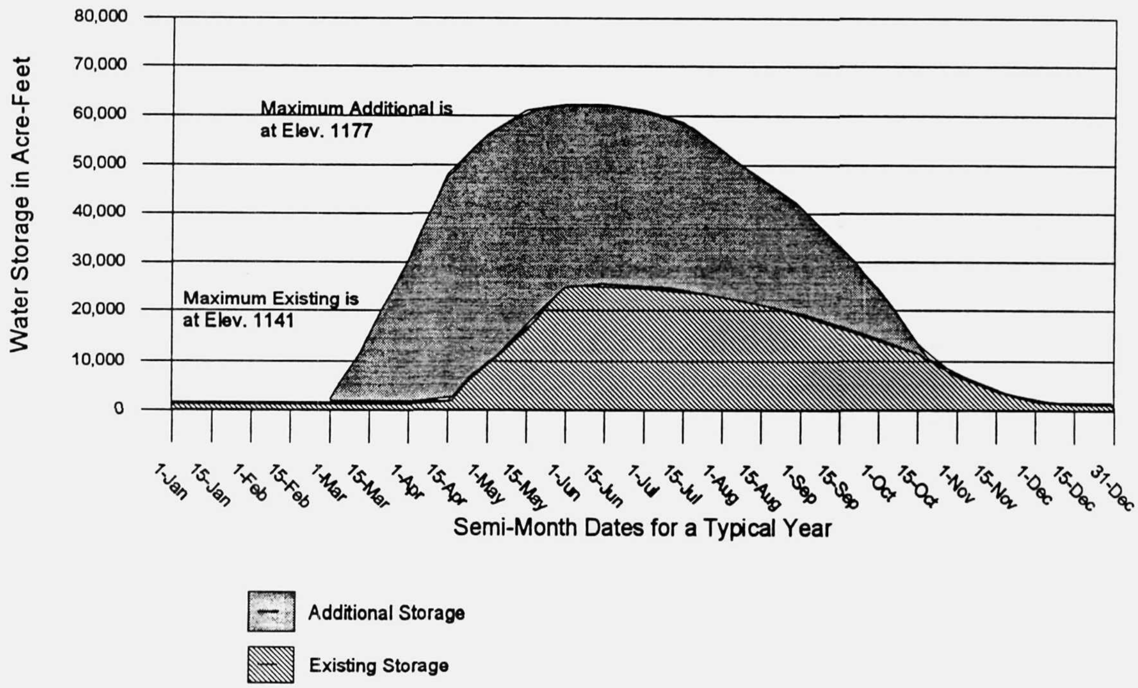


Figure 6. Storage Zones in Howard Hanson Reservoir - Existing and Additional Storage

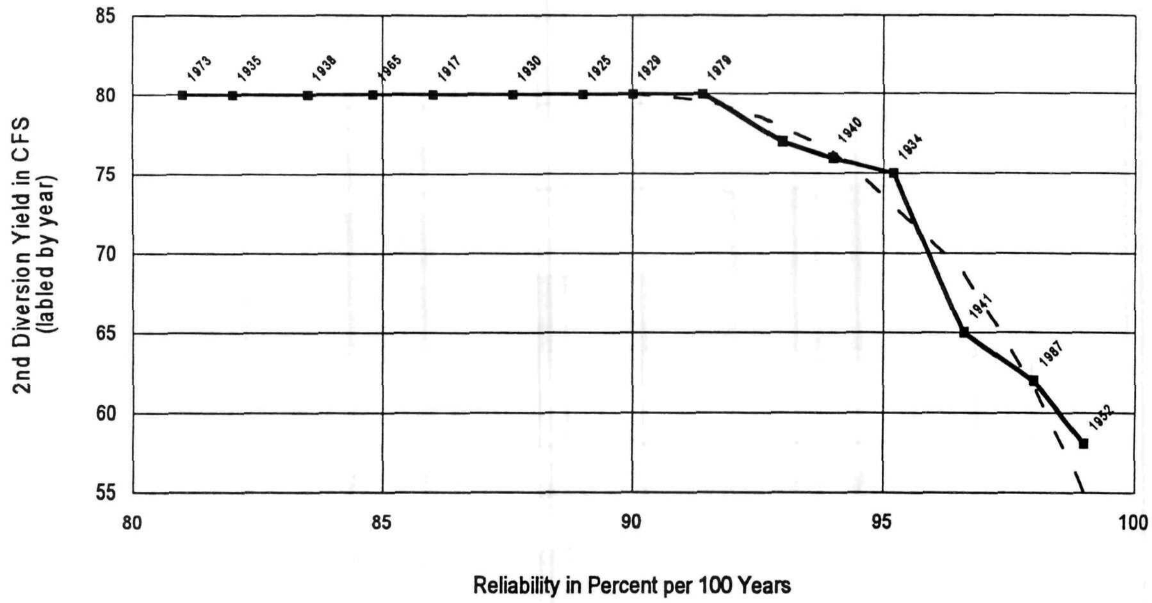


Figure 7. Reliability of Second Supply Water Right Diversion

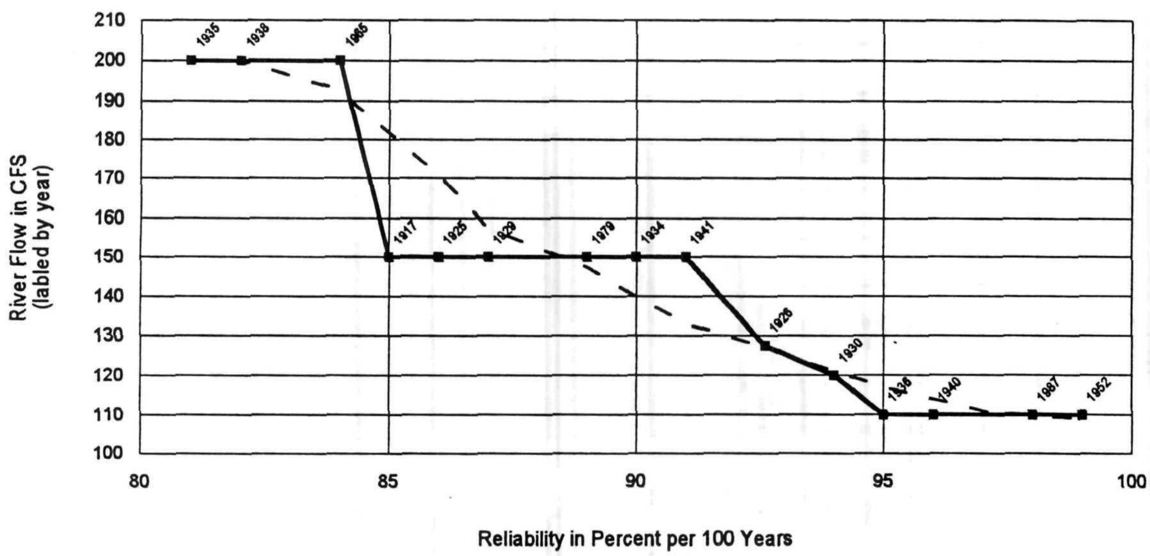


Figure 8. Reliability of Instream Flow

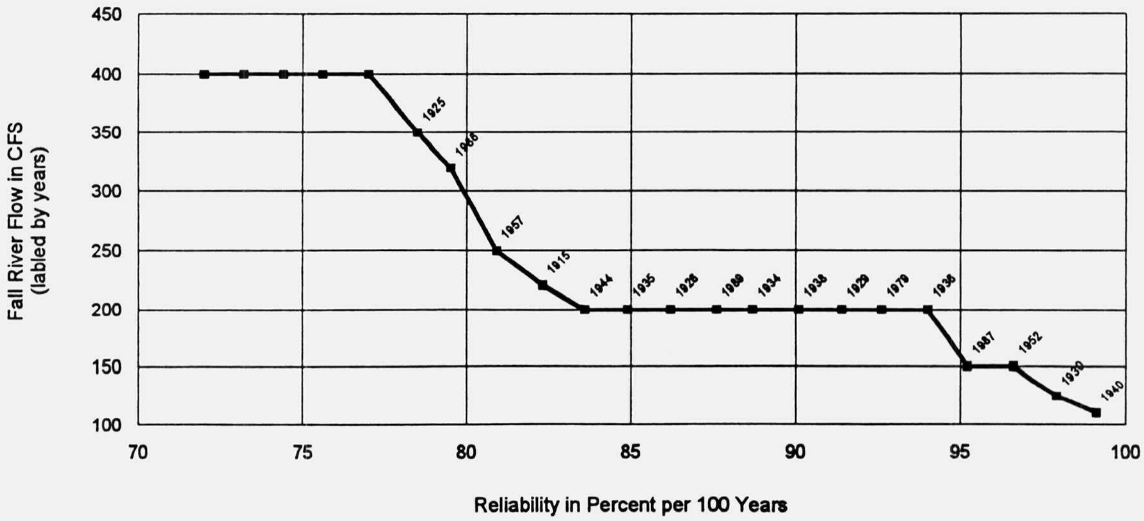


Figure 9. Reliability of Fall Flow, mid-September through October

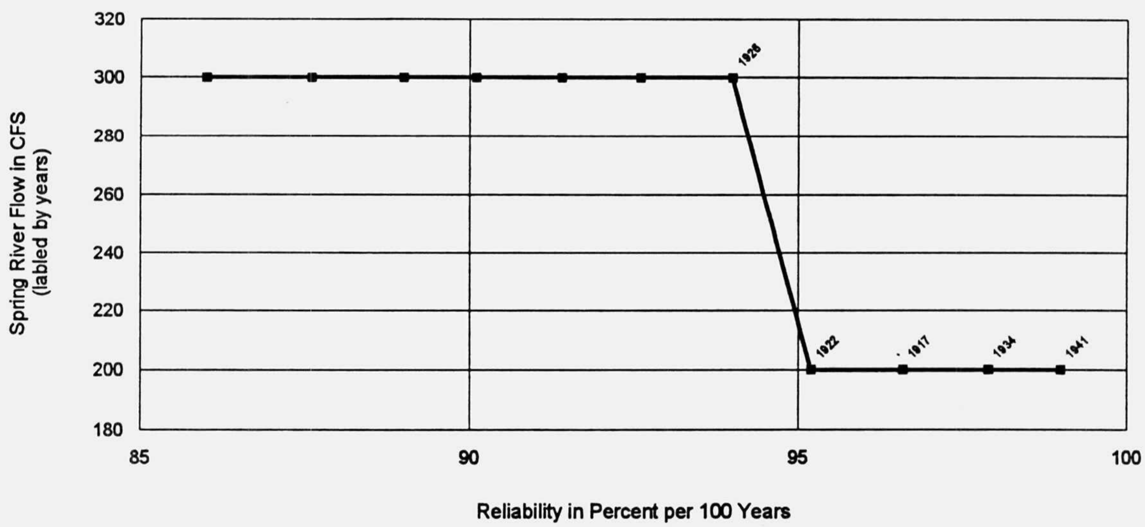


Figure 10. Reliability of Spring Flow, March through mid-May

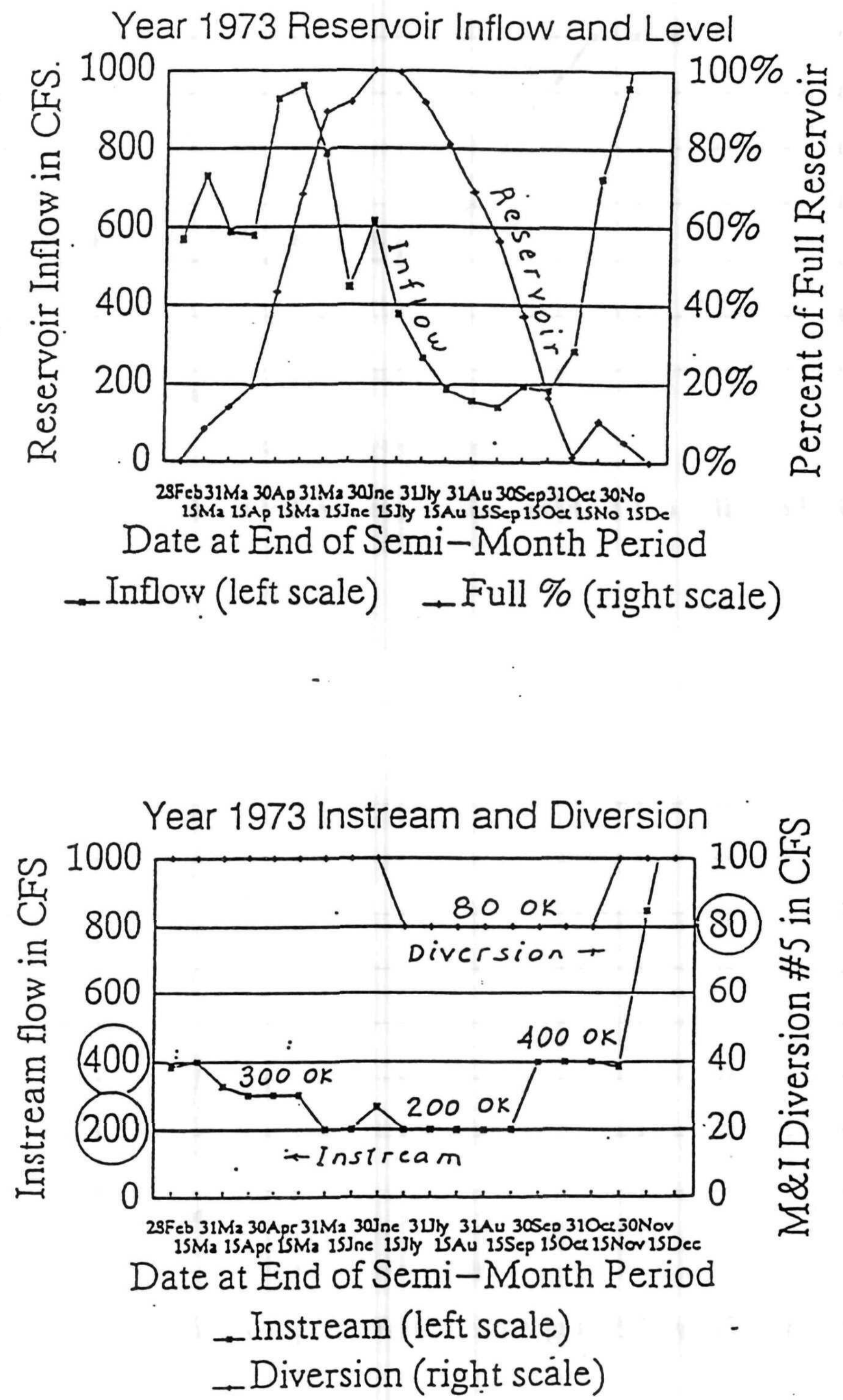


Figure 11. Example Year 1973 – Green River Discharges, Diversion, and Reservoir Level

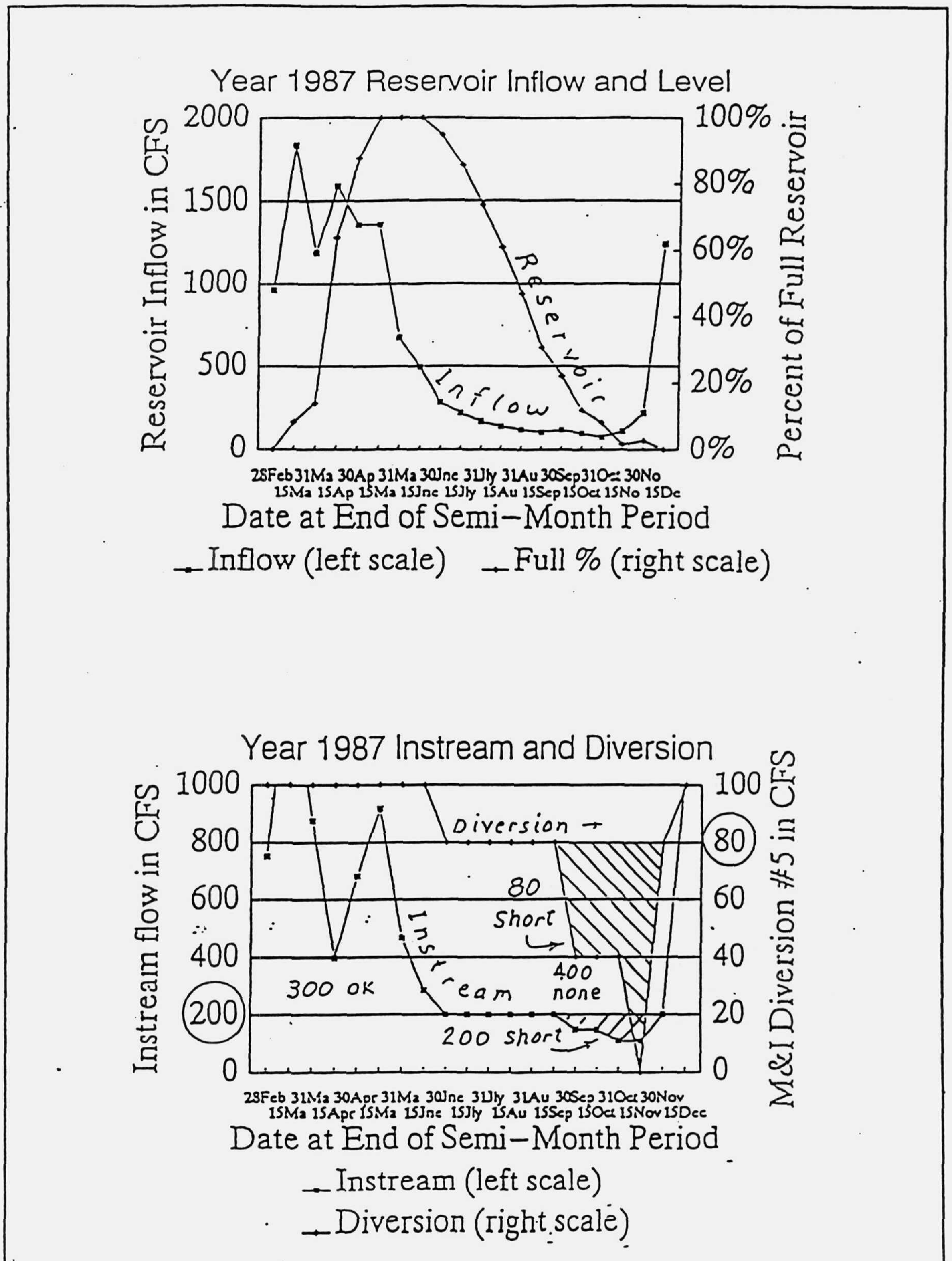


Figure 12. Example Year 1987 – Green River Discharges, Diversion, and Reservoir Level

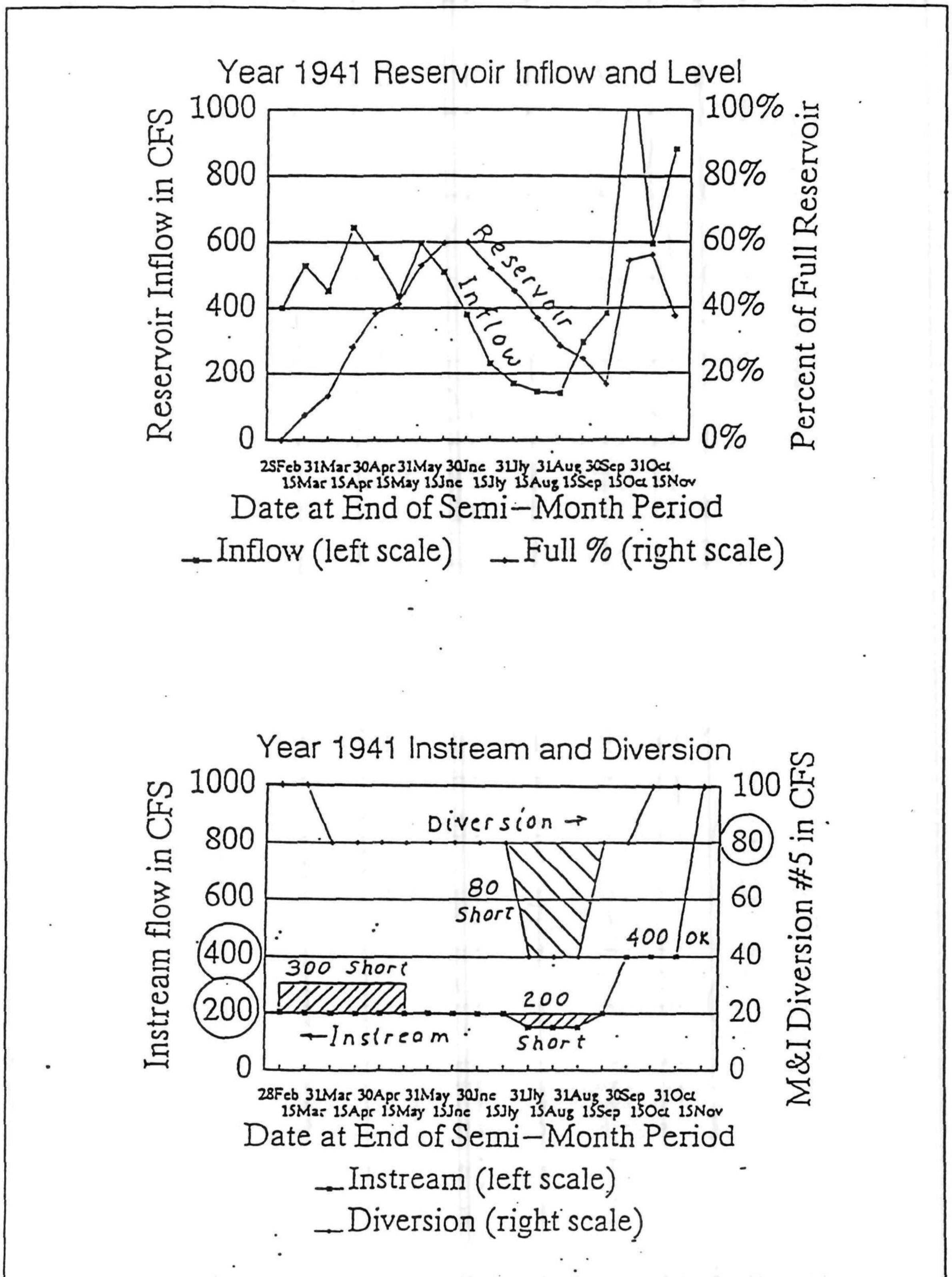


Figure 13. Example Year 1941 – A Year with Low Spring Runoff

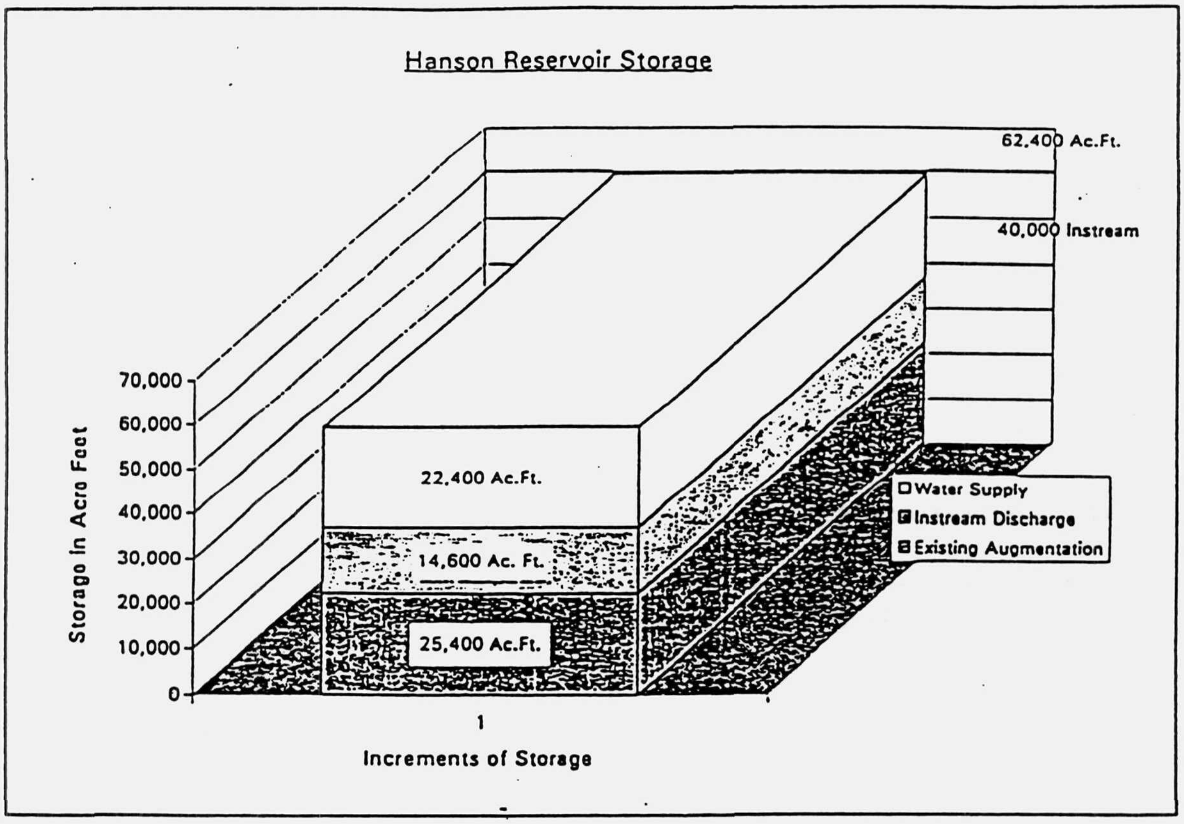


Figure 14. Allocation of Howard Hanson Storage

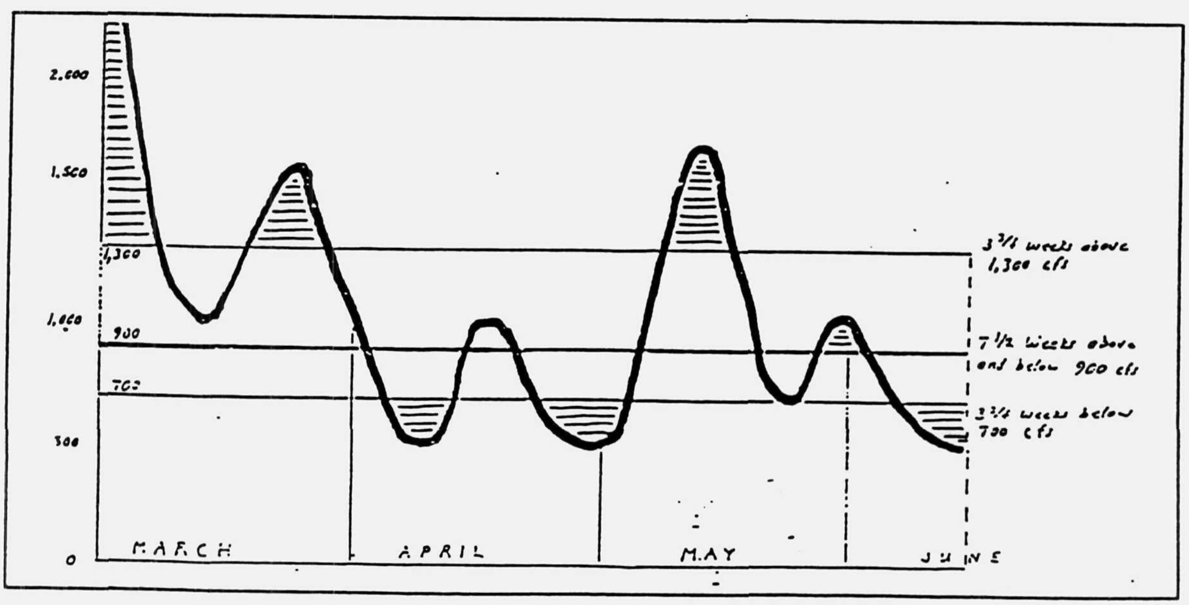


Figure 15. Average Hydrograph of Outflow from March through mid-June

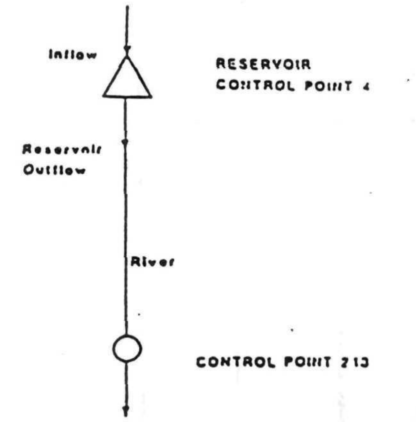


Figure 1. SINGLE RESERVOIR WATER SUPPLY SYSTEM

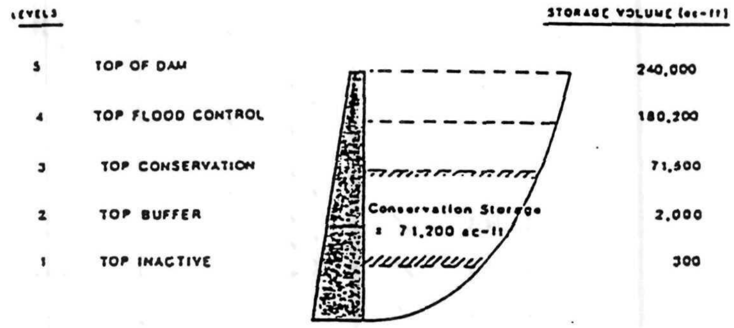
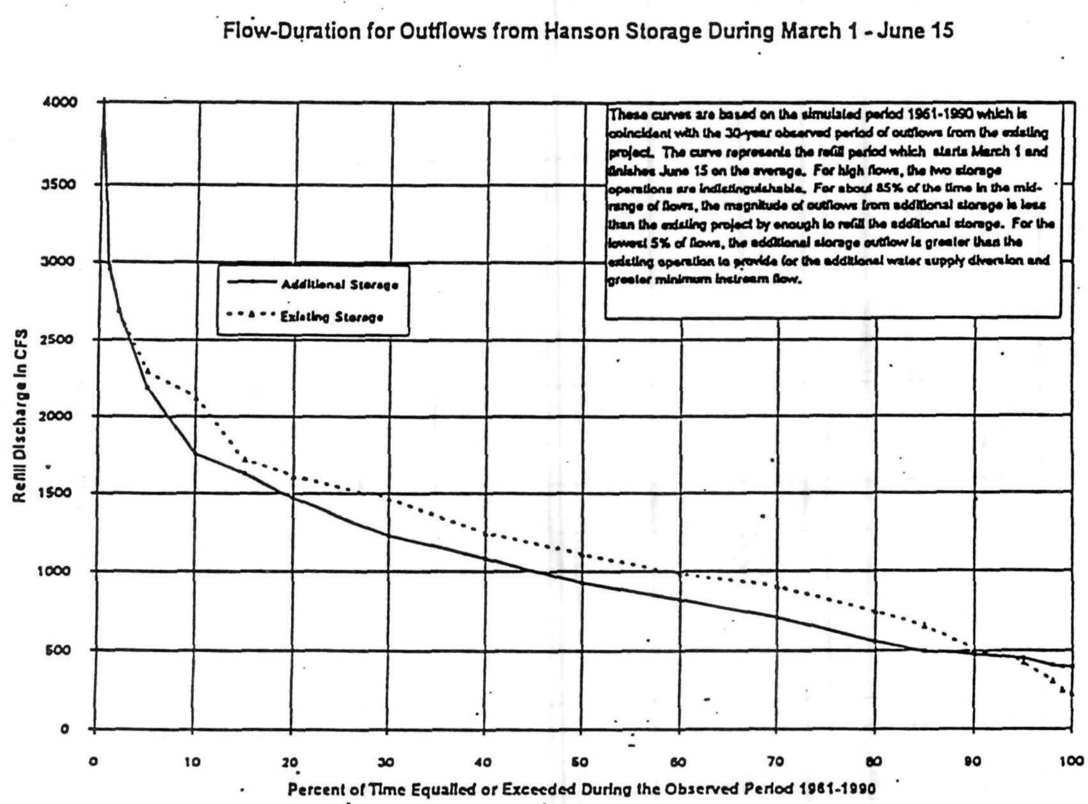


Figure 2. RESERVOR STORAGE LEVELS AND VOLUMES

Figure 16. Two Figures From the HEC-5 User's Manual



APPENDIX D, Hydrology & Hydraulics
Part D2, Hydraulic Design

Additional Water Storage Project, Draft Feasibility Report & EIS

Howard Hanson Dam,
Green River, Washington
April 1998

prepared by
Seattle District

US Army Corps of Engineers®

APPENDIX D
HYDROLOGY AND HYDRAULICS
PART 2 — HYDRAULIC DESIGN

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SECTION 1 INTRODUCTION

1.1 PURPOSE AND SCOPE OF PART 2

The hydraulics portion of the Hydrology and Hydraulics Appendix discusses the hydraulic design considerations of the proposed downstream migrant fish passage facilities at Howard A. Hanson Dam (HAH) as part of the Additional Water Storage project.

Included in this portion of the Hydrology and Hydraulics Appendix are hydraulic design details for the fish passage facility and a discussion of the hydraulic model studies which will be accomplished to support the final design during the PED phase of this project.

1.2 FISH PASSAGE DEFICIENCIES IN EXISTING FLOOD CONTROL OUTLET STRUCTURE

The existing flood control outlet structure was not designed to pass downstream migrant fish. Two low level entrances to the flood control tunnel at elevation 1035 feet provide for flood control releases from the reservoir up to 12,000 cubic feet per second (cfs) regulated discharge, and a 48-inch-diameter low flow bypass at elevation 1069 provides for releases during the summer low flow augmentation period. When the reservoir is operating near the flood control pool elevation of 1070, downstream migrants have passed relatively safely through the two 10 foot by 12 foot tunnel control gates and into the open channel flow of the flood control tunnel. However, as the reservoir rises during spring refill, submergence of the tunnel entrances hampers the ability of fish to locate the outlet to the reservoir. During the spring refill period and summer high pool, the low flow bypass is opened and also becomes submerged by as much as 70 feet and operates under very high head. Similar conditions of low attraction flow and deep submergence of the outlet at other reservoir projects has been linked to poor passage success.

Under these conditions, fish may have difficulty locating the outlet, and thus may stay in the reservoir until the next flood control season when the pool is drawn down again. If they do reach and pass through the low flow outlet under high head, the hydraulic conditions throughout the low flow outlet conduit and control gate at the downstream end are such that very few fish survive the passage. As part of the additional water supply study, tests were conducted to determine rough estimates of survival through the flood control sluices and through the low flow outlet. In addition, tracking studies were conducted to determine the ability of the fish to sense the outlet flow and actively seek it from the upstream limits of the reservoir. Vertical distribution studies were conducted to determine the distribution of fish throughout the vertical plane in the near vicinity of the outlet. The data and results of these studies are included in Appendix F of this Feasibility Report.

SECTION 2 DESIGN CONSIDERATIONS AND CRITERIA

2.1 HYDRAULIC DESIGN CONSIDERATIONS

Basic design considerations for hydraulic features of the proposed structures are twofold. The first and foremost consideration was to develop an acceptable hydraulic design, and the second was to develop the most economically feasible and fish-friendly fish passage facility for downstream migrant anadromous fish. The complex design issues surrounding the type of fish passage system needed to meet the operating conditions at HAH required the establishment of a Fish Passage Technical Committee (FPTC) to resolve the issues and assist in developing an acceptable fish passage design for the project. The FPTC consisted of recognized engineering and biologic experts in the area of anadromous fish passage: Mr. Steve Rainey from the National Marine Fisheries Service (NMFS), Mr. Ken Bates from the Washington State Department of Fish and Wildlife (WSDF), as well as private consultants Messrs. Milo Bell, Ed Donahue and Phil Hilgert. The FPTC met throughout the course of the design process to review updated design concepts and recommend changes to better meet the requirements of the project. The proposed design was required to satisfy the following conditions:

- Provide for unrestricted operation of the existing flood control outlet facilities at all pool elevations;
- Provide for positive and complete closure of all fish passage facility outlet works during the flood control season, if necessary;
- Provide for unrestricted capability of the existing spillway to safely pass the spillway design flood (SDF);
- Provide emergency closure capability of all operating conduits within the fish passage outlet works;
- Provide for variable elevation withdrawal of near surface flows under full additional water supply pool elevation operating range for enhanced fish passage success; and
- Provide for fish capture and transport within biological criteria for all pool elevations within the additional water supply operating range.

2.2 HYDRAULIC DESIGN CRITERIA AND GUIDANCE

2.2.1 Biological Criteria

Hydraulic features of the proposed design were required to meet a number of criteria for flow characteristics, fish residence time limits, attraction, predation limitations, and screening velocities as specified by the various fisheries and resource agencies and members of the FPTC. These criteria can be categorized as biological criteria and hydraulic criteria, and are summarized below. Biological criteria are separated into two general categories: bypass and screening criteria, referring to the individual components of fish passage facilities. In addition, general guidance was provided in the publications "Fisheries Handbook" and "Fish Passage Through Turbines", written by Milo Bell for the Portland District, U.S. Army Corps of Engineers.

a. Fish Passage Structure Criteria

- Design operating pool range 1070 ft to 1177 ft
- Design operating discharge range 410 cfs to 1250 cfs
- Maximum velocity increase of 0.1 fps/linear ft through various components
- Primary debris control should be with a forebay log boom
- Fish to be collected in the vicinity of their predominant distribution in reservoir at any specific time or condition
- Controlled acceleration approaching collection intakes and bypass entrance

b. Bypass Criteria

- No pumping of fish
- No free-fall within shafts
- Constant bypass flow (within a narrow range)
- Maximum plunge impact velocity = 35 fps, deceleration control required
- Maximum open channel flow velocity = 30 fps in smooth channels (e.g. brushed aluminum, HDPE) and 10 fps in hydraulically rough channels (typically finished concrete)
- Full pipe or open-channel flow
- No negative pressure
- Pipe radius of curvature > 3 diameters
- No constrictions that may cause rapid pressure change, direct impact or injury to fish, or may cause collection of debris
- Smooth wall and joints required for all conduits and channels
- Maximum velocity = 25 fps for full pipe flow (higher rates need verification)
- Maximum bypass entrance velocity equal to or greater than the maximum resultant velocity vector of flow approaching screens
- Fish transport bypass system to be designed to minimize debris accumulation; minimum pipe diameter = 24 inches
- Access necessary to check locations of potential debris accumulations
- No closure valves (e.g., butterfly or gate type) within the bypass system (further refined to state, no partially open valve operation)
- Minimum 9-inch depth for open channel flow
- Minimum capture velocity at entrances to bypasses of 5 fps
- Fish to be attracted or guided to bypass

c. General Screen Criteria

- Apply Washington Department of Fish and Wildlife (WDFW), and National Marine Fisheries Service (NMFS) screen criteria
- Maximum 0.4 fps approach velocity
- Minimum 1:1 approach angle
- Maximum screen opening: 1/8 inch
- Entire screen visible & accessible for monitoring, observation and maintenance
- 100 percent exclusion screening
- Uniform velocity distribution in flow approaching screens
- Automatic cleaning of screens
- No straining of flow (e.g., using a wolf trap to completely separate fish from flow)

d. MIS and Eicher Screen Criteria

- Maximum approach velocity of 8 fps
- Maximum velocity normal to screen of 4 fps
- Maximum fish exposure time on screen of 30 seconds

2.2.2 Hydraulic Criteria

Hydraulic features of the proposed fish passage facilities were also required to meet the hydraulic design criteria and guidance included in the following publications:

- EM 1110-2-1602, "Hydraulic Design of Reservoir Outlet Works"
- EM 1110-2-1601, "Hydraulic Design of Flood Control Channels"
- EM 1110-2-1603, "Hydraulic Design of Spillways"
- USBR Engineering Monograph No. 25, "Hydraulic Design of Stilling Basins and Energy Dissipators"
- "Hydraulic Design Criteria", published by the Waterways Experiment Station
- WES Publication "Prototype Evaluation of Sluiceway Aeration System, Libby Dam, Kootenai River, Montana, " Technical Report HL-84-2 dated March 1984

SECTION 3 PROPOSED PROJECT

3.1 GENERAL

The proposed plan (Plates 29 through 34, Appendix H) is the left abutment intake tower configuration with the floating MIS chamber and fish bypass lock and conduit (Alternate 9A8) based on its combined passage efficiency and cost effectiveness over more costly alternatives requiring new tunnels and much larger tower and screen capacity. During PED the final design of the project will require significant amounts of physical modeling and evaluation The selected alternative generally meets the fish passage criteria specified by the resource agencies except in some specific areas where the FPTC has agreed to a relaxation of the criteria.

3.2 HYDRAULIC DESIGN OF FEATURES

The proposed tower location and alignment is immediately adjacent to the left side of the existing intake tower and trashrack, with the centerline of the new tower angled into the abutment mass. The tower extends from elevation 1035 up to the working deck at elevation 1185, with trashrack from bottom to top similar to the existing flood control tower trashrack. Generally the geometry of the new tower is long and narrow, extending well back into the abutment. The existing spillway approach area access road would be modified to provide access to the elevation 1185 working deck from both the spillway approach area and from the left abutment rim of the reservoir. When the reservoir elevation is above 1160, access to the working deck from the project office would only be available via the existing spillway bridge and left abutment reservoir rim.

In it's proposed location, the fish passage facility is located immediately adjacent to the existing flood control works intake tower, near the upstream end of the spillway approach channel and approximately 400 ft upstream from the spillway crest. The existing spillway was never physically modeled, therefore any effects on the spillway's theoretically computed discharge rating curve resulting from obstruction of the flood control outlet works intake tower are not really known. Theoretical steady state water surface profile computations with the obstructions from the additional fish passage facility features simulated indicate that any effect on the spillway rating relationship would be quite small and within the accuracy of the theoretic equations used to compute the spillway rating. However, this conclusion must be confirmed through use of a physical model (Section 5) to ensure that the resulting spillway discharge relationship with the fish passage facility does not impact dam safety performance of the Howard Hanson project.

The fish passage facility will not be operated during the winter flood season. Winter flood season pool elevations will infrequently (statistically on the order of about once every 80 years) exceed the 1185 foot elevation top of the intake working deck and the air vent shaft entrance. Therefore, the fish passage facility operating equipment, gates, etc., will all be designed to be capable of handling periodic submergence without impacting operational capability. A removable cover will be installed over the air vent entrance at the beginning of the winter flood season to eliminate the potential of water entrance during the winter flood season. The service and emergency gates for the fish passage facility wet well outlet conduit will be positively fixed in a fully closed position during the winter flood season to eliminate any possibility of an uncontrolled loss of reservoir storage via the fish passage facility. During PED, consideration will be given to re-designing the intake tower to raise the air vent entrance, operating equipment and emergency gate above the PMF pool elevation as an alternative to the existing proposed design in order to eliminate the removable air vent entrance cover and the positive closure feature on the gates.

3.2.1 Debris Structure

a. Operating Range

Under the proposed operating rule curve, the reservoir forebay will vary from elevation 1070 to 1177 during the period of operation of the proposed new intake tower. The pool will be lowest at the beginning of operation in March and inflows to the reservoir will be highest. The design operating discharge capacity of the fish passage facility is 400 cfs to 1250 cfs. The facility will operate at discharges as low as 200 cfs and possibly as high as 1650 cfs although it may not meet acceptable fish passage design criteria or desired attraction conditions under such flows. Operating discharges as low as 200 cfs may be required for short times in some years to allow for summer release temperature control via low level operation of the existing bypass pipe in the flood control outlet tower. In some years, flood freshets may occur as late as April. These events may carry substantial volumes of woody debris to the reservoir. Most of this debris should be captured at the existing log boom containment structure upstream of the intake area. Following spring refill, the reservoir should reach elevation 1177 sometime in June. Large woody debris should not reach the trashrack from June until October, during the summer low flow period.

b. Sizing and spacing of trashrack members

Main trashrack support columns will be teardrop shaped to minimize turbulence and vortex formation as well as to limit the acceleration of flow into the intake. Short axis dimension is about 2 feet, while long axis dimension is about 6.5 feet. Columns will be arrayed in a 27.5-foot-radius (to the tail of the teardrop shape) semicircle at about 11 feet on center spacing to provide more uniform approach flow into the entrance. Horizontal support ring beams are provided at 25-foot vertical spacing on center. They will be set back behind the vertical columns and will be about 2 feet in the vertical dimension by about 4 feet deep in the horizontal dimension. The design criteria is to limit the rate of velocity increase to 0.1 feet per second per linear foot along the path of flow. This velocity criteria cannot be maintained in the immediate vicinity of the trashrack columns, but the necessity of some type of woody debris exclusion structure is readily apparent and the FPTC has acknowledged that the criteria must be somewhat relaxed. Clear space between columns will be about 9 feet. The trashrack open area varies from about 1800 sq feet at PE 1070 ft (assuming no debris collector rack) to about 7200 square feet at PE 1177 ft (no debris collector rack). At minimum design flow of 410 cfs, trashrack approach velocity will average about 0.2 fps at PE 1070 ft and less than 0.1 fps at PE 1177 ft. At the maximum design flow of 1250 cfs, trashrack approach velocity will average about 0.8 fps at PE 1070 ft and 0.2 fps at PE 1177 ft. The trashrack column drag coefficient was assumed to be 0.2 and corresponding head loss was determined by assuming losses in a reduced cross section or constriction from the approach area available per trashrack bay to the narrowed section at about the trashrack column longitudinal center point. At low pool (elevation 1070 ft), the area reduction is about 30 percent, with a head loss coefficient of 1.69, while at high pool (elevation 1177 ft), area reduction is about 31 percent, with a head loss coefficient of 1.72 (assuming orifice discharge coefficient of about 1.0). The computed head loss through the trashrack assuming 50 percent blockage of the trashrack by debris and uniform velocity distribution through the entire trashrack is about 0.1 feet at minimum pool elevation. However, flow distribution approaching and through the trashrack will almost certainly not be uniform. Therefore, actual flow and velocity distribution conditions, and subsequently head losses, will be determined by physical scale modeling PED.

c. Floating surface debris collector

During high inflow events or when debris is expected to reach the intake area, a secondary debris collector rack will be deployed between the columns of the trashrack. These individual trashracks will have 12 inch bar spacing and will be floating but restrained in separate guide slots in each column. They will extend to at least 35 feet below the surface of the reservoir while they are deployed. With the debris collector rack in place (assuming 80 percent open area), average velocities through the rack would increase approximately 25 percent above those through the main trashrack structure at all operating conditions. Assuming 50 percent blockage of the floating trashrack, head loss through the trashrack is computed to be about 0.2 feet. When no longer needed, such as during the summer low flow period, the floating trashrack sections will be stored on the working deck of the new intake tower. The necessity for debris exclusion and the limiting criteria for intake flow acceleration rates are at times not compatible. To compensate for this violation of the ideal criteria, the deployable trashracks will need to be kept very clean while in place and the fish collection facility withdrawal flow will be closely monitored to prevent impingement of fish upon the individual bar elements or upon debris trapped against the racks.

3.2.2 Entrance well

Between the trashrack support columns and the collection horn bulkhead panels is an entrance well extending from elevation 1035 ft to 1185 ft, approximately 50 feet wide behind the trashrack, reducing to 22.5 feet wide at the bulkhead panels, and extending 35 feet from the trashrack to the bulkhead panels. This entrance well serves to separate the trashrack from the collection horn by sufficient distance to prevent long slender logs or tree tops from extending through the trashrack into the MIS chamber. It also serves as a flow acceleration section, providing nearly uniform acceleration into the MIS. The length and shape of this entrance does not meet the acceleration criteria under all operating conditions, however. Uncertainty in this design configuration and improvements in hydraulic characteristics cannot be addressed until physical model studies are completed during the PED phase, and only then will the configuration be firmly established.

3.2.3 Bulkhead separator

As presently designed, the MIS chamber wet well is separated from the entrance well and trashrack by a series of stackable, bulkhead panels placed in guide slots in front of the collector horn. These panels are 10 feet in height and about 25 feet wide, with side, top, and bottom seals and smooth rear skins.. The MIS collector horn is designed to seal tightly against the rear surface skin of these panels such that minimal leakage occurs under normal operating conditions of no more than 2 feet of head drop across the seal. Blow out panels will be furnished within the bulkhead sections to insure against catastrophic failure and collapse of the bulkheads in the event of unexpected wet well dewatering. By removing or adding panels as necessary to maintain the wet well elevation within 2 feet of the entrance well elevation, the operating range of the wet well is from water surface elevation 1035 ft to 1177 ft. During PED, consideration will be given to using nearly buoyant, telescoping bulkheads to eliminate the manual operations of the presently designed system as the reservoir elevation fluctuates. With such a system, the retracted bulkheads would be stored in a pit in the bottom of the structure which would require some positive means of keeping debris and sediment out of the pit.

3.2.4 Floating collection horn and MIS

a. Sizing, geometry, operating range

All outflow through the new intake tower will pass through the large collector horn located immediately behind the bulkhead separator panels. The mouth of the collector horn will be of a bellmouth shape, about 25 feet wide by 20 feet high which results in an entrance velocity range of 0.8 fps to 2.5 fps for the design discharge range of 410 to 1250 cfs, respectively. The entrance will be the Corps of Engineers short bellmouth-shaped entrance (EM1110-2-1602). This geometry will not meet the maximum linear velocity increase criteria. However, due to the very large size of the horn that would be required to meet the criteria, and the great difficulty of meeting the same criteria because of the influence of the trashrack, the horn entrance is designed to provide a uniform velocity of approach rather than a uniform acceleration of velocity through the horn. The collector horn and MIS housing are suspended from a pontoon float in the wet well which allows the housing to move with the reservoir and held in position below the pontoon by a locking vertical positioning assembly. Submergence depth to the centerline of the horn below the pool surface is physically set in position by means of this locking positioning assembly and is typically about 15 feet.

The computed rate of increase in velocity from the trashrack to the horn mouth at PE 1070 ft is about 0.02 to 0.06 fps/linear ft with discharges of 410 cfs and 1250 cfs, respectively. The rate of increase in velocity at PE 1177 ft is about 0.03 fps/linear ft to about 0.1 fps/linear ft at discharges of 410 cfs and 1250 cfs, respectively. However, these computed values assume uniform approach flow into the trashrack and collection horn. Verification of approach velocity conditions will require physical scale model study data. The rate of increase in velocity within the approximately 25-foot long intake horn itself varies from about 0.07 fps/ft at 410 cfs to about 0.18 fps/ft at 1000 cfs, and to about 0.2 fps/ft at 1250 cfs. The velocity increase criteria (0.1 fps/linear ft) is met only for flows up to about 560 cfs due to the practical limitations to horn length required to fully meet the criteria. This limitation in meeting criteria is considered acceptable by the FPTC based on the presumption that since the fish were already essentially trapped behind the trashrack they would not avoid the collection horn.

b. MIS Chamber

The downstream end of the collector horn is fixed to a chamber about 30 feet long, 16 feet wide, and 10 feet high, containing a rectangular MIS. The screens are approximately 31.5 feet long and inclined about a horizontal axis from front to rear at an angle of about 16 degrees. Screen composition is typically wedge wire or bar arranged either perpendicular to flow or parallel to flow, and have shown excellent survival results for anadromous juvenile fish (Reference No. 3). Rotation about a central pivot point provides capability for self cleaning of the screen. The screen assembly rotates to a declining position and debris is flushed by the reverse flow through the screen structure. Under normal operating conditions, fish are swept up to the center top section of the screen and into a 2-foot by 2-foot bypass entrance leading to a 24-inch-diameter low pressure bypass conduit. Screen rotation capability is provided by a dual hydraulic cylinder arrangement on top of the screen chamber itself. To accommodate the criteria of providing for access to the MIS chamber under all operating conditions, a short access shaft will be provided to a viewing window in the top of the chamber.

At discharges of 410 cfs to 1250 cfs screen approach velocities vary from 2.6 fps to 7.8 fps, respectively. Maximum approach velocity at 1600 cfs is 10 fps (outside the design criteria). Operation of the fish passage facility will be limited to result in screen approach velocity of less than 7.8 fps unless prototype operation proves that higher velocities will not result in unacceptable injury rates of fish. At discharges of 410 cfs to 1250 cfs, fish exposure time on the screen varies from about 12 seconds to 3 seconds, respectively. At a discharge of 200 cfs, fish exposure time on the screen is about 25 seconds. Screen area when in the screening position is about 410 square feet, resulting in a normal velocity (beyond the near-screen orifice effects) of from 1 fps at 410 cfs to about 3.0 fps at 1250 cfs and about 3.9 fps at 1600 cfs. Head loss through the screen was assumed to be about the same as that measured at the Puntledge Eicher screen (References No. 8 and No. 9) and Elwha Eicher screen (Reference No. 10) installations. While in the screening position, head loss from the screen itself should not exceed about 0.5 foot, and when debris accumulation results in head loss greater than about 2.0 feet, the screen will automatically rotate to the flushing position. The computed total headloss from just upstream of the collector horn to the entrance to the fish bypass pipe at the downstream end of the MIS is 0.7 feet with a discharge of 1650 cfs assuming a horn entrance loss coefficient of 0.05, a loss through the screen of 0.5 ft and Manning roughness coefficients of 0.01 and 0.02 for the portion of the chamber upstream of the screen and along the screen, respectively. When combined with the trashrack loss, a head drop of about 1 foot will exist from reservoir elevation to water level in the MIS chamber wet-well. Screen area when in the flushing position is about 496 square feet, resulting in back flushing velocities of from 0.8 fps at 410 cfs, to about 2.5 fps at 1250 cfs.

During screen cleaning operation the small type debris which will be deposited on the screen will be flushed into the wet well chamber. The present plan to remove this debris is to lower the water level in the wet well by increasing discharges out of the outlet conduit or bypass to a level where the submergence on the outlet entrance is small enough to allow the debris to be drawn into the outlet entrance and then through the outlet itself. During PED, consideration will be given to developing some provisions to prevent the debris flushed from the MIS during the cleaning operations from entering into the wet well chamber.

c. Fish bypass

A 24-inch by 24-inch entrance near the top downstream end of the MIS delivers fish and a small percentage of the total intake flow into an approximately 20 ft long, 24 inch-diameter bypass conduit which leads to the fish holding lock. A gate located in the bypass conduit will be operated either in a fully closed or fully open position. The gate will be fully open when fish are being bypassed into the lock chamber and will be fully closed when the lock chamber is being lowered to discharge the fish out of the lock chamber. Operating capacity of the fish bypass entrance section is from about 10 cfs to about 30 cfs, roughly proportional to 2.5 percent of the total attraction flow into the MIS screen chamber under all operating conditions. Entrance velocity is about 2.5 fps to about 7.8 fps with flows of 10 cfs and 30 cfs, respectively. This entrance velocity is dependent upon the net head on the bypass exit section in the fish lock with respect to the entrance well water surface elevation.

Transition from the 24-inch square section to 24-inch-diameter conduit is accomplished within a short length of conduit immediately downstream of the bypass entrance. Two vertical, 90 degree bends carry the bypass conduit up to near the wet well surface before passing straight through a bulkhead slot into the fish lock. Capture velocity of 5 fps minimum is maintained at the entrance section under most operating conditions. Under very low flow conditions, entrance velocity may fall below the 5 fps minimum unless bypass entrance acceleration criteria is violated. Bypass entrance velocity and bypass flow is controlled by the depth of submergence of the bypass exit section within the lock pool and the depth of submergence of the intake collection horn.

Velocity through the 24-inch-diameter bypass conduit ranges from 3.2 fps at an attraction flow of 410 cfs to 10 fps at an attraction flow of 1250 cfs. Minimum bend radius in the bypass pipe is 7 feet (3.5 diameters to compensate for the high velocity) to meet the criteria. Bypass flows normally enter the fish lock as a slightly submerged jet or plunge a short distance to the lock water surface. Plunge distance is controlled by the fish lock bleed off weir setting, but does not exceed about 6 to 8 feet. The elevation of the bypass exit section above the MIS chamber is fixed. Thus, deeper submergence of the MIS and collector horn would require submergence of the bypass exit section in the fish lock if bypass flow was to remain constant.

The computed head loss through the 20-ft long fish bypass pipe is 2.1 feet at a discharge of 30 cfs assuming a pipe Manning roughness coefficient of 0.01, a square-to-round transition (contraction) loss coefficient of 0.05, a loss coefficient of 0.3 for the back-to-back 90 degree bends and a full velocity head exit loss. The total computed headloss between the reservoir and the fish bypass conduit exit (or the water level in the fish lock if the exit is submerged) is about 3 feet at maximum attraction flow design discharge 1250 cfs.

3.2.5 Wet well

a. General

The MIS chamber and collector horn float inside a large open chamber extending from a floor elevation of 1035 ft to elevation 1185 ft. The wet well will be covered with a removable working deck and be provided with man access ladders and/or lifts to the water surface and MIS under all operating conditions. Guide slots in the walls carry the collector horn pontoon float and MIS chamber assembly up and down throughout the operating range of the wet well. Under normal operating conditions, less than two feet of head differential between the entrance well and the wet well will occur. As discussed above, the wet well is separated from the entrance well by stacking bulkhead panels. During periods when outflow exceeds 500 cfs, wet well discharge is passed through a floor-level outlet conduit controlled by a 5.5-foot-wide by 7-foot-high radial gate. Low flows will be controlled by the existing 48-inch-diameter bypass conduit and slide gate which will be connected to the wet well chamber through a separate opening.

b. Wet well outlet conduit

A 5.5-foot wide by 10-foot high open channel conduit extends from the wet well, exiting into the existing flood control tunnel just downstream of the tunnel splitter wall. This conduit would be operated when project releases are in excess of about 500 cfs.
To provide for adequate flushing of the wet well during maintenance periods, the outlet invert elevation would be the same as the wet well floor elevation of 1035 ft.
The wet well outlet entrance is shaped in accordance with the 'short' sluice entrance geometry described in EM 1110-2-1602. The entrance control opening is 5.5 ft by 7 ft which provides a discharge capacity of about 1620 cfs at minimum pool elevation 1070 feet assuming an entrance orifice coefficient of 0.95 and a 1 foot head loss through the collector horn and MIS. Theoretical computation of water surface profiles downstream of the gate assuming a Manning roughness of 0.013 indicated that the flow regime should remain open channel through the 0.005 ft/ft sloping conduit between the control gate and the exit into the flood control tunnel. Based on criteria presented by Plate C-35 of EM 1110-2-1602, vortexes may occur within the wet well chamber when pool elevations are less than about 1086 feet if the facility is operating at attraction discharge of 1650 cfs. Vortexes within the wet-well will probably be detrimental to satisfactory operation of the MIS. Therefore, unless some vortex prevention appurtenances can be developed through the physical model studies, the discharge capacity of the facility may need to be limited to about 1000 cfs at minimum pool elevation 1070 feet and not operated at the full design capacity of 1250 cfs until the pool elevation exceeds about 1080 feet.

Physical model studies during PED will be used to ensure that open channel flow exists in the outlet conduit for all flows and that the final design of the outlet conduit entrance results in hydraulic conditions within the wet well structure stable enough (i.e., no significant turbulence, vortexes, etc.) to not effect satisfactory operation of the MIS.

A 5.5 foot by 7 foot standard radial-type gate will be used to provide conduit flow control because of its suitability for a moderate head outlet and the historical reliability of the radial gate design at other Seattle District projects. Upstream gate location and open channel flow was selected over downstream gate location and a smaller pressure conduit primarily because of gate control chamber access concerns. Maximum velocity at the gate would not exceed 100 fps under operating conditions. The gate chamber must be fully accessible under all wet well operating conditions, and the downstream control location would not reliably meet this requirement. Air demand to the conduit downstream from the gate will be provided by an air shaft exiting into the conduit downstream of the gate. The air vent entrance will be at about elevation 1185 feet, therefore a removable cover will be provided to seal off the entrance throughout the winter flood season when the fish passage facility is not operational. Alignment of the outlet conduit between the wet well and the existing flood control tunnel as shown in this report will be revised during PED to eliminate the flow disturbances and non-uniform loading on the control gate (i.e., eliminate the horizontal curve immediately upstream of the gate) which would result with the presently proposed design.

A 6.5-foot by 7.5-foot hydraulically operated tractor-type emergency gate will be provided just upstream of the radial control gate to provide emergency closure capability. Maximum velocities in the vicinity of the emergency gate slots will not exceed about 40 fps under radial gate control operation. In accordance with guidance contained in EM 1110-2-1602, a separate air shaft is not required for the emergency gate. With the present design configuration, the emergency gate will be operational only when the pool elevation is below about 1185 feet. Therefore, during the winter flood season the emergency gate will be lowered and positively fixed in the closed position to prevent any potential of an uncontrolled release of water via the fish passage facility.

During PED, consideration will be given to re-designing the intake tower to raise the air vent entrance and emergency gate above the PMF pool elevation as an alternative to the existing proposed design in order to eliminate the need for a removable air vent entrance cover and the positive closure feature on the gates.

c. Conduit exit into existing flood control tunnel

The wet well outlet conduit will enter the existing flood control tunnel just downstream of the existing tunnel divider, or splitter wall at an invert elevation of about 1034.5 feet. Review of flood control tunnel water surface profiles as documented in the physical scale model studies conducted for the original flood control outlet works showed that at this location the invert of the wet well outlet conduit would be above the water surface in the flood control tunnel under normal flood control tunnel operating conditions with discharges up to the maximum regulated flood control release of 12,000 cfs. The potential for cavitation damage to the tunnel wall in the vicinity of offsets in boundary surfaces has been well documented, and Seattle District's experiences with cavitation damage resulting from surface irregularities and offsets at other projects led to the decision to keep the wet-well conduit exit opening above the water surface elevation in the flood control tunnel
A short radius horizontal curve of slightly smaller outer wall radius than inner wall radius in the vicinity of the connection would help to deflect the issuing jet downstream in the tunnel instead of directly impacting the opposite wall. Physical model studies during PED will be used in final design of the confluence and to develop any necessary measures to prevent damage to the flood control tunnel walls from flow exiting from the fish passage facility outlet conduit

d. Low flow bypass

A separate 48-inch-diameter low flow bypass pipe would be provided from the wet well wall to operate during the summer low flow period when project releases are less than about 500 cfs. The 48 inch pipe would parallel the wet well outlet conduit as far as the existing flood control tunnel and connect to the existing 48-inch bypass pipe beneath the floor of the flood control tunnel. The present drawings in the feasibility report depict two 90 degree bends in this pipe near it's downstream end—these bends will be revised to 45 degree bends during PED. A "short" bellmouth entrance shape would be provided at the wet well wall entrance to the 48 inch bypass. A positive closure bulkhead for the existing 48 inch bypass entrance in the existing intake structure would be placed each season prior to the pool filling above the elevation of the existing working deck. This bulkhead would be necessary to prevent additional withdrawal of reservoir outflow into the existing 48 inch bypass entrance during operation. During PED, consideration will be given to use of a hydraulically controlled closure gate in lieu of the manually operated bulkhead to minimize maintenance labor.

Control of the bypass pipe flows would remain at the existing downstream slide gate at the flood control bypass pipe bypass exit near the downstream toe of the dam. Capacity of the 48 inch bypass was estimated to be about 550 cfs at pool elevation 1178 based on existing rating curves developed from observed data and extrapolated to pool elevation 1178.

3.2.6 Fish lock

a. Bypass bulkhead

The wet well is separated from the fish lock by stackable bulkhead panels about 30 inches wide and 10 feet long. The fish bypass conduit is fixed to a top panel which seals against the stackable bulkhead panels such that the bypass can slide up and down the wet well side of the narrow bulkhead panels as necessary to adjust to the changing wet well elevation. Bypass flows jet out at low head from the bypass exit section into the fish lock over the top of the top bulkhead panel. As the wet well elevation rises or falls with changes in operation, bulkhead panels are removed or added as necessary to bring the fish lock water surface to near the wet well water surface. Under normal operating conditions, the head differential across the bulkhead panels is less than 1 foot. However, when the fish lock is discharged (up to several times each day) to flush collected fish downstream, the panels must withstand as much as 143 feet of full head from the wet well. As with the bulkheads on the upstream end of the wet well, PED design will consider the use of telescoping, nearly buoyant bulkheads instead of the presently envisioned stackable design concept to eliminate the manual operations required with the stacked concept..

b. Lock chamber

The fish lock chamber is a large 30-foot-long by 24-foot-wide open chamber similar to the wet well, extending from an inclined floor screen at elevation 1050 ft up to the working deck at elevation 1185 ft. The working deck can be removed for access to the lock chamber and equipment. Access ladders and/or lifts would be provided for access under all operating conditions. The lock chamber may need to be partitioned by a secondary screen with openings large enough to provide an avenue of escape for the smallest of migrating anadromous fish from possible predation by larger smolts when the two are both present in the chamber volume. This will be further considered during PED. If a screened partition is deemed necessary, separate fish bypass pipe entrances will be provided on both sides of the screen. Refinement of the proposed operation of the lock chamber and of the requirements for escape cover will be investigated more fully during PED. Maximum volume of the lock chamber (at reservoir elevation 1177 ft) above the floor screen is about 90,000 cubic feet. Minimum volume at reservoir elevation 1070 ft is about 14,000 cubic feet. Lock chamber volume was determined by assuming that 10 percent of the total estimated migration of 2 million fish arrive at the intake within an 8 hour period, and that the lock must hold all these fish for the full 8 hours. Using data from Milo Bell's Fisheries Handbook (Reference No. 4), the minimum holding chamber volume must be at least sufficient for holding 200,000 fish (at 5 fish/lb), or about 90000 cubic feet. Width, length, and depth of the minimum lock chamber volume was checked against the minimum volume required for energy dissipation in fish holding chambers, and was also checked against jet decay requirements under maximum discharge conditions. Minimum volume for turbulence dissipation of 40 cfs plunging 6 feet (26.6 fps entrance velocity) based on the $[4\,ft-lbs/\sec / ft^3]$ criteria is about 13,700 cubic feet. Jet decay distance was not a criteria, but a decay in velocity to 0.1 fps was assumed necessary before any hard surface such as a wall was encountered by the jet. Therefore, based on the equation:

$$\frac{V_z}{V_{z\,max}} = \frac{1}{[1+r^2/(.016z^2)]^2}$$

from Daily and Harleman, pg 421 (Reference No. 5) with a radius of 12 feet (1/2 the 24-foot lock width), an initial velocity of $V_{z\,max} = 12.73$ fps, and a desired decay to $V_z = 0.1$ fps, a chamber about 30 feet long is required.

c. Lock chamber drain and underdrain floor screen

The lock chamber water level is lowered to an elevation where the fish bypass conduit can be opened to safely pass fish by a 24-inch-diameter floor drain conduit. The entrance to the drain conduit is separated from the upper portions of the chamber by a wedge wire or profile bar screen at about elevation 1052 to prevent fish from entering into the drain conduit. Directional louvers or variable porosity plate would be required below the floor screen to insure uniform approach velocity to all areas of the floor screen. The drain conduit discharge will be controlled by a valve to control the water level in the lock chamber when the lock is full and the MIS bypass system is feeding water into the lock chamber.

The floor screen has a surface area of 720 ft^2. The computed discharge capacity for the 24-inch drain conduit flowing full, with lock chamber elevation 1177 ft and exit section elevation 1025 ft, is about 110 cfs as computed using the Darcy-Weisbach equation: $headloss_{friction} = f\frac{LV^2}{D2g}$, where f =0.011 to 0.013 for steel, and L = 1100 ft. Assuming a uniform flow distribution across the screen, the average velocity through the screen is about 0.15 fps which is well below the maximum screen velocity criteria of 0.4 fps.

d. Operation During Lock Operation

During the short time period when the lock chamber is being lowered to discharge fish, the gate in the MIS bypass pipe which feeds the lock chamber will be closed and all water entering the MIS chamber will be passed through the MIS and into the wet well. During this time period, any fish entering the MIS chamber will be held up in the MIS chamber until the lock chamber is re-filled and the MIS bypass pipe gate is re-opened to allow the fish to enter the lock chamber.

e. Fish bypass conduit entrance and gate

The entrance to the fish bypass conduit is 2-ft diameter and located at about elevation 1055 ft, just above the floor screen separating the lock chamber drain conduit entrance from the fish bypass conduit entrance. A fast action knife gate in the fish bypass conduit entrance section will be opened to release fish and small debris from the lock chamber into the fish bypass conduit when the lock chamber water level drops to less than 15 feet (e.g., maximum velocity of about 30 fps to meet fish passage criteria) above the conduit entrance during the drain cycle. The entrance size will limit the discharge through the fish bypass conduit to about 90 cfs. The floor screen is slightly inclined toward the fish flush knife gate to insure complete evacuation of the lock chamber. Fish capture velocity and flow acceleration criteria is not an issue at this entrance because the entrance will provide the fish the only means of egress from the lock chamber. A constant flushing flow will be fed into the lock chamber via the lock refill valve (see paragraph g) to flush the chamber of any fish remaining at the end of the fish lockage operation. At the present time, the potential for fish to attempt to hold in the wet well chamber instead of entering the fish bypass pipe is considered to be small. However, some disagreement remains on this issue, therefore more consideration will be given this issue during PED. If considered necessary, some physical device such as a fish crowder could be provided to positively move the remaining fish into the bypass entrance. The entrance shape for the fish bypass conduit is based on EM 1110-2-1602 for bellmouth entrances, using the 'long' bellmouth coordinate geometry. The 'long' entrance geometry was selected for no other reason than to smooth the exit conditions into the fish transportation conduit.

f. Fish bypass conduit

Fish will be passed from the lock chamber to a location downstream of the dam in a HDPE conduit from the fish bypass entrance gate through the dam abutment parallel with and adjacent to the wet well outlet conduit. From the confluence point of the wet well outlet sluice and the existing flood control tunnel, the fish bypass conduit is suspended from the flood control tunnel ceiling centerline. Minimum slope of the conduit is 0.01863 which conforms to the slope of the existing flood control tunnel ceiling from which the conduit will be suspended. Although the present design calls for a 24-inch conduit, a conduit comparable in size to 36-inches diameter is required to ensure that open channel flow conditions will exist in the bypass conduit throughout fish release operations. Assuming a Manning roughness of 0.011 for HDPE and a 36-inch diameter conduit, a discharge of at least 15 cfs is required in the bypass conduit to provide the minimum flow depth of 9 inches specified by fisheries criteria. The flow velocity with the minimum discharge condition is about 11 fps. This minimum discharge will be maintained by the setting of the lock refill valve during the fish flush period following lock draining to ensure that the bypass conduit minimum depth criteria is not violated. At the minimum discharge condition (15 cfs), the water elevation in the lock chamber will be about 1.7 ft above the invert elevation of the fish bypass entrance. Open channel flow (assuming a water depth to conduit diameter ratio of 0.7) would exist in a 36-inch diameter HDPE conduit, if it is properly vented throughout its length, for discharges as high as about 90 cfs which is the maximum flow possible through the fish bypass conduit entrance section. Horizontal bends in the conduit will need to have long radii to eliminate potential for spiraling flow and subsequent shift of flow regime from open channel to pipe control .

Physical model studies accomplished for design of the flood control tunnel indicate that the water surface profile in the flood control tunnel will not impinge on the fish passage conduit for flows at least as large as 10,000 cfs, but flow will spiral to the tunnel roofline at discharges of 20,000 cfs and probably less. Therefore. PED will consider the feasibility of embedding the fish passage conduit in the wall of the concrete flood control study.

As presently designed, the fish bypass conduit and the lock drain conduit are connected just downstream from the lock chamber. However, during PED design a sole-purpose fish bypass conduit will be provided to eliminate the potential of fish damage at the confluences presented with the present design concept. At the existing flood control tunnel outlet portal the fish bypass conduit bends to follow the right wall of the stilling basin a short distance to a free fall outlet section into the deep portion of the stilling basin. PED design will also modify the proposed design to extend the fish bypass conduit to a suitable, "fish-friendly" location downstream from the stilling basin as releasing fish into the stilling basin will likely create a situation of high fish mortality. A simplified fish evaluation facility will be constructed near the outfall of the release conduit to capture and assess condition of fish upon exiting the passage system.

g. Lock refill system

A 24-inch-diameter refill valve in the wall of the lock chamber above the floor screen draws from the wet well to flush the lock of remaining fish and refills the chamber after the knife gate closes. Refill rate is controlled to prevent undesirable effects upon or damage to the lock chamber floor screen.

3.2.7 Attenuation chamber

An attenuation chamber with total volume of about 90,000 cubic feet (about the same as the lock chamber) is provided on the right bank of the river just downstream of the existing stilling basin. Lock drain discharge is passed through the fish release conduit and into the attenuation chamber to eliminate river flow surges during low flow periods. Maximum head within the attenuation chamber is limited to less than about 25 feet, and outflow is provided by a low head uncontrolled orifice. A shunting gate in the fish release conduit is provided just upstream of the attenuation chamber to discharge fish into the existing stilling basin when the fish release gate is opened. During PED, studies to determine the natural flow attenuation in the river channel between HAH and the Tacoma headworks (about 3 miles) will be accomplished to determine whether the attenuation chamber can be eliminated.

The invert of the chamber will be at about elevation 1018 ft, with an uncontrolled orifice outflow. Fish lock chamber drain time was estimated by routing the drain flow rate through the conduit and into the attenuation chamber. Orifice size (about 12 inches) and attenuation chamber depth (about 10 feet) was optimized roughly to minimize downstream flow surges to less than about 15 cfs during low flow periods. Surges less than about 15 cfs were thought by the FPTC to attenuate within the reach between Howard Hanson Dam and the Tacoma water diversion dam 3.2 miles downstream and to have insignificant downstream impacts. Based on the results of this analysis, the lock drain-flush-refill cycle would be about 40 minutes, while the attenuation chamber filling-emptying cycle would take about 3 hours.

SECTION 4 CONSTRUCTION CONSIDERATIONS

4.1 DIVERSION DURING CONSTRUCTION

The construction cofferdam will be a steel-walled structure tied to, and extending upstream from, the left (looking downstream) wall of the existing flood control outlet works intake tower. The cofferdam is located such that unlimited use of the existing flood control and low flow bypass facilities will be retained and no additional diversion features will be required. The top of the cofferdam is at elevation 1150 ft which provides 4 ft of freeboard above the highest summer pool reached at the project and protection from winter floods have recurrence intervals slightly less than 10 years. A review of historic pool elevations reveals that only in five years over the 35 year time period since HAH has been in operation has the pool exceeded elevation 1150 during the winter flood season. During these five years, six separate flood events have caused the pool to exceed elevation 1150 ft for durations on the order of four days (each event). Therefore, with a cofferdam top elevation of 1150 ft, construction of the structure can proceed behind the cofferdam essentially year around.

The wet well outlet conduit connection to the existing flood control tunnel will be performed during the summer low flow period with a construction window extending from about the end of June to the first of October. Project outflows during that period will be through the existing 48-inch-diameter bypass conduit. The 48-inch bypass pipe from the wet-well will be connected to the existing bypass pipe located under the floor of the flood control outlet tunnel during the summer low flow season when releases are on the order of 200 cfs. During this period, project outflows will be via the left hand entrance and side of the flood control tunnel. The bypass pipe connection will be located where the existing bypass pipe runs under the right hand side of the tunnel but downstream from the splitter wall. Therefore, a low height wall will be constructed downstream from the end of the splitter wall to permit construction of the bypass pipe connection when water is passing through the left hand side of the flood control tunnel.

Construction of the attenuation chamber downstream of the dam and associated fish evaluation and release facilities could be constructed at any time, regardless of most project outflow conditions.

A more detailed description and discussion of the cofferdam design is presented in Appendix A, "Design". The construction schedule and sequencing is discussed in Appendix C, "Construction Cost Estimate."

SECTION 5 HYDRAULIC MODEL STUDIES

A physical model program will be developed during PED to assist in final design of the fish passage structure. The existing spillway was not model studied prior to it's construction and the flood control outlet works intake tower is located at the upstream end of the spillway approach channel. The effect of additional obstructions in the approach channel resulting from construction of the fish passage facility immediately adjacent to the flood control outlet works intake tower needs to be evaluated to ensure that the project's ability to pass the spillway design flood with an acceptable pool elevation has not been compromised. A general, 1 to 50 scale physical model of the spillway, spillway approach and upstream forebay is proposed to evaluate the existing and with fish passage facility spillway flow capacity. Additionally, this model will be used to determine approach flow characteristics into the proposed fish bypass intake structure for both hydraulic efficiency and acceleration patterns into the trashrack and collection horn.

A separate, 1 to 25 scale model of the MIS wet well chamber, outlet conduit and approximately 200 foot length of the upstream end of the existing flood control tunnel from it's entrance to downstream from the fish passage structure outlet conduit confluence is proposed for final design of the wet well conduit confluence with the existing flood control tunnel and to evaluate flow conditions within the wet well chamber and the wet well chamber outlet conduit. A third separate model, at a scale of 1 to 8, is proposed to evaluate the detailed hydraulic flow conditions, velocities, and losses on and immediately adjacent to the MIS and fish bypass entrance transition and develop the preferred geometry for lowest fish mortality. Information from this model is required to provide sufficient localized hydraulic characteristic data to alleviate agency concerns regarding acceptability of this type of screen to operate with low fish mortality.

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APPENDIX D, Hydrology & Hydraulics
Part D3, Water Quality

Additional Water Storage Project, Draft Feasibility Report & EIS

Howard Hanson Dam,
Green River, Washington
April 1998

prepared by
Seattle District

US Army Corps of Engineers®

APPENDIX D
HYDROLOGY AND HYDRAULICS
PART 3 — WATER QUALITY

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PREFACE

This water quality narrative is compiled from the two reports of separate analyses of temperature and turbidity as influenced by the Howard Hanson Dam Additional Water Storage Project. Temperature is discussed Section 1, followed by turbidity in Section 2. Sections 3 through 6 are graphs of reservoir outflow temperature as described in Section 1.

SECTION 1 TEMPERATURE ANALYSIS

1.1 PURPOSE AND SCOPE OF STUDY

The purpose of this temperature analysis is to examine changes in the thermal budget of the reservoir and the Green River below the project that would result from the raised summertime conservation storage. The goal is to develop a target temperature regime that benefits the river downstream of the dam and that the simulated years can meet with some degree of reliability.

Reservoir release temperatures modeled for the proposed additional storage project are compared with historic outflow temperatures. For the additional storage project, two designs are considered: 1) the existing tower with no modification; and 2) the existing tower with a selective withdrawal structure added. The selective withdrawal structure is also referred to as the "upper port" or "fish gulper."

This analysis follows that used in a previous report by Schneider and Price (1988). The thermal budget model is the WESTEX one-dimensional, numerical model with modifications intended to mimic the unique design of the "preferred" alternative identified in 1994. To determine the uncertainty of meeting various temperature goals of the reservoir outflow, the additional storage project was simulated using 33 years of inflows and outflows. The results of simulations using 1992 weather and flows are discussed in detail. The summer of 1992 was chosen for more detailed examination because of its dry, warm weather. That summer represents a challenging set of weather conditions in which to attempt to meet cooler temperature targets.

The analysis of downstream river temperature used a simple, one-dimensional, stream heating model that took into account daily average equilibrium temperature, initial temperature, coefficient of heat exchange, and travel time. Downstream temperature data from 1992 was available for this analysis.

1.2 MATHEMATICAL METHODOLOGY

The WESTEX model is a one-dimensional, thermal simulation, numerical model. A detailed description of it may be found in Schneider and Price (1988) and Holland (1982). This study used a version of the model calibrated for Howard Hanson Reservoir in a previous study by Schneider and Price (1988). Modifications of the model to meet the unique design of the preferred alternative were made by Schneider (1995).

1.2.1 Model Input

The WESTEX model required input data on the physical, meteorological, and hydrologic characteristics of the reservoir. The physical characteristics included geographical information, the elevation-storage relationship and outlet locations.

Meteorological data (average daily values for wet and dry bulb temperatures, wind speed, and cloud cover) were supplied by the National Weather Service. The HEATEX program (Eiker 1977) was used to convert these parameters to equilibrium temperatures, surface heat exchange coefficients, and daily average solar radiation quantities for the 33 years of study, 1962-1994.

The model required average daily values for hydrologic data. Daily inflows were available since the beginning of operation of the project. Average weekly outflows were simulated using an HEC-5 model as part of the larger additional storage project studies. The average weekly outflows were converted to daily values. During winter and spring periods when flow changes are made on a daily or even hourly basis, this is an unrealistic assumption of the reservoir's outflow. However, during the conservation period when the reservoir is thermally stratified, these average weekly values would be similar to reservoir operation on a daily basis. To maintain a daily mass balance of water in the reservoir, the simulated outflows were adjusted using the change of storage equation and the proposed water surface elevation.

The temperature of the inflow was not available for the entire period of project operation. During recent years, project personnel measured the temperature of the inflow once each day except for weekend and holidays. These data (2500 measurements) were used to determine a linear relationship ($\mathbf{R}^2 = 0.84$) of inflow rate and air temperature to inflow temperature. A 33-year time series of daily average inflow temperature was developed using this linear equation:

$$\text{inflow temp}(°\text{F}) = 0.531*\text{air temp}(°\text{F}) - 6.285*\log_{10}(\text{inflow}) + 36.37$$

1.2.2 Model Output

The model predicted an average daily reservoir release temperature for each day of simulation. For the purposes of this study, the period between 1 April and 31 October for each of the 33 years is examined.

1.3 MODEL PERFORMANCE

The performance of the model was examined by simulating the existing reservoir operation for the years for which outflow temperature is known. Hourly outflow temperature monitoring at the tailwater gauge 0.7 mile below the dam began in March 1991. The results of the model showed poor correlation with this observed data. However, when compared with observed temperature profiles of the reservoir, the modeled release temperatures matched the observed temperatures at the withdrawal point of the forebay. It appears that warming of the tailwater can occur in the 0.7-mile reach between the dam and the temperature gauge. Subsequent temperature measurements collected at the dam outfall and at the downstream temperature gauge show the water warming 1.1°F in that reach on a sunny (85°F) day with low flow (230cfs). In summary, the model performed well by matching the expected outflow temperatures (determined by historic forebay temperature profiles) to within 1 degree Fahrenheit.

1.4 EXISTING RESERVOIR OPERATION

The reservoir currently has outlets at two elevations. The larger flow, flood control outlets are located at the lowest elevation of the reservoir, 1035 feet MSL, and pull water from the lowest and coldest location. The low flow outlet at 1069 feet is used during late spring and the summer conservation period when outflows are below 500cfs. This outlet, often referred to as the 48-inch bypass, withdraws water close to the same temperature as the bottom outlet.

The current practice of withdrawing water from close to the bottom of the reservoir results in early use of cold water and an accelerated lowering of the thermocline. The reservoir eventually runs out of cold water, usually in August, and releases water that has been nearer to the surface all summer absorbing and storing heat from the sun. A typical graph of release temperature between 1 April and 31 October is given in Figure 1. The release temperature is colder than the inflow temperature until the end of June. By mid-August, the reservoir releases water significantly warmer than the inflow until autumn rains bring colder inflow. In years when autumn rains arrive late in the season, the reservoir releases very warm water into October. Temperature graphs for 1991-94 are in Section 3 of this report.

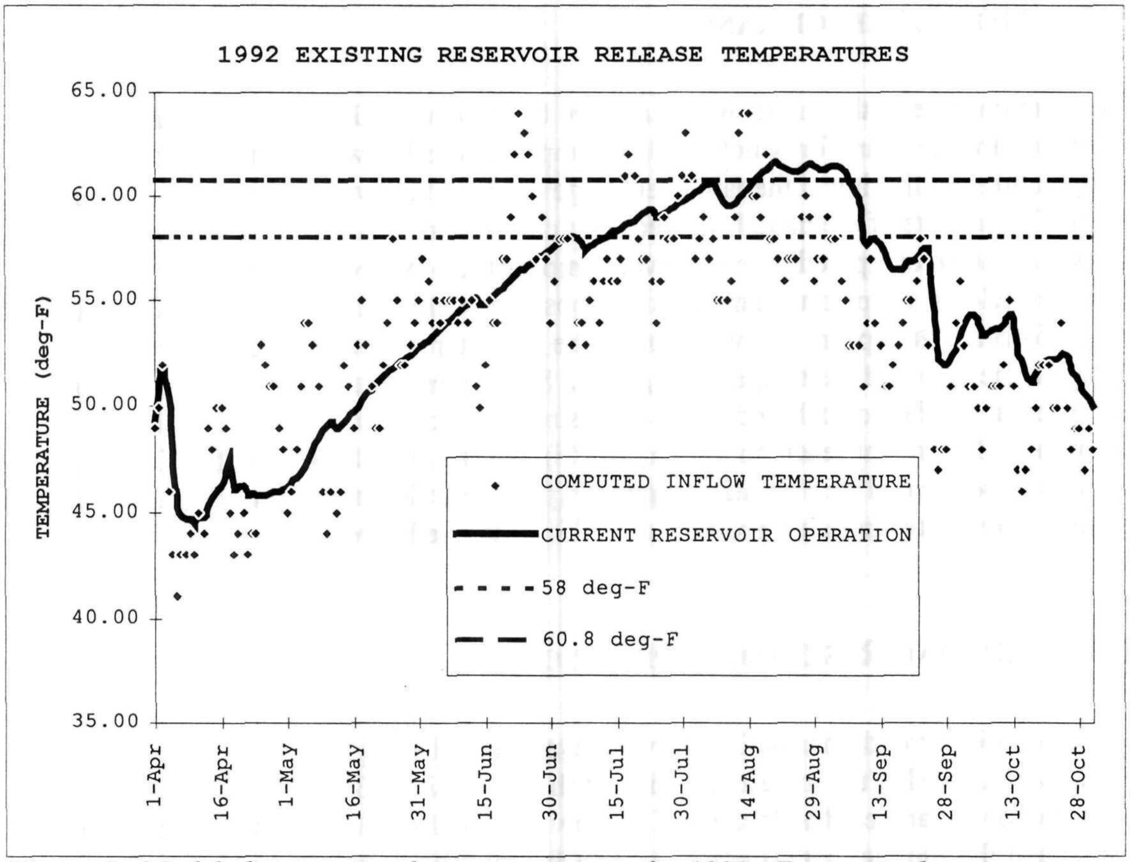


Figure 1. Modeled reservoir release temperature for 1992. Two critical temperature limits are shown: 58°F is a critical temperature for steelhead trout and 60.8°F is the Washington State standard applicable to this section of the Green River.

1.4 ADDITIONAL STORAGE SIMULATIONS

1.4.1 Existing Outlets - Deep Withdrawal

The additional storage project was modeled with the existing outlets in order to show the potential value of the preferred alternative selective withdrawal design. The results (Section 4 of this report) show the same pattern as for the existing reservoir operation. The most important difference is that the earlier refill period and the increased water surface elevation allow for more heat absorption and a more highly developed thermocline. The late spring releases would be even colder than under the current operation, and the autumn releases would be even warmer. Figure 2 compares the current operation of the reservoir with the additional storage flows routed through the existing outlets for 1992.

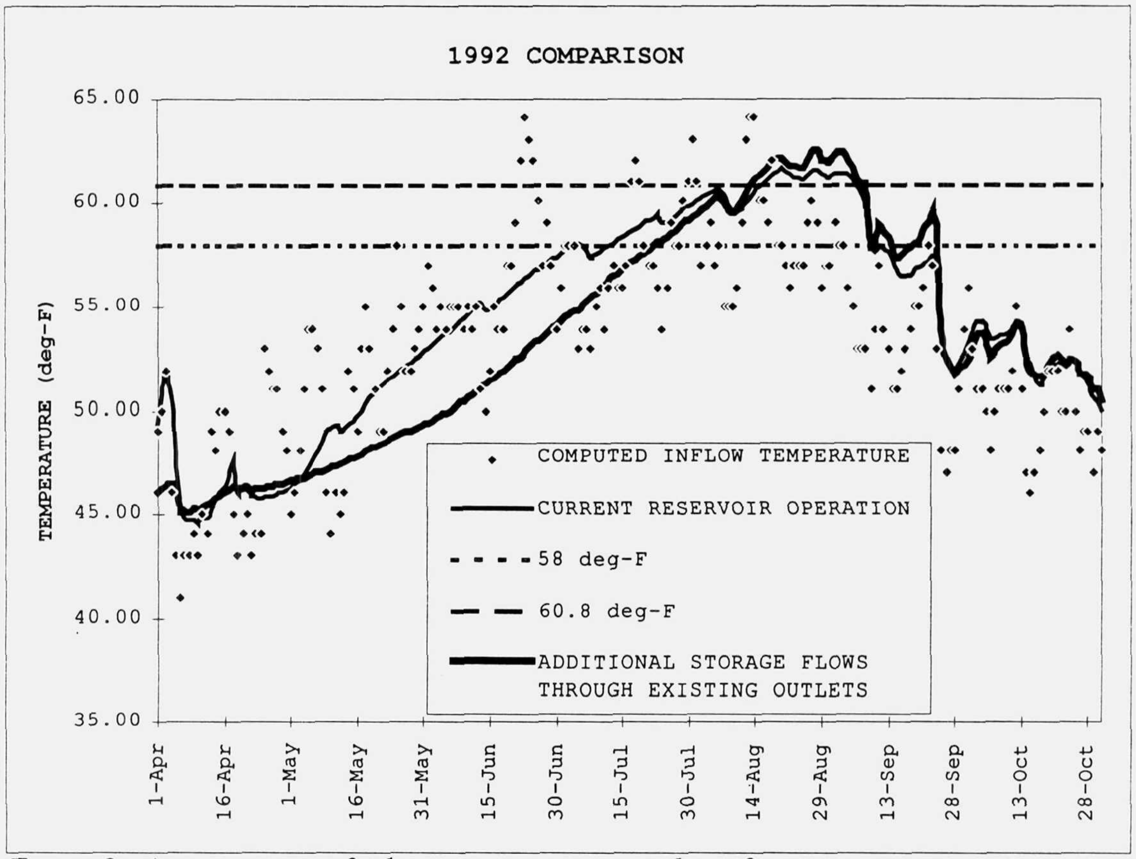


Figure 2. A comparison of release temperature resulting from existing reservoir operation and that resulting from additional storage flows through the existing outlet. Using the existing outlets for the proposed additional storage project would result in greater development of the thermocline, cooler releases in the late spring and warmer releases in the early fall. (Two critical temperature limits are shown: 58 °F is a critical temperature for steelhead trout and 60.8 °F is the Washington State standard applicable to this section of the Green River.)

1.4.2 Preferred Alternative - Selective Withdrawal

The preferred design presented in early 1995 called for a floating fish gulper with a capacity of 200 to 600 cfs and a submergence depth for the top of the structure of 5 to 15 feet. There would still be a low flow outlet near the bottom of the reservoir to use for blending with surface water in the summer. Temperature targets would be met by blending of water from the fish gulper near the surface and the low flow outlet near the bottom. Flood control gates would continue to function at elevation 1035 feet.

Fisheries agencies requested that temperature simulations target the inflow temperature. Observed inflow temperature varies significantly from day to day, however, the model needs smooth transitions between daily inflow temperatures for stability. In an attempt to develop a uniform set of target temperatures, Schneider and Price (1988) fitted a sine curve to inflow temperature data and used this curve for each of their simulations. Their study had a maximum target temperature of 58°F. The curve used by Schneider and Price (1988) :

target temp (in deg-C) $= A * \sin(B*\text{julian day} - C) + D$

where A=6, B=0.0174, C=2.234, D=8

Inflow and target temperatures for 1992 are shown in Figure 3. The parameters of the above equation were adjusted to produce a better fit for 1992 to be used in the modeled simulation of that year displayed in Figure 4.

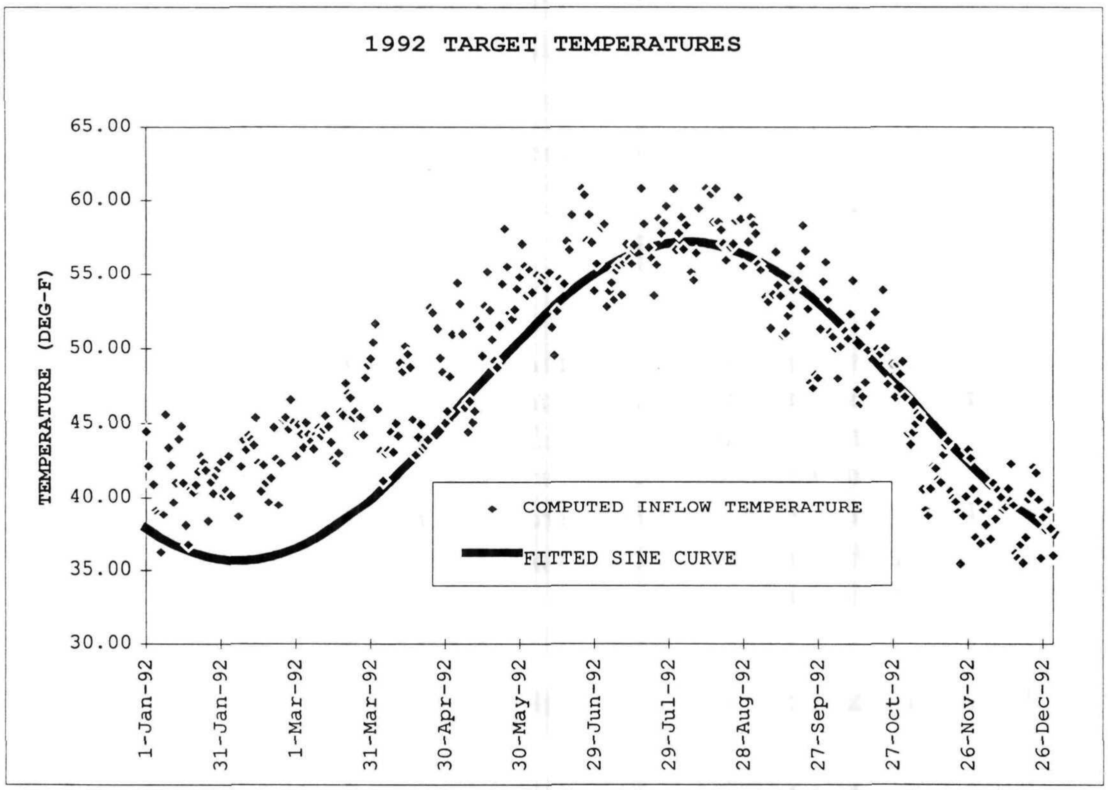


Figure 3. Outflow temperature targets developed by fitting a sine curve to observed inflow temperatures. The purpose of using inflow temperatures as release temperature targets was to mimic natural conditions in the river.

Simulations that targeted an inflow temperature sine curve were performed for the years 1962-1969 and 1992. Visual examination of the graphs in Section 5 of this report show that during eight of the nine simulations, the model failed to meet temperature targets in September and October. During most years, the reservoir would be depleted of cold water by mid-September. While this is certainly better than the existing outlets, which would deplete the cold water by mid-August, this does not achieve the goals of the project. Figure 4 shows the results of using inflow temperatures as a target for releases under 1992 weather and inflow conditions.

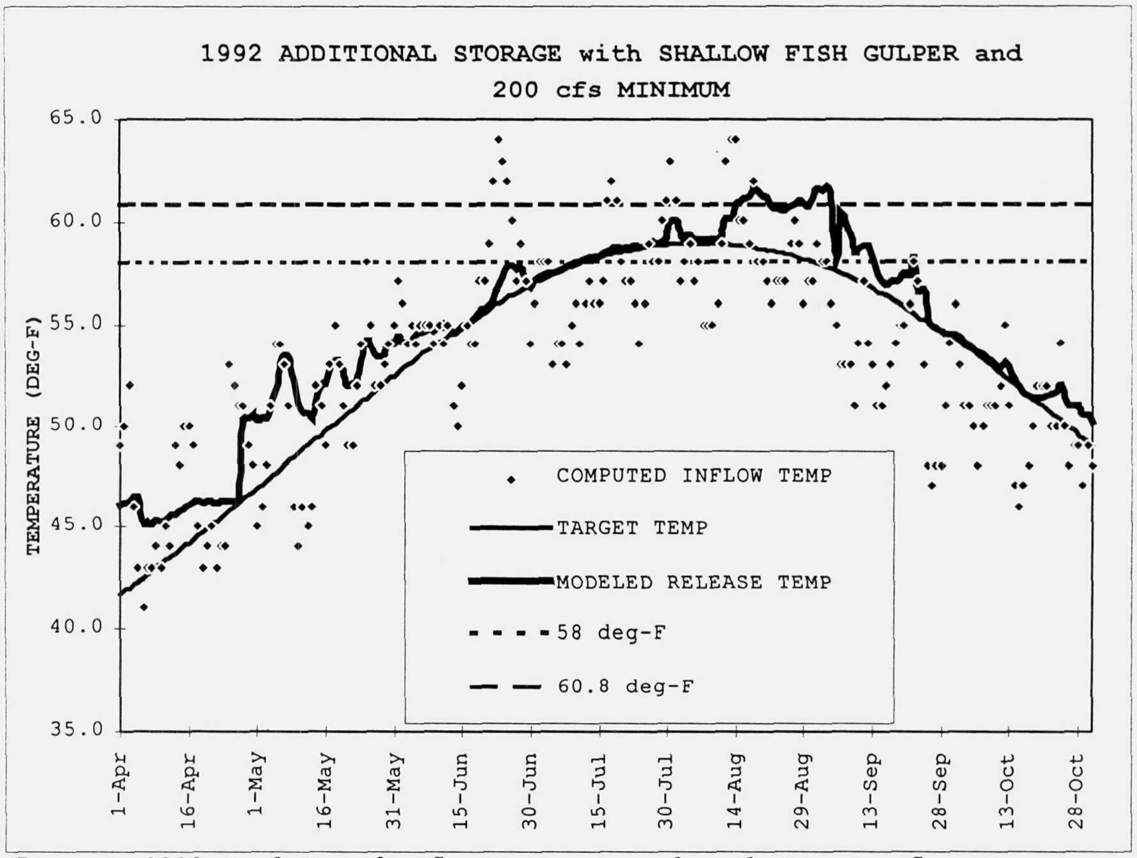


Figure 4. 1992 simulation of outflow temperature where the target outflow temperatures are a sine curve match of inflow temperatures. Because this year represents a warmer and drier than normal summer, the target curve was adjusted upward to a peak of 59 °F. Even with this allowance, the reservoir would be depleted of cold water by mid-August and would fail to meet outflow temperature targets. (Two critical temperature limits are shown: 58 °F is a critical temperature for steelhead trout and 60.8 °F is the Washington State standard applicable to this section of the Green River.)

1.4.3 Preferred Design with New Temperature Targets

A goal of the fisheries agencies is to maximize the opportunity for spring migrants to exit the reservoir via the surface outlet. An additional goal is to provide as cool water as possible in September and October so that the incubation of Fall Chinook eggs is not accelerated. These goals could best be accomplished by raising the target temperature in the spring and early summer in order to remove as much warm surface water as possible. To achieve this, flow through the upper port would be maximized. The higher velocity would better attract fish to this to the gulper. Removing the warmest water in the spring provides a second benefit of decreasing the storage of heat in the reservoir. More cold water storage would be preserved and used to provide cooler outflows in the fall.

Personal communications in August 1995 with fishery agencies resulted in the suggestion of a new target temperature regime as well as a measurement technique by which to compare the results. The new target temperature sine curve was broadened to create a higher target in the spring. In addition, the peak (59°F) of the new target occurs a week earlier, on the first of August. Figure 5 compares the temperature targets used previously with the new target regime.

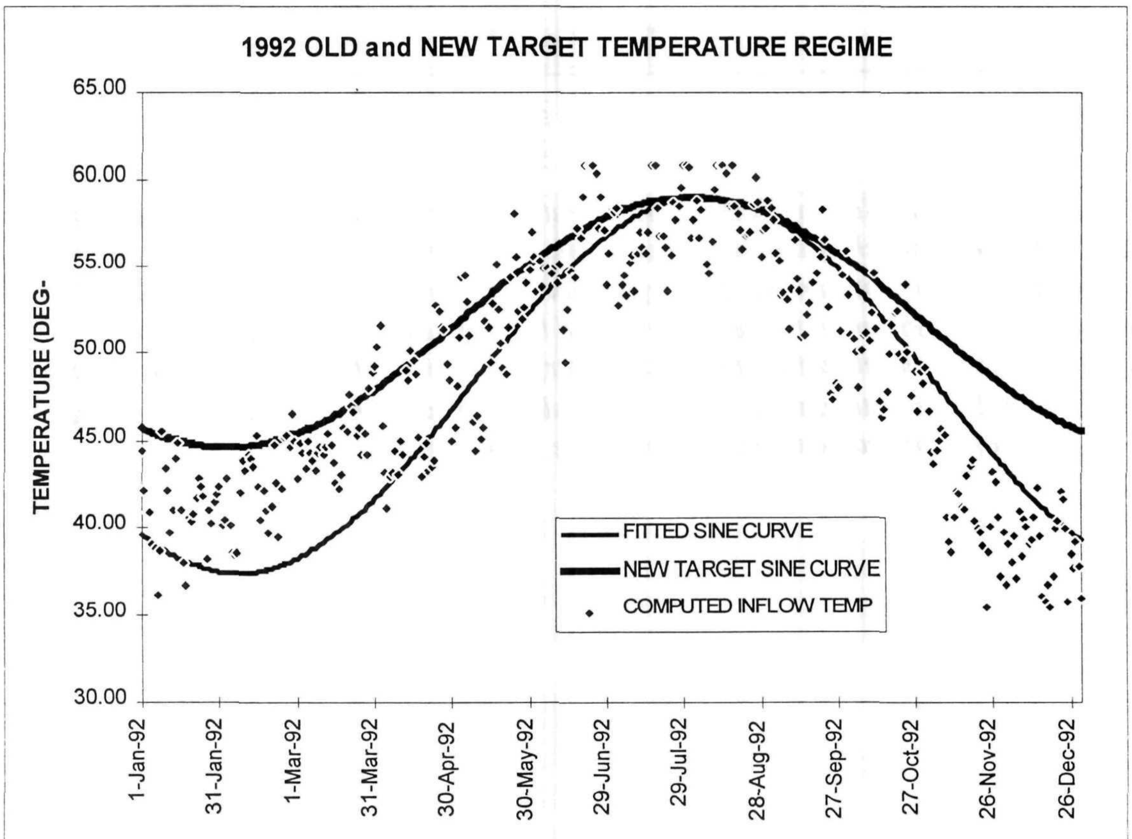


Figure 5. Comparison of the old and the new temperature targets.

Figure 6 shows the results of using the new target temperatures for 1992 weather and inflows. During May, June and July, the release temperatures spiked above the target temperatures due to very warm weather. Because warm water was released early in the summer, this simulation preserved cold water and resulted in cooler releases during September and October.

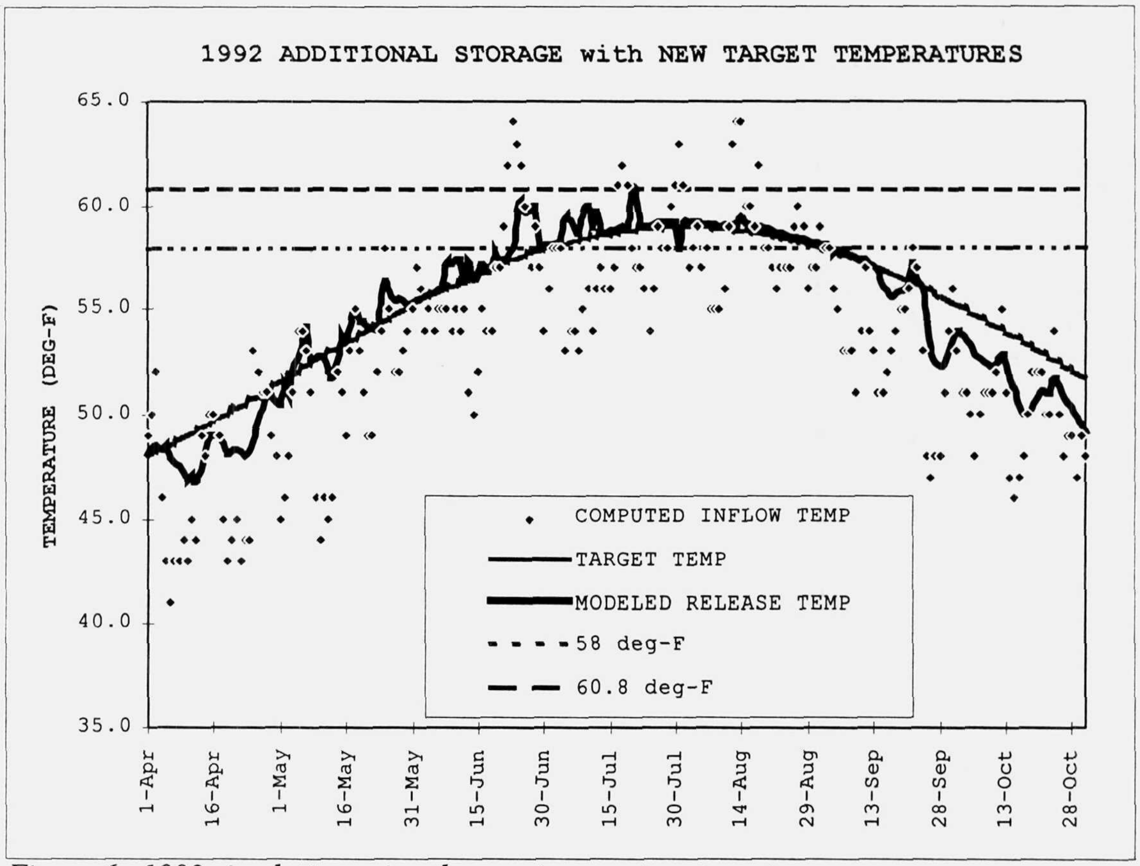


Figure 6. 1992 simulation using the new temperature targets.

The results of 33 years of simulations are in Section 6 of this report. A visual examination of the graphs shows that the reservoir has enough cold water storage to meet or be below the target temperatures in 22 of the 33 simulations, a reliability of about 70%. Failure to meet target temperatures can be attributed to high inflow temperatures and low inflow quantity in the latter part of summer. When inflow temperature is high, the reservoir stores that incoming heat energy in the upper layers while depleting cold water to meet the lower target temperatures. In the case of very warm summers, the reservoir benefits the river by lowering the temperature in mid-summer, while increasing the risk that target temperatures will not be met in the fall.

Historically, for years that receive significant inflow during September, the outflow temperature during September and October is relatively close to the inflow temperature. Under the proposed additional storage project, this would continue to be true. For years that are relatively dry in September, the outflow temperature is more strongly influenced by the stored heat energy in the reservoir's contents. Under the proposed project, the reservoir contains more water in September, so the outflow temperature would be more influenced by stored heat.

The Washington State standard for Class AA (extraordinary) waters is 16°C (60.8°F) due to human activities. The *natural* inflow temperature exceeds this value at some point during most years. With the preferred alternative simulations, reservoir releases exceeded this temperature in only 1 of 33 years. Therefore, the preferred alternative has a reliability of about 97% for maintaining the release temperature below the state standard.

The fisheries agencies requested that "degree days" in September and October also be used as a measure of reservoir performance. Degree days are defined as the number of Celsius degrees that the release temperature is above or below a certain target each day. Three comparisons were made:

1. Modeled temperatures of the proposed additional storage project releases with the preferred alternative (selective withdrawal) outlets, minus the 5-day average inflow temperature (1962 to 94);

2. Modeled temperatures of the proposed additional storage project releases with the existing outlets minus the 5-day average inflow temperature (1962 to 94); and

3. Historic releases minus the 5-day average inflow temperature (1991 to 94).

The sum of degree days of heating and cooling for September and October are given in Table 1. "Degree days" are defined as the number of Celsius degrees that the release temperature is above or below a certain target each day. The releases under each condition are compared with inflow temperature.

TABLE 1. COMPARISON OF "DEGREE DAYS" SUMMED OVER SEPTEMBER AND OCTOBER FOR YEARS SIMULATED

YEAR	ADDITIONAL STORAGE WITH PREFERRED ALTERNATIVE	ADDITIONAL STORAGE WITH EXISTING OUTLETS	HISTORIC RELEASES
	Celsius degrees/day	Celsius degrees/day	Celsius degrees/day
1962	90	244	
1963	53	33	
1964	157	113	
1965	90	168	
1966	73	155	
1967	120	173	
1968	126	110	
1969	113	116	
1970	70	117	
1971	120	119	
1972	158	124	
1973	58	138	
1974	84	124	
1975	108	123	
1976	105	137	
1977	130	122	
1978	105	124	
1979	76	138	
1980	77	127	
1981	195	116	
1982	109	141	
1983	128	133	
1984	96	142	
1985	91	126	
1986	67	123	
1987	19	114	
1988	84	132	
1989	35	135	
1990	88	144	
1991	46	153	124
1992	74	120	111
1993	71	118	112
1994	53	148	126
sum 1962-94	3069	4350	
sum 1991-94	244	539	473

1.5 DOWNSTREAM TEMPERATURE CONTROL

Fish biologists at the Corps, state agencies, and tribes were interested in the effect of additional storage withdrawals on Fall Chinook spawning beds. Those located closest to the project are between RM 58 and RM 61. The dam is at RM 64.5.

1.5.1 Current Condition

An investigation of Green River temperature at several locations was done in 1992 by the Muckleshoot Indian Tribe (Caldwell, 1994). A major conclusion of the report was that "water temperatures downstream of the Tacoma Diversion (RM 61) were found to be independent of Howard Hanson Dam outfall temperatures (RM 64.5)." This study concurs with the Caldwell finding for 1992 weather, channel, and particularly, *flow* conditions.

Data available for analysis in this study include hourly temperature collected year-round at RM 63.8 and daily maximum and minimum temperature collected at RM 61 as part of the 1992 river temperature study mentioned above. Both sets of temperature were converted to average daily values to be compatible with daily values for heat exchange and equilibrium temperature. The one-dimensional model used in this analysis can be expressed as:

$$T = T_E + (T_I - T_E)\, e^X \qquad \text{where } X = (-\Delta t\, C\, A / \rho\, C_p\, V)$$

T = Water Temperature (°F) at RM 61
$\mathbf{T_E}$ = Equilibrium Temperature (°F): the temperature at which the net rate of heat exchange between a water surface and the atmosphere is zero; a function of air temperature, cloud cover, wind speed, and dew point
$\mathbf{T_I}$ = Initial Temperature (°F) at dam outfall, RM 64.5
Δt = Time Interval or Travel Time (days) from dam to diversion
C = Coefficient of heat exchange (BTU/°F/ft^2/day)
ρ = water density (62.4 lb/ft^3)
$\mathbf{C_p}$ = Specific Heat of Water (0.998 BTU/lb/°F)
A = Surface Area (ft^2)
V = Volume (ft^3)

Both historical data and an analysis using this stream-heating model show that on a typical warm summer day, the water between the dam and the diversion can warm as much as 4 to 6 °F.

1.5.2 Additional Storage

Conditions under the proposed additional storage project are different and merit a recalculation of river heating. The reservoir outflow in September (400 to 600cfs) under the proposed project would be significantly higher than in July 1992 (223cfs). The reservoir outflow temperature would be lower. An estimate based on the previous equations, current river channel conditions, and typical September weather indicates that warming would be less than 2°F between the dam and the diversion.

To compare the potential benefits of the proposed additional storage project, the stream temperature below the Tacoma Diversion was modeled for the current flow regime and under the proposed additional storage project. This analysis was limited to September, a month of concern for Fall Chinook redds. With the current dam configuration, outflow temperature is generally highest in September. The year chosen for this analysis, 1992, experienced normal temperature and less than normal precipitation (about 60% of normal) in September.

Assuming that the stream channel conditions remain the same, RM 61 would experience lower water temperature during September under the additional storage project. This is due to two factors: dam outflow temperatures are lower and stream flows are greater. Faster traveling, deeper streams tend to absorb less heat from the atmosphere. For the month of September 1992, stream temperature at RM 61 would be 23 Celsius degree-days lower under the proposed additional storage project than under current flow conditions. By the time the water reaches the downstream end of this spawning area, RM 58, the benefit would be diminished somewhat. Figure 7 is a graph of modeled stream temperature at RM 61, just downstream of the Tacoma Diversion.

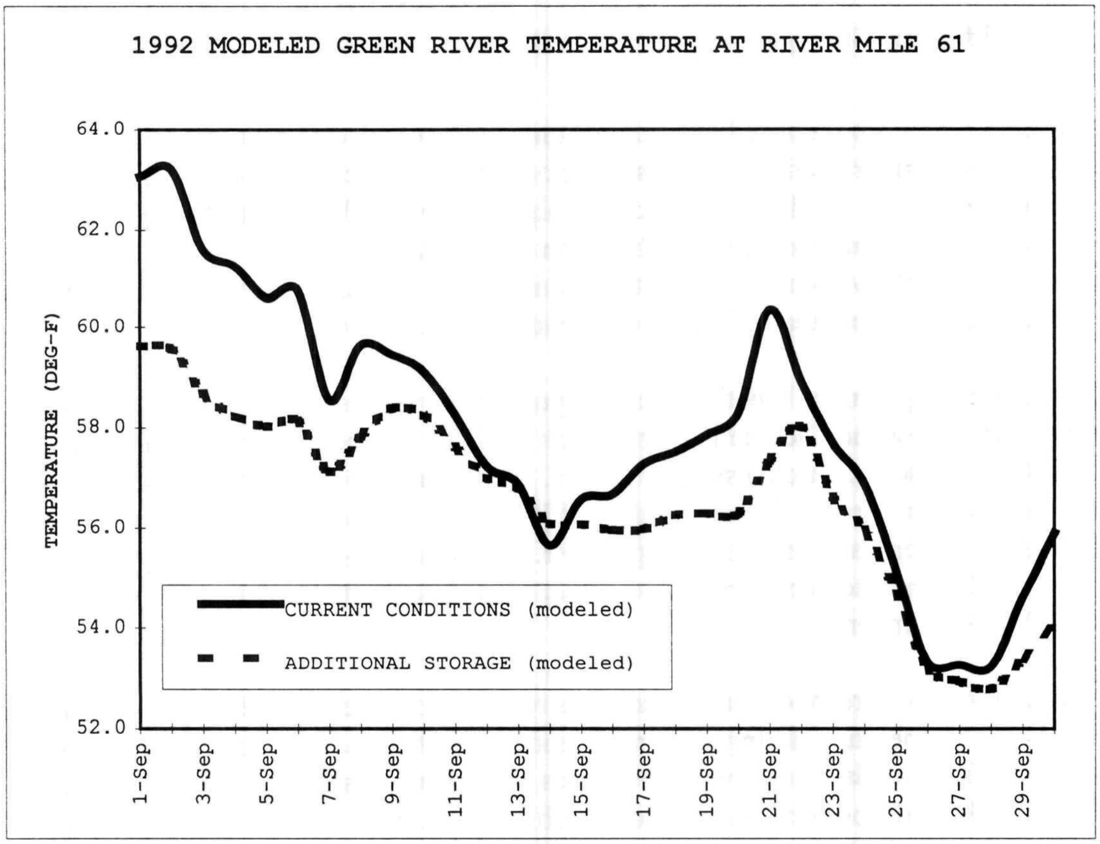


Figure 7. Modeled stream temperature at RM 61, downstream of the Tacoma Diversion, under current flow conditions and under additional storage flows.

The results of this downstream temperature analysis should be considered to have a relatively high degree of uncertainty. The calibration data set was collected at flows significantly less than the proposed project's flows. In addition, ground water entering the stream was not considered, nor were ponded or backwater portions of the stream. More definitive analysis of downstream heating could be obtained with hourly temperature data collected at several locations between the dam and RM 58.

1.5.3 Diurnal Fluctuations

The river downstream of the dam experiences a significant diurnal fluctuation in temperature, although the dam outflow temperature remains relatively steady. The Corps maintains a river temperature gauge 0.7 miles downstream of the dam. During a warm, dry September, the water temperature can fluctuate diurnally as much as 2°F at this gauge, warming during the day and cooling at night. At the Tacoma Diversion, temperature records show a fluctuation of 3 °F during the same time period.

1.6 CONCLUSIONS OF TEMPERATURE ANALYSIS

This study determined that the reservoir with the proposed storage reallocation would be unable to use inflow temperature as a target for outflow temperature due to the heat energy stored during the warmer summer months. A compromise temperature target regime was discussed with fishery agencies as an attempt to determine how much temperature moderation the reservoir could provide. The new set of target temperatures furthers the release of relatively warmer surface water early in the summer in order to preserve cooler water for release in the early autumn. In addition, the new target temperature regime enhances smolt outmigration by passing more water through the upper port. The preferred alternative design was able to meet these target temperatures for 70% of the years simulated. The modeled release temperatures met the Washington State standard for 97% of the years simulated.

In-stream temperature below the dam would be affected by the proposed additional storage project. Cooler reservoir releases coupled with faster, deeper water would result in less heating of the river. A simple model showed that this temperature benefit would extend as far as the spawning area below the Tacoma Diversion. Future changes in the river channel between RM64 and RM58 could significantly alter this conclusion.

SECTION 2 TURBIDITY ANALYSIS

2.1 PURPOSE AND SCOPE OF STUDY

This section of the water quality narrative addresses the issue of how the proposed additional storage project would affect turbidity of outflows from Howard Hanson Dam.

Turbid water is defined as water containing suspended matter that interferes with the passing of light through the water. Turbidity can be caused by a wide range of material (soil particles, algae, organic decomposition, natural chemicals, etc.). The duration of turbidity in water is directly related to the physical properties of the material (size, weight, shape, bonding strength) and the characteristics of the water (density, temperature, circulation patterns). This report will focus on soil particles, given that the other materials that cause turbidity are insignificant or will not be affected by the proposed project.

The input of soil particles to the water in Howard Hanson Reservoir occurs in two ways. High inflows from the Upper Green River during storm events are generally very turbid and carry high sediment loads. Occasional landslides along the banks of the reservoir adds soil particles which can become suspended depending on local water velocities.

Currently, the reservoir is operated for flood control about half of the year and for conservation storage to augment low flows during the summer and fall. The overall pattern of operation would remain the same with the proposed project, although the timing of spring refill would change. Filling for conservation storage would start at the beginning of March rather than mid-April, depending on snowpack and rain forecasts. The reservoir would be emptied to provide space for flood control in the fall after streamflows have returned to higher levels.

The questions this analysis seeks to answer are:

1. Will beginning the refill period 5-6 weeks earlier cause the reservoir to store more turbid water? If so, how would this effect reservoir outflow turbidity and for how long?

2. Raising the elevation of the reservoir could result in more frequent landslides. If so, would these landslides increase the turbidity of the outflow during the period of conservation storage?

2.2 HISTORIC OPERATION

2.2.1 Data

Turbidity measurements of the reservoir's inflow and outflow are collected once per day, excluding weekends and holidays, by project personnel. For weekend data, the Corps uses data collected by Tacoma Public Utilities at their diversion structure about three miles downstream of the dam. The database of inflow turbidity extends as far back as 1975, though the early readings are irregular. All available turbidity data from 1975 through 1994 are used in this report. The units for all of the turbidity data in this report are Nephelometric Turbidity Units (NTU).

2.2.2 Flood Control

During most of the year, both inflow and outflow turbidity remains low. Small storms bring in turbid water that is quickly passed through the reservoir. During larger storms when water is impounded behind the dam, high sediment loads enter the reservoir and are deposited on the reservoir floor. If the reservoir is completely emptied, these sediments are eroded and the outflow turbidity can exceed the criteria of no more than 5 NTU's above ambient inflow levels. Therefore the project is regulated to maintain enough of a pool so that, inflow turbidity permitting, the water released will meet criteria.

2.2.3 Turbidity Pool

"Turbidity pool" refers to the pool of clean river water on the upstream side of the dam that is maintained during the flood season to prevent sediment erosion. During current operation of the reservoir, this pool is maintained at about elevation 1070 feet. When the elevation is lowered below this level, the river cuts a new channel through deposited sediment increasing the turbidity of the reservoir and outflow.

The reservoir's sluice gates are located at elevation 1035 feet and withdraw water from the bottom of the turbidity pool. During the first several years of reservoir operation, the reservoir was entirely evacuated after a storm and most of the accumulated sediment was washed back into the river. The elevation of the turbidity pool has gradually increased over 34 years of project operation. Figure 1 shows the yearly elevation of the turbidity pool.

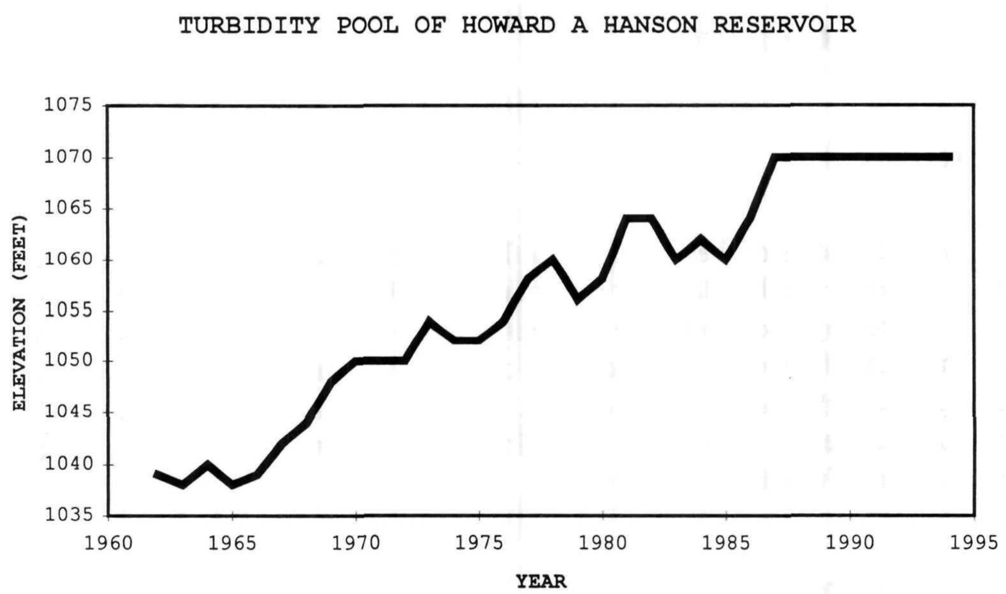


Figure 8. Turbidity pool elevation.

2.3 SPRING REFILL FOR CONSERVATION STORAGE

2.3.1 Refill Strategy

Operation of the reservoir for refill of conservation storage has changed since 1962. The original refill strategy was to delay refill until as late as possible given the snowpack and rain forecast. The purpose of delaying refill was to store the cleanest water possible. In response to the concerns of fisheries agencies in the last few years, the Corps began to refill earlier in order to more gradually decrease river flow and protect salmon redds. Table 2 is a list of refill starting dates for the 20 years examined in this report.

TABLE 2. REFILL STARTING DATES FOR 1975-1994

YEAR	START OF REFILL	YEAR	START OF REFILL
1975	June 5	1985	May 3
1976	May 20	1986	May 1
1977	April 28	1987	May 18
1978	May 2	1988	May 8
1979	May 20	1989	May 1
1980	May 12	1990	April 20
1981	March 23	1991	May 20
1982	May 28	1992	April 1
1983	May 1	1993	April 20
1984	May 4	1994	April 15

2.3.2 High Turbidity During Refill

High inflows to the reservoir are caused by two phenomena which can occur separately or together, rainfall and snowmelt. Both types of events can contribute significant river flows with high sediment loads and very turbid water. Figure 2 shows the qualitative relationship between river flow and turbidity.

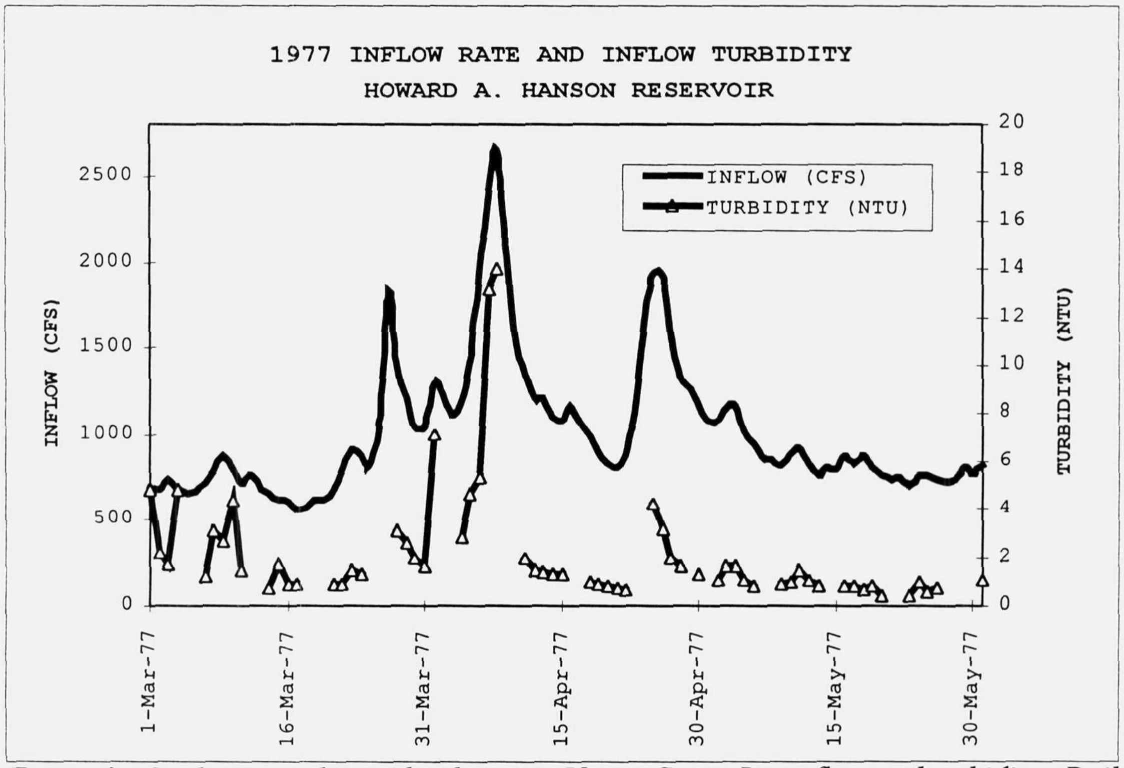


Figure 9. Qualitative relationship between Upper Green River flow and turbidity. Daily turbidity data is not continuous as weekend data is unavailable.

Historically, few storms with significant turbidity (greater than 5 NTU) have occurred after the start of refill, because refill usually started in May. Typically those few storms increased the turbidity of the water in the reservoir only slightly for up to several days before the suspended sediment settled or was flushed through the reservoir. Table 3 shows a selection of higher flow events that entrained suspended sediment into the reservoir during the refill period. In the May 1978 storm, outflow turbidity reached a high of only 5.1 NTU. For all storms considered, the highest outflow turbidity was significantly less than the inflow turbidity (the natural river turbidity). Elevated outflow turbidity tended to recede to lower levels within 2 to 6 days.

TABLE 3. SELECTED HIGH FLOW/TURBIDITY EVENTS

FLOW EVENT	DATE	INFLOW (CFS)	INFLOW TURBIDITY (NTU)	OUTFLOW (CFS)	OUTFLOW TURBIDITY (NTU)
May 1978	14-May-78	1511	no data	393	2.6
	15-May	1688	6.8	408	2.8
	16-May	1644	14.0	420	3.7
	17-May	1543	7.5	434	4.2
	18-May	1337	4.8	441	4.5
	19-May	1200	5.0	448	5.1
	20-May	1190	no data	455	5.0
	21-May	1134	no data	462	4.3
	22-May	1035	2.8	593	4.3
	23-May	898	2.8	708	3.6
April 1981	21-Apr-81	1684	2.8	1860	6.3
	22-Apr	2718	8.8	2290	4.4
	23-Apr	3212	20.0	3140	5.6
	24-Apr	3072	no data	3360	7.8
	25-Apr	2225	no data	3220	7.2
	26-Apr	1769	no data	3160	8.9
	27-Apr	1509	3.2	1850	8.3
	28-Apr	1893	no data	864	6.4
	29-Apr	2447	6.2	1030	4.7
	11-May		1.2		2.0
May 1986	12-May-86	1377	1.2	507	1.2
	13-May	2640	13.0	527	10.0
	14-May	2320	4.9	776	1.7
	15-May	1852	3.0	1290	2.0
May 1988	12-May-88	2531	1.6	348	1.1
	13-May	2928	27.0	367	2.5
	14-May	2080	no data	389	10.0
	15-May	1642	no data	400	11.0
	16-May	1215	4.2	554	10.0
	17-May	1688	4.4	989	10.0
	18-May	2359	2.0	1160	8.0
	19-May	1526	2.0	1170	5.7
	20-May	1491	1.4	1250	5.1
	21-May	1474	no data	1310	4.8

2.3.3 Flushing Rate

When turbid water enters the slack water of the reservoir, larger particles settle and smaller particles mix with the stored water resulting in increased turbidity of the outflow. Some of the sediment that remains in the water column is diluted and is eventually flushed out of the reservoir. The flushing rate indicates how often the stored water is exchanged for fresh inflow. In three of the above instances, the flushing time was too long to explain the gradual decrease in outflow turbidity following a high turbidity event. In contrast, during the April 1981 event, the higher outflow allowed for an exchange of water in just three days. Though little inflow turbidity data is available for this event, turbidity was probably high due to the large inflows. In addition, greater water velocities through the reservoir would have held more particles in suspension, thus flushing the reservoir.

2.4 REFILL UNDER THE PROPOSED ADDITIONAL STORAGE PROJECT

Under the proposed project, refill for conservation storage would start at the beginning of March. The reservoir would store turbid water from storms that would, under current operation, pass through the reservoir. A frequency analysis summarized in Table 4 indicates how often high turbidity events occur during the proposed refill period. The exceedance percentile represents the percent of time the corresponding inflow turbidity was equaled or exceeded for the years 1975 - 1994. May, with the fewest high turbidity events, was the preferred month for refill during early operation of the project. During more recent years of project operation, in response to requests by fisheries agencies, refill has begun in April, a month with more frequent high turbidity events. The effect on reservoir outflow turbidity was negligible. Shifting the start of refill to March would result in somewhat more frequent storage during refill of high turbidity events. As seen in previous reservoir operation, the suspended particles would settle out of the reservoir within several days, or be flushed out by higher flows.

TABLE 4. INFLOW TURBIDITY EXCEEDANCE PERCENTILES

MONTH	TURBIDITY (NTU)	EXCEEDANCE PERCENTILE
MARCH	5	9.0
	10	4.0
	20	1.6
	50	0.8
APRIL	5	18
	10	6.0
	20	2.5
	50	0.6
MAY	5	3.9
	10	1.4
	20	0.3
	50	0

2.5 DILUTION AND FLUSHING OF A "WORST CASE"

In recent discussions with fisheries agencies, mid-February has been suggested as a possibly better time to begin refill. There is some concern that beginning refill in February would result in the storage of turbid stormwater that would be unusable for domestic drinking water during the summer conservation period. Although river water with a turbidity above 4 NTU can be diluted with water from the North Fork well field, that option decreases significantly by the end of May.

This analysis uses a conservative, or "worst case," look at reservoir outflow turbidity. For this purpose, turbidity is assumed to be totally colloidal with no in-reservoir settling taking place. Any decreases in outflow turbidity would be the result of mixing and flushing with less turbid inflow. In reality, turbidity in this reservoir would not be expected to be colloidal as no glacial runoff is involved. In addition, soils surrounding the reservoir are not of a colloidal nature. In-reservoir settling does take place, though it has not been quantified.

The proposal discussed in this section involves storage of 5,000 ac-ft by 28 February, 35,000 ac-ft by 31 March, and 60,000 ac-ft by 31 May. While storage target volumes and dates have tended to change as the proposed additional storage project has evolved, these target dates are the earliest that have been suggested and therefore help to define the conservative, "worst case" scenario.

This analysis looks at 2 periods when turbid water is likely to enter the reservoir: February and April. Analysis of historic reservoir inflow turbidity data shows that

February is one of the months most likely to have turbid inflows. March is significantly clearer. April inflows are generally more turbid than March.

Table 4 shows frequency of inflow turbidity greater than 5 NTU by month, based on irregular data, 1975-1995. Total number of values is about 350 per month total over 20 years of record.

TABLE 5. FREQUENCY OF INFLOW TURBIDITY GREATER THAN 5 NTU

Month	Frequency
February	16%
March	9%
April	18%
May	4.0%
June	1.4%

The amount of water stored during February is relatively small, 5,000 ac-ft, such that highly turbid water stored during February would be flushed by much cleaner water in March. Figure 10 shows the decrease in turbidity in March that would result from flushing and dilution of an initially 5,000 ac-ft pool of 30 NTU water. The clean water is assumed to be 2 NTU (Water that is 2 NTU or less occurs 72% of the time in March.) and the reservoir fills to 35,000 ac-ft by the end of March. The flows used are daily averages from a summary hydrograph of 33 years of data. "P = 0.10" refers to the 10% frequency of lowest flows, or flows that are exceeded 90% of the time.

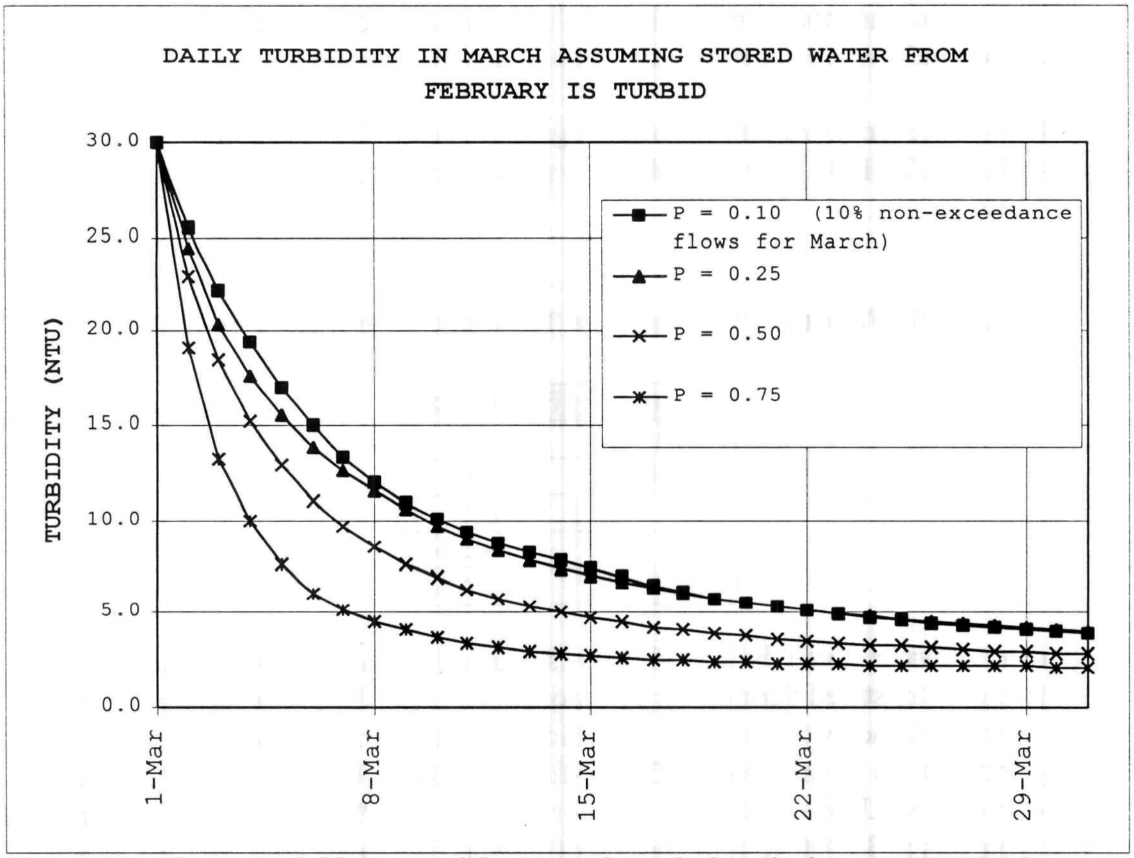


Figure 10. Theoretical dilution and flushing of a turbid pool of water (30NTU) by a month of clean water inflows and a filling reservoir.

By the end of March, 35,000 ac-ft of water would be in storage in time to enter the second period of high turbidity inflows, April. If a turbid event occurred in the first week of April, such as occurred in 1991, the reservoir would be flushed down to 4 NTU or less by June 1 (see Figure 11). Once again, clean water, 2 NTU, was used to flush the reservoir. (Inflow with turbidity of 2 NTU or less occurs 62% of the time in April and 85% of the time in May.)

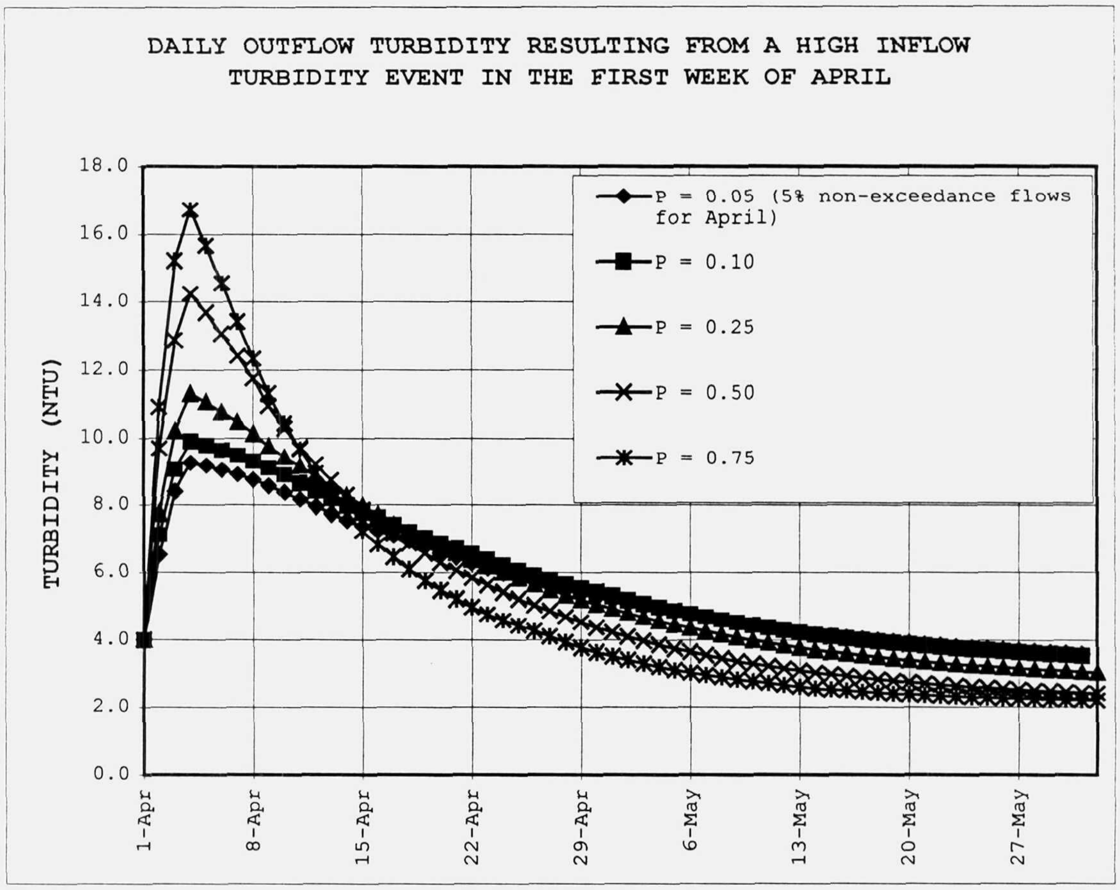


Figure 11. Theoretical dilution and flushing of a turbid pool occurring when over 35,000 ac-ft of water is stored in the reservoir.

Highly turbid water is usually associated with a high volume of inflow and therefore a large "mass" of turbidity-causing material enters the reservoir. The analysis shown in Figure 12 uses the actual daily average inflows associated with the high turbidity values. Four years with high turbidity inflows were modeled. The model showed a result for each year of 4 NTU or less by June 1.

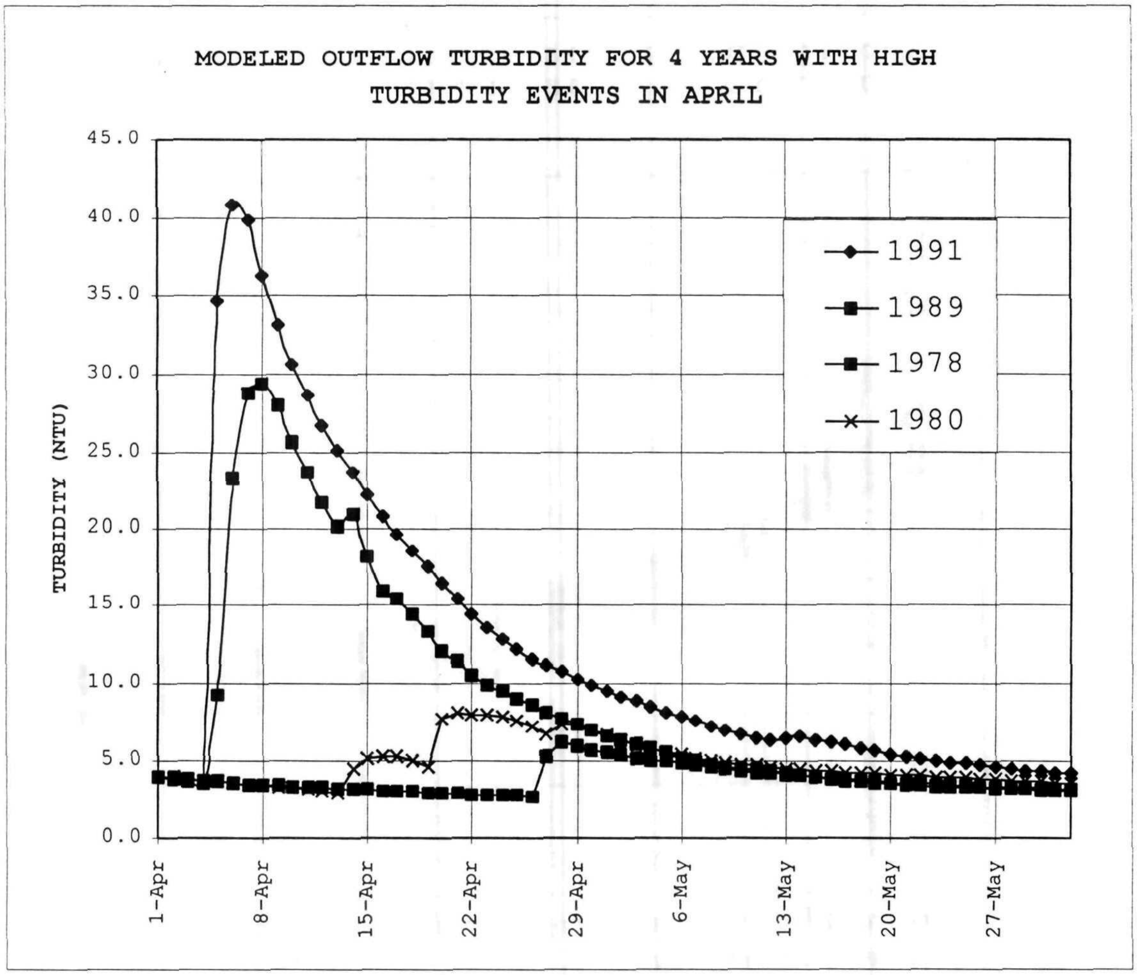


Figure 12. Modeled outflow turbidity using observed inflow rates and observed inflow turbidity for April and May.

One last combination of flows and turbidity involves a summary of the highest inflow turbidity value on record for each calendar day. This would represent the scenario of multiple high turbidity events in a single year. These high turbidities were routed through the reservoir using high flows (P = 95%). High inflow turbidity values are associated with much higher than normal inflow rates. The result is turbidity of 6.3 NTU on June 1, Figure 13. Under these very high flow conditions, the North Fork well fields would be capable of providing dilution water for an extended period. By the end of June, the turbidity would be reduced to 4 NTU.

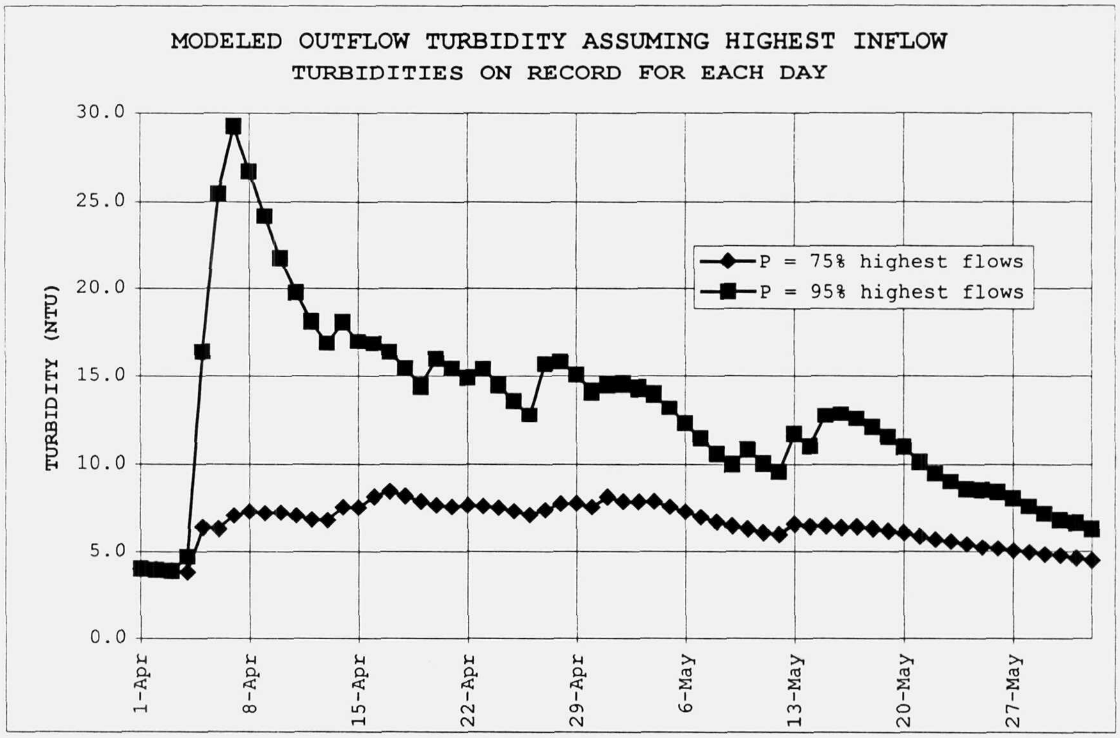


Figure 13. Modeled outflow resulting from multiple high turbidity events during April and May.

In summary, storing turbid water in the refill period does not necessitate dumping of the pool. The turbid water would be diluted and flushed by June 1. Settling that will likely occur as the pool enlarges will facilitate further cleansing of the water.

2.6 AN UPSTREAM LANDSLIDE

In mid-May 1997, more than a year after the previous sections of this report were written, a landslide occurred on an unnamed creek that flows into Tacoma Creek in the Upper Green River Basin, upstream from Howard Hanson Reservoir. Highly turbid water entered the reservoir for about a week. Outflow turbidity was high as well. Prior to the slide, the Corps was filling the reservoir with a constant capture target of about 400 cfs. After the slide, the Corps reduced the filling rate for about a week. This paper discusses how that action affected outflow turbidity. An alternative to that action would have been to continue the constant capture of 400 cfs. This paper also projects the impact to outflow turbidity of implementing that alternative.

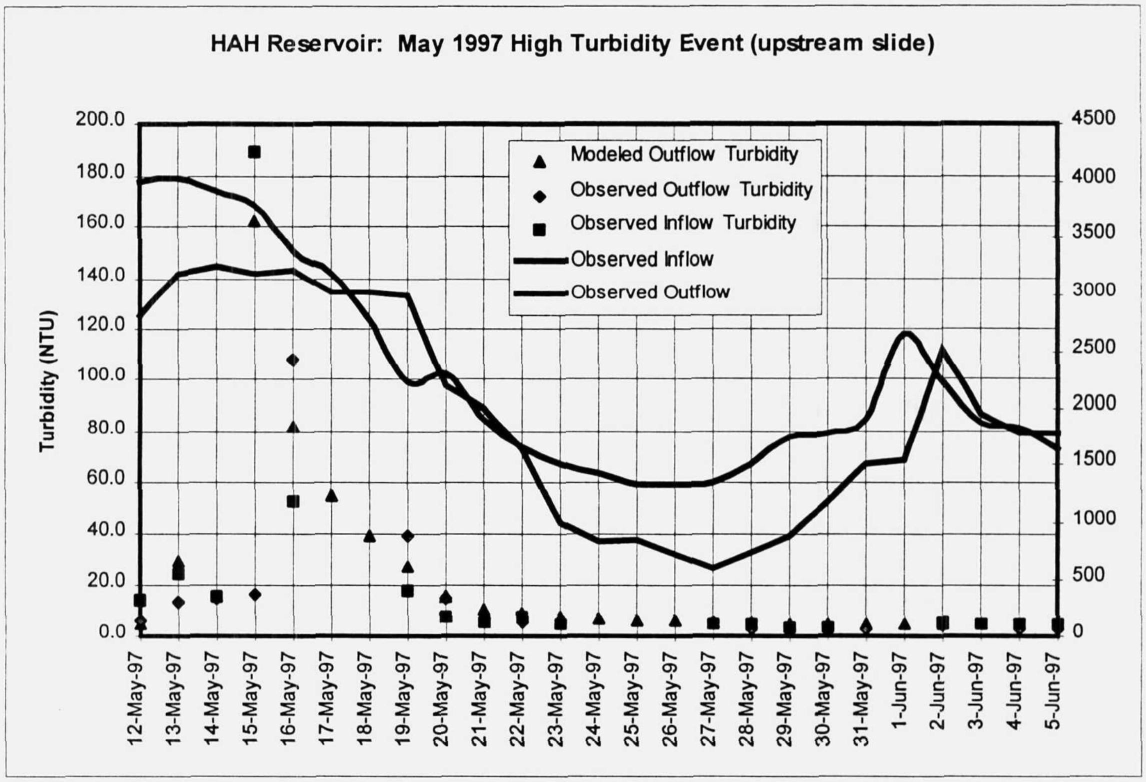
Historically, few storms with significant turbidity (greater than 5 NTU) have occurred after the start of refill. Typically those few storms increased the turbidity of the water in the reservoir only slightly for up to several days before the suspended sediment settled or was flushed through the reservoir. The May 1997 slide, however, increased outflow turbidity for about 2 weeks.

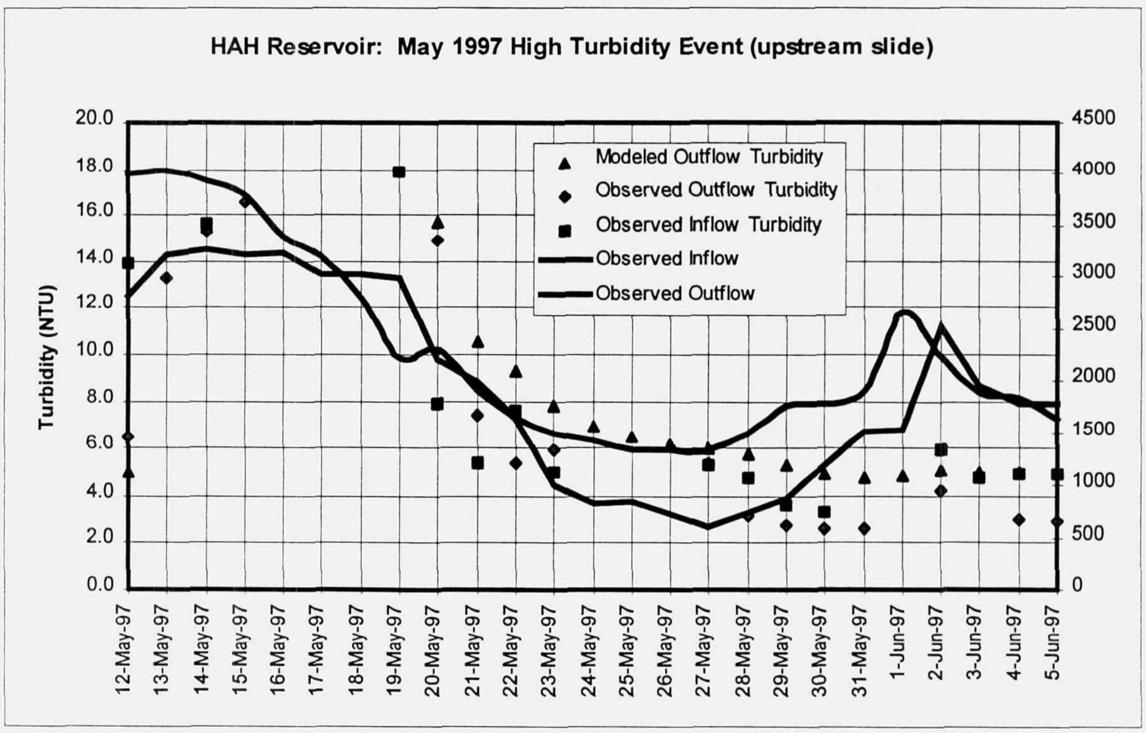
The mixing/dilution model of reservoir turbidity discussed in Part 2, Section XIII of this report was employed to study this event. This model assumes that turbidity is a measure of the mass of suspended sediment. Furthermore, it assumes that the only exit for turbidity is reservoir outflow. In other words, turbidity is assumed to stay in suspension and does not settle out of the water column. During the high flows of May 1997, this is a good assumption. Inputs to the model are:

- Observed inflow turbidity (measured once per day)
- Average daily reservoir inflow
- Average daily reservoir outflow

The model output is outflow turbidity measured in Nephelometric Turbidity Units (NTU).

Figures 14 and 15 are summaries of what was observed in May 1997. (The difference between the two figures is the scale of the left-hand vertical axis. In figure 2, this axis is expanded.) Prior to the slide, inflow turbidity was between 3.5 and 6 NTU. On 12 May, it began to rise rapidly and reached a high of 108 NTU. A week later, inflows had cleared to below 6, while outflows were slightly more turbid. Within another week, outflows cleared to below 5 NTU, the drinking water standard.





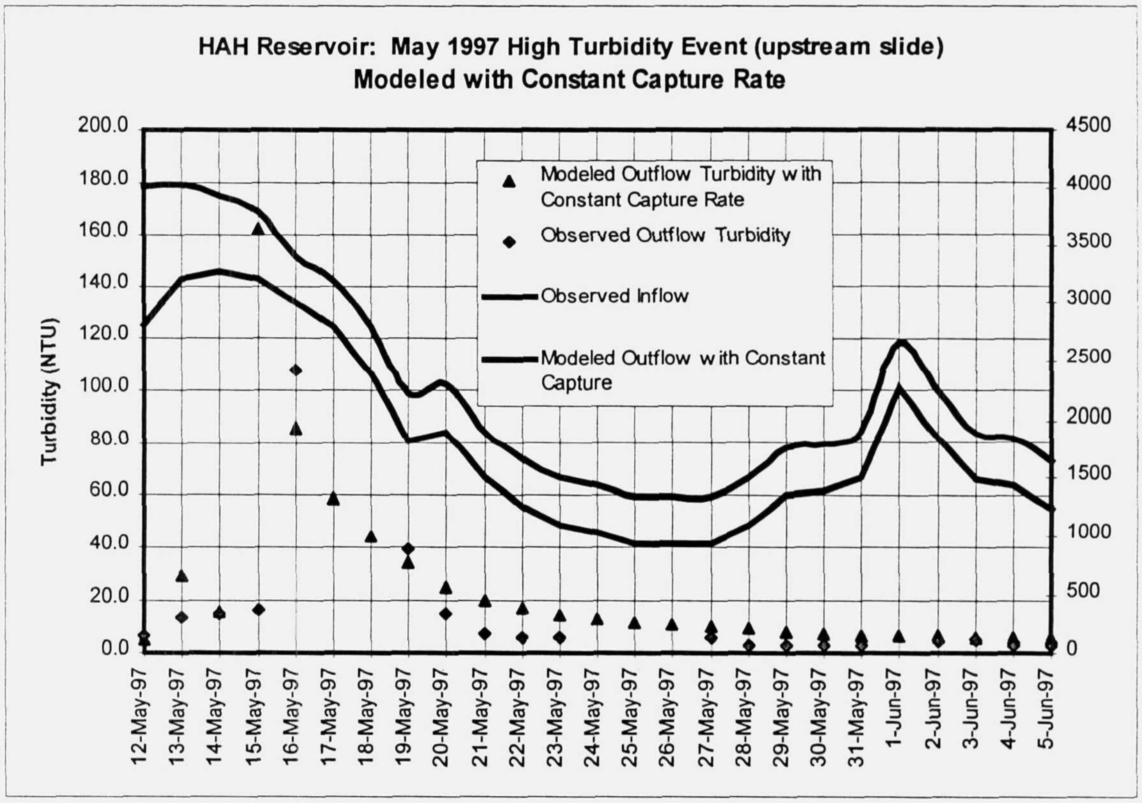
Figures 14 and 15. Flow and turbidity during the May 1997 high turbidity event resulting from a landslide upstream of the reservoir. The 2 figures differ in scale only on left-hand, vertical axes.

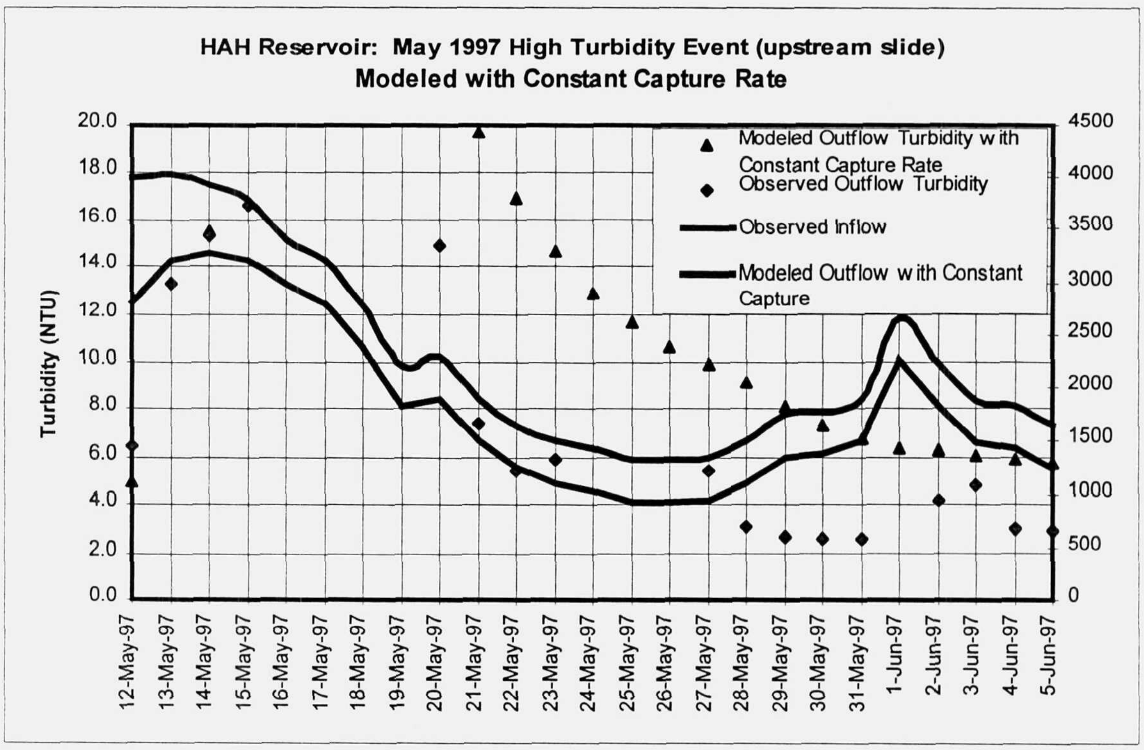
Figures 14 and 15 also show how well the model represents what happened. As expected, the model is fairly conservative and overestimates outflow turbidity as settling of sediment from the water column is not considered. However, the model *does* represent the trends in outflow turbidity and matches some of the higher points pretty closely. Observed turbidity dropped to a low of 2.6 by the end of May, while modeled turbidity was about 5 NTU. These results show the model to be a good tool for studying this issue.

What would have happened if the capture rate had not been reduced? The time it took to flush the reservoir would have been increased and the outflow turbidity would not have decreased as rapidly. Figures 16 and 17 show the modeled results of continuing a 400 cfs constant capture. The modeled outflow turbidity declined at a slower rate. By the end of May, the modeled turbidity was just under 7, compared with the previously modeled turbidity of 5 NTU. Within another week, the two modeled results were the same.

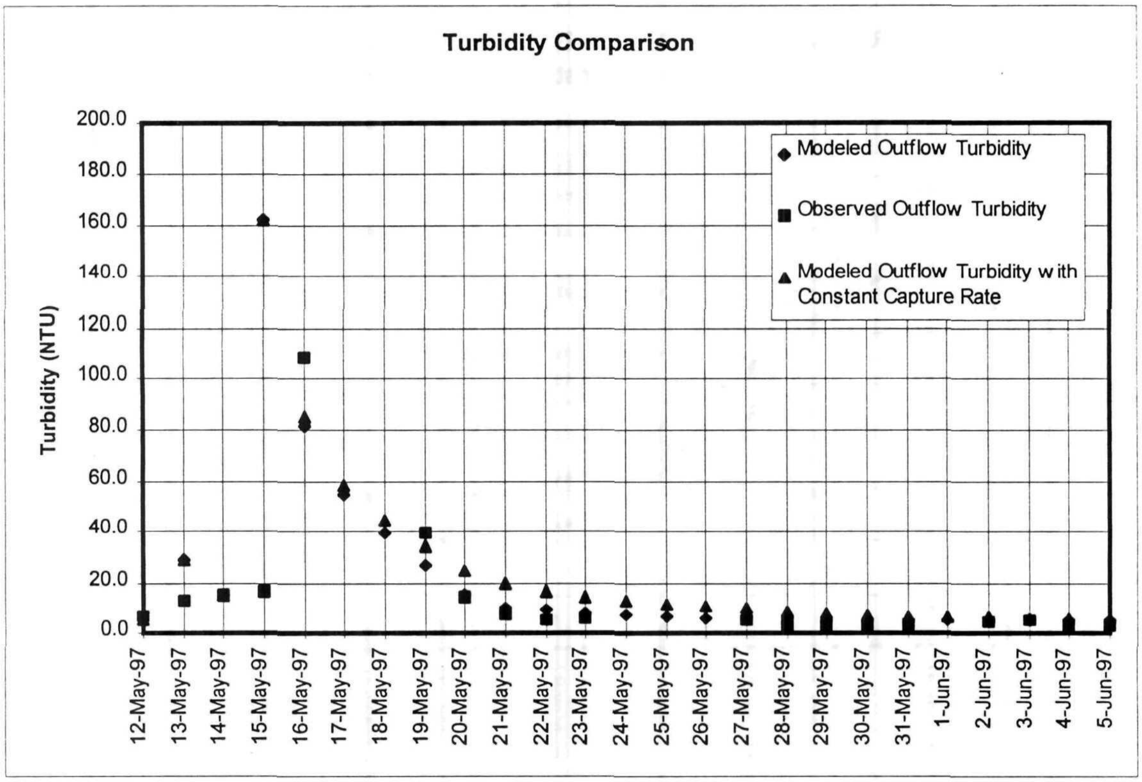
Figures 18 and 19 summarize the observed outflow turbidity and the modeled turbidity of the two alternatives. If the 2.5 NTU overestimation of observed turbidity is considered, the turbidity that would have resulted at the end of May from *not* deviating from the refill plan would have been under 5 NTU. The major difference that would have occurred had the capture rate remained constant would have been that the river turbidity would have taken a few more days to drop to 5 NTU. It is likely that further settling would have occurred and turbidity would have been even lower.

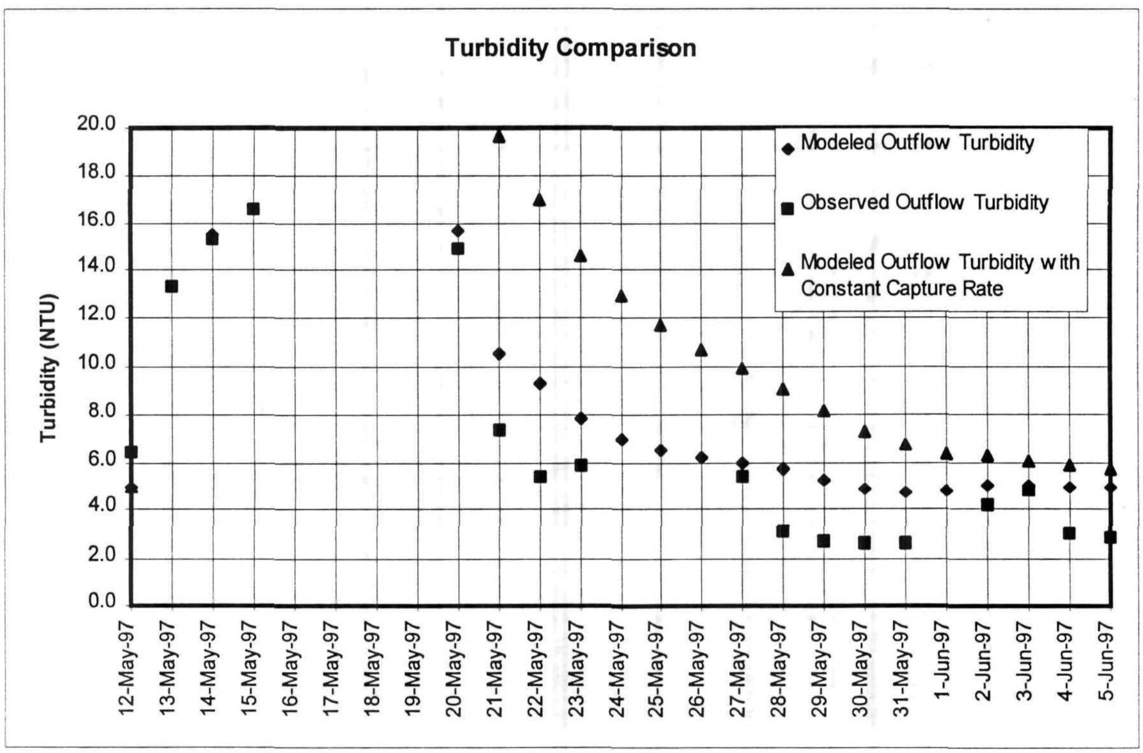
In summary, this analysis of the May 1997 high turbidity event showed that (1) the mixing/dilution model presented previously is provides a good, conservative estimate of outflow turbidity resulting from storms that occur during the spring refill period; (2) these rare high sediment loads entering the reservoir during refill are effectively flushed within a few days to a few weeks; (3) slowing of refill during periods of high turbidity is not necessary as it has only minor effects on outflow turbidity.





Figures 16 and 17. Modeled flow and turbidity of the May 1997 high turbidity event as would have occurred under a refill strategy of constant capture of 400 cfs.





Figures 18 and 19. Summary of modeled and actual turbidity of the May 1997 high turbidity event during spring refill.

2.7 BANK STABILITY

The general issue of how reservoir bank stability would be affected by the proposed additional storage project has been addressed by specialists in that area in a separate report (Eckerlin, October 1995). The analysis herein does not address the likelihood of episodic slides, but how these slides would affect turbidity.

Two types of slope failure have occurred at Howard Hanson Reservoir: raveling of sand and gravel and slumping of more clayey material. Failure of a sand or gravel slope would have little effect on long-term reservoir turbidity. The particles are large and heavy enough to settle. In contrast, slumping and calving of glaciolacustrine deposits adds smaller clay particles that remain in suspension for a longer period and could affect turbidity if the slide were very large. Either type of failure can be the result of excessive rainfall, wave erosion, or reservoir drawdown.

In December 1961 during the first inundation of the reservoir for flood control, slumping did occur. According to Eckerlin(1995), small slides such as this should be anticipated following initial inundation of the conservation pool to elevation 1177 feet. The effect of the slides would be localized, causing a negligible increase in outflow turbidity.

An area of the reservoir at the mouth of Charley Creek is prone to sliding. Slides in this area result from soil saturation during rainstorms. These slides have been occurring at this site for many years and are independent of the reservoir's existence. They will continue to occur for many more years. During large rainstorms, the sediment load entering the reservoir from the upstream area is so high that it would mask any turbidity due to a slide at Charley Creek. As such, sliding at Charley Creek has not impacted turbidity.

Increased turbidity that would affect water supply is that which occurs during the dry season when water is impounded. Charley Creek would not be expected to slide routinely during this period. During the initial inundation, however, there could be some temporary suspension of material. This material would settle out of the water column and would be diluted as water is exchanged. Due to the high water elevation, water would be backed up into the North Fork Green River. The City's North Fork well field would be well recharged. The impact of such a slide could be that the City would need to pump water to mix with reservoir outflow for several days. This type of slide is not expected during subsequent inundation.

During operation of the reservoir for flood control, the pool elevation rises and falls within a relatively short period of time. The reservoir elevation has risen above 1150 feet on five occasions, most recently in February 1996. Slides did occur in the recent flood event of late Fall 1996, although there were no lasting effects on reservoir turbidity.

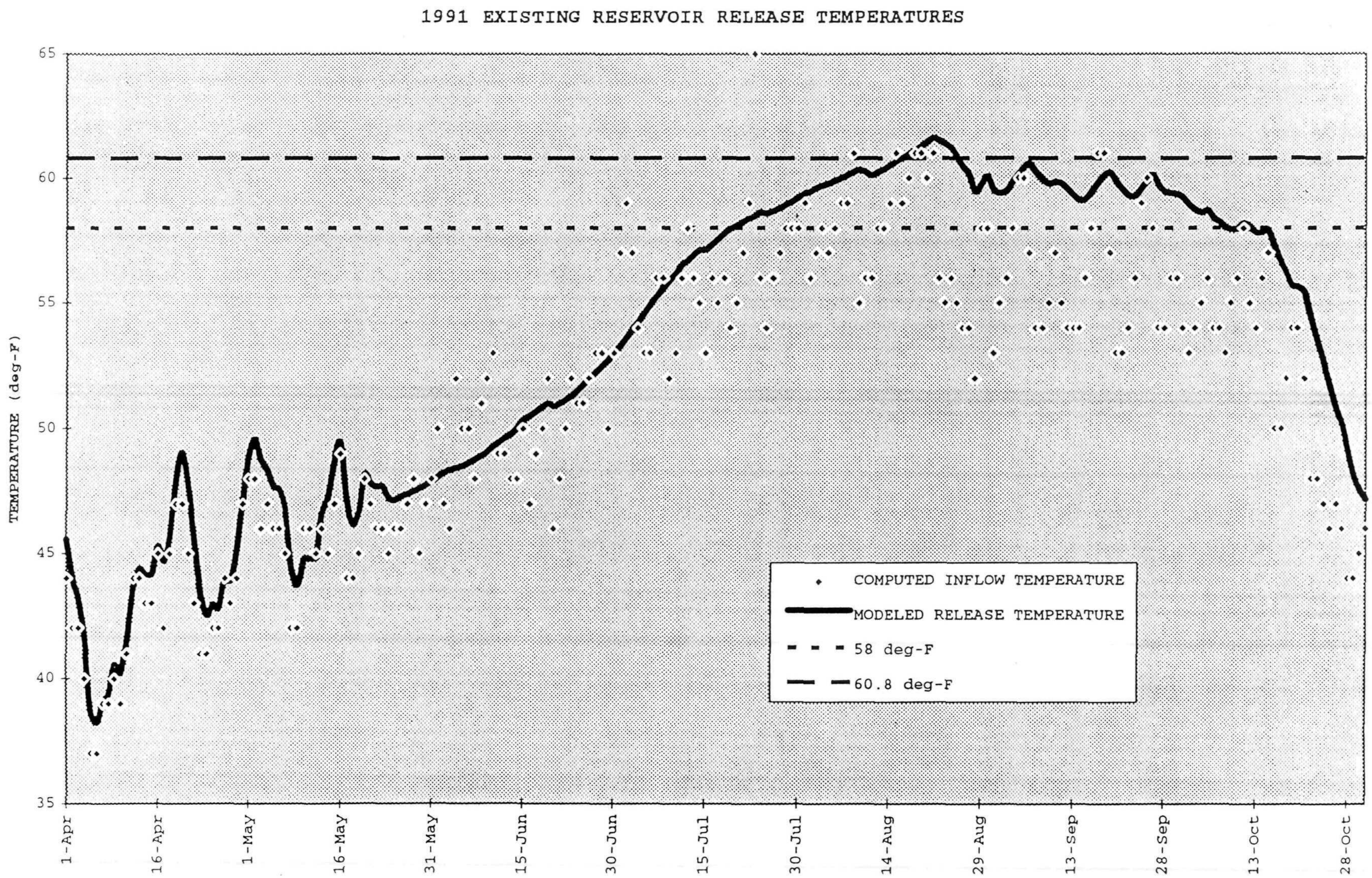
2.8 CONCLUSIONS OF TURBIDITY ANALYSIS

The proposed additional storage project would begin the spring refill period 5-6 weeks earlier than current operation of the reservoir, increasing the likelihood of storing water from high turbidity events. Historic records show that March inflow turbidity is no higher than April inflow turbidity and that suspended sediments tend to settle from the water column within a few days. Under the proposed project, high turbidity flows stored in the reservoir would be more frequent, however, the effect on outflow turbidity would be minor and short-lived, no different than under current operation. Refill strategy should not be modified if more turbid water enters the reservoir as settling and flushing will clear the water.

The proposed project would cause small and localized bank instability during initial inundation of the conservation pool resulting in insignificant effects on turbidity (Eckerlin, October 1995). The reservoir has recently filled for flood control to the elevation of the proposed conservation pool with only temporary impacts to outflow turbidity.

Removal of trees is expected prior to inundation of the first proposed conservation pool. This may decrease bank stability and should be reconsidered.

SECTION 3 MODELED HISTORIC RELEASE TEMPERATURES


1991 EXISTING RESERVOIR RELEASE TEMPERATURES
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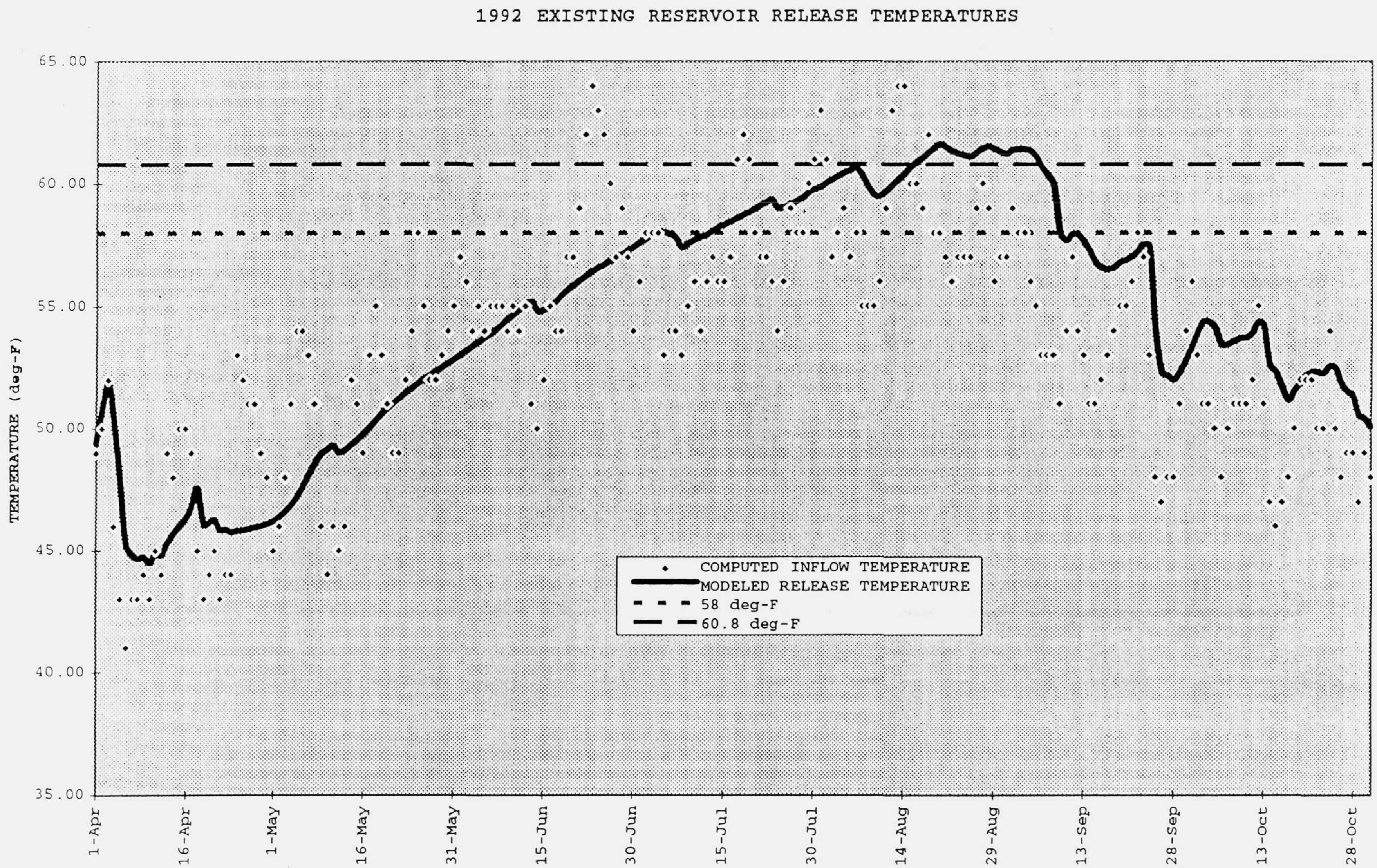
60
55
50
45
40
35
1-Apr
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMPERATURE
MODELED RELEASE TEMPERATURE
58 deg-F
60.8 deg-F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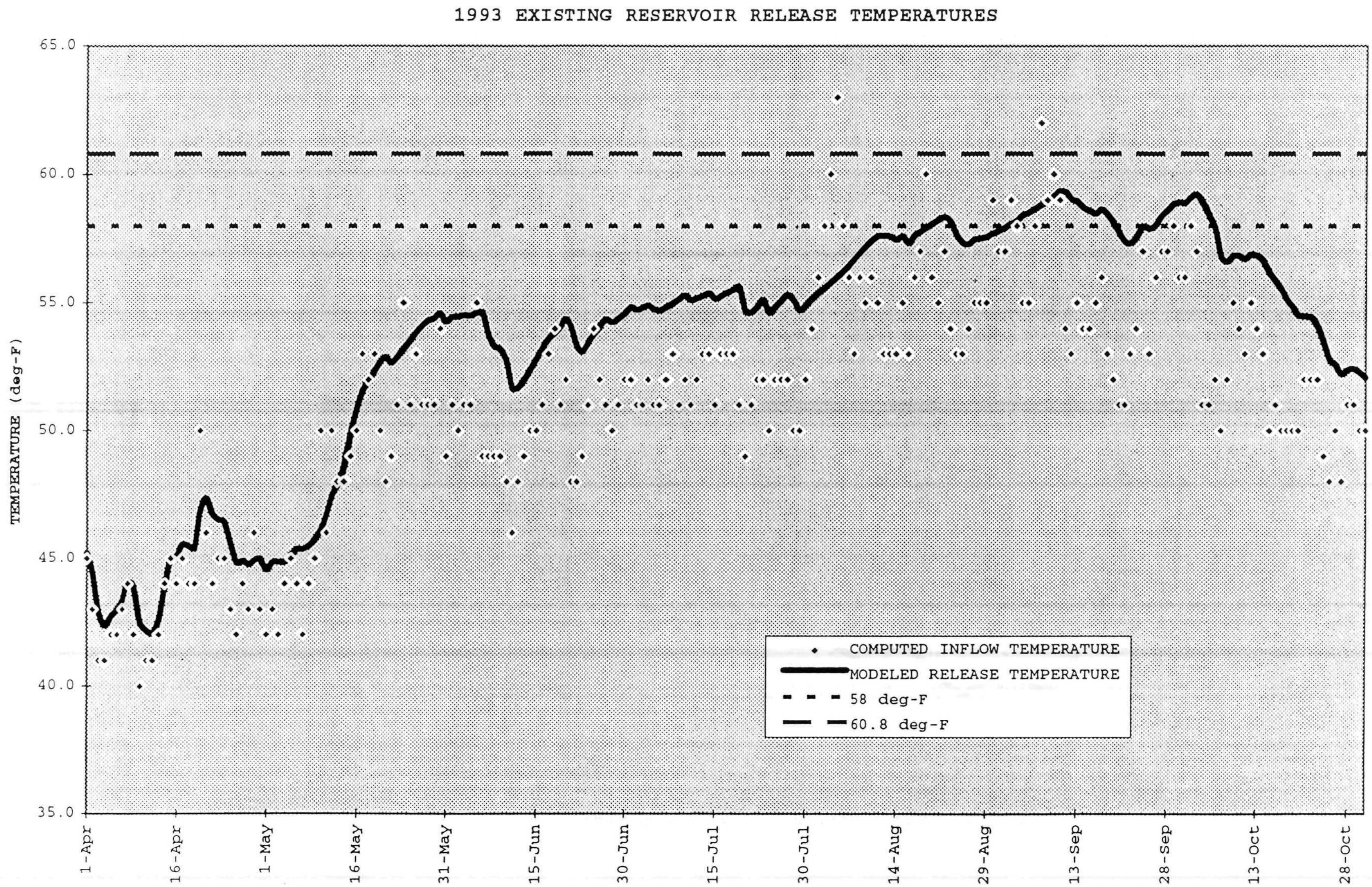
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15-Jul
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MODELED RELEASE TEMPERATURE
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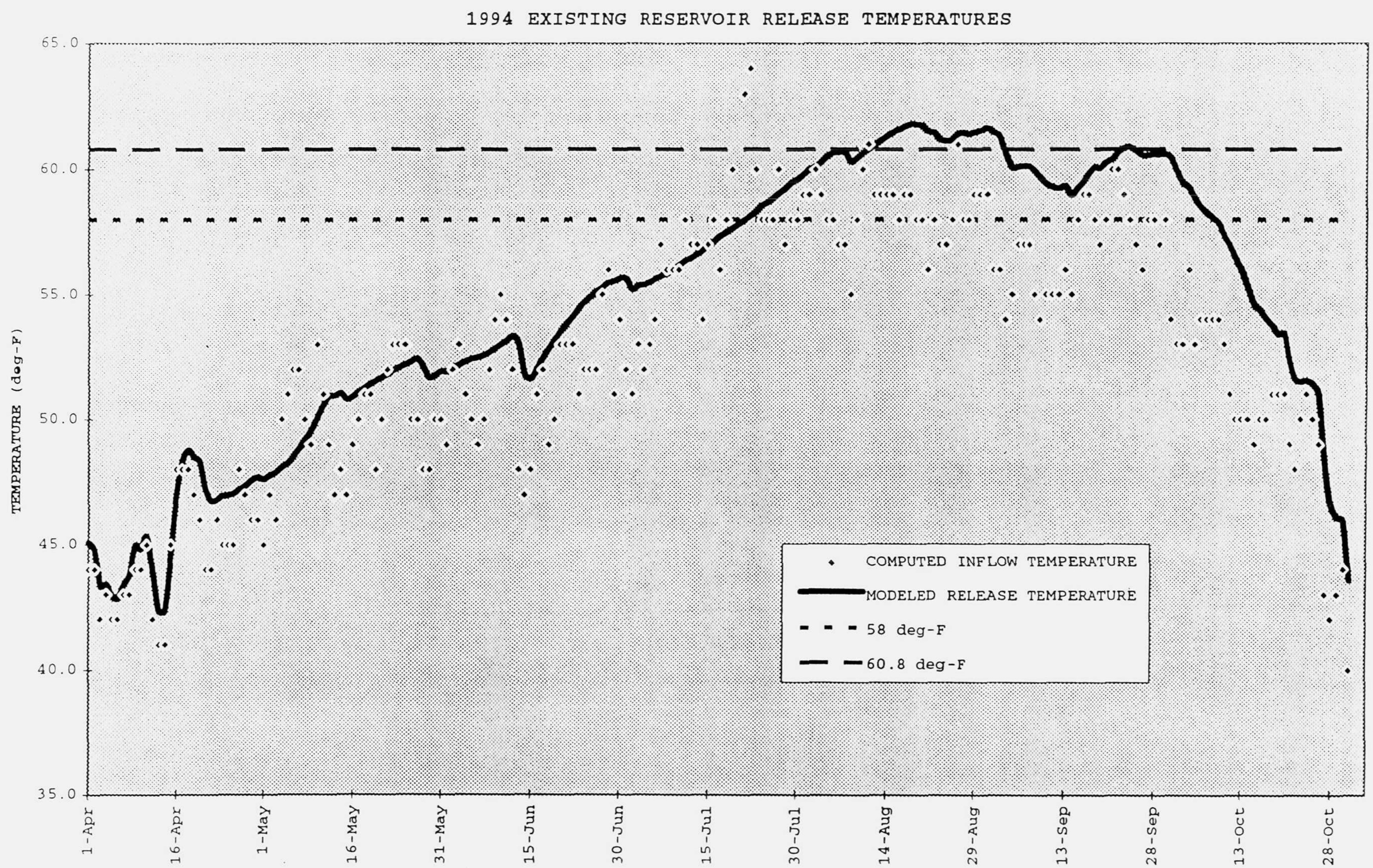
60.8 deg-F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16-Apr
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16-May
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15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMPERATURE
MODELED RELEASE TEMPERATURE
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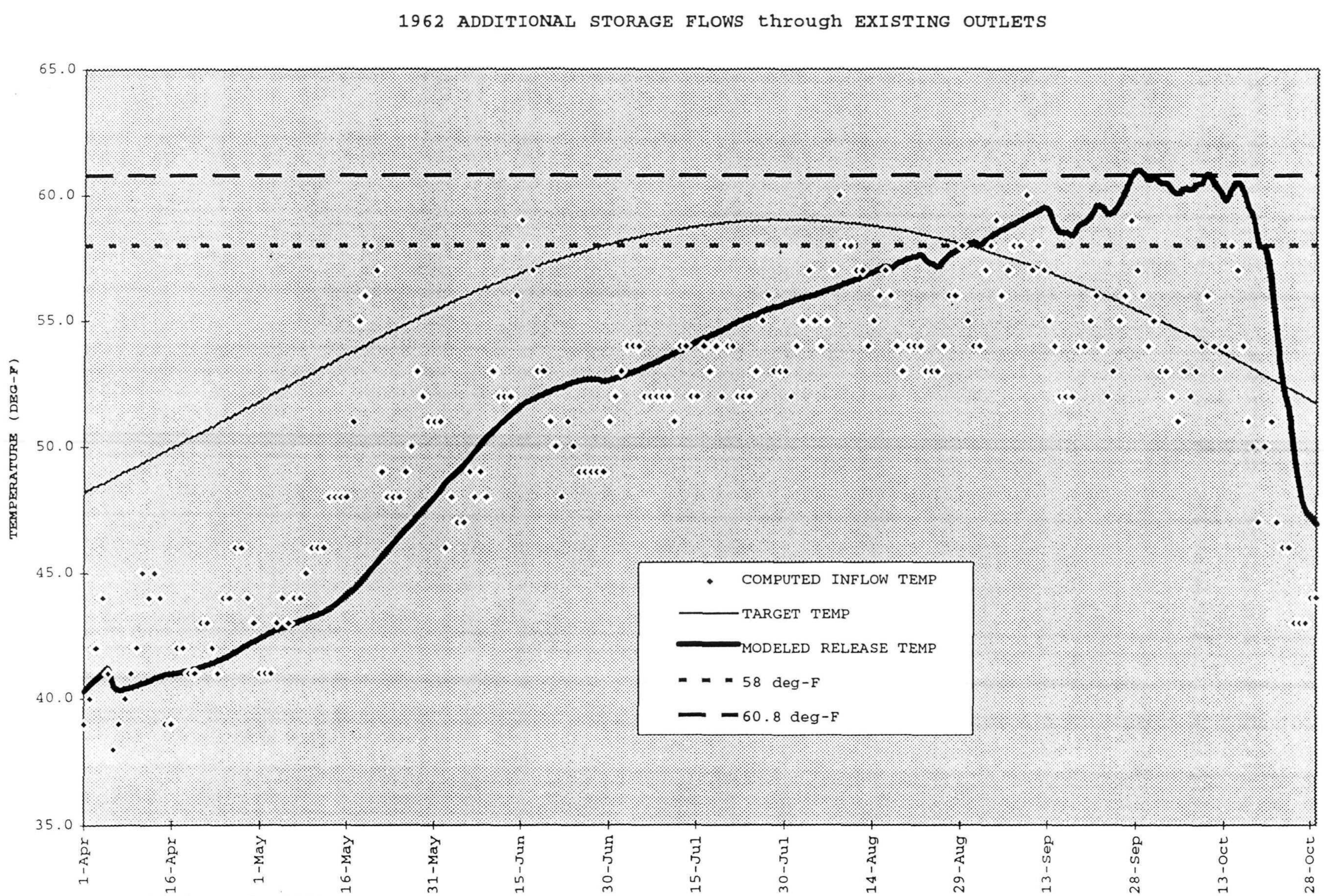
60.8 deg-F

SECTION 4 RELEASE TEMPERATURES OF PROPOSED ADDITIONAL STORAGE FLOWS MODELED WITH EXISTING OUTLETS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15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
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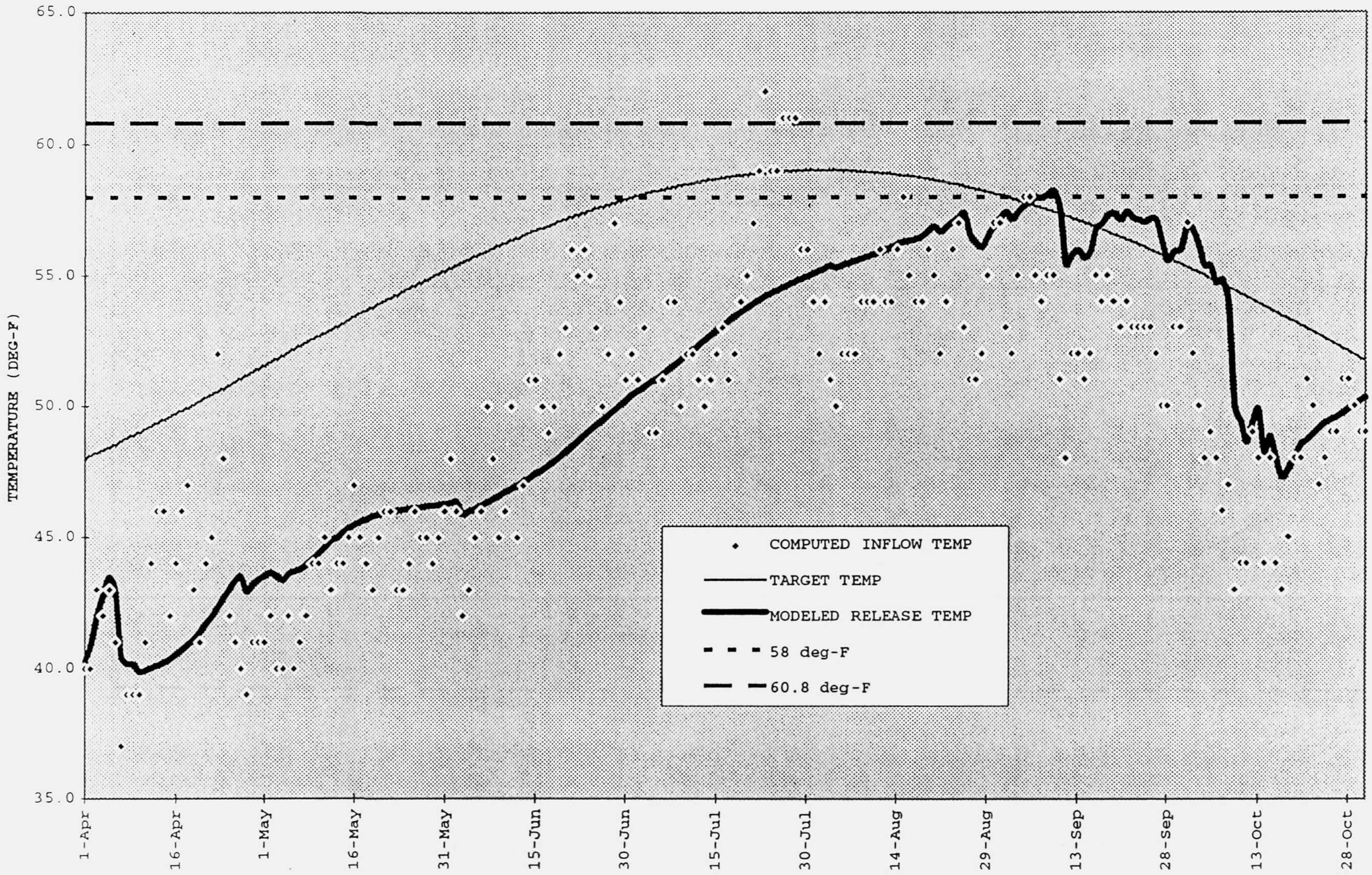
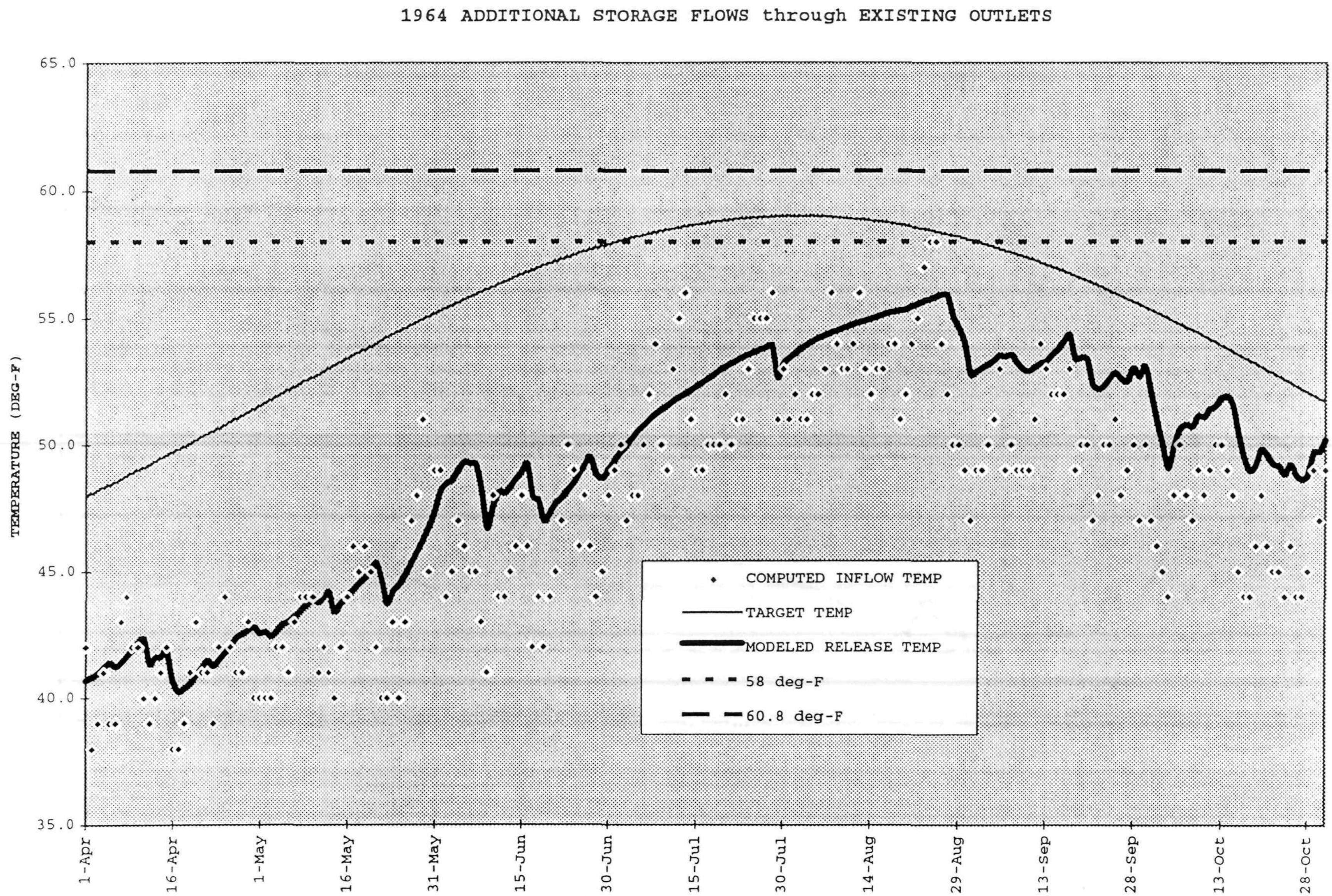
60.8 deg-F

1963 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS




1964 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS
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40.0
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15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
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TARGET TEMP
MODELED RELEASE TEMP
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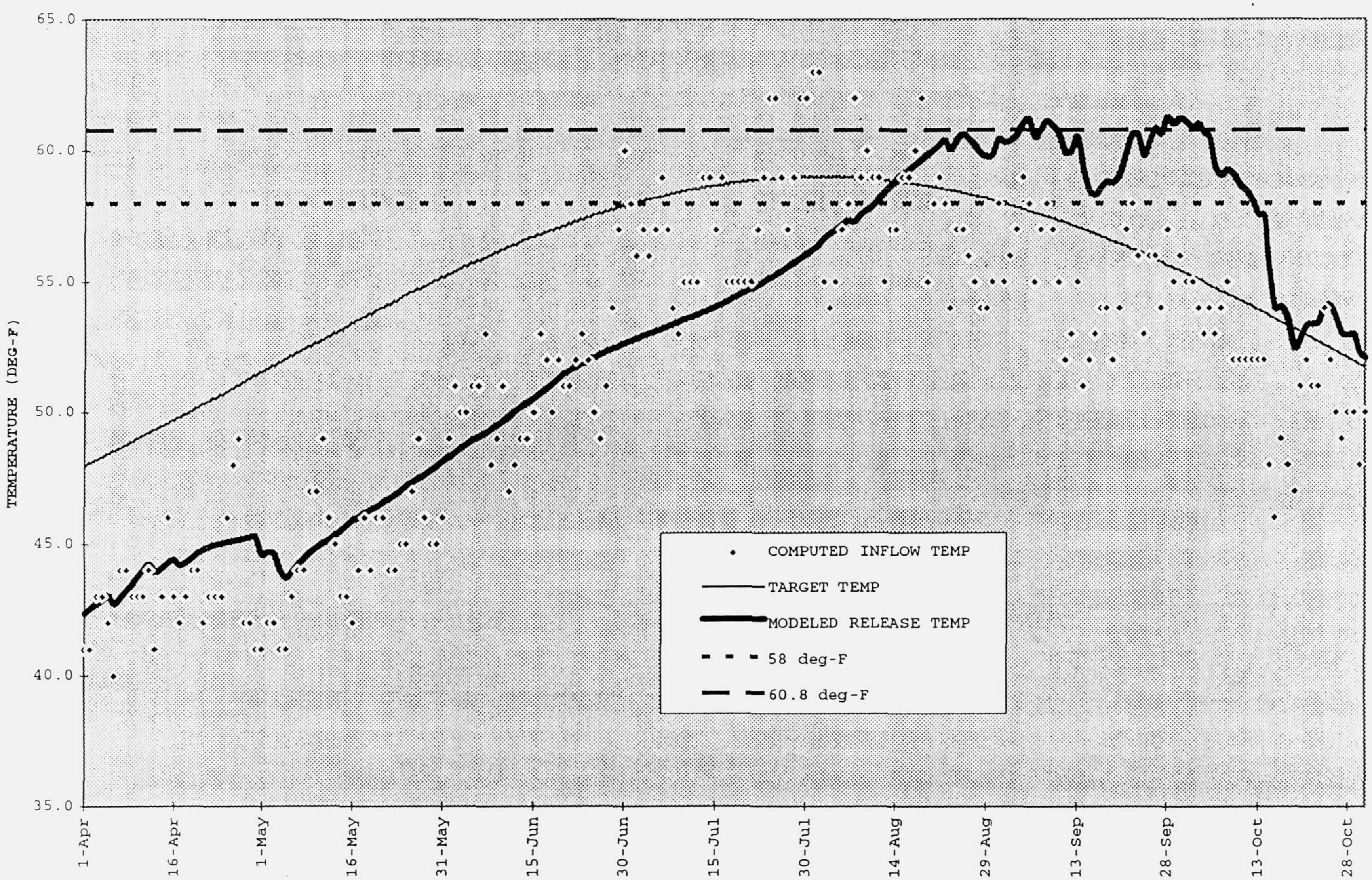

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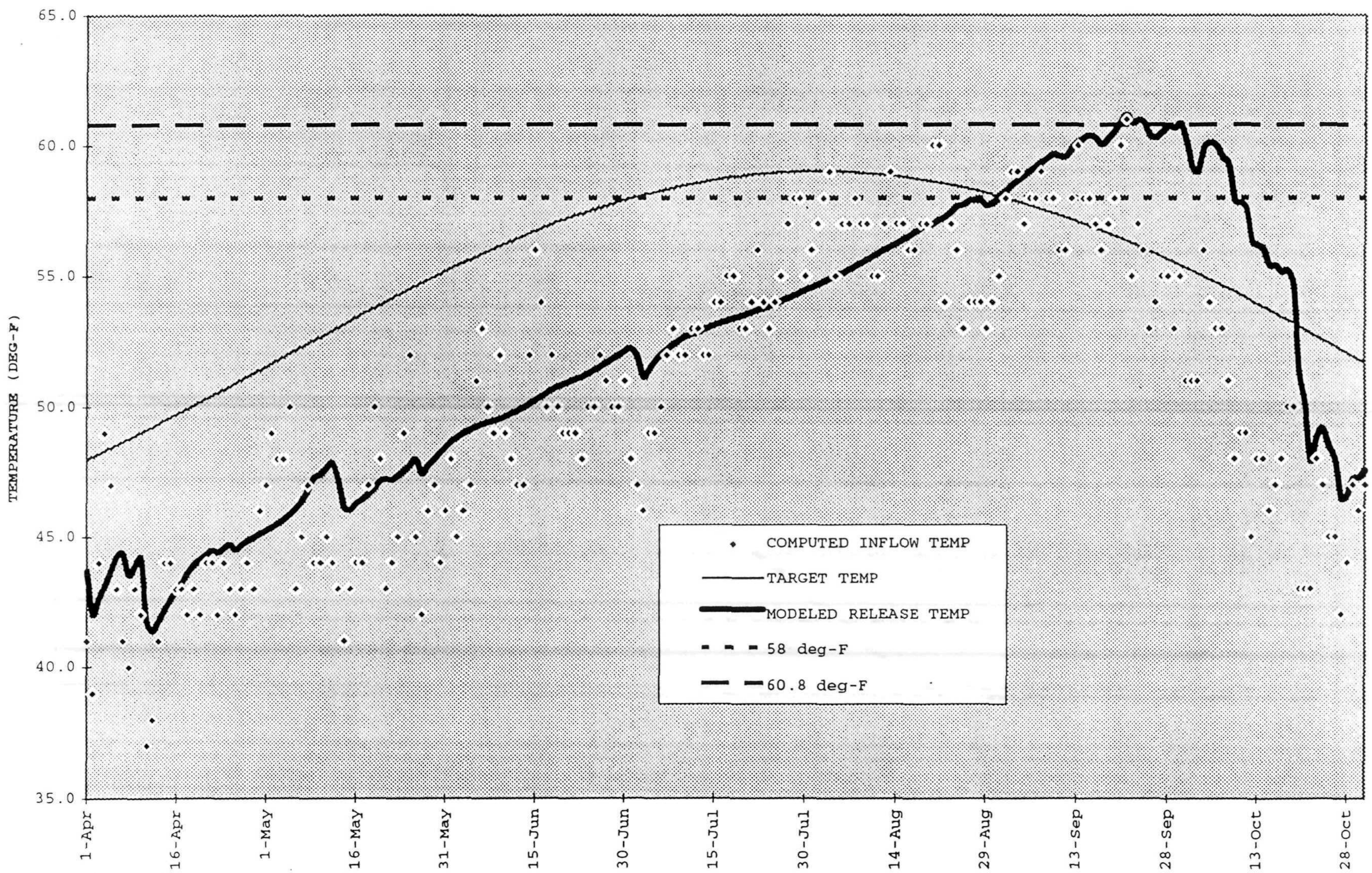

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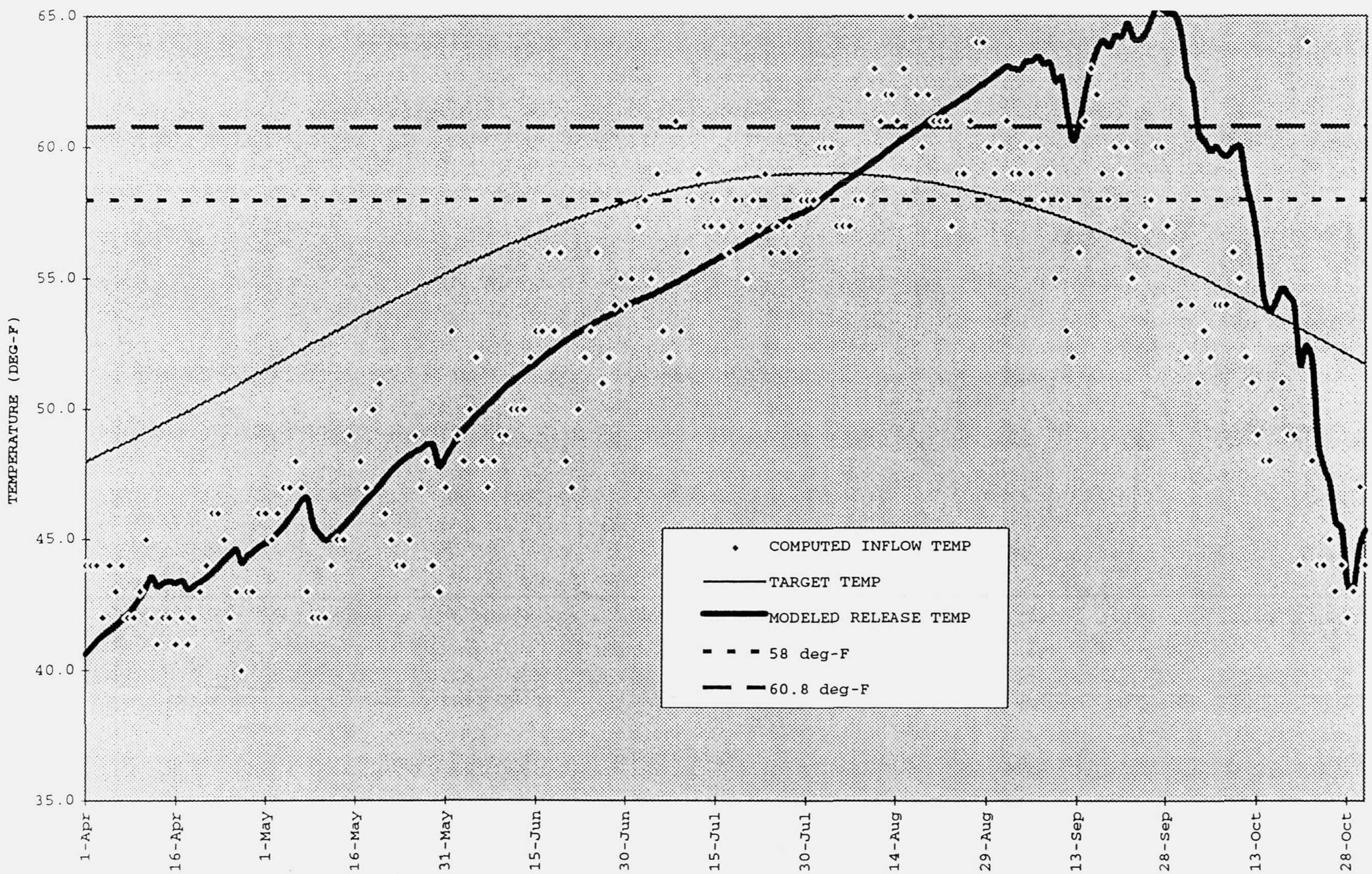

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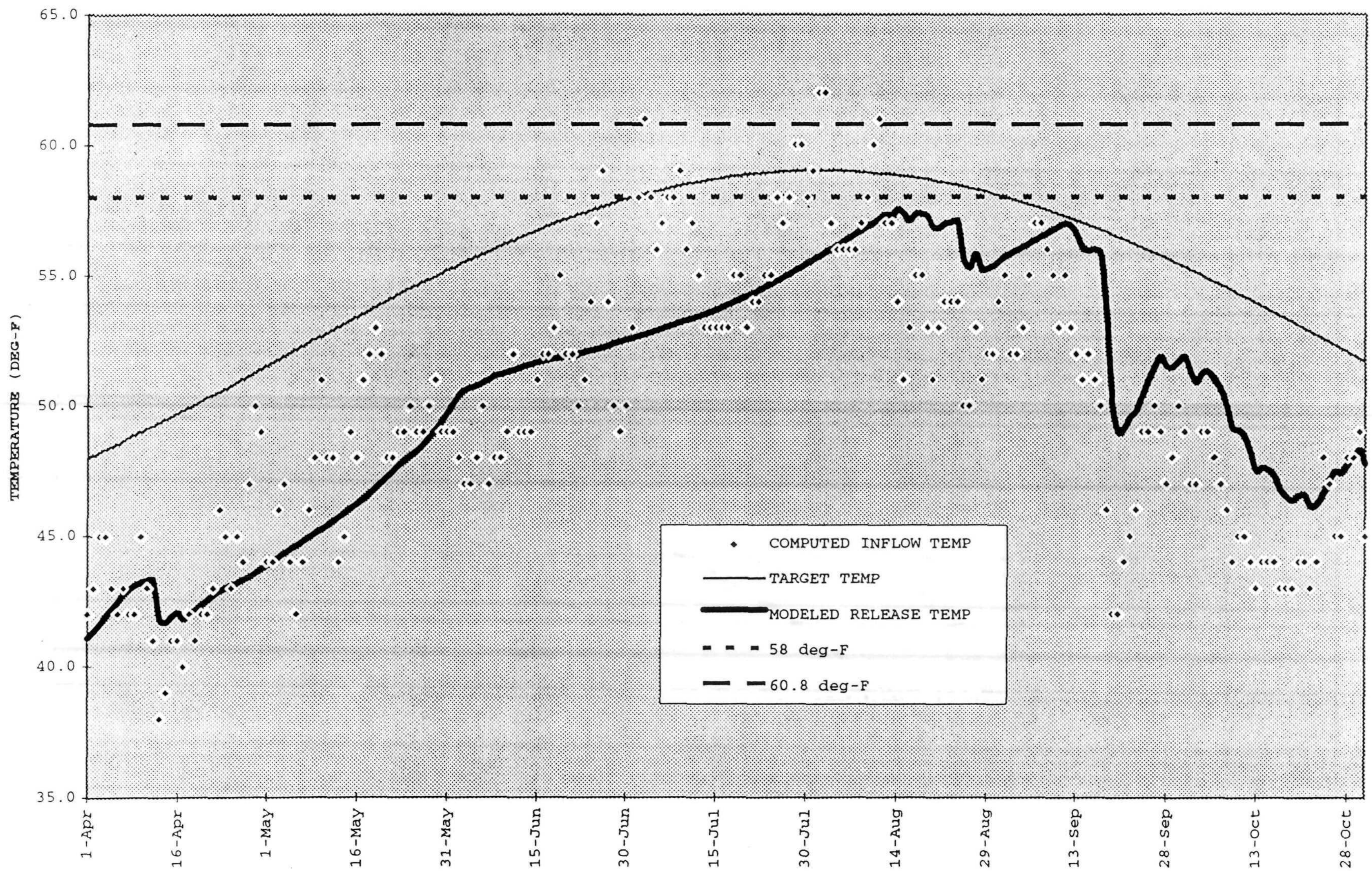
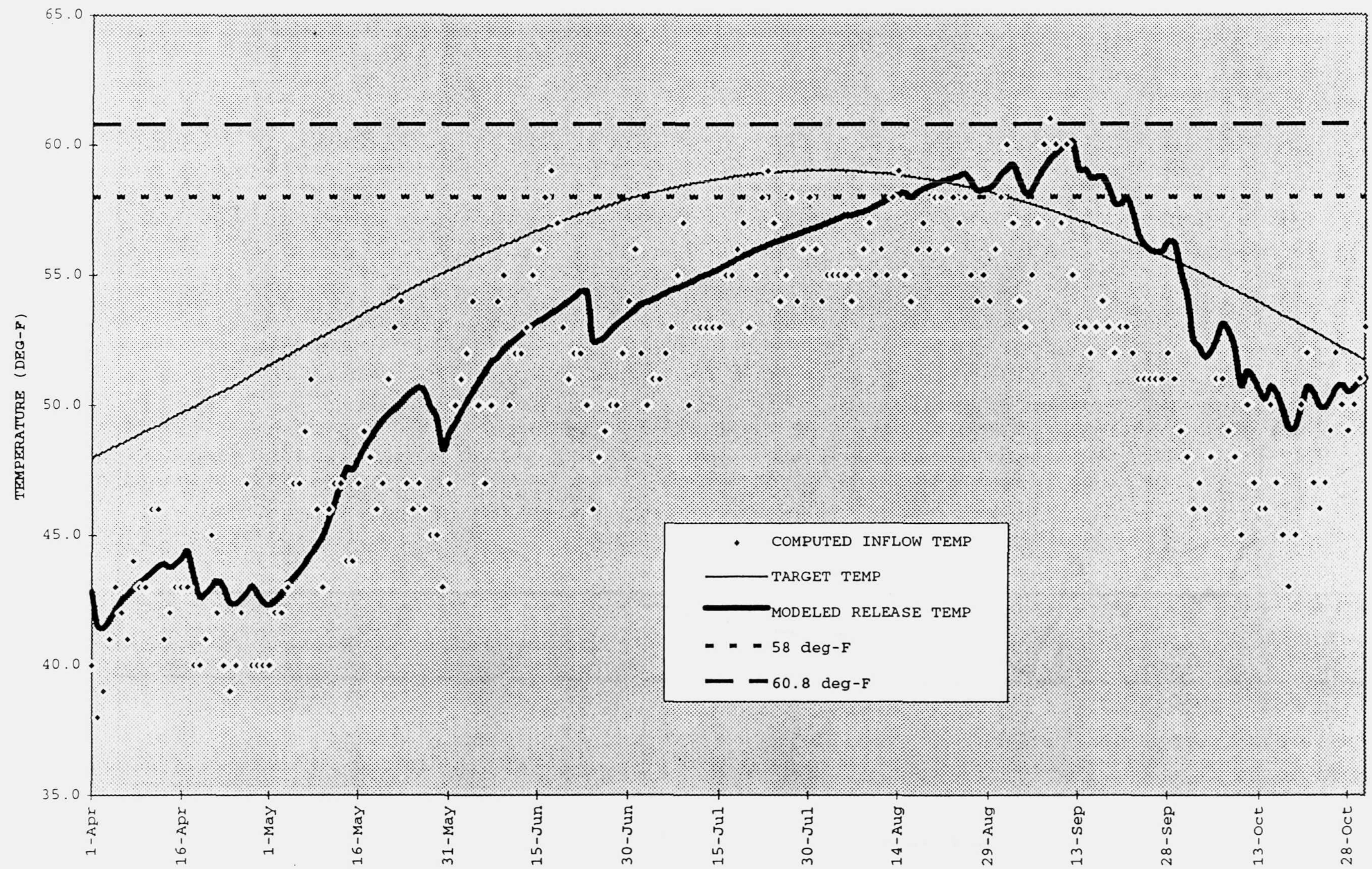
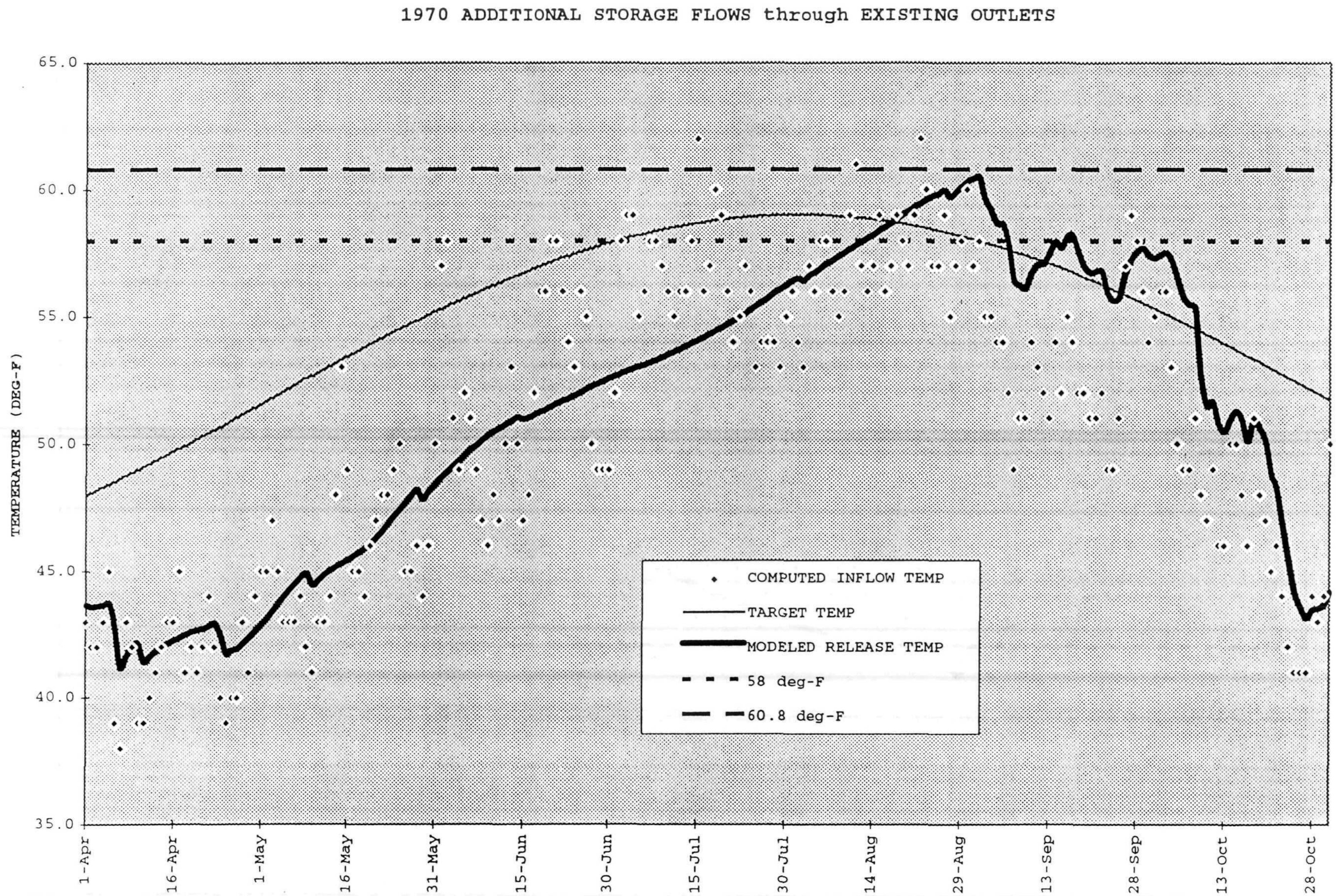
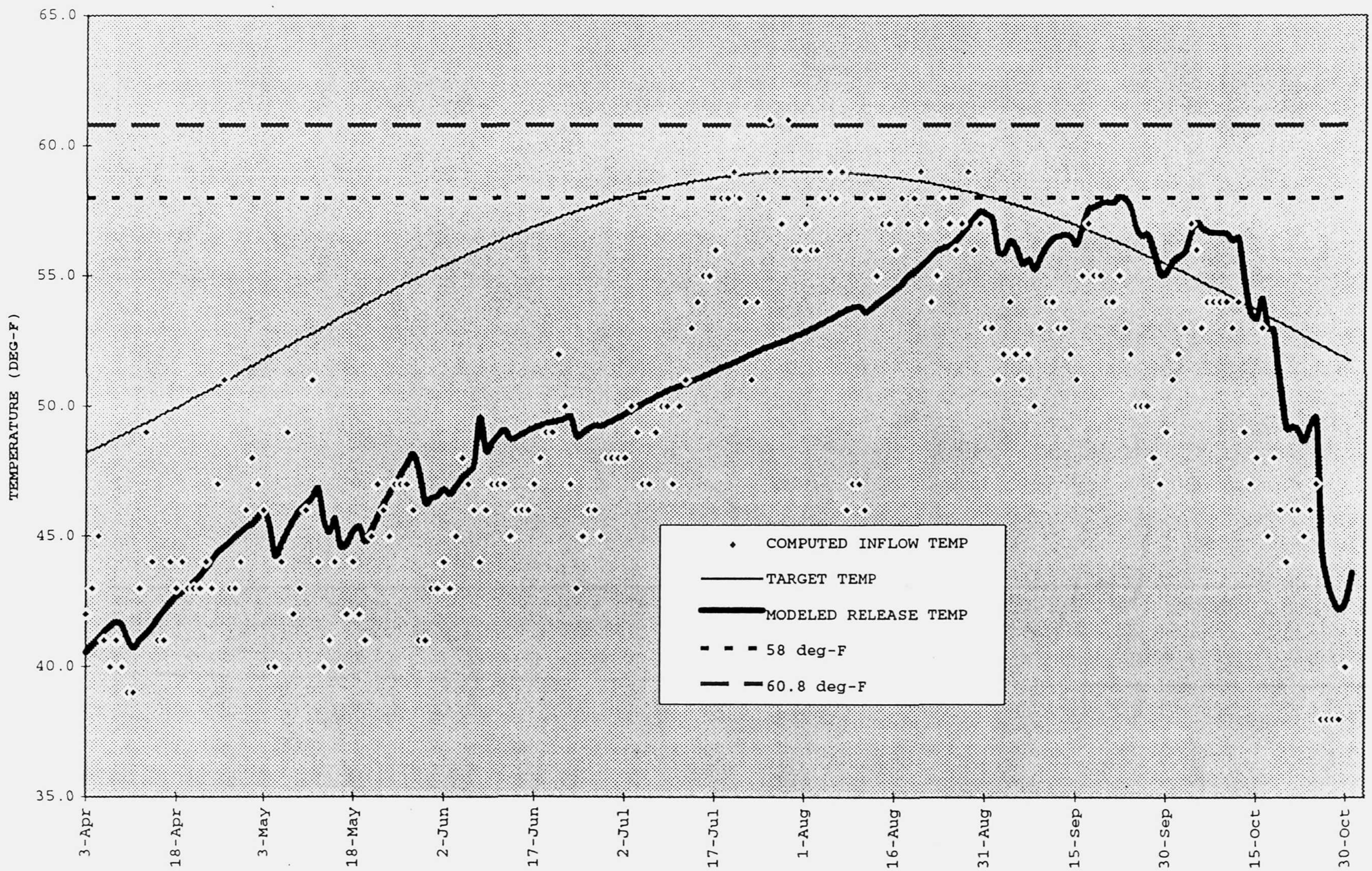


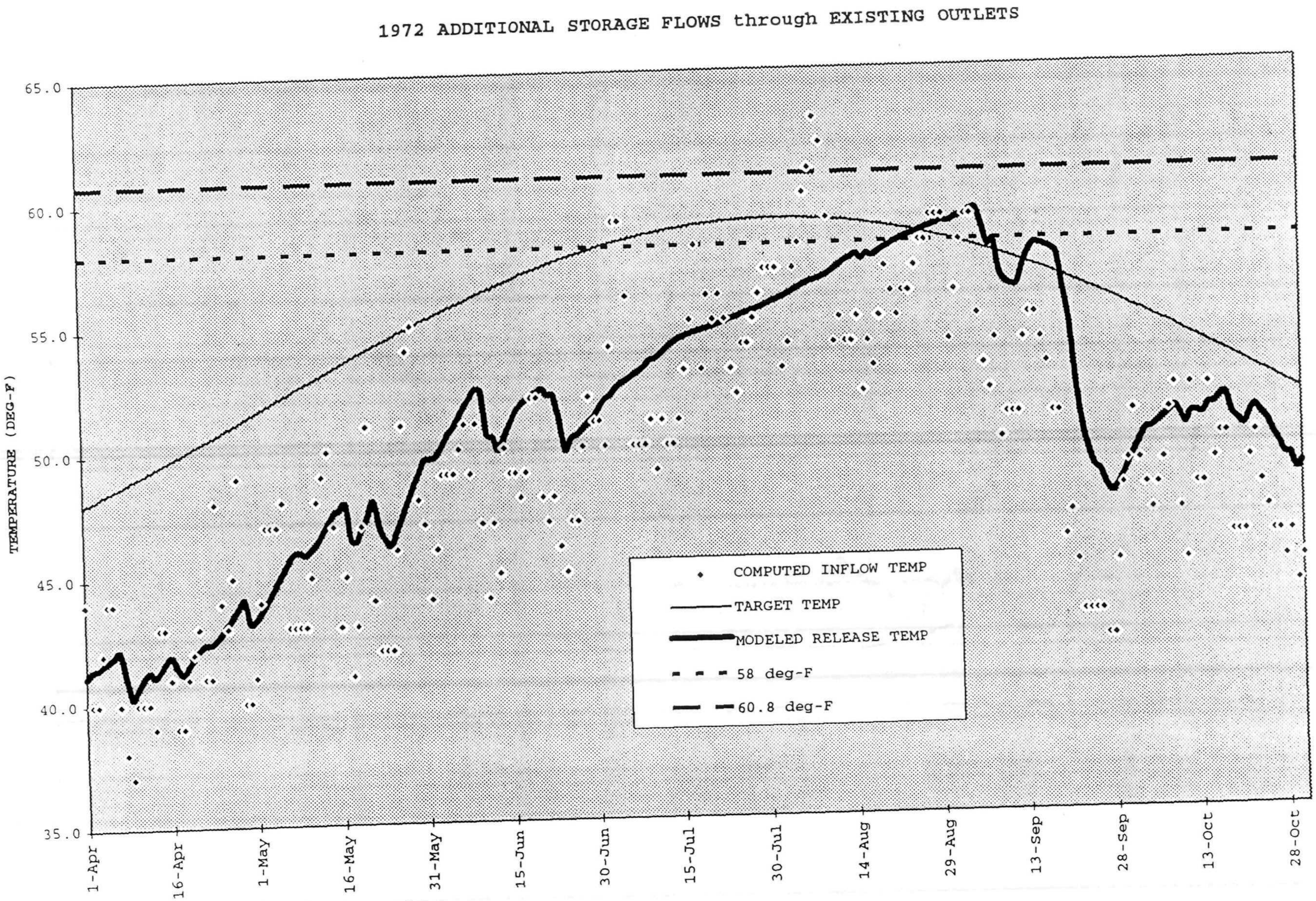
1969 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS



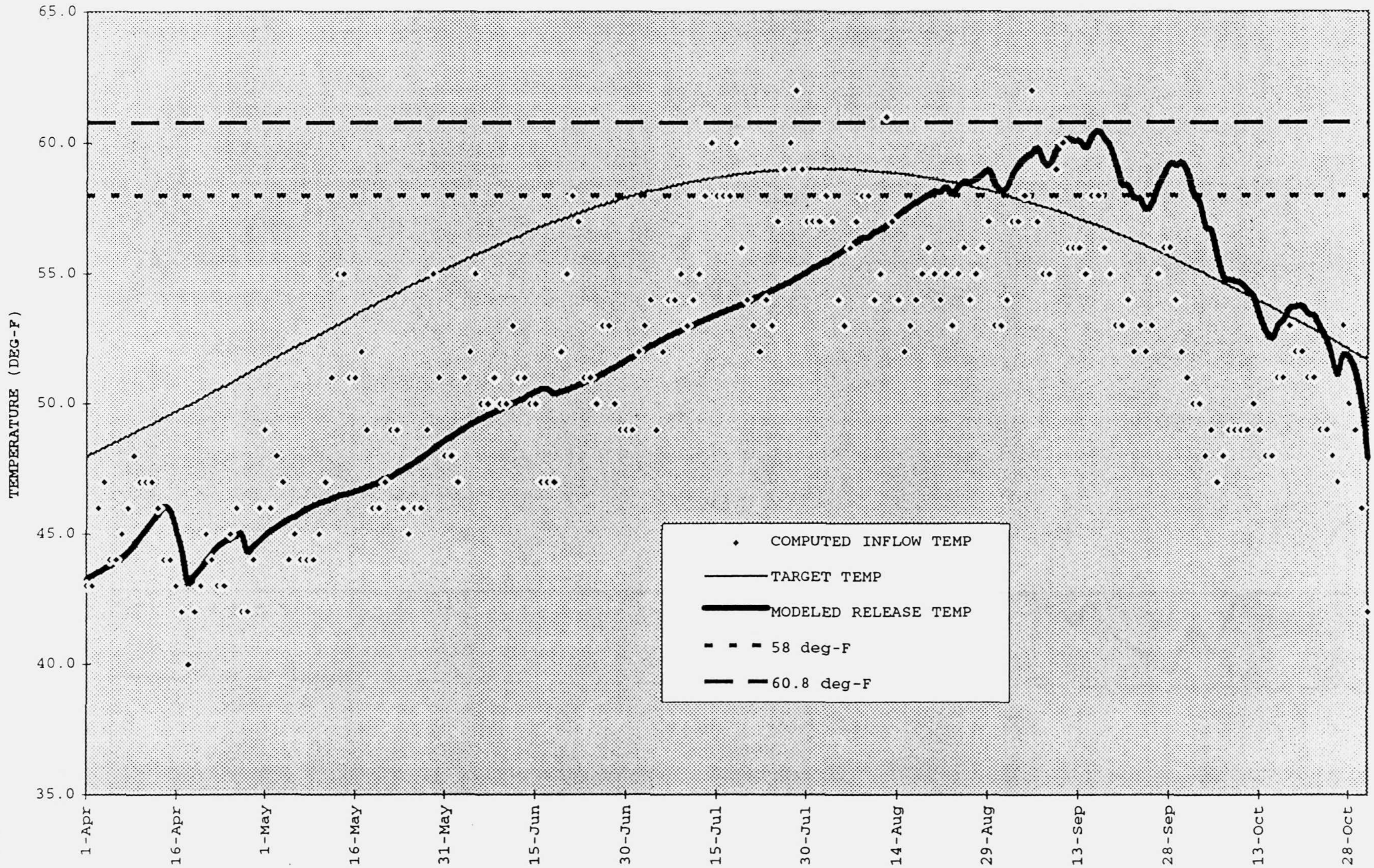

1970 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS
TEMPERATURE (DEG-F)
65.0
60.0
55.0
50.0
45.0
40.0
35.0
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F
1-Apr
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct

1971 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS

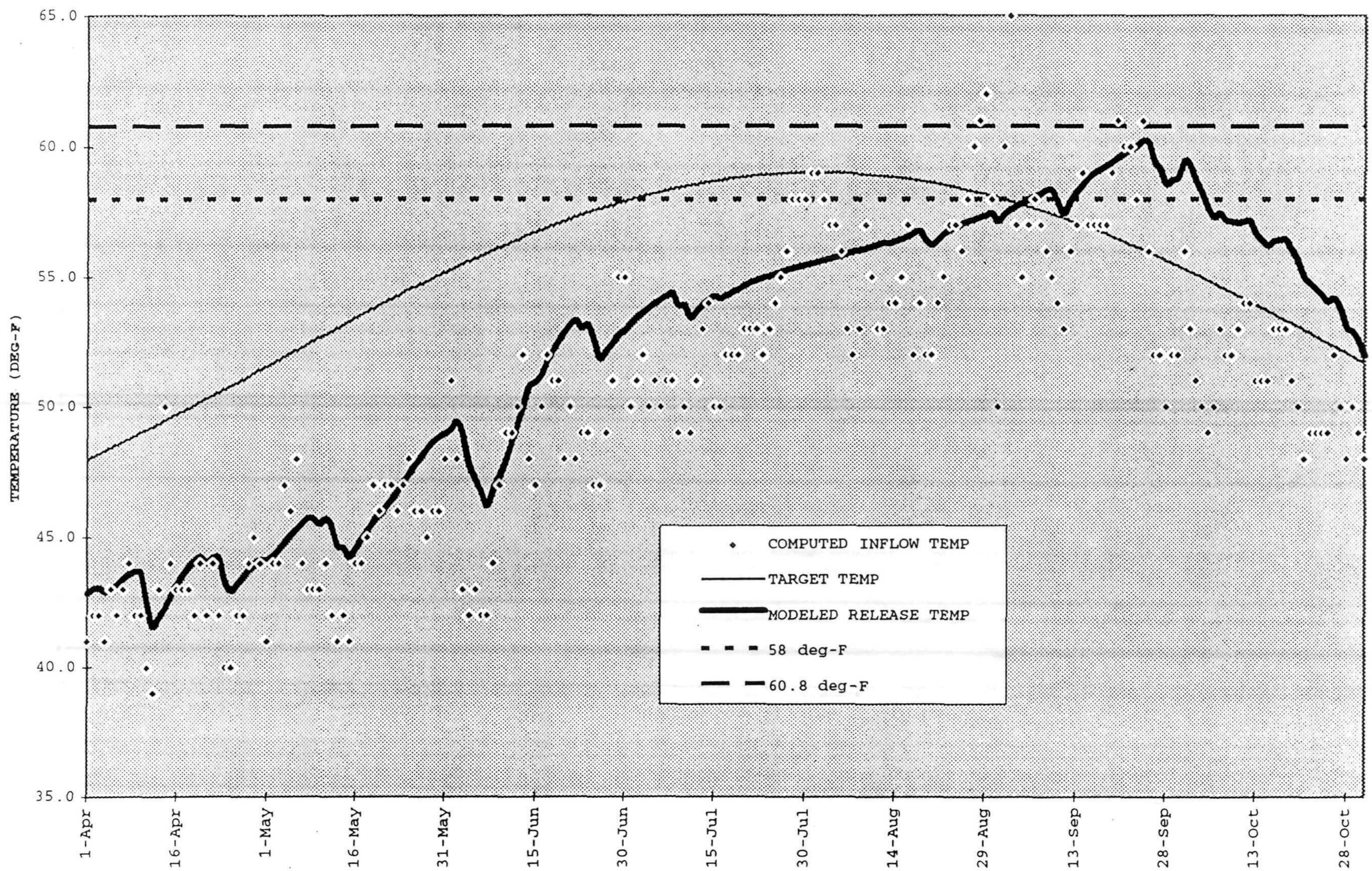



1972 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS
TEMPERATURE (DEG-F)
65.0
60.0
55.0
50.0
45.0
40.0
35.0
1-Apr
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F

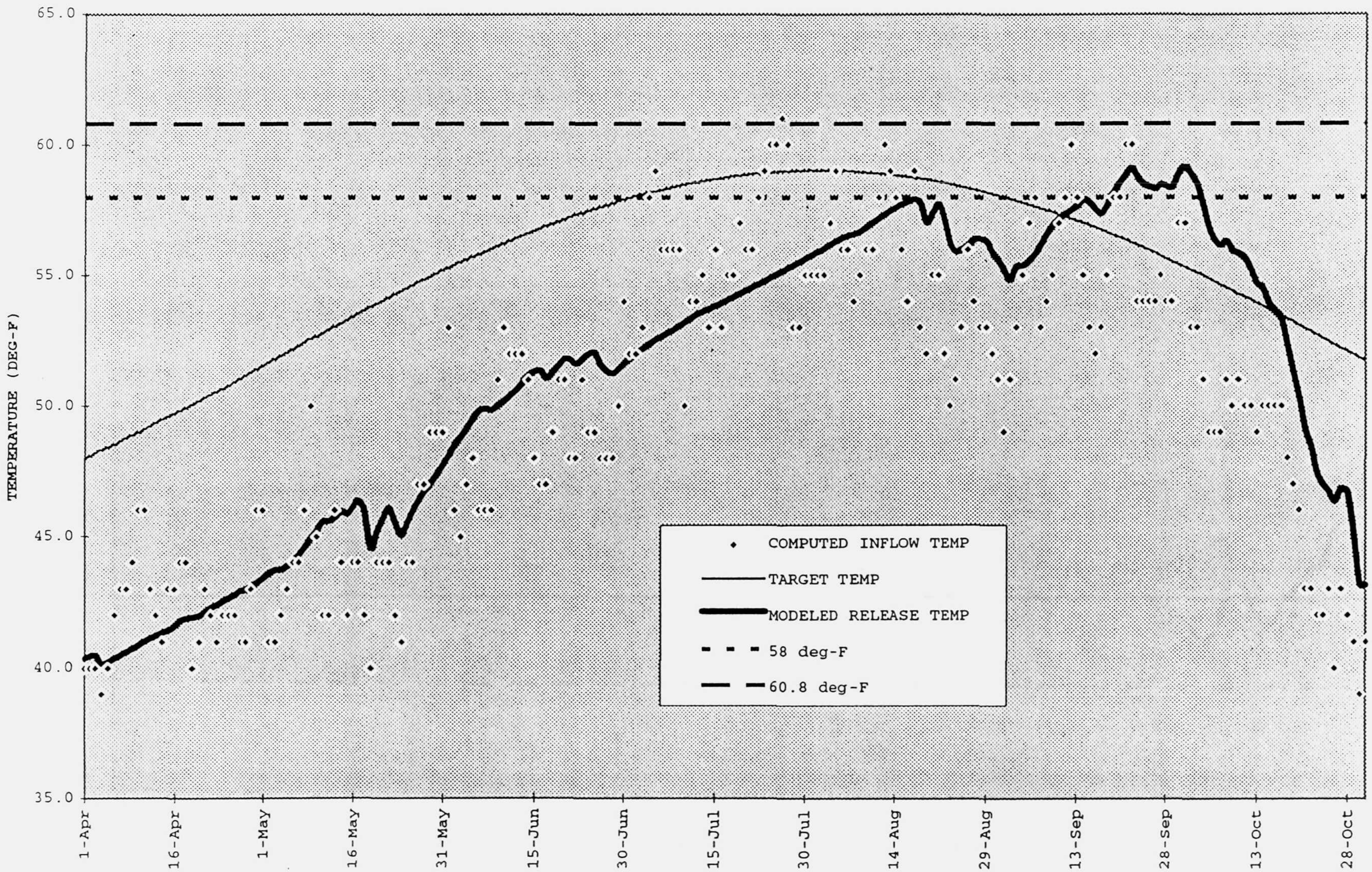
1973 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS

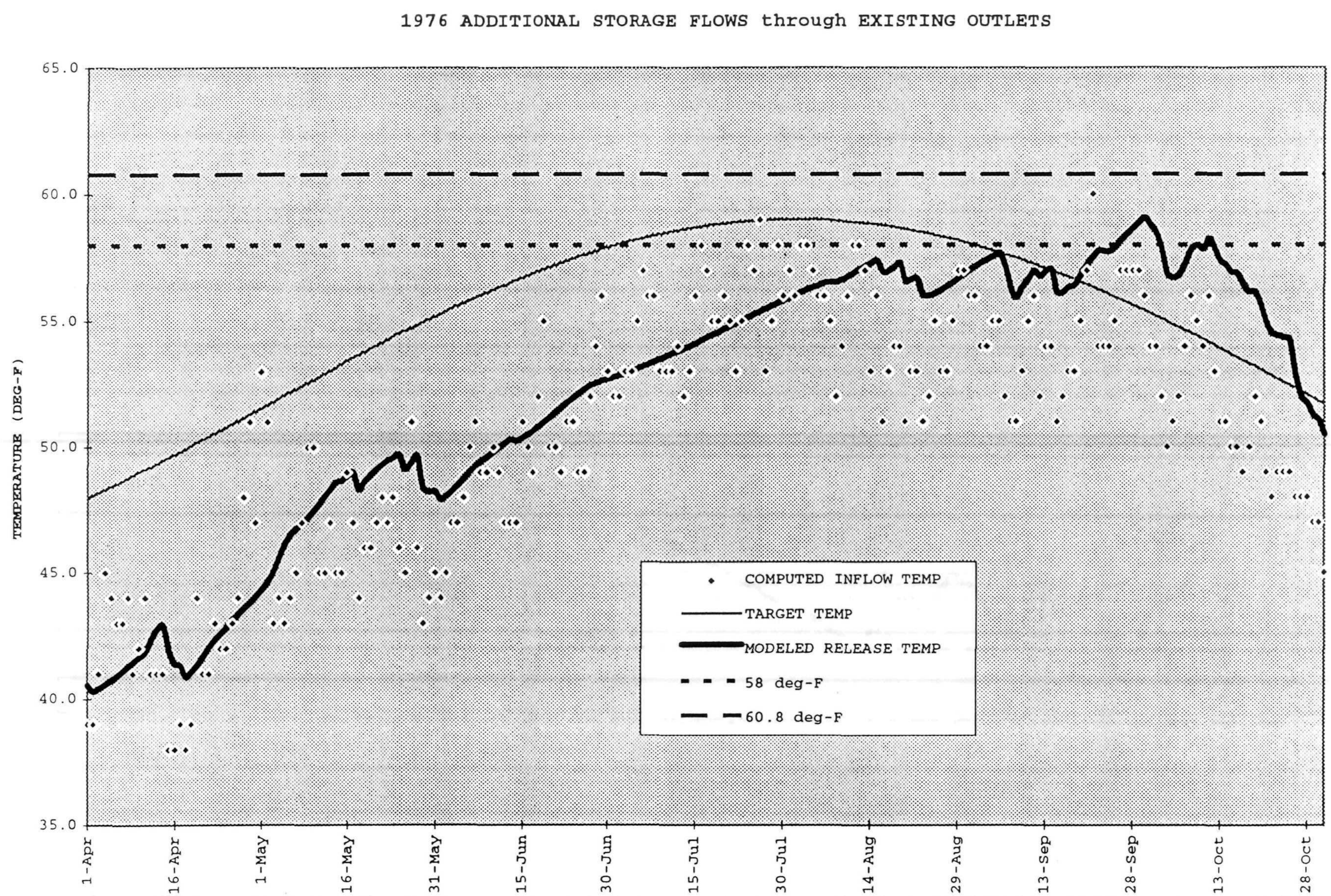


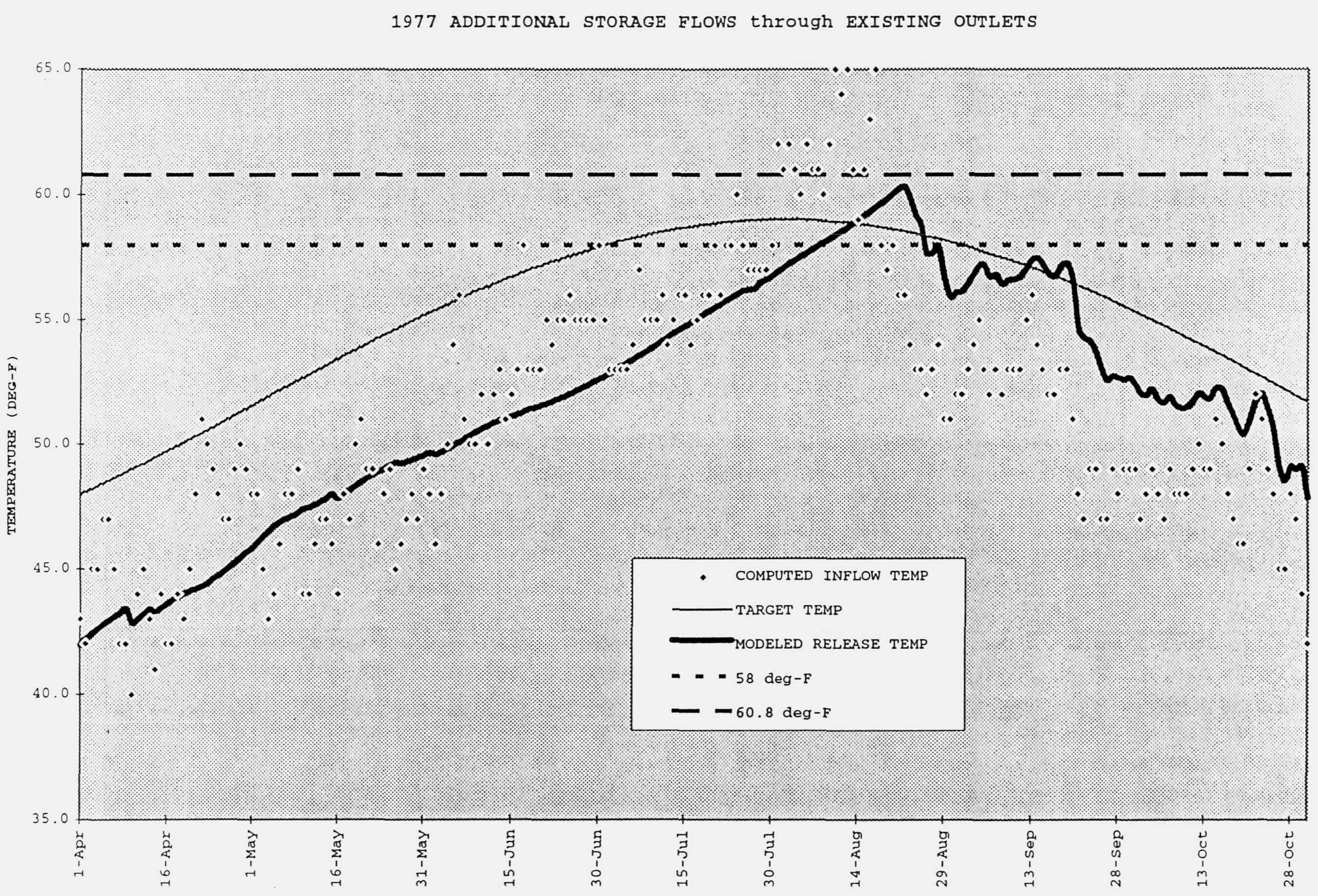
1974 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS



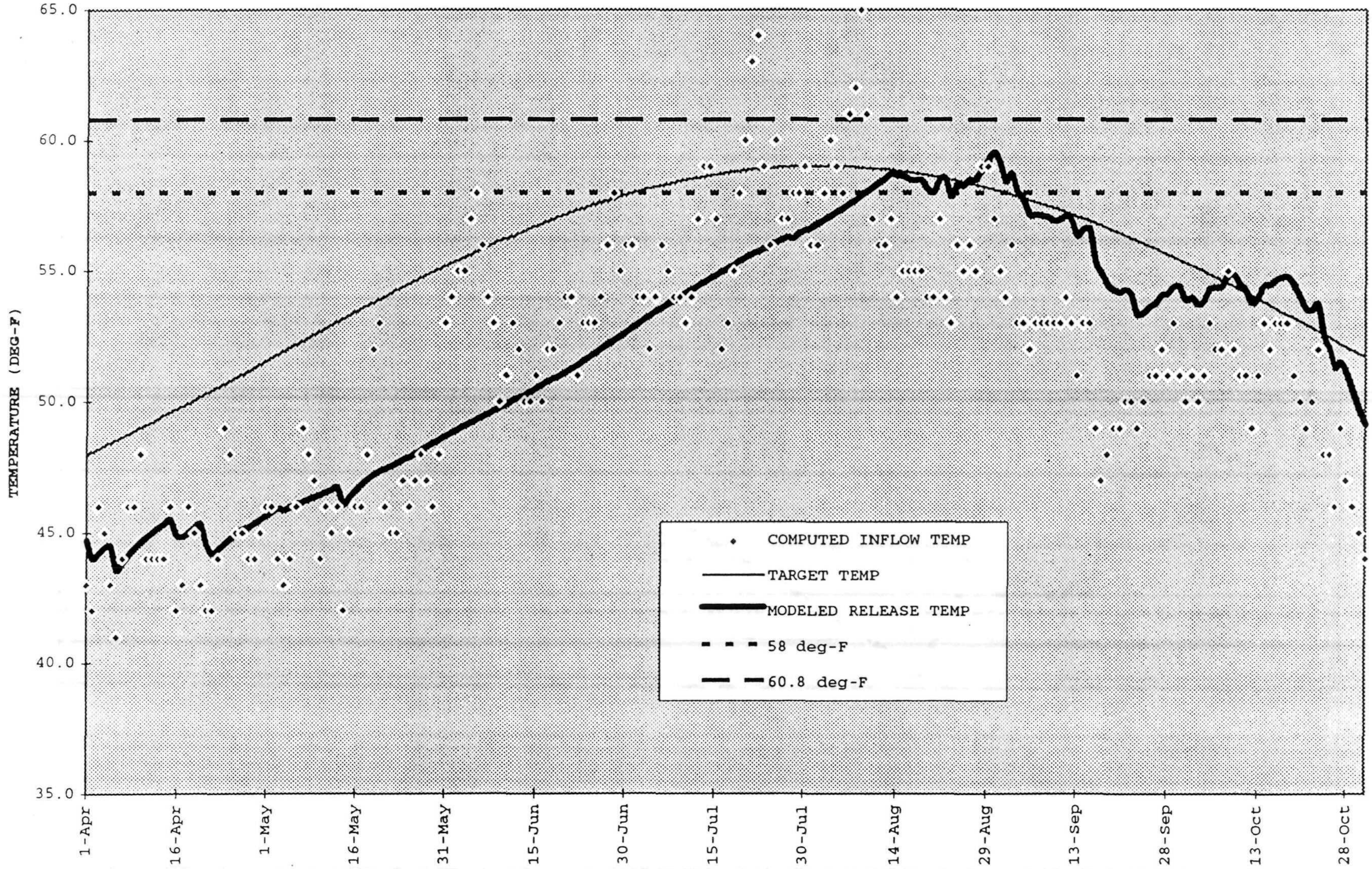
1975 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS

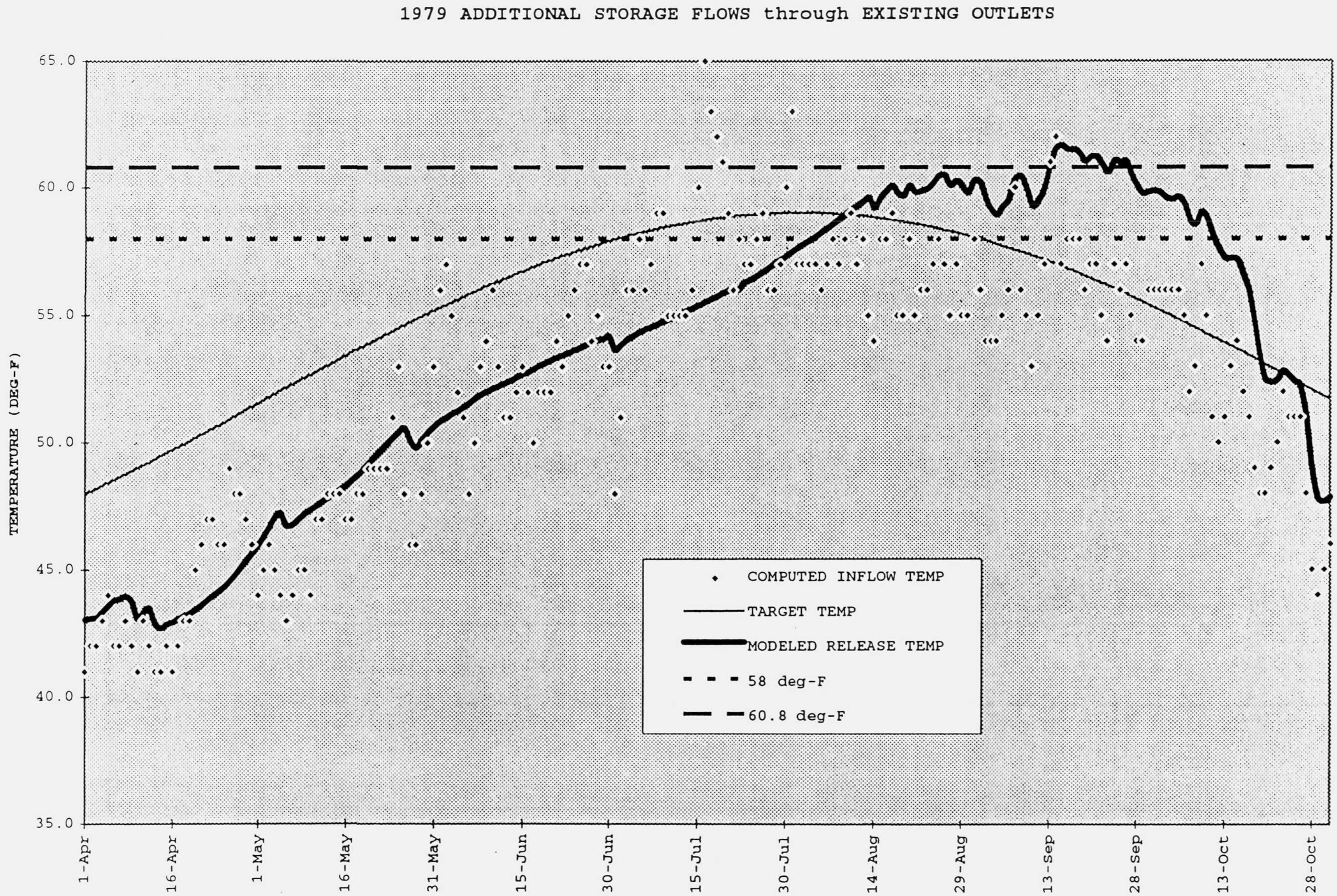



1976 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS
TEMPERATURE (DEG-F)
65.0
60.0
55.0
50.0
45.0
40.0
35.0
1-Apr
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F

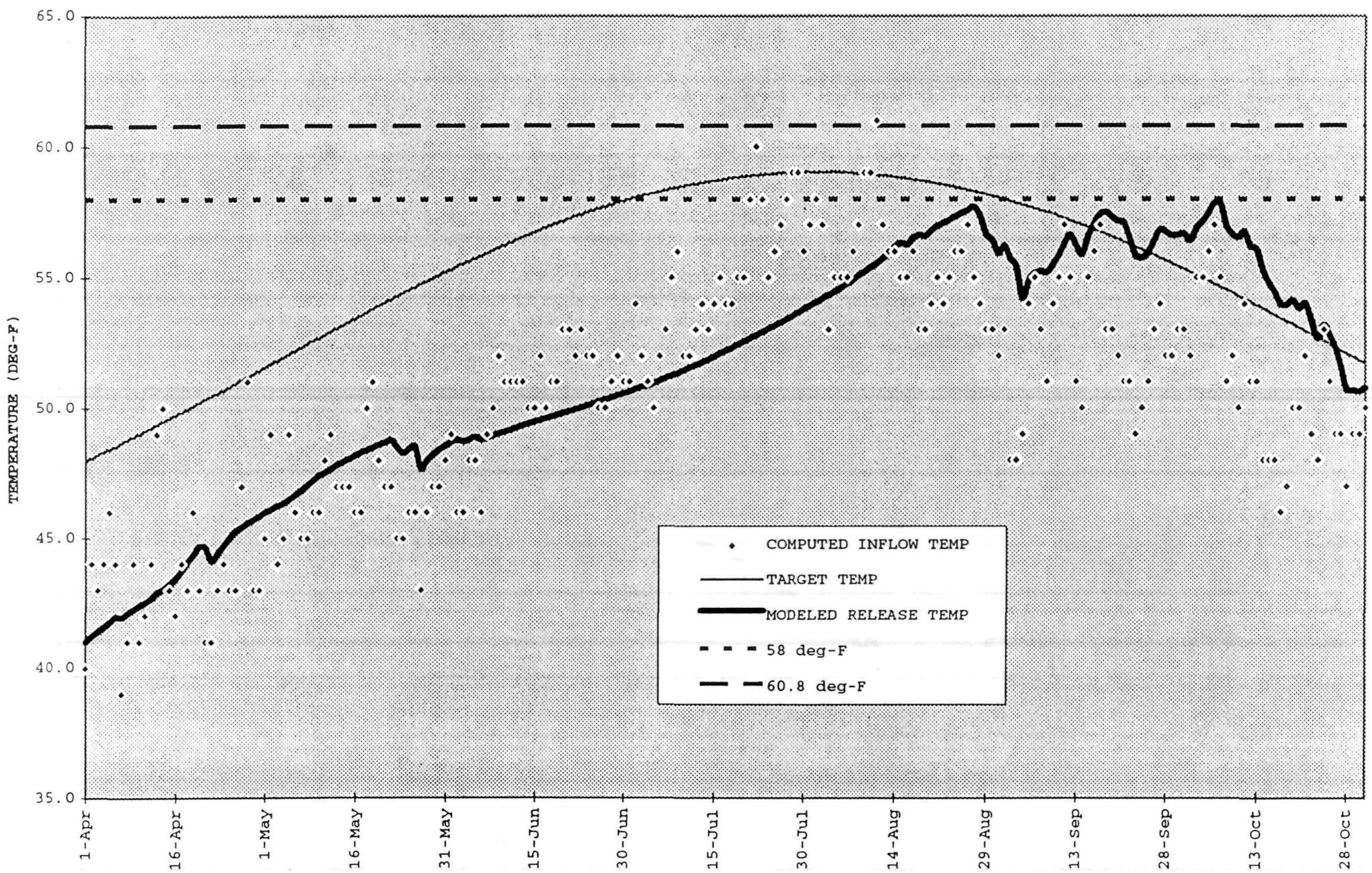

1977 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS
TEMPERATURE (DEG-F)
65.0
60.0
55.0
50.0
45.0
40.0
35.0
1-Apr
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F

1978 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS

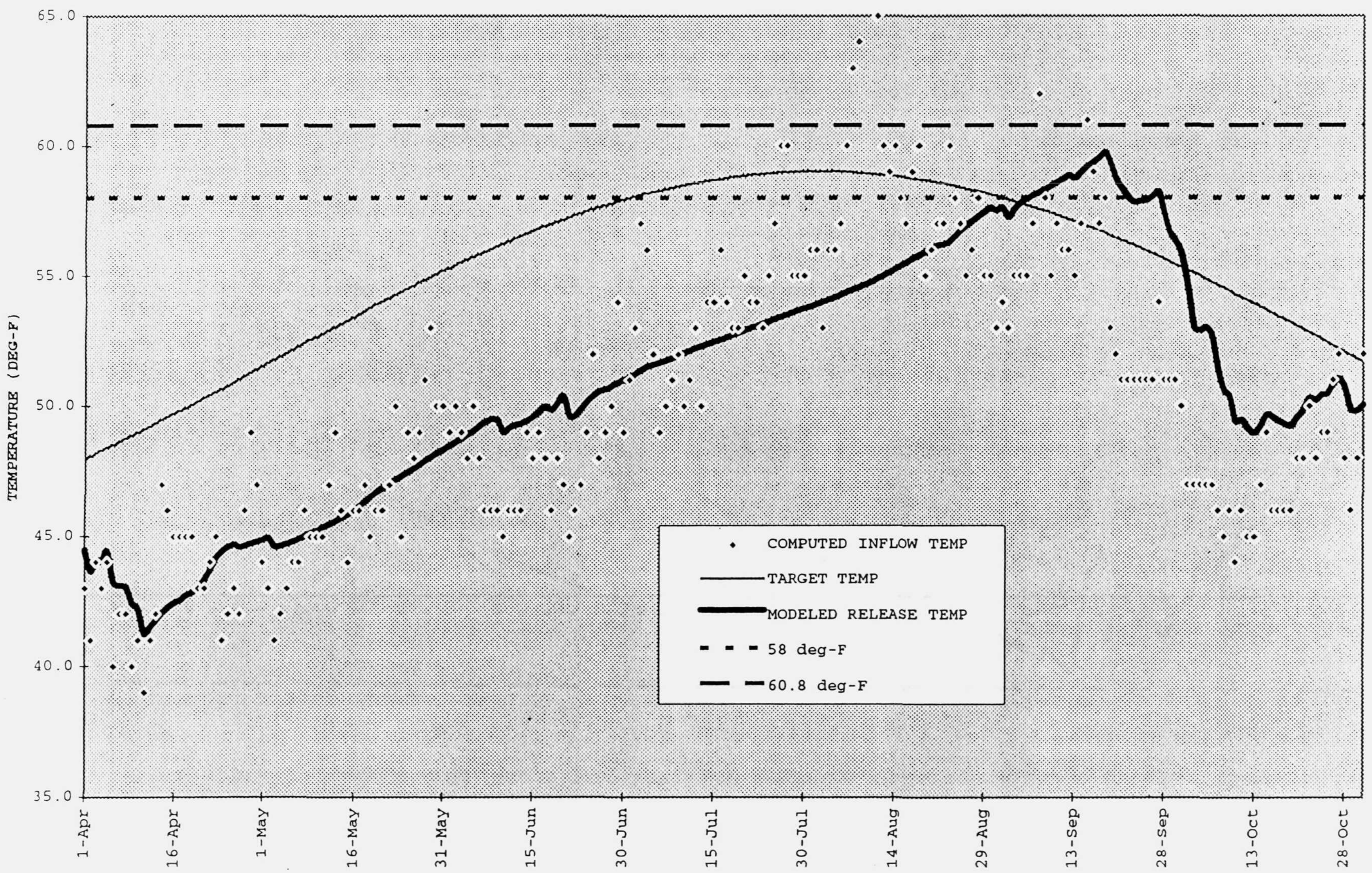


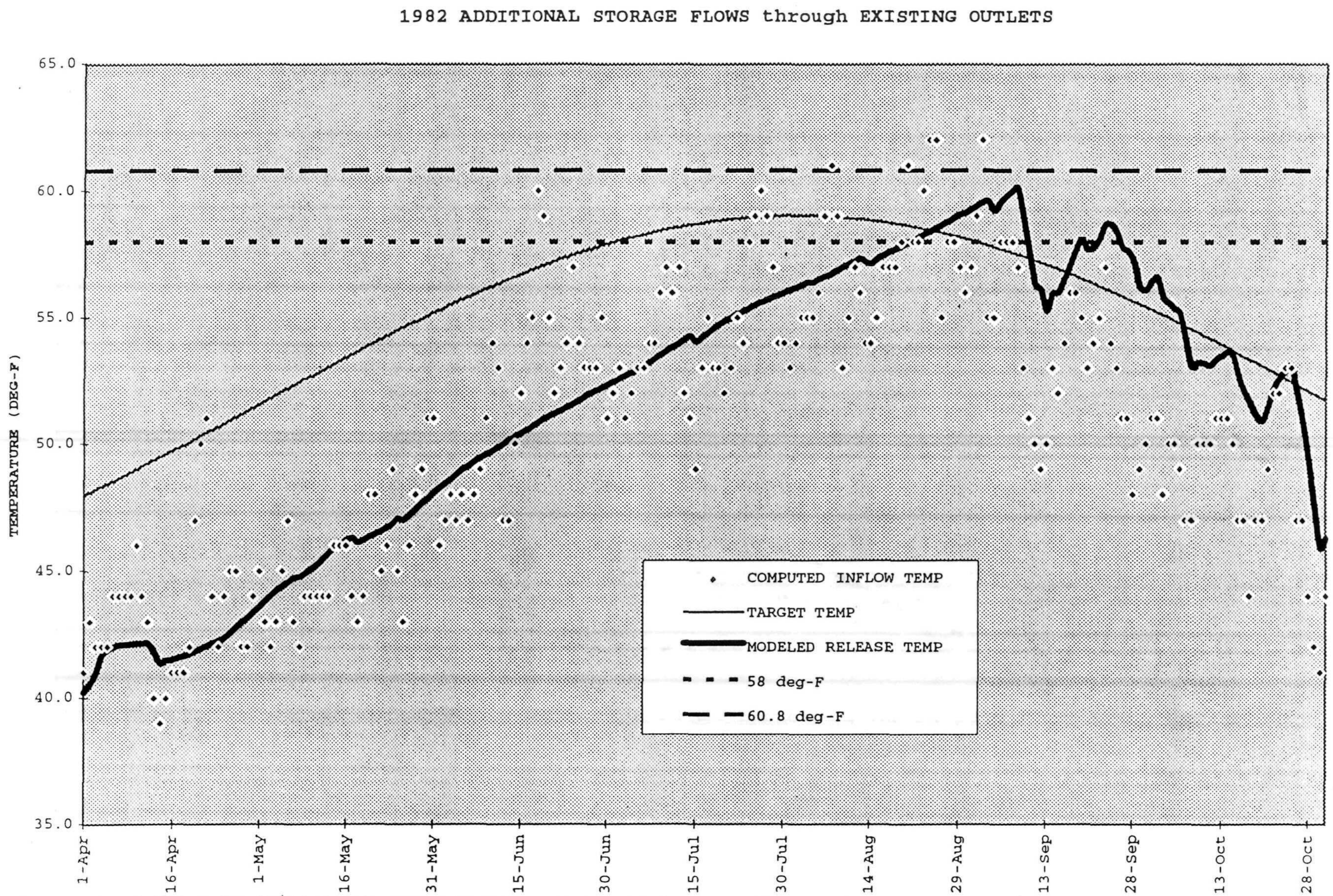

1979 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS
TEMPERATURE (DEG-F)
65.0
60.0
55.0
50.0
45.0
40.0
35.0
1-Apr
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F

1980 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS



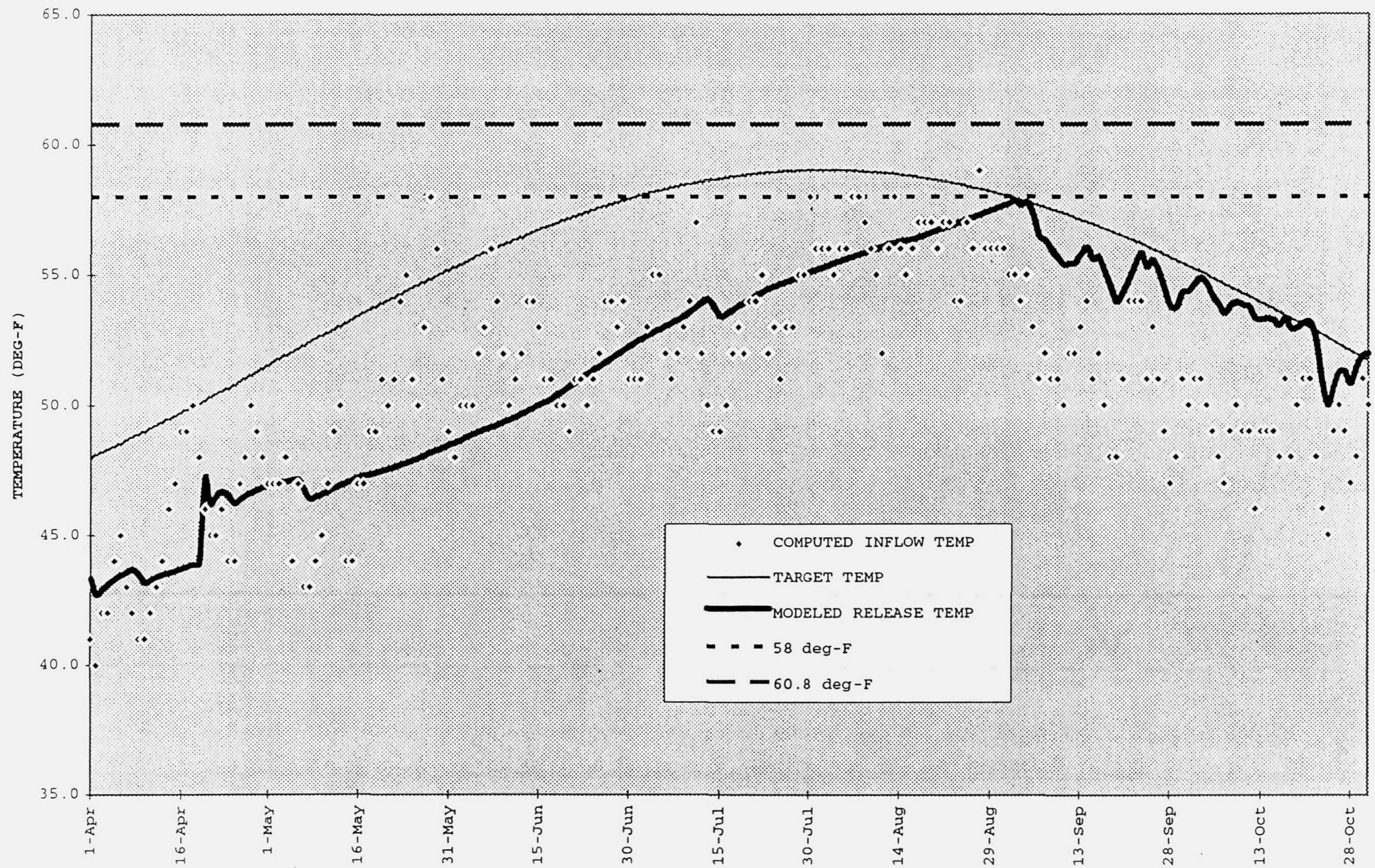
1981 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS

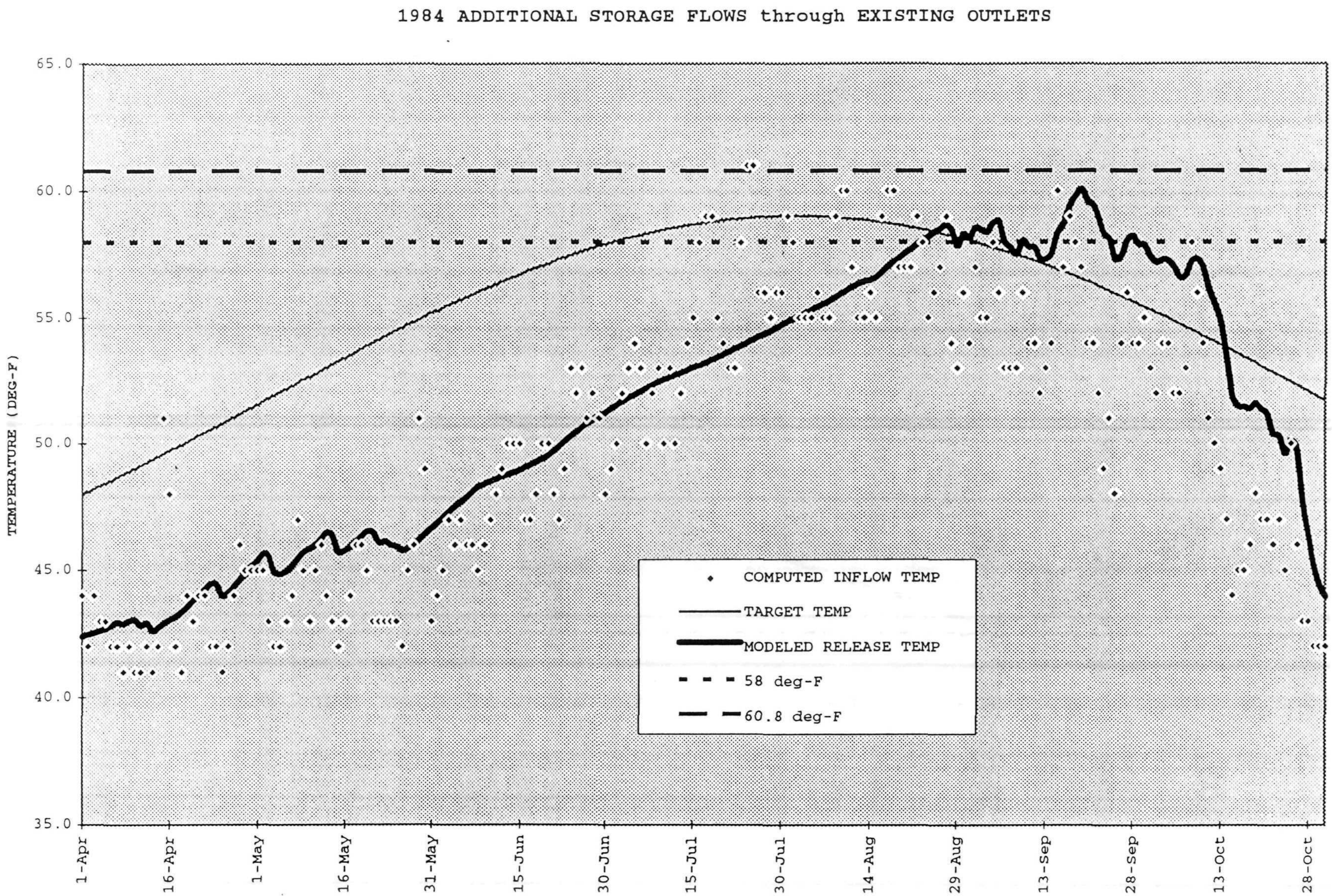



1982 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS
TEMPERATURE (DEG-F)
65.0
60.0
55.0
50.0
45.0
40.0
35.0
1-Apr
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F

D3-4-22

1983 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS

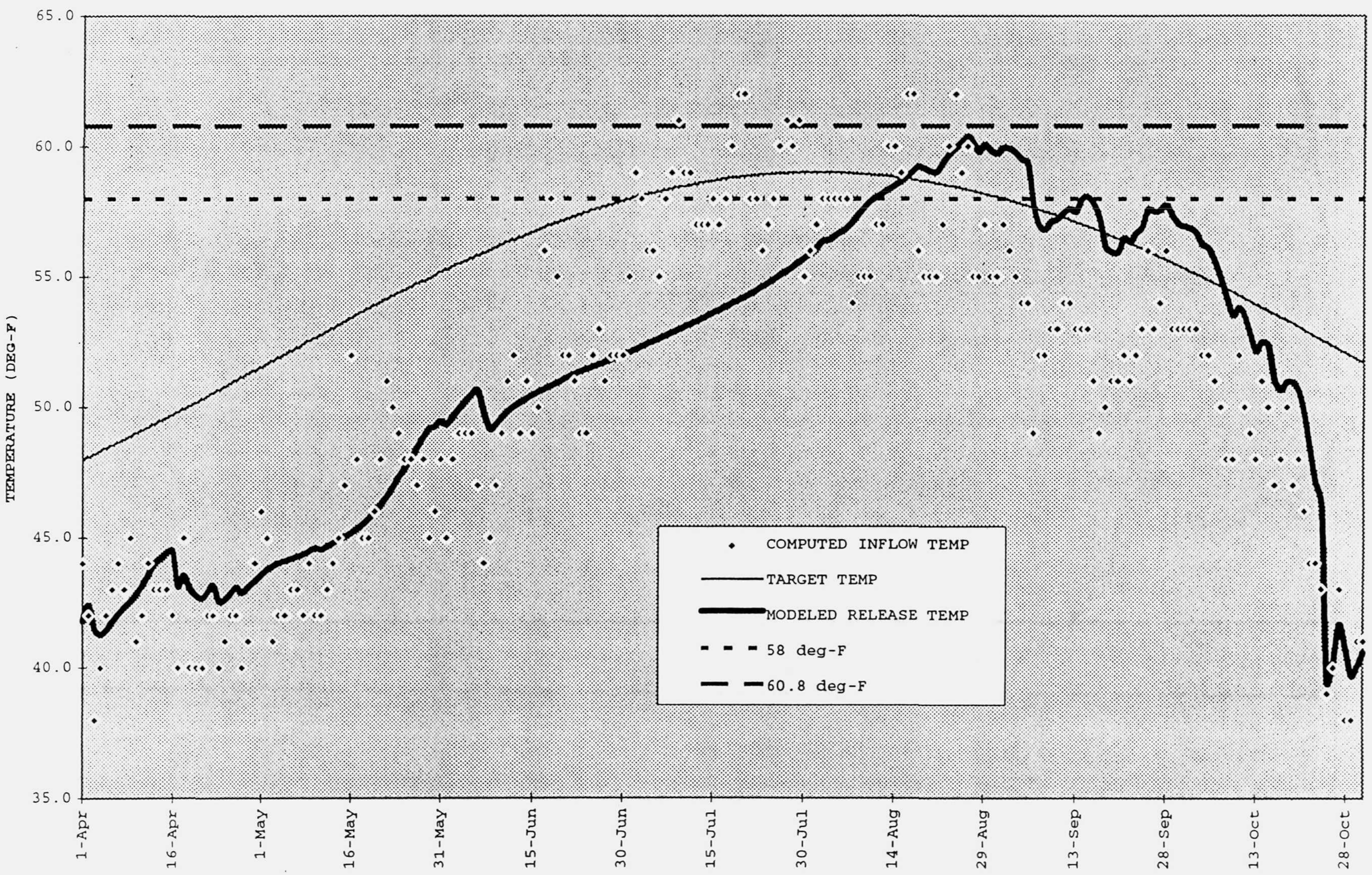




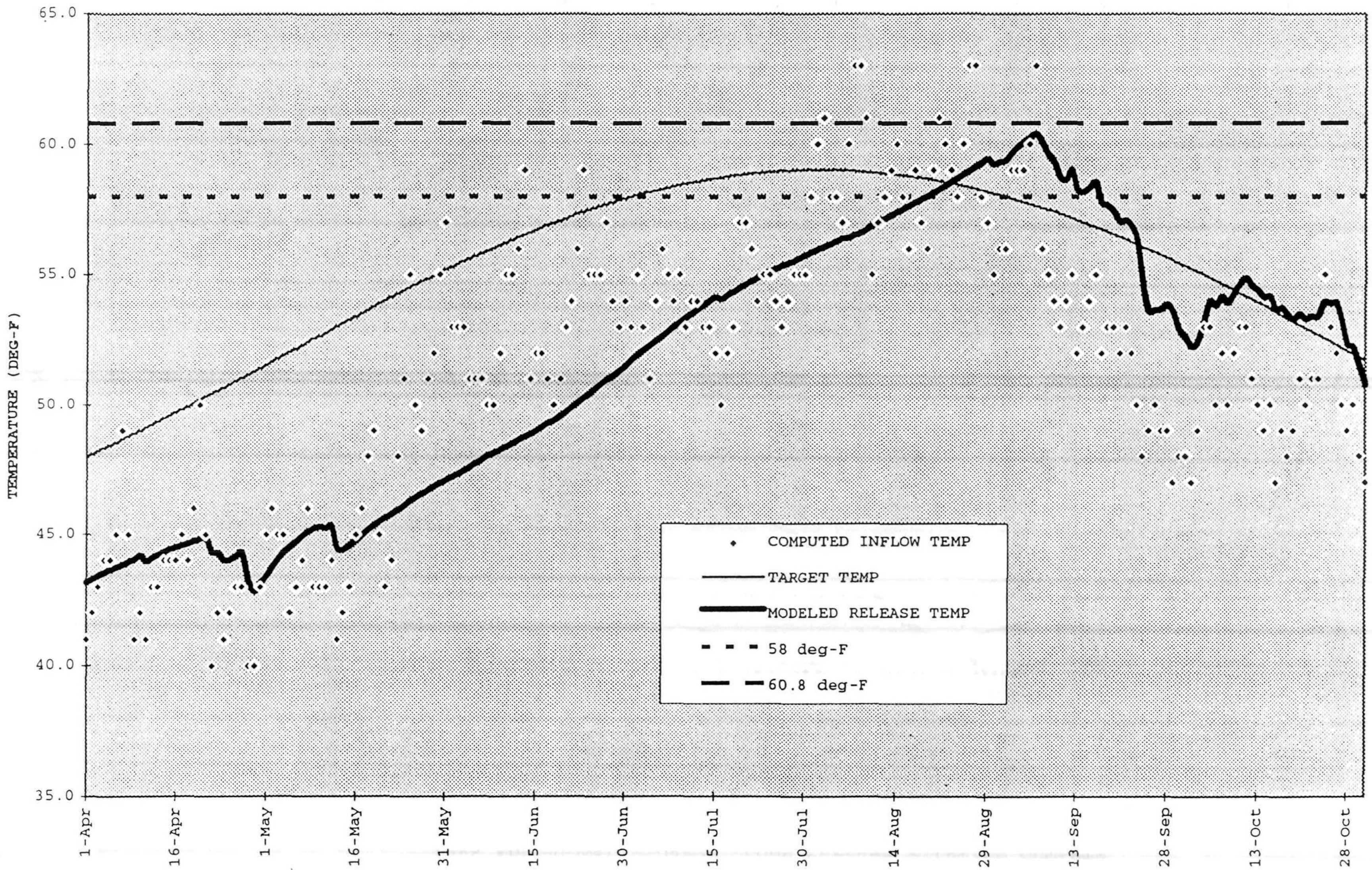
1984 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS
TEMPERATURE (DEG-F)
65.0
60.0
55.0
50.0
45.0
40.0
35.0
1-Apr
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F

D3-4-24

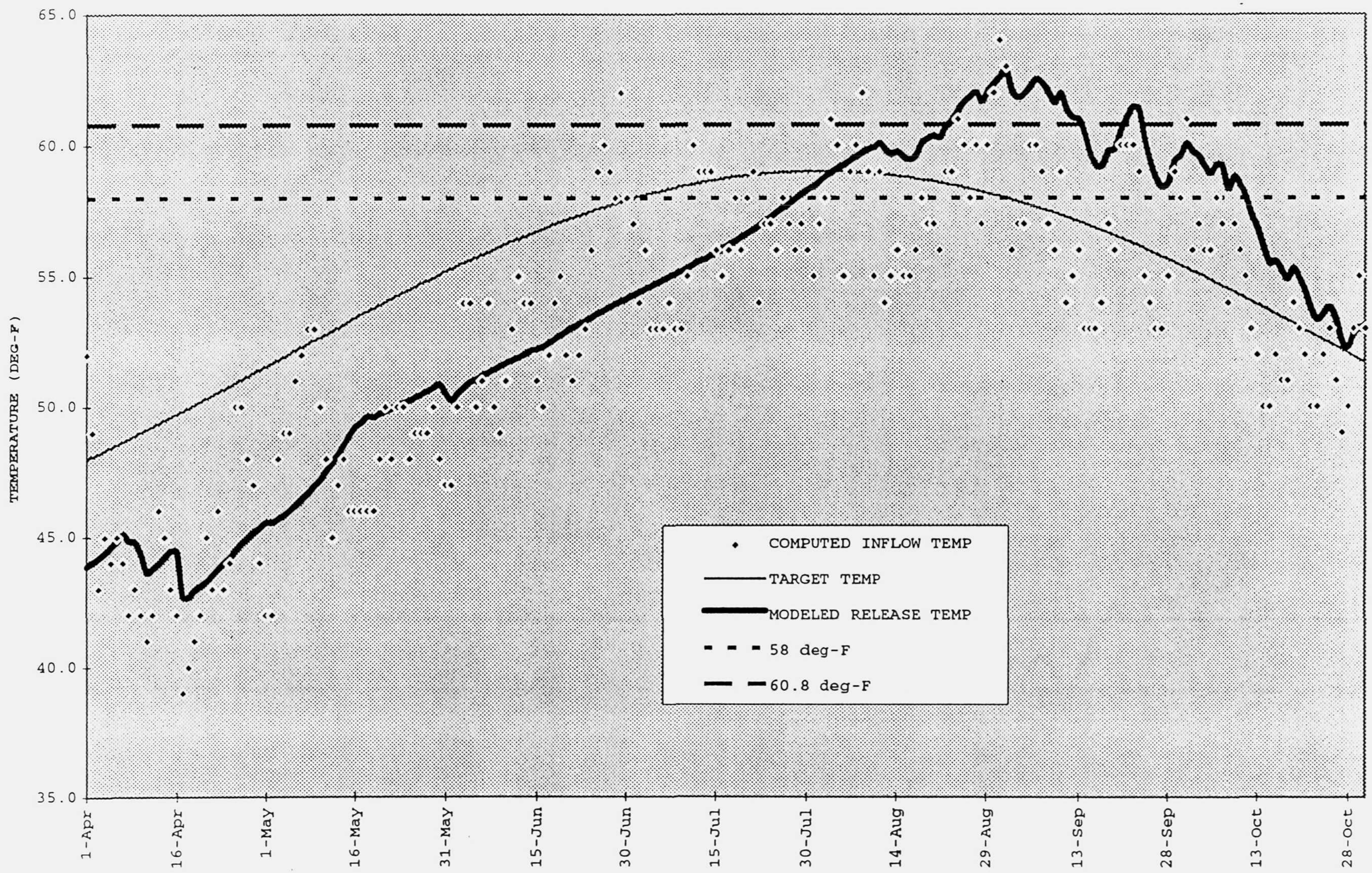
1985 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS

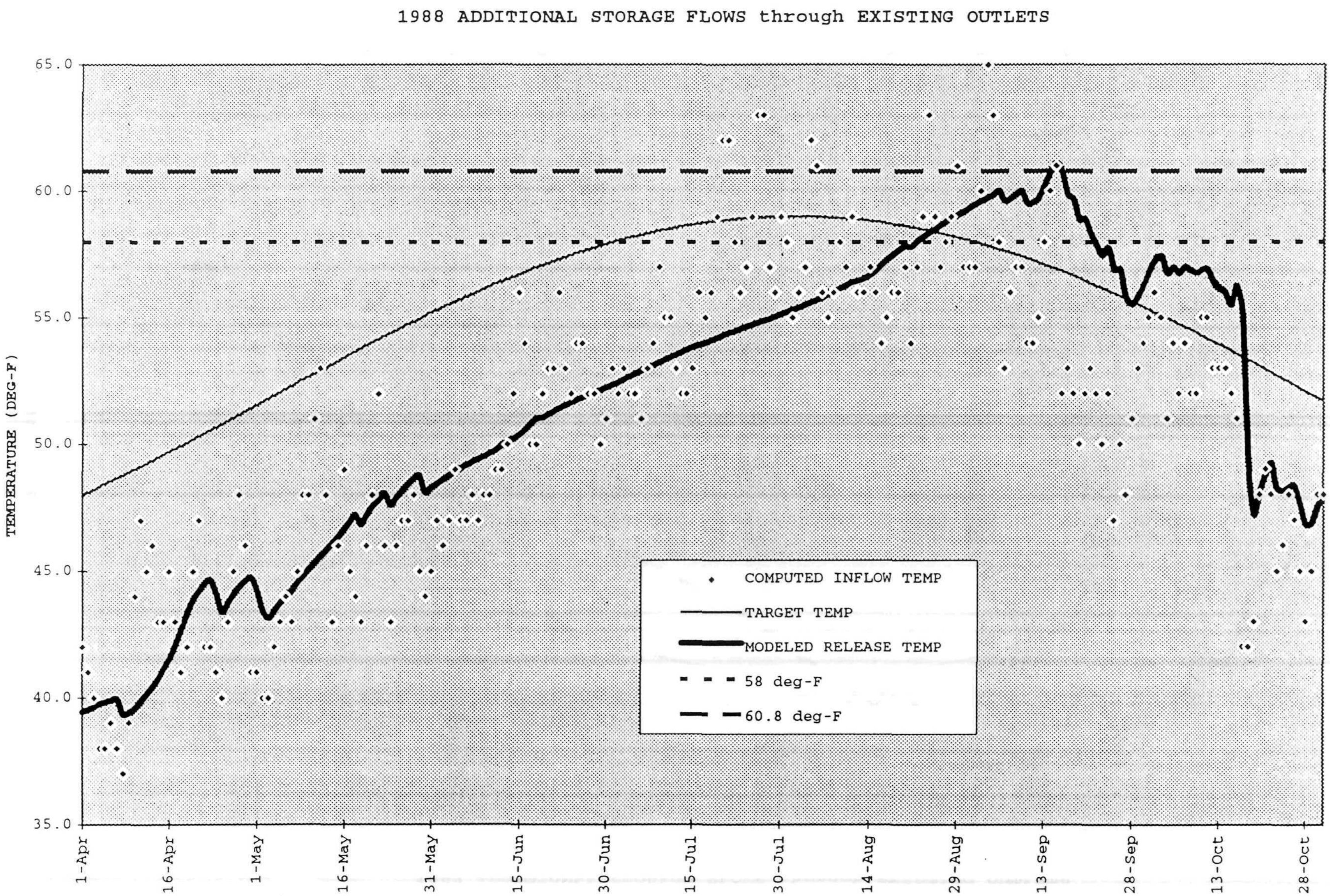


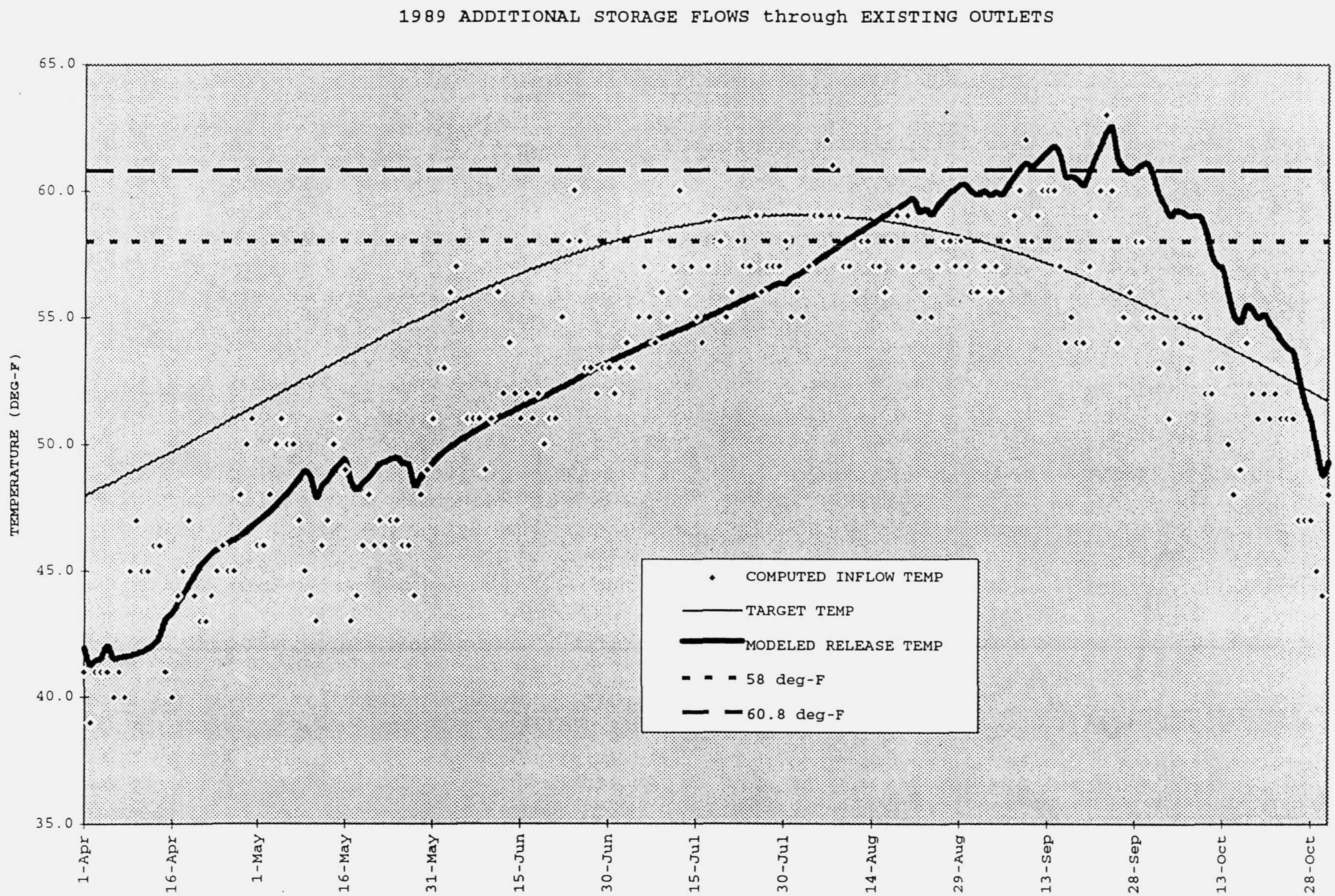
1986 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS



1987 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS

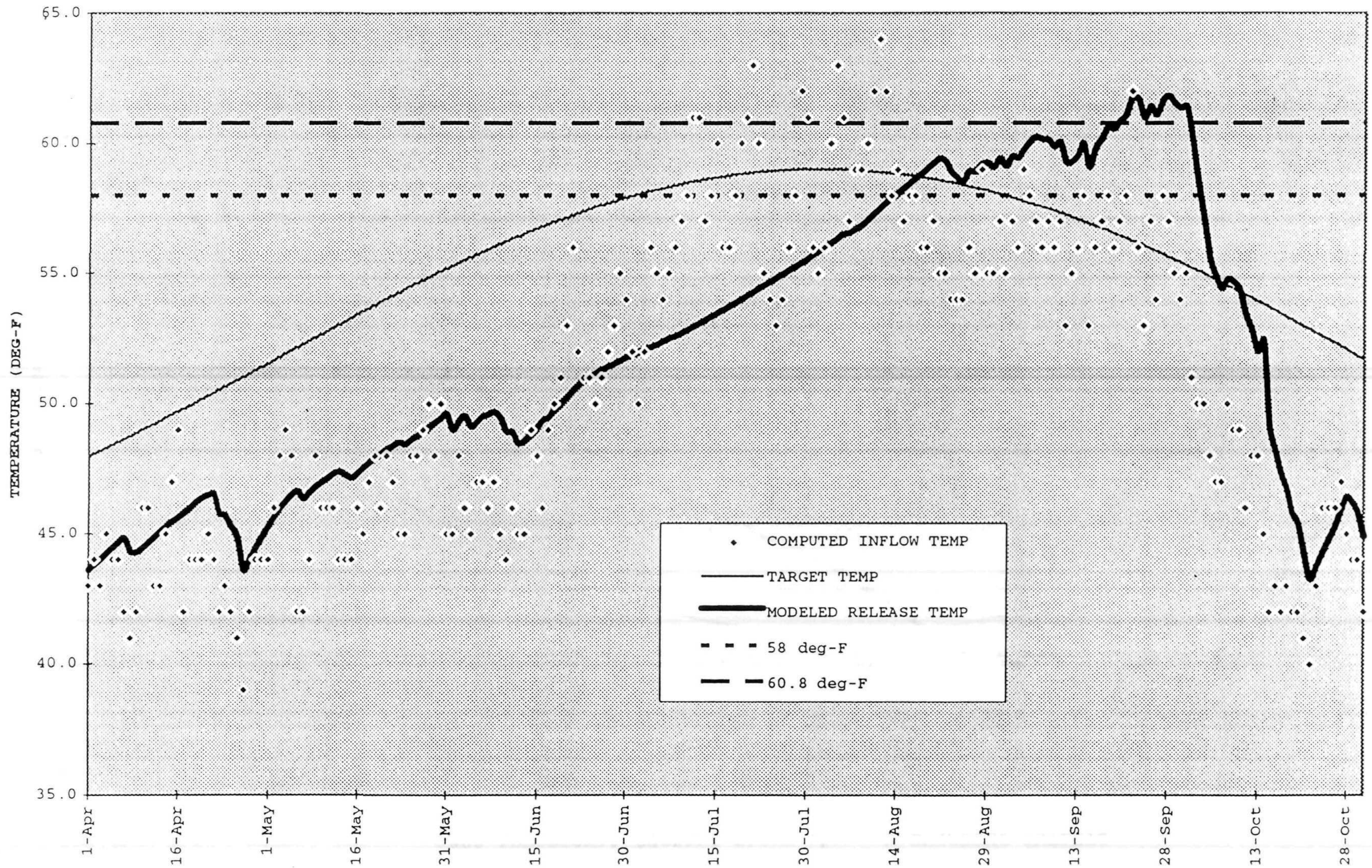



1988 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS
TEMPERATURE (DEG-F)
65.0
60.0
55.0
50.0
45.0
40.0
35.0
1-Apr
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F

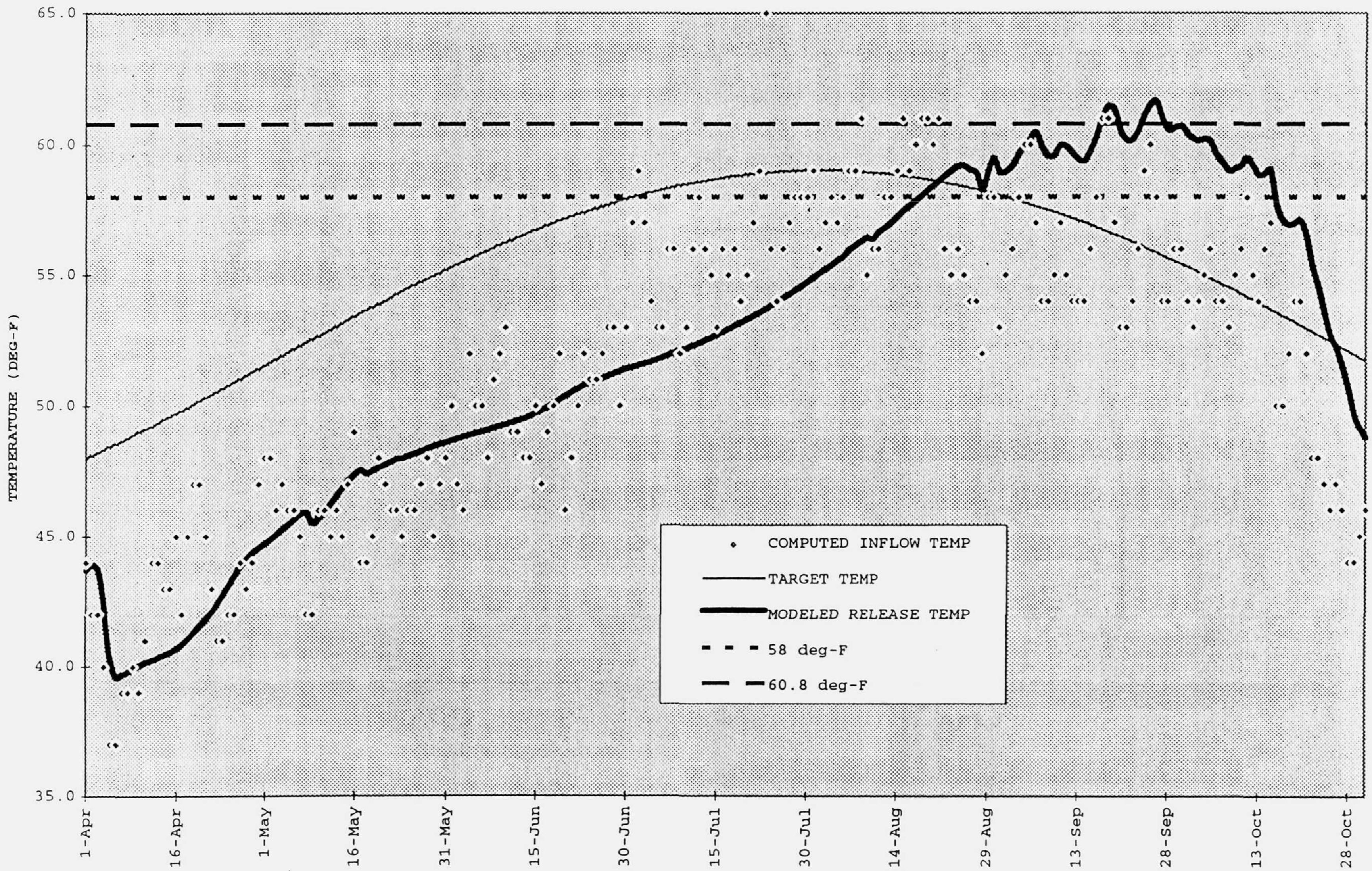


1989 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS
TEMPERATURE (DEG-F)
65.0
60.0
55.0
50.0
45.0
40.0
35.0
1-Apr
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F

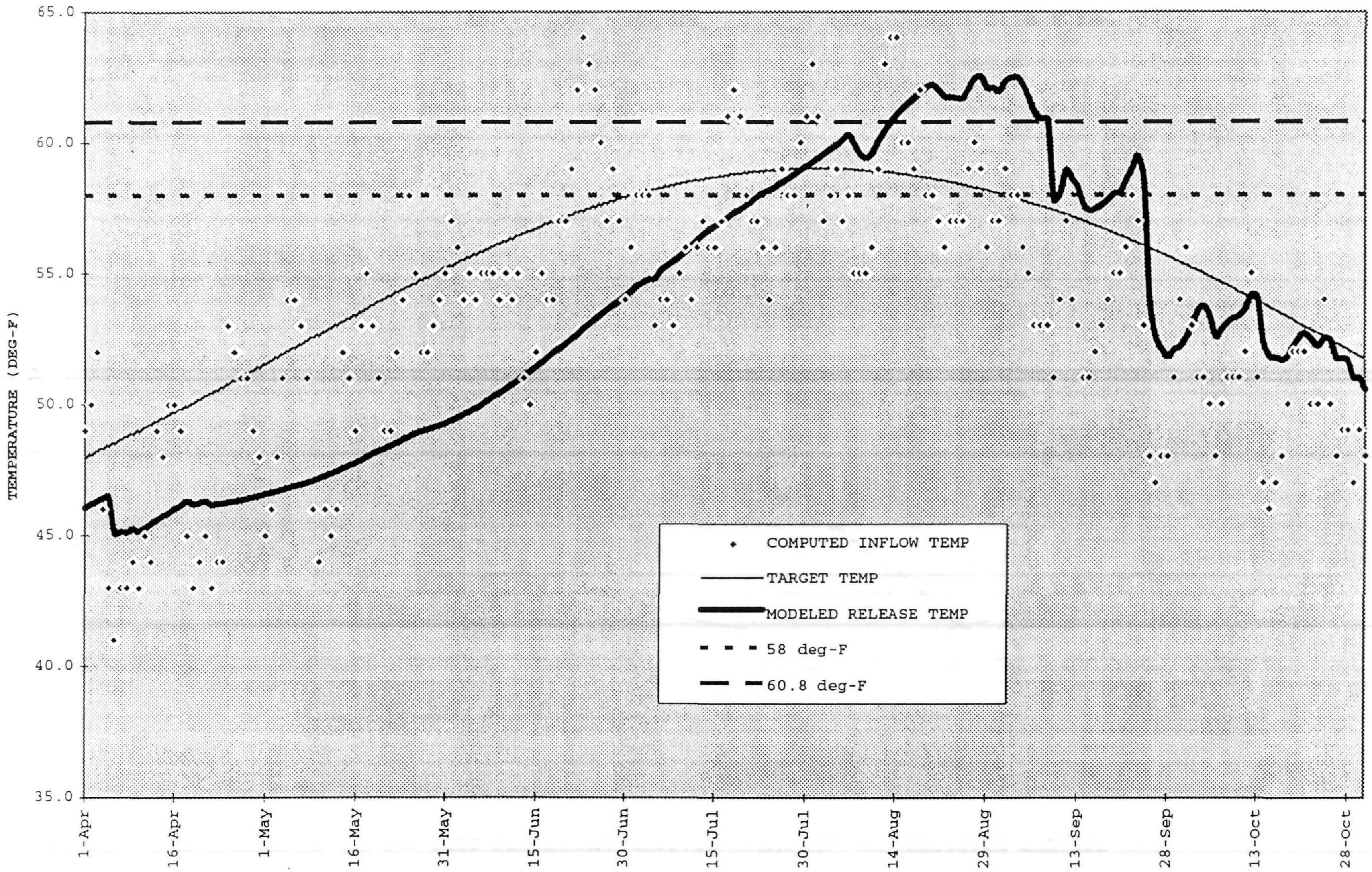
1990 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS



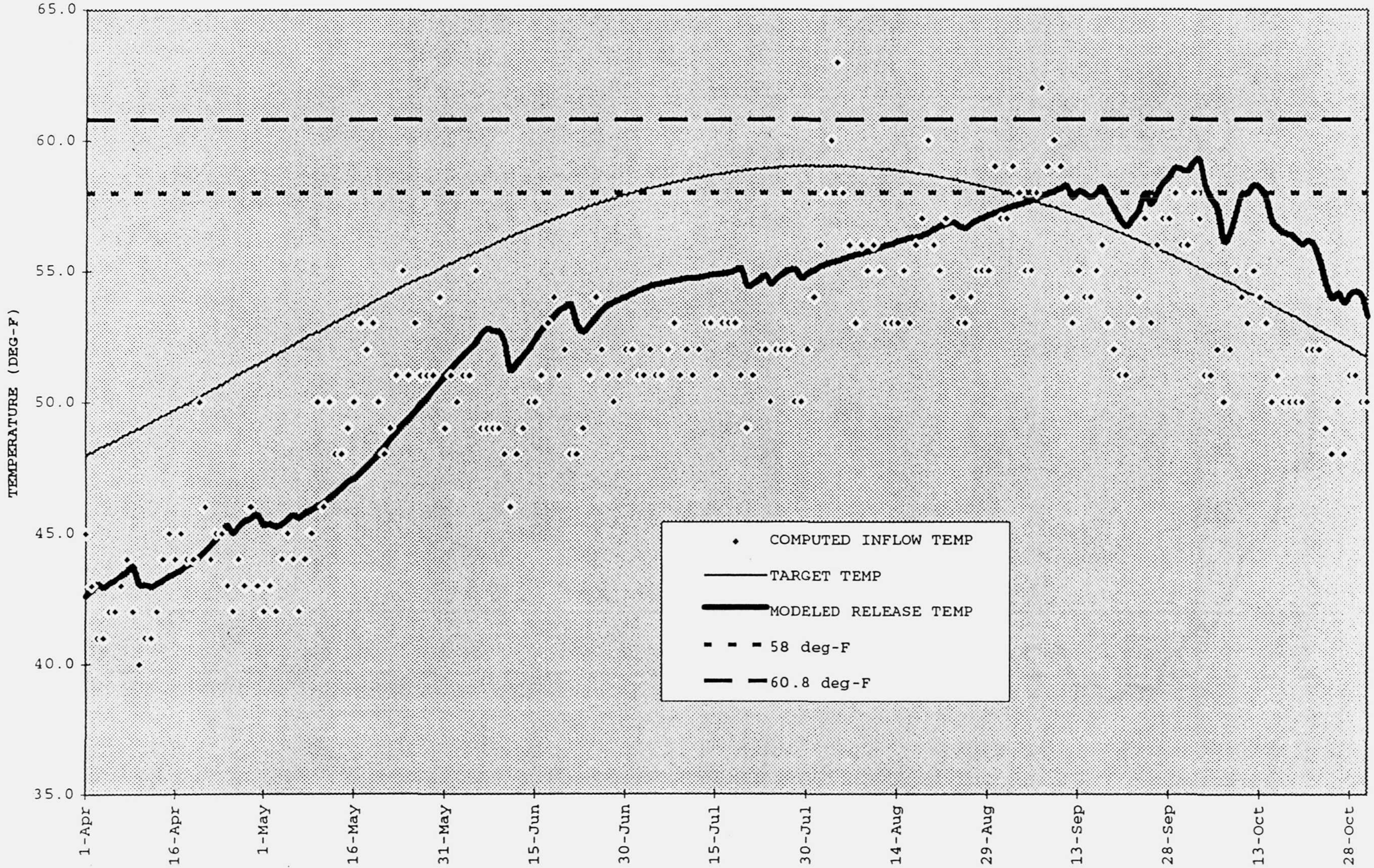
1991 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS



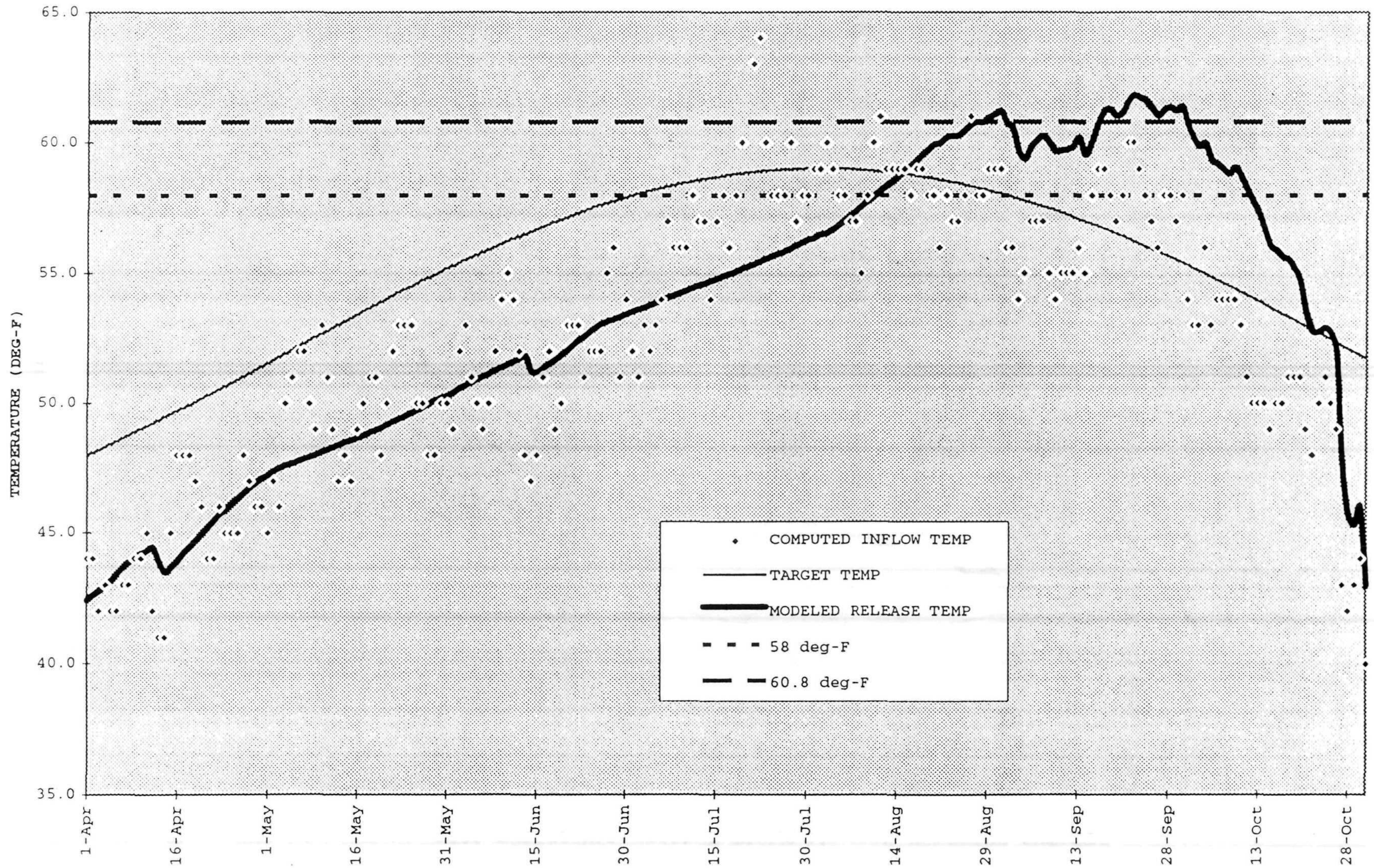
1992 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS



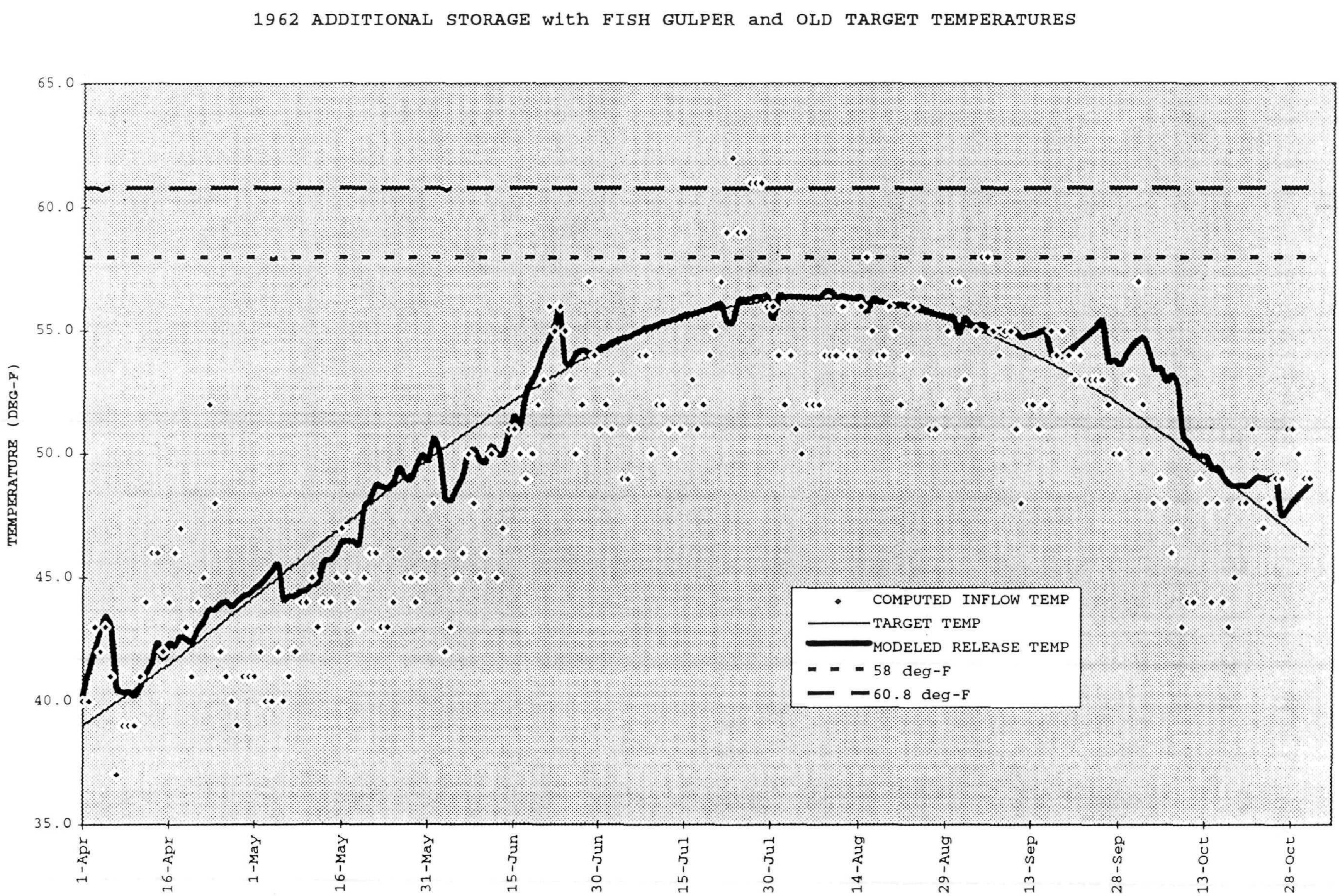
1993 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS



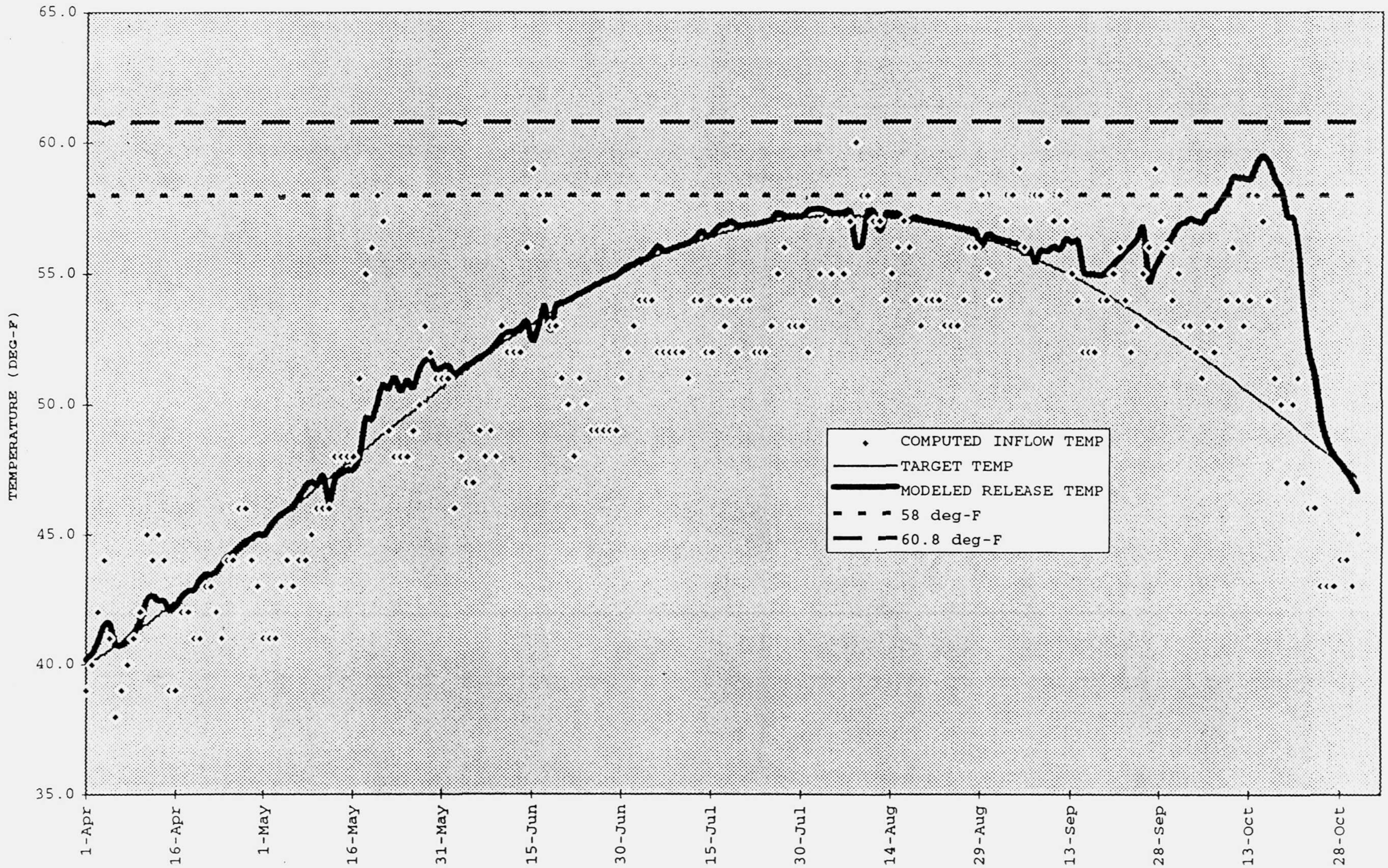
1994 ADDITIONAL STORAGE FLOWS through EXISTING OUTLETS



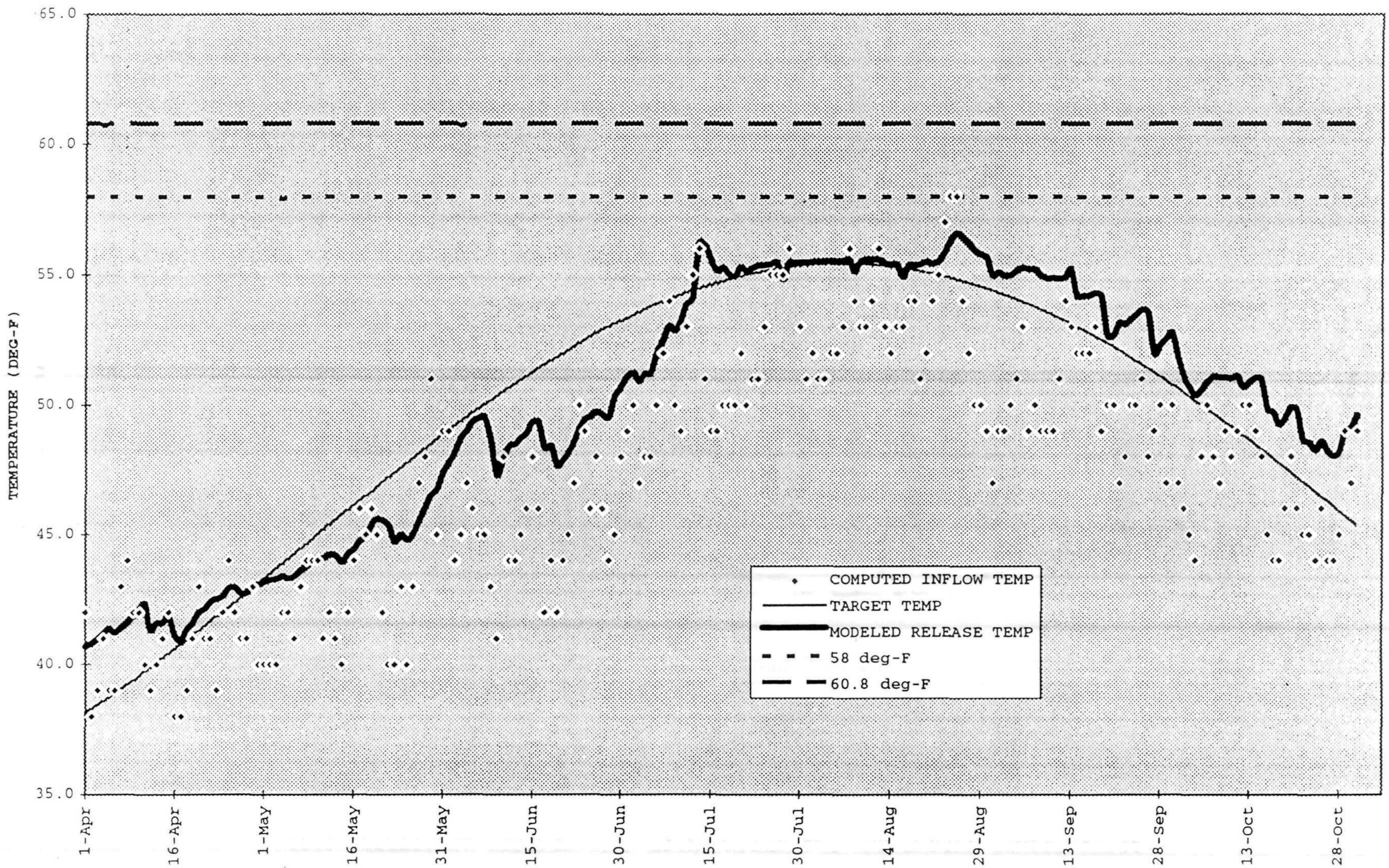
SECTION 5 Release Temperatures of Proposed Additional Storage Flows Modeled with the Preferred Alternative Design, 1962-70, 1992


1962 ADDITIONAL STORAGE with FISH GULPER and OLD TARGET TEMPERATURES
TEMPERATURE (DEG-F)
65.0
60.0
55.0
50.0
45.0
40.0
35.0
1-Apr
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F

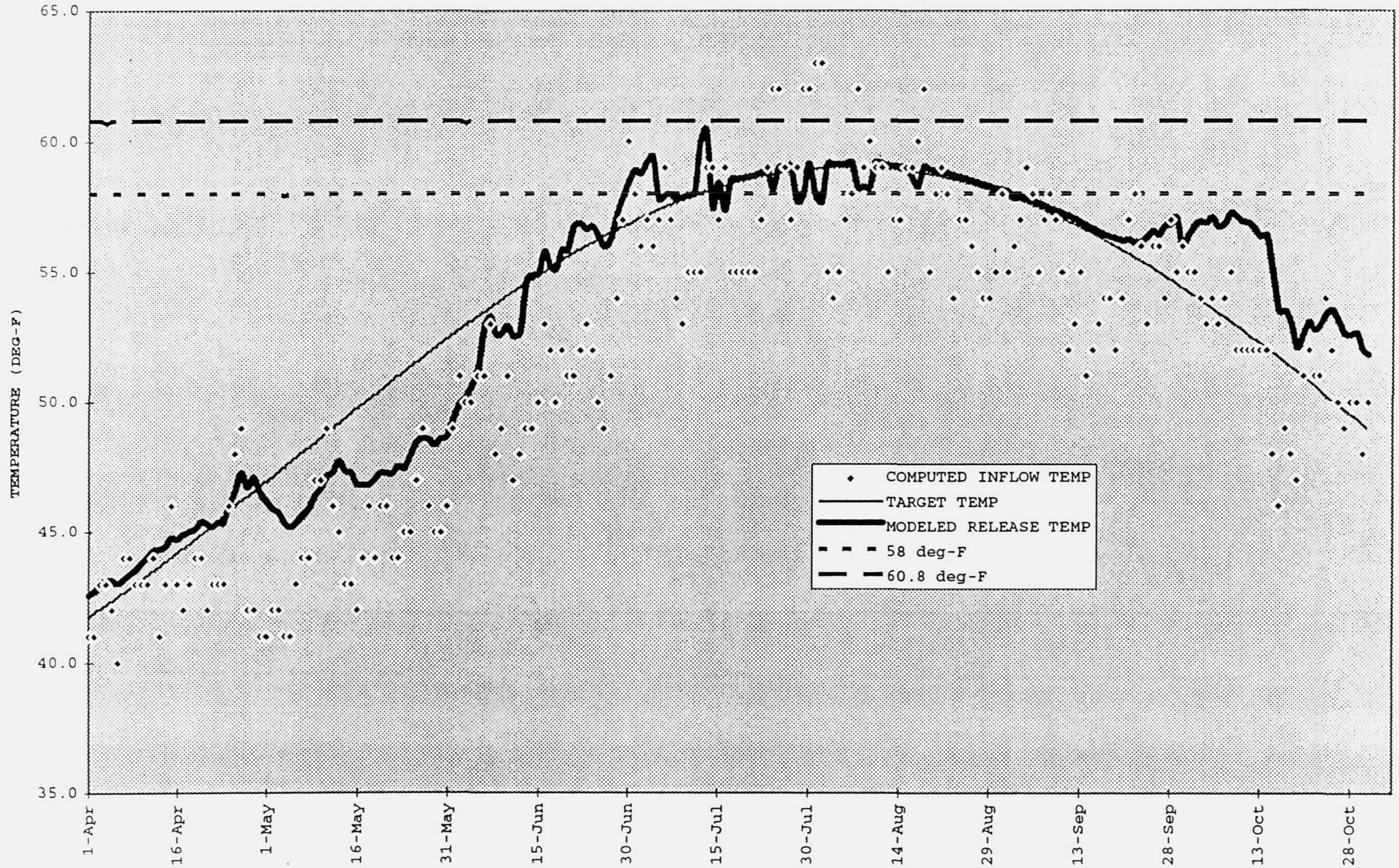
1963 ADDITIONAL STORAGE with FISH GULPER and OLD TARGET TEMPERATURES

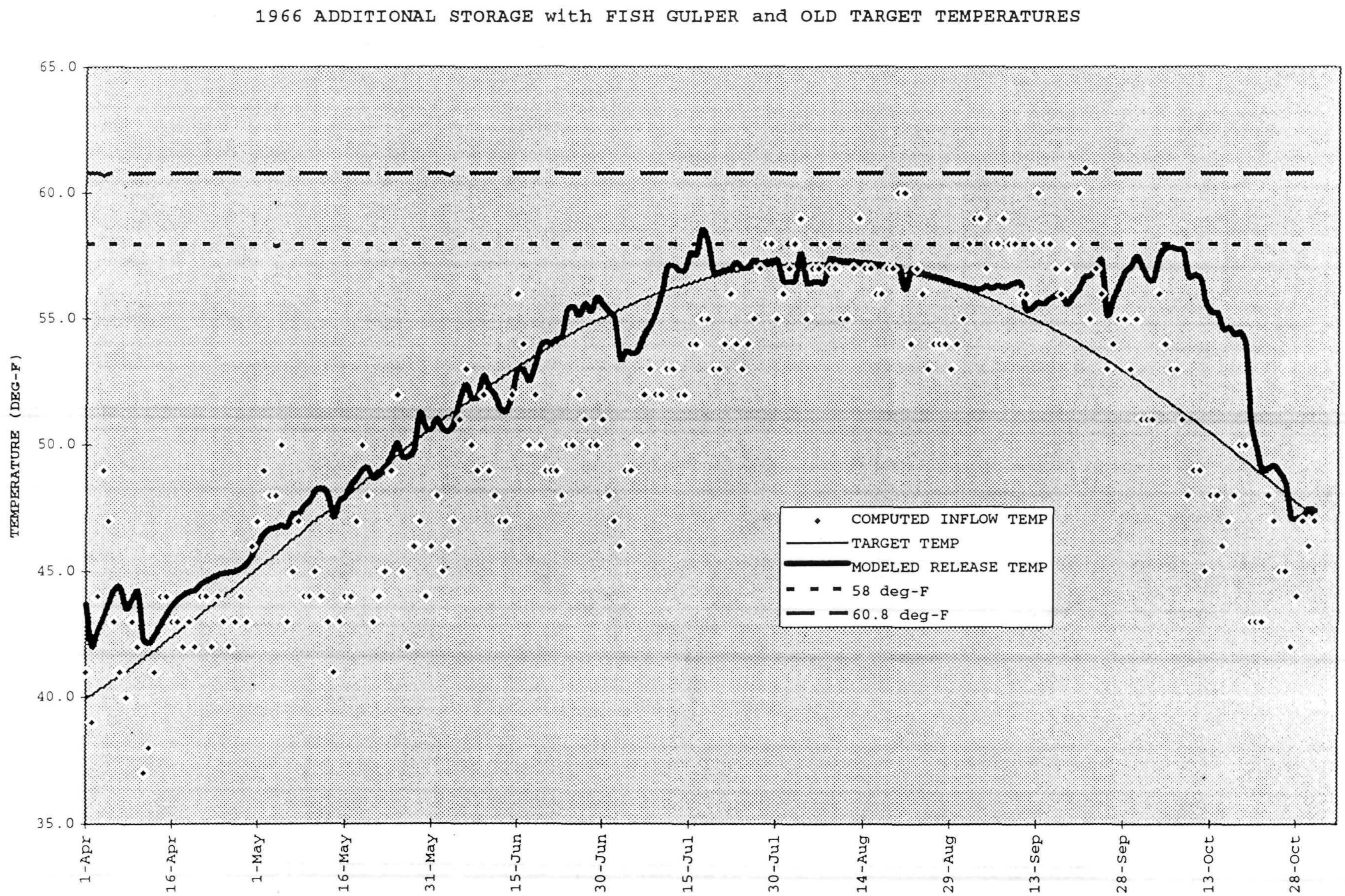


1964 ADDITIONAL STORAGE with FISH GULPER and OLD TARGET TEMPERATURES

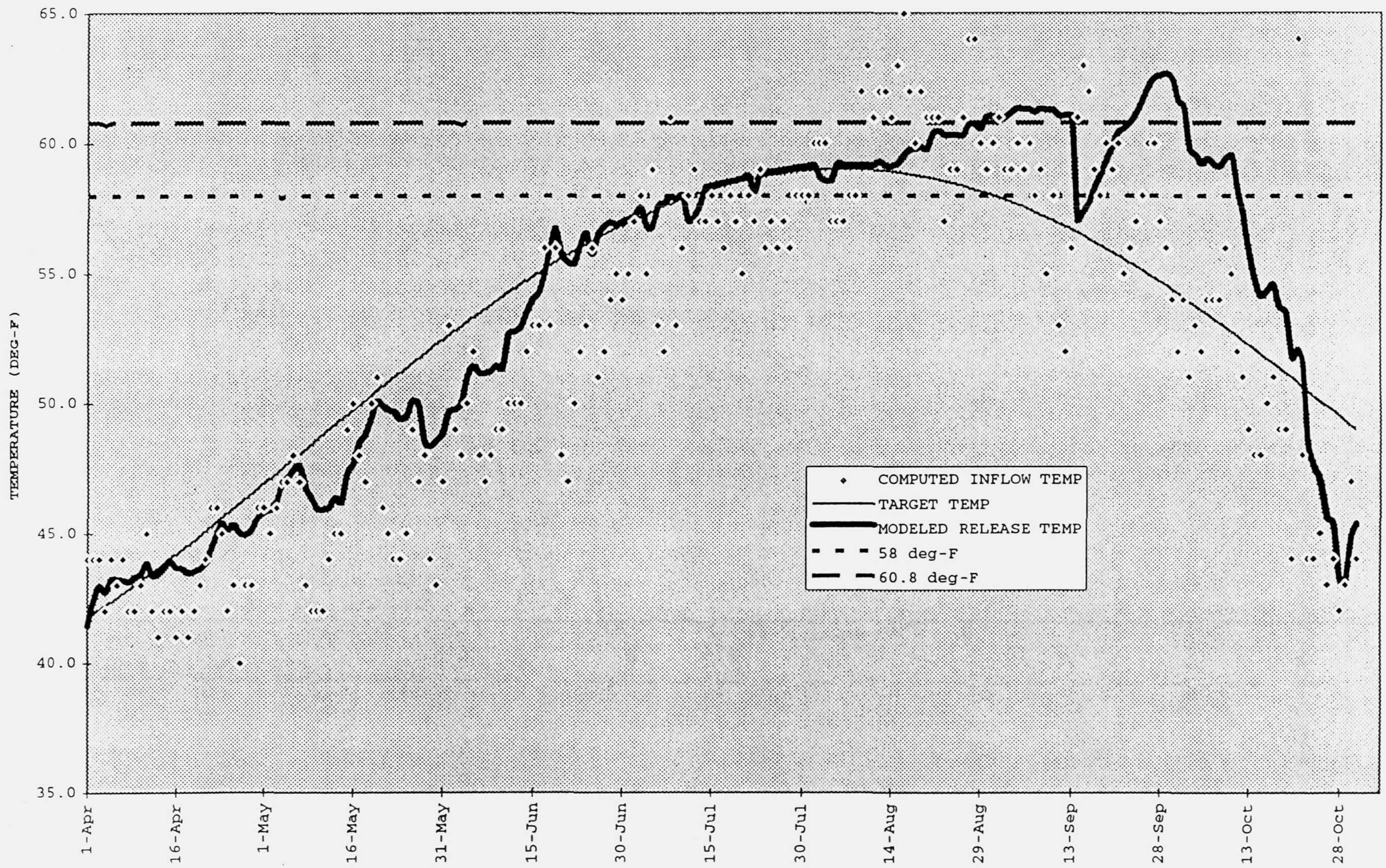


1965 ADDITIONAL STORAGE with FISH GULPER and OLD TARGET TEMPERATURES

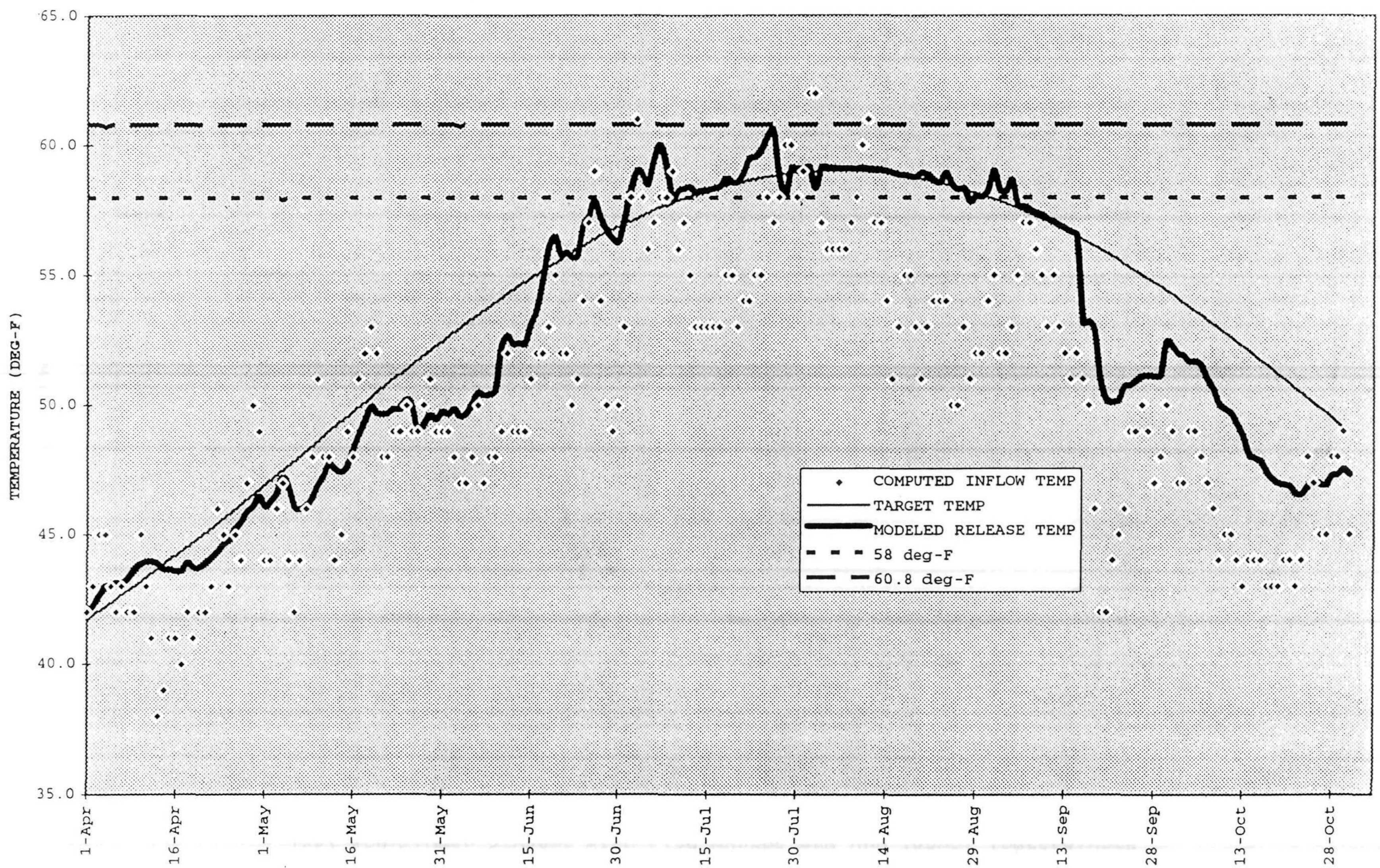



1966 ADDITIONAL STORAGE with FISH GULPER and OLD TARGET TEMPERATURES
TEMPERATURE (DEG-F)
65.0
60.0
55.0
50.0
45.0
40.0
35.0
1-Apr
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F

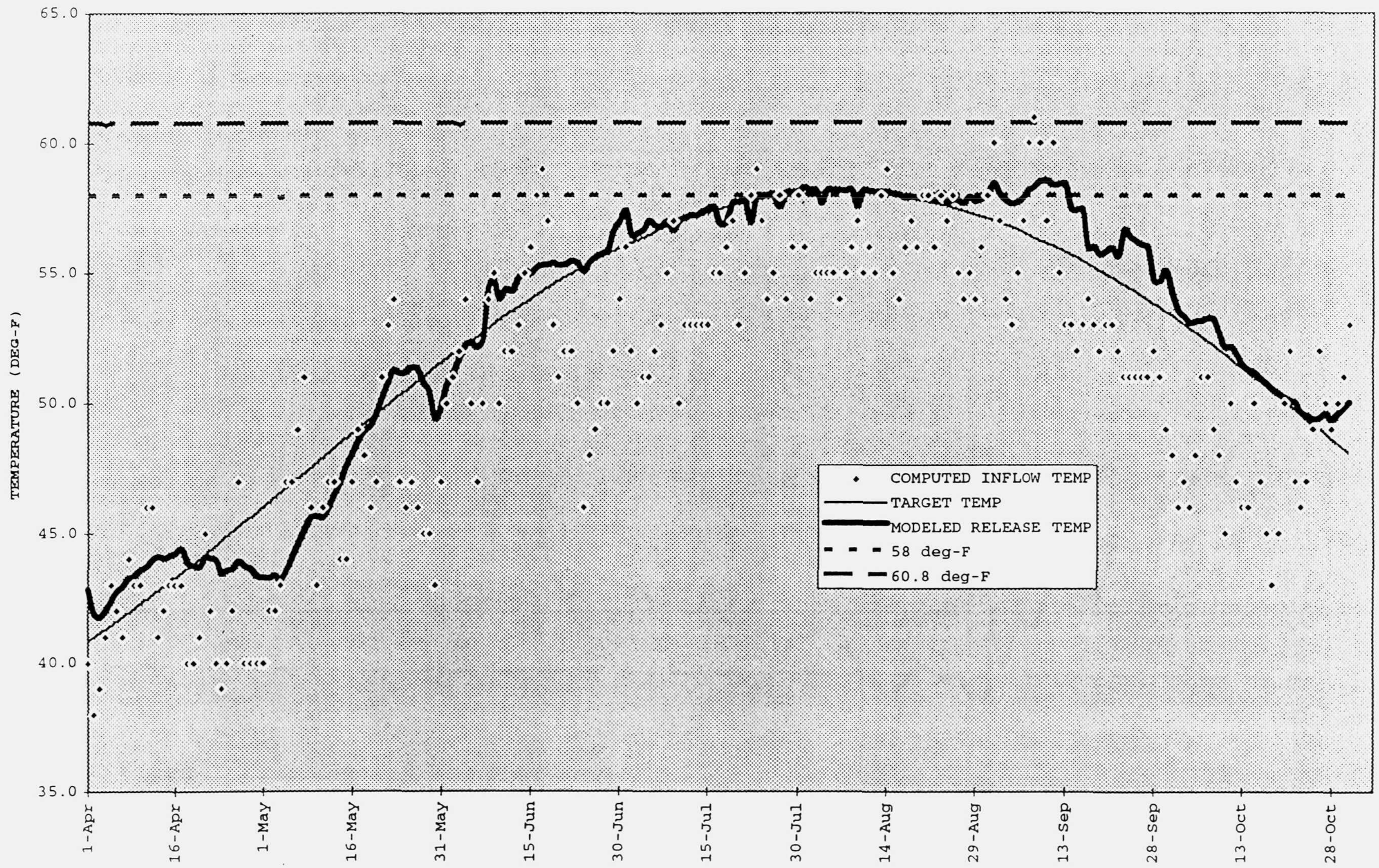
1967 ADDITIONAL STORAGE with FISH GULPER and OLD TARGET TEMPERATURES

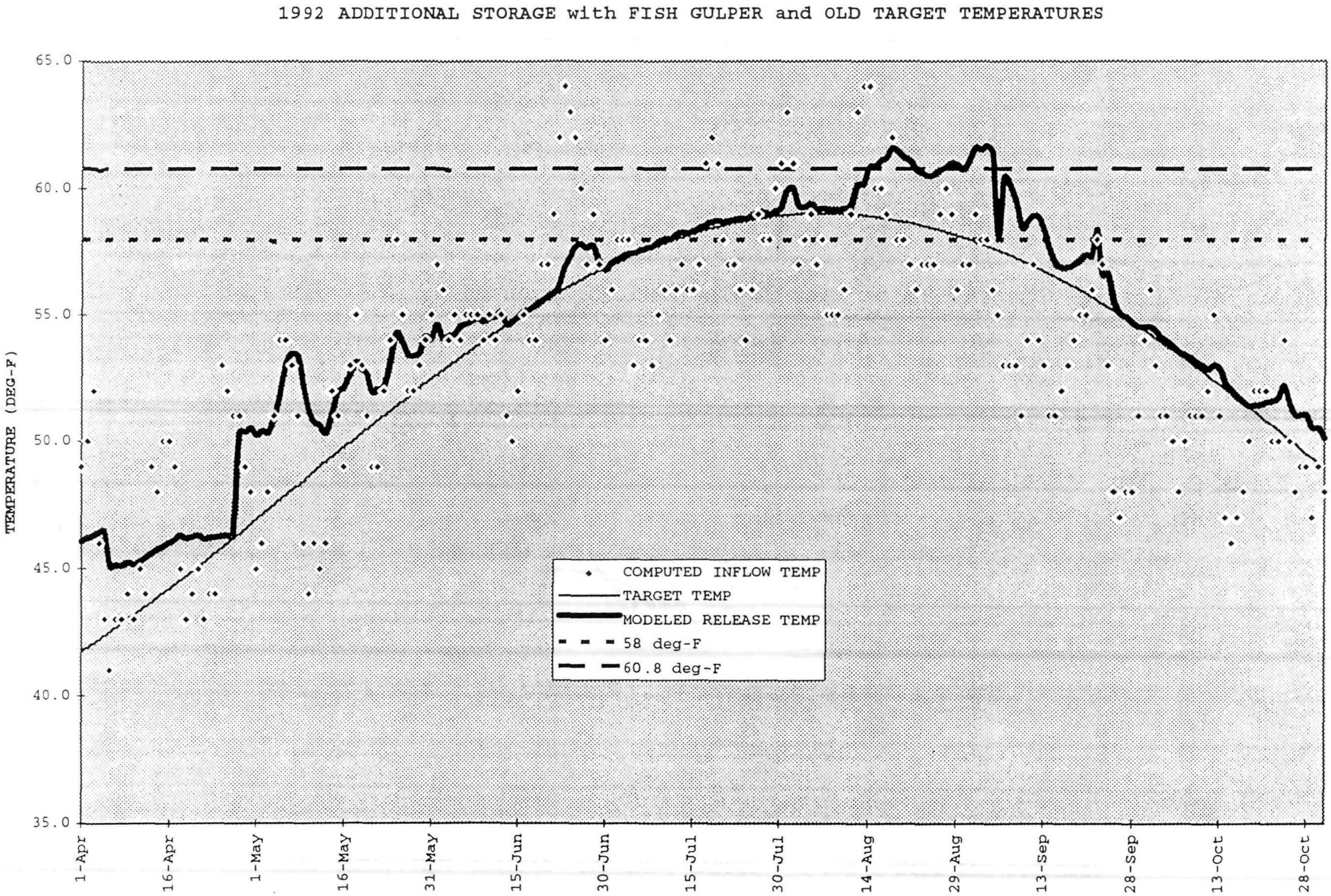


1968 ADDITIONAL STORAGE with FISH GULPER and OLD TARGET TEMPERATURES



1969 ADDITIONAL STORAGE with FISH GULPER and OLD TARGET TEMPERATURES

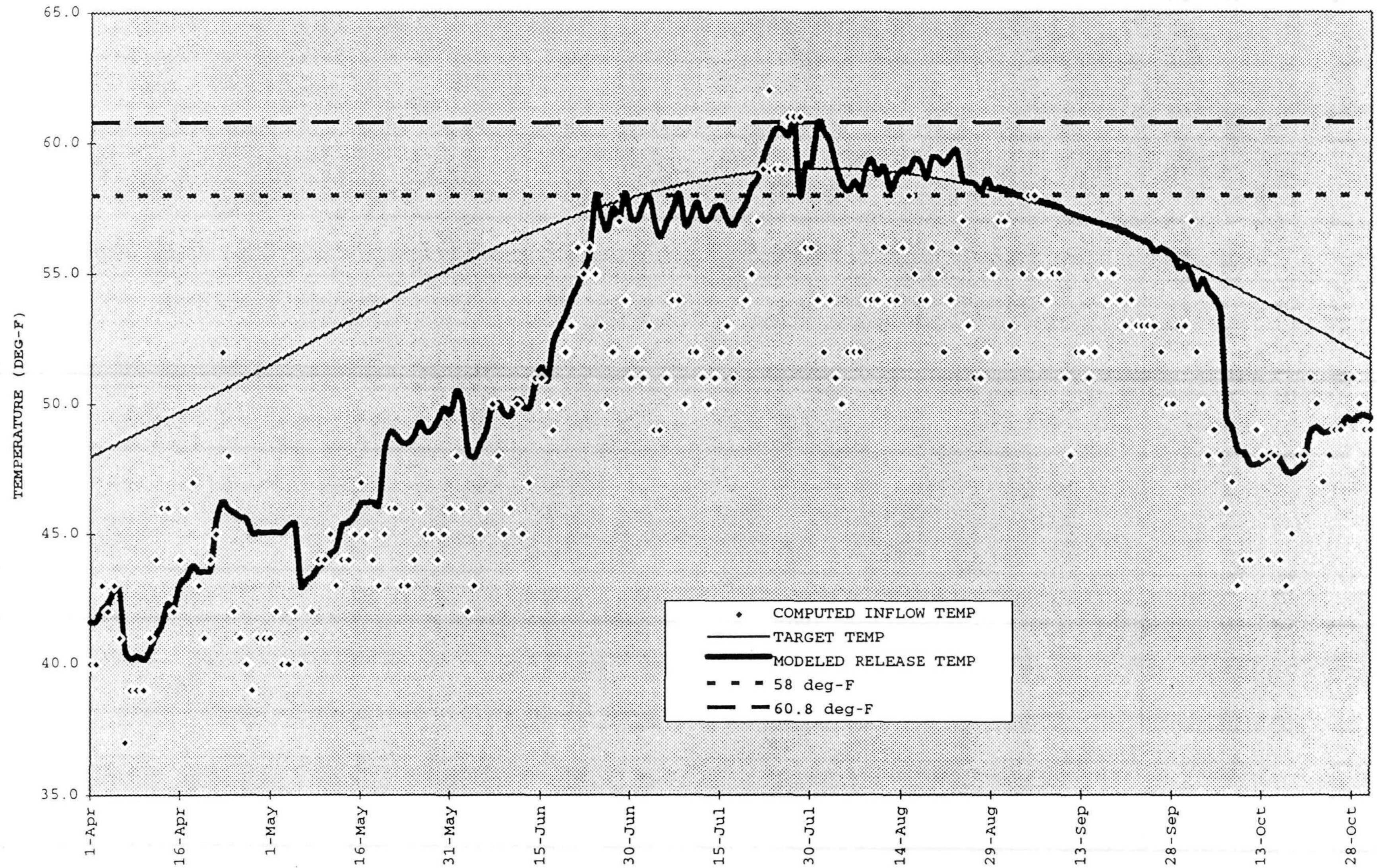



1992 ADDITIONAL STORAGE with FISH GULPER and OLD TARGET TEMPERATURES
TEMPERATURE (DEG-F)
65.0
60.0
55.0
50.0
45.0
40.0
35.0
1-Apr
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F

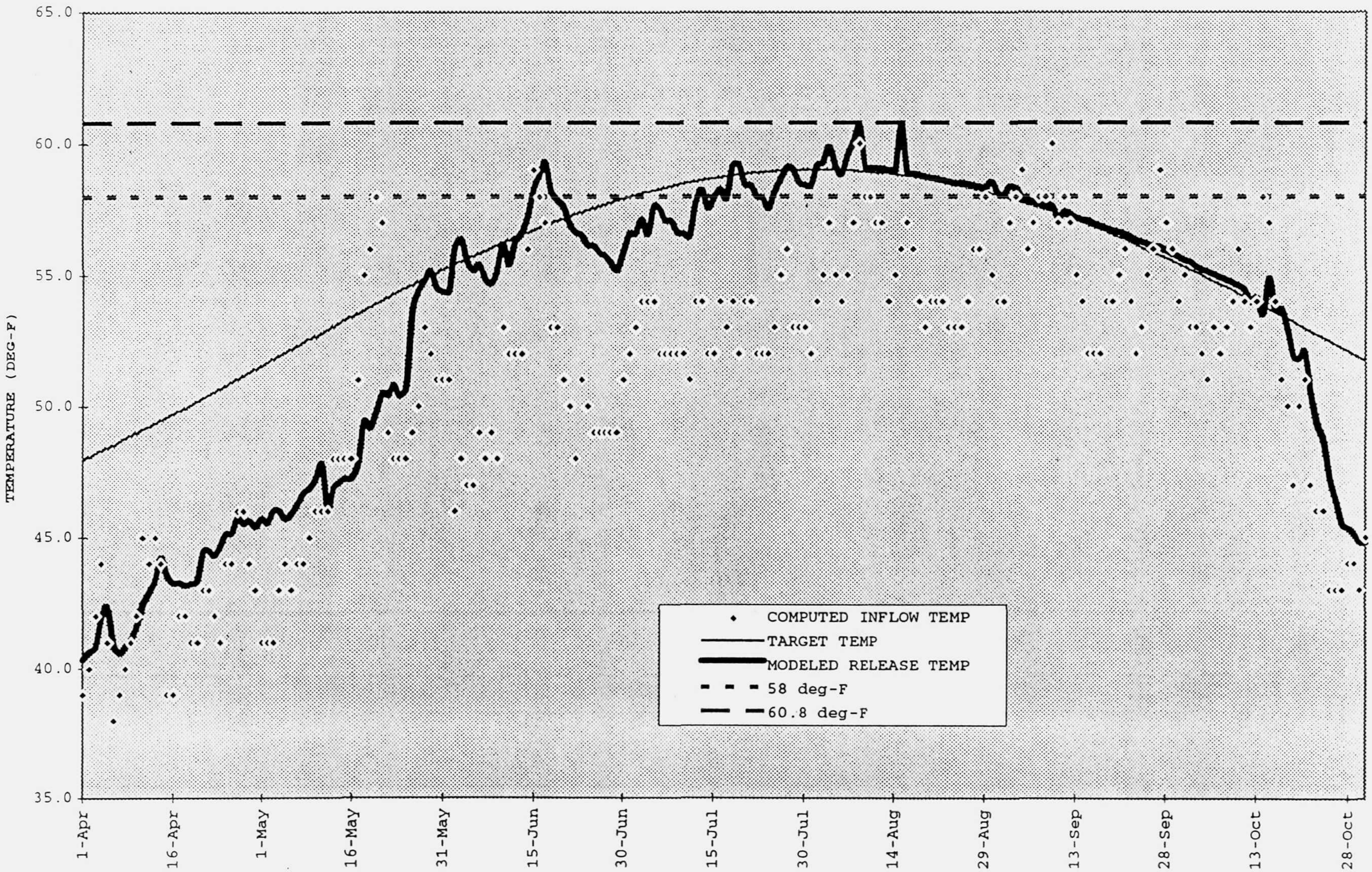
D3-5-10

SECTION 6 RELEASE TEMPERATURES OF PROPOSED ADDITIONAL STORAGE FLOWS MODELED WITH THE PREFERRED ALTERNATIVE DESIGN AND NEW TARGET TEMPERATURES, 1962-94

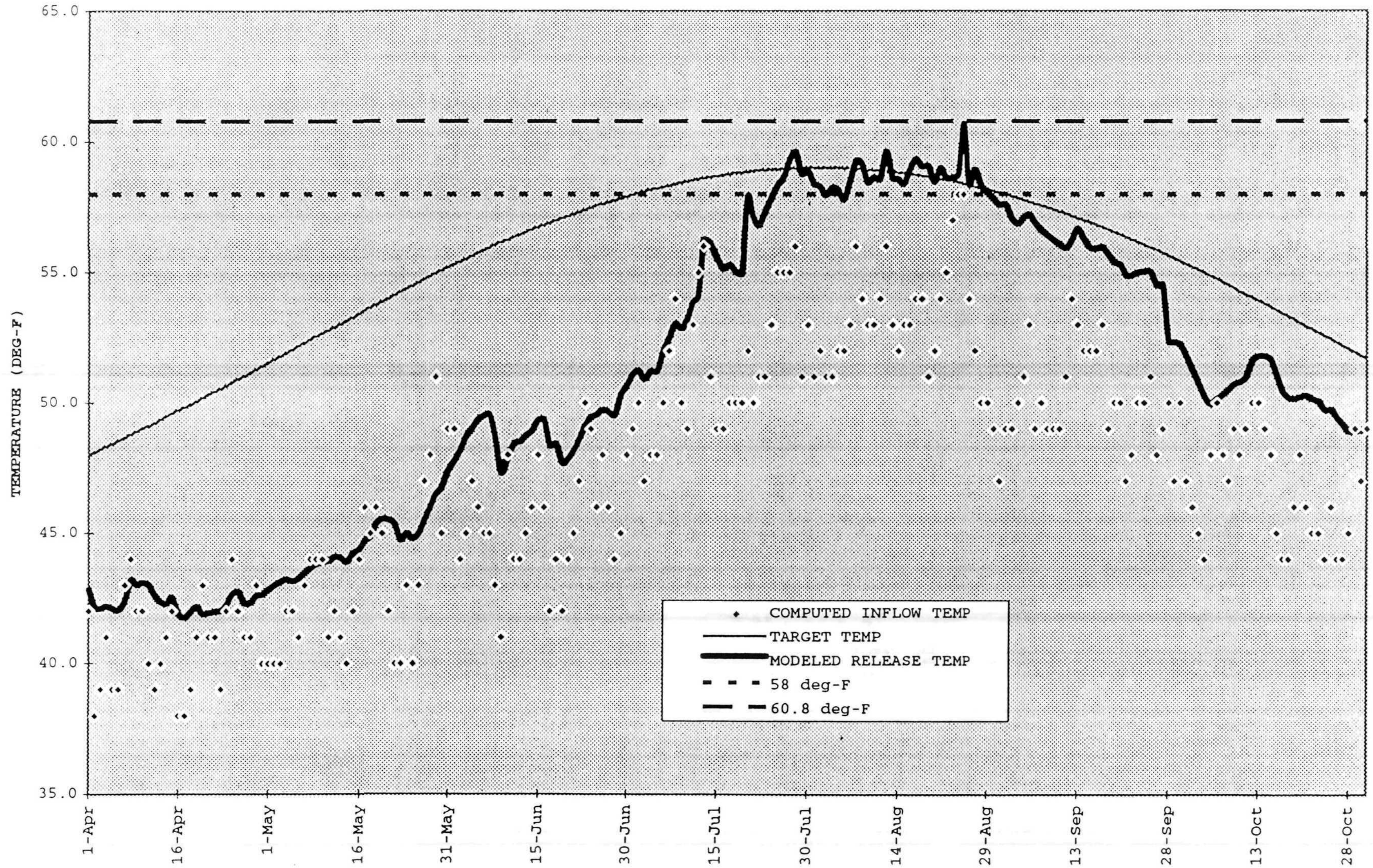
1962 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES

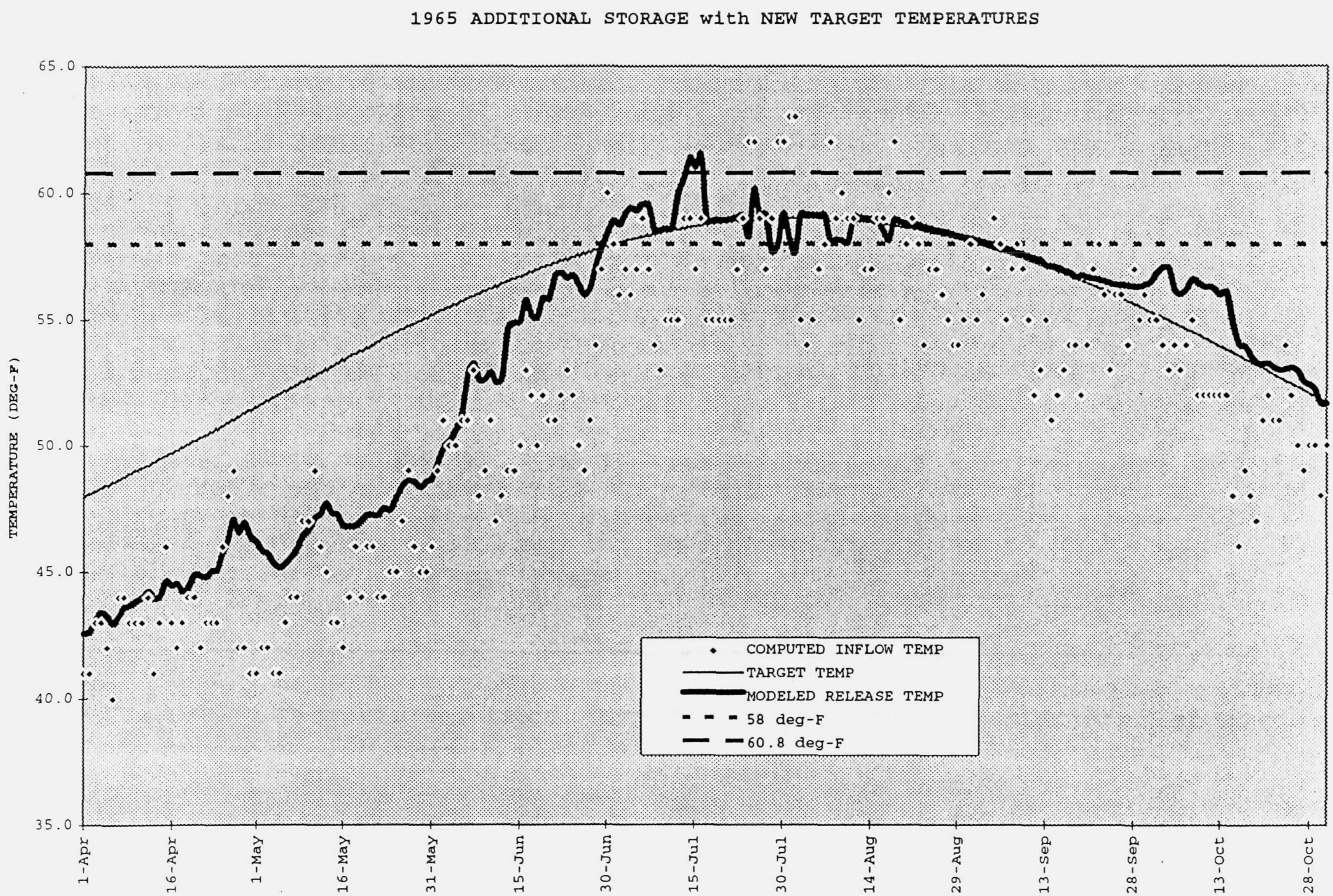


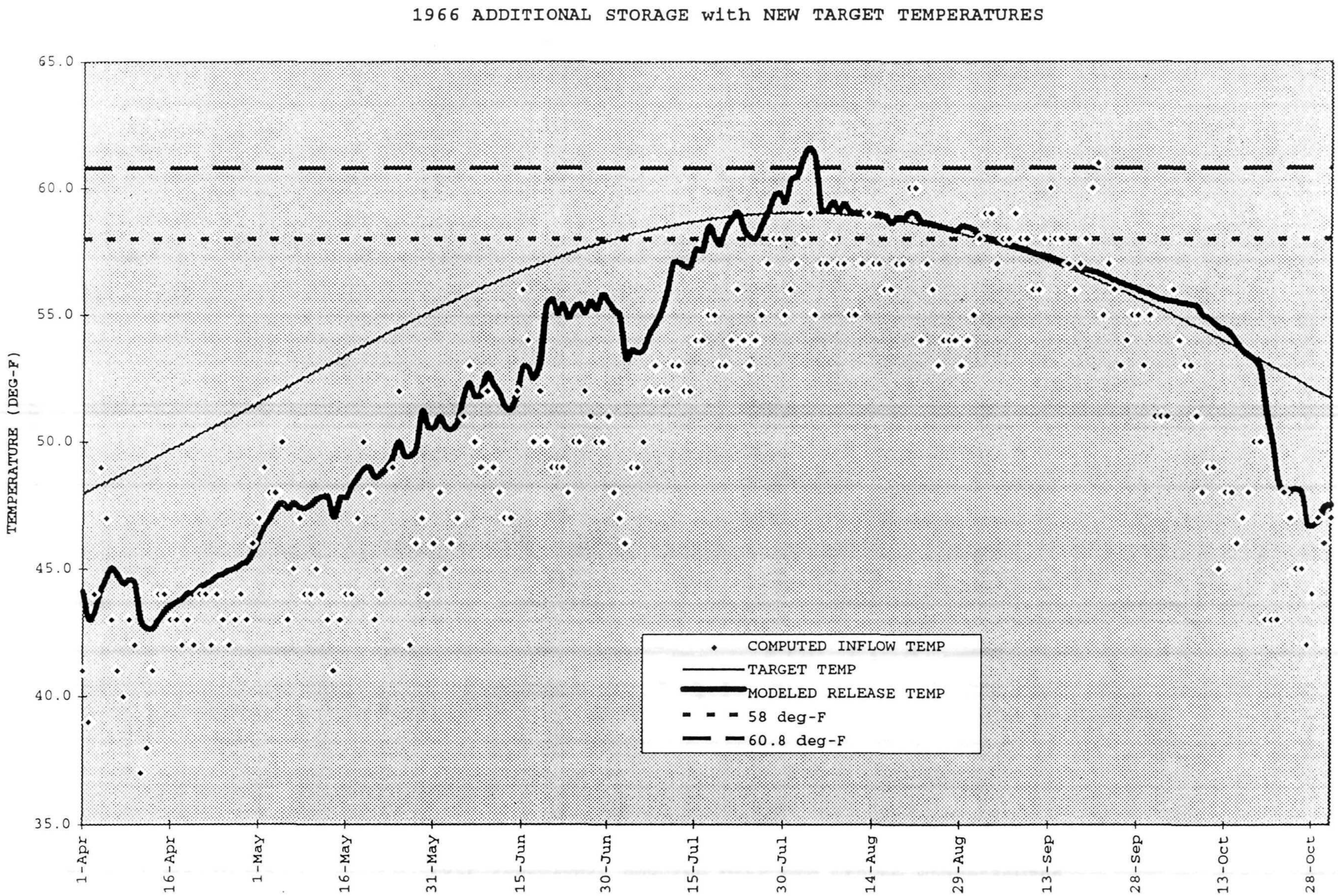
1963 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES



1964 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES

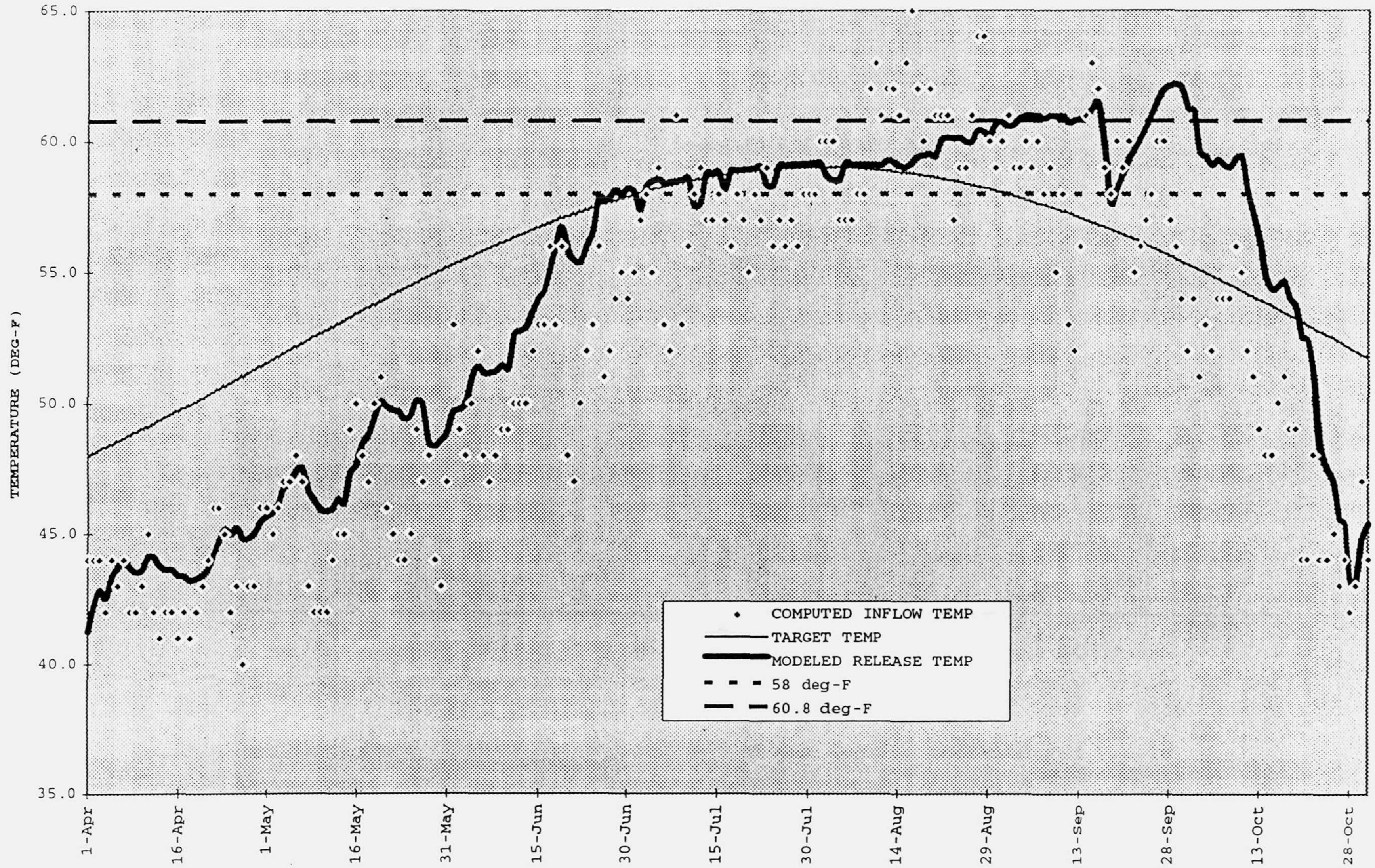


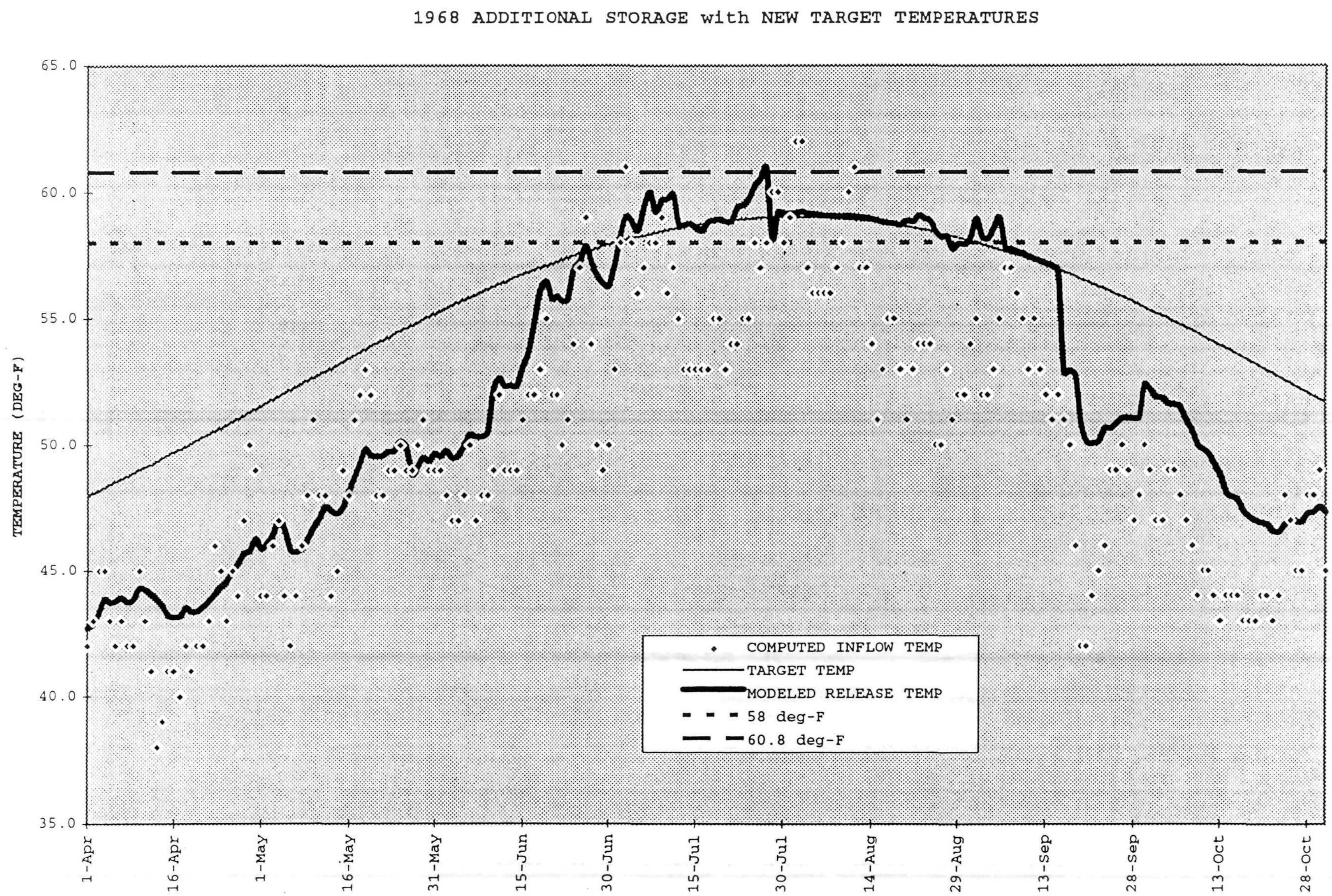

1965 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES
TEMPERATURE (DEG-F)
65.0
60.0
55.0
50.0
45.0
40.0
35.0
1-Apr
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F



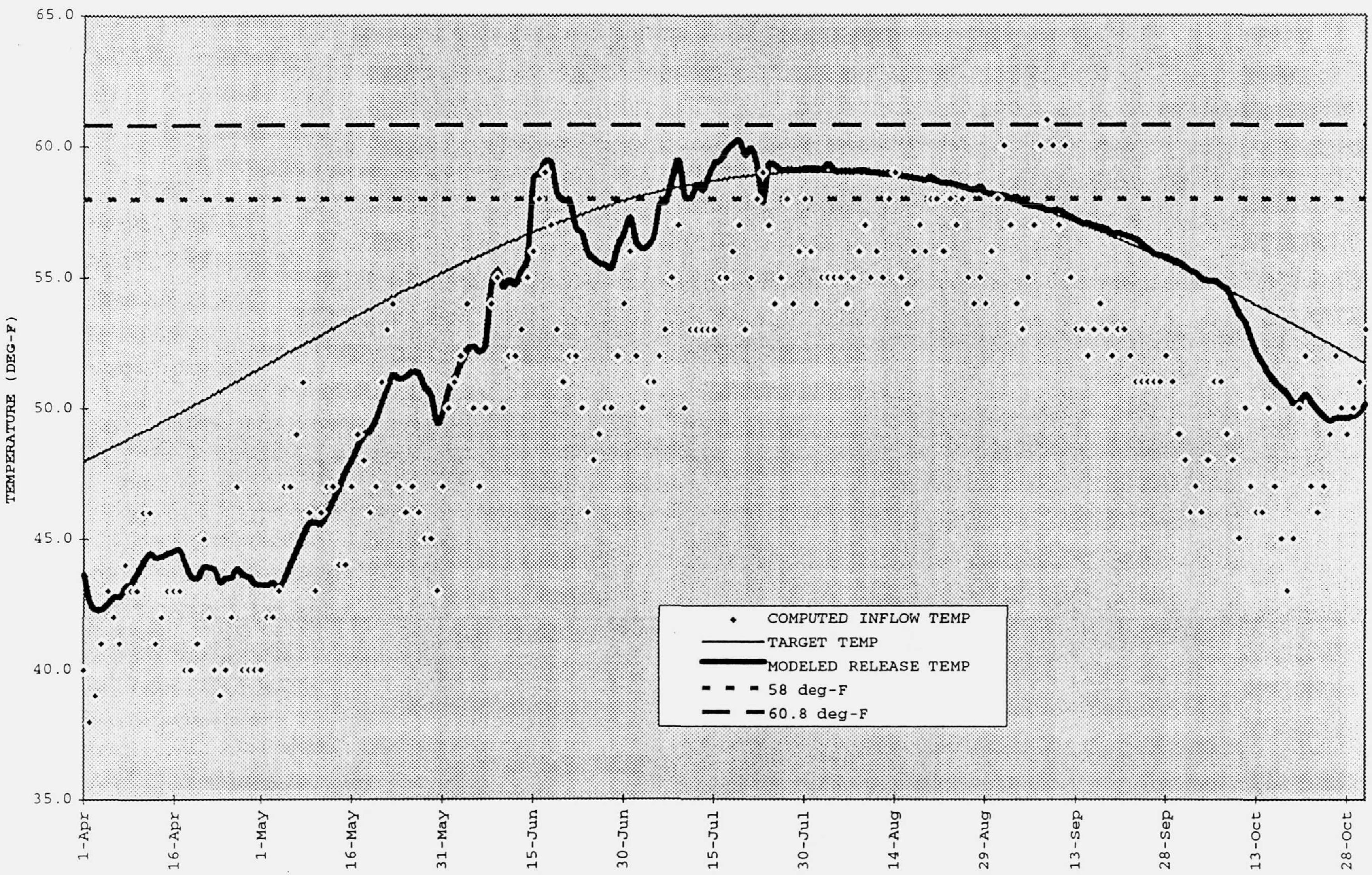
1966 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES
TEMPERATURE (DEG-F)
65.0
60.0
55.0
50.0
45.0
40.0
35.0
1-Apr
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F

1967 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES

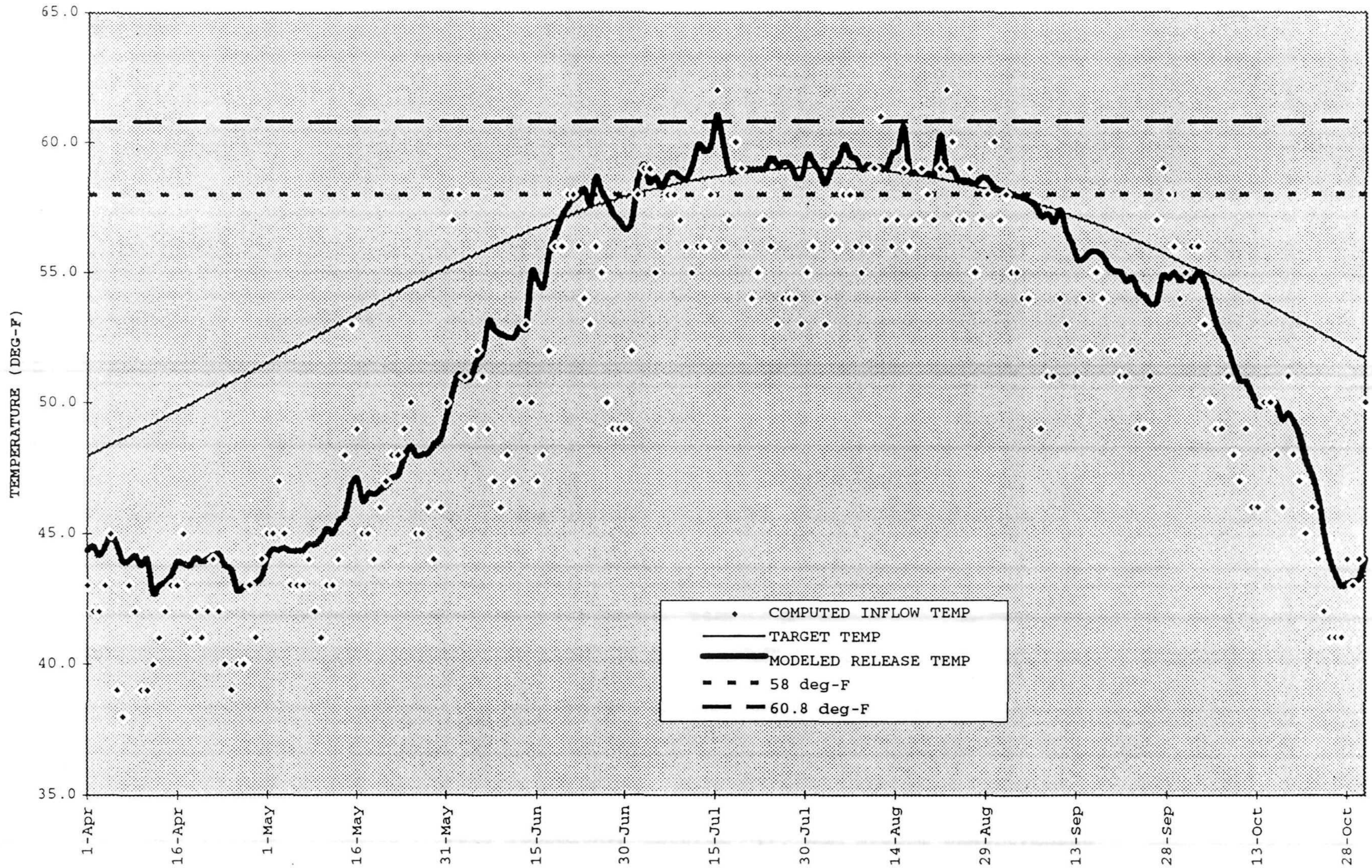



1968 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES
TEMPERATURE (DEG-F)
65.0
60.0
55.0
50.0
45.0
40.0
35.0
1-Apr
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F

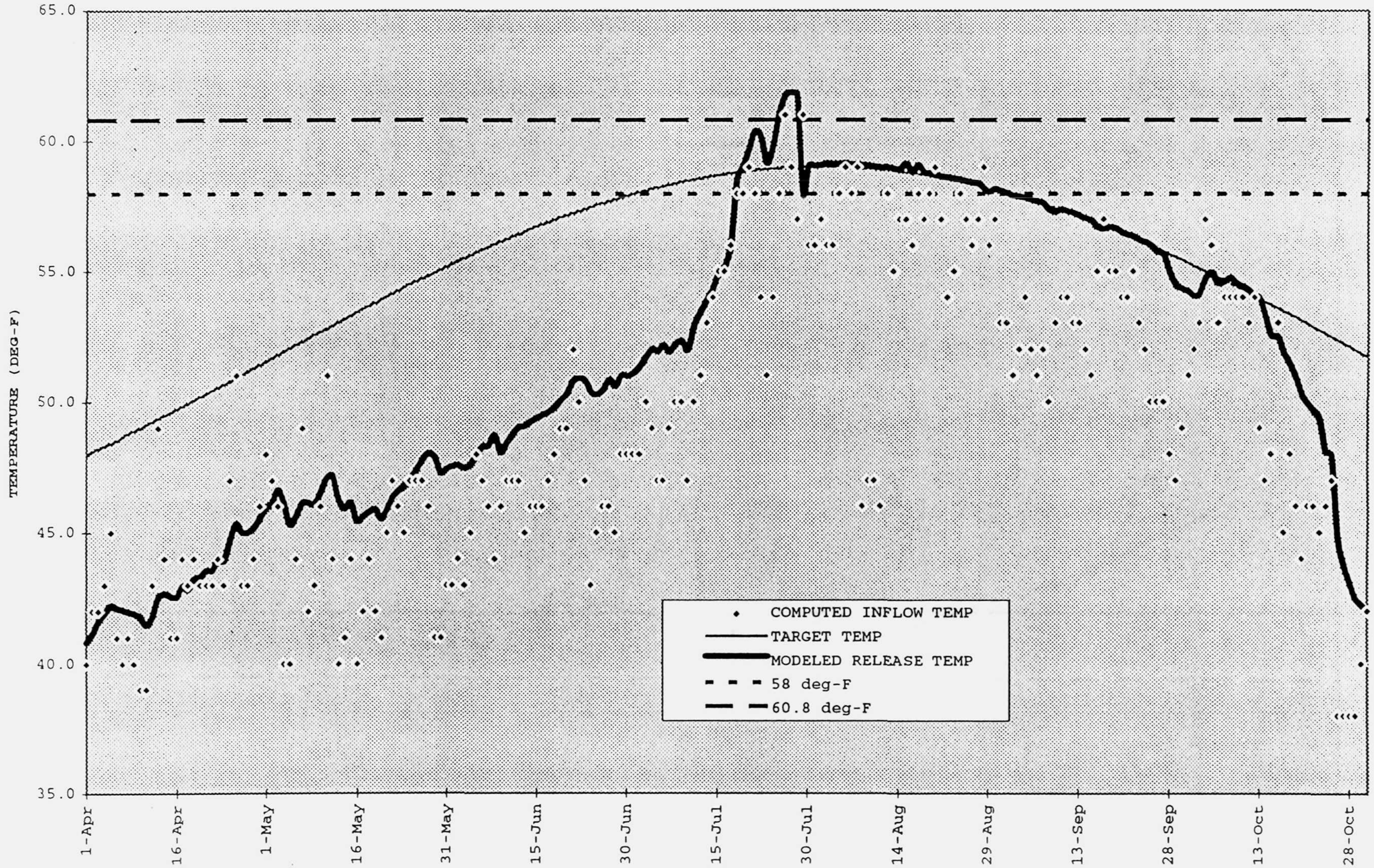
1969 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES

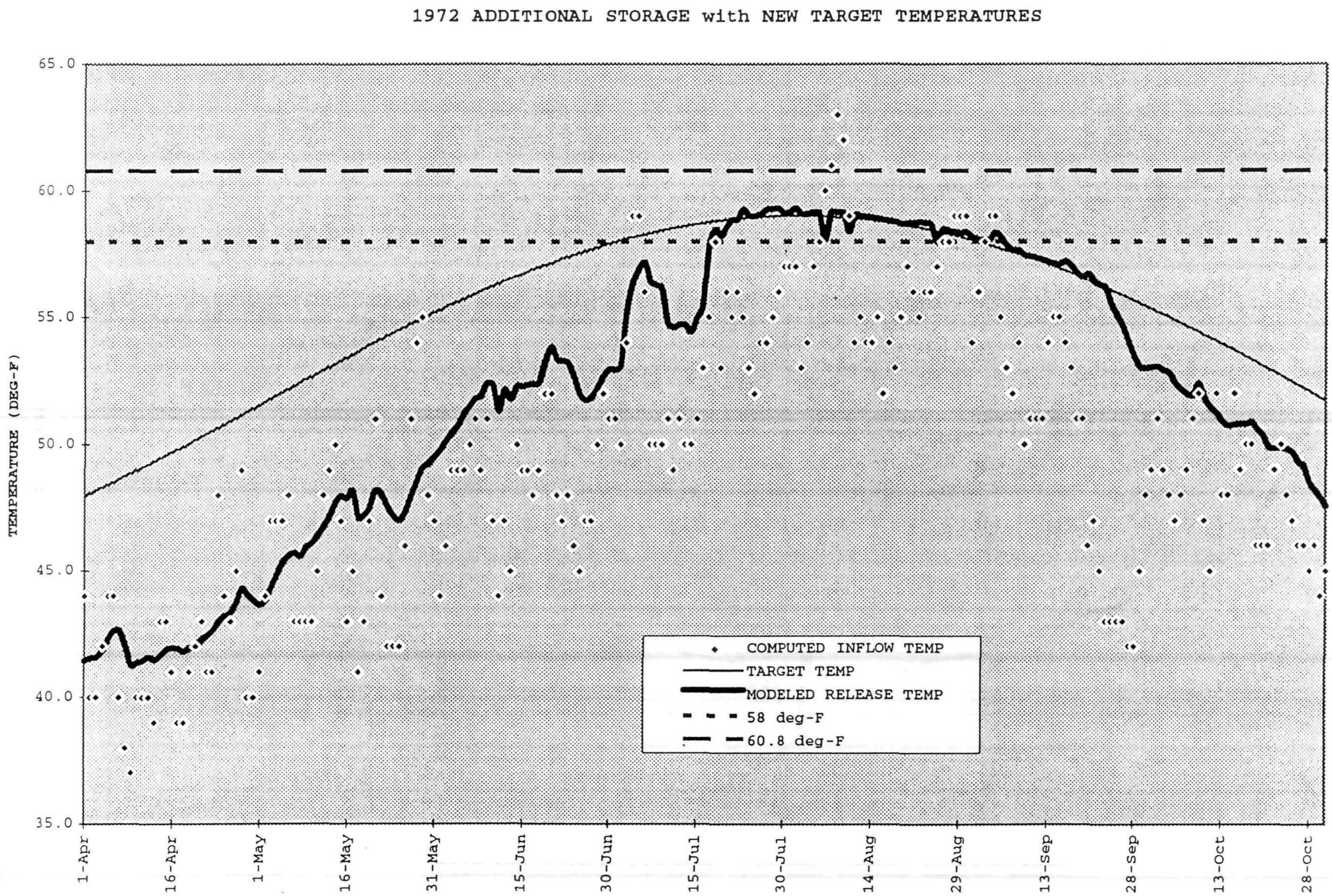


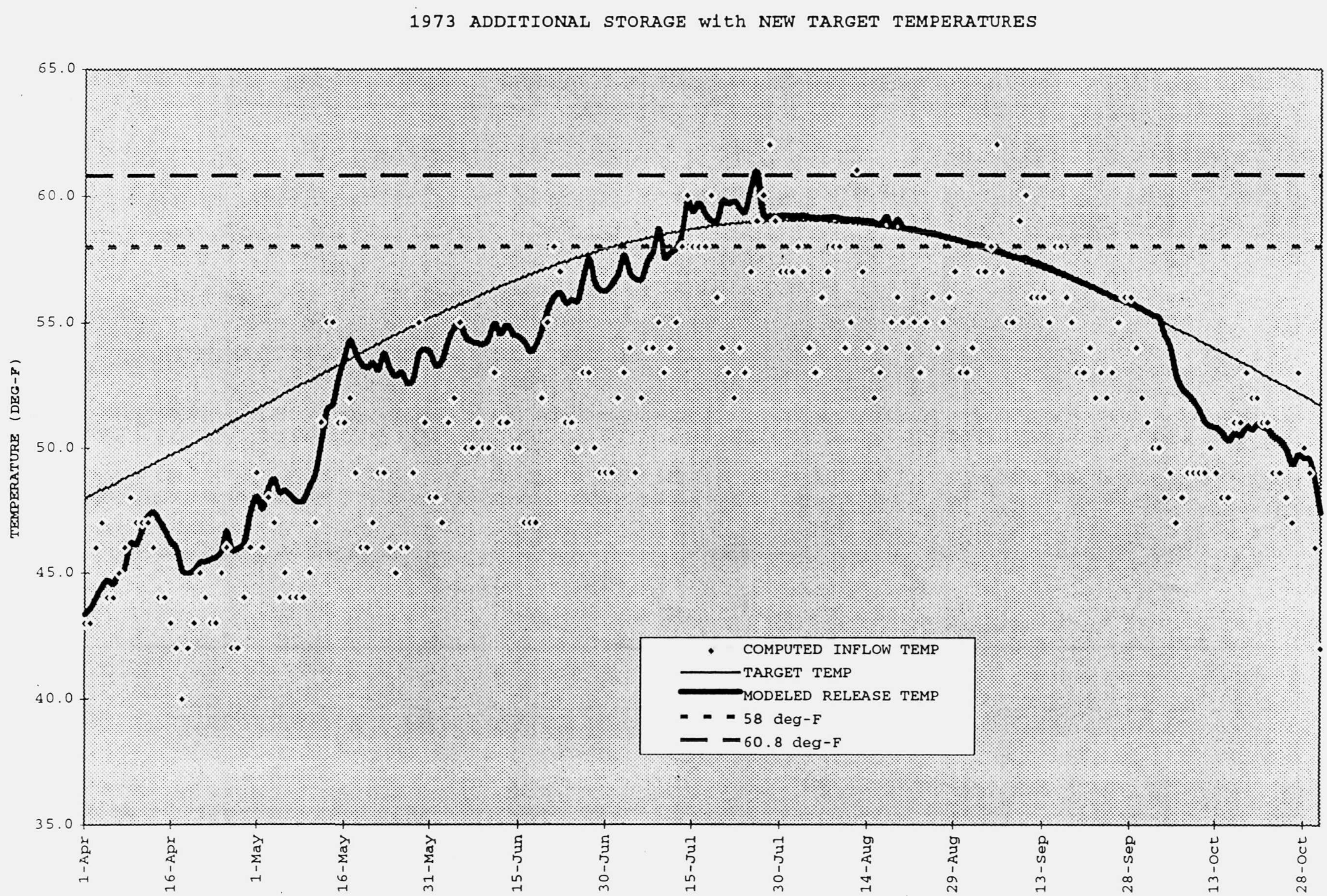
1970 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES



1971 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES




1972 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES
TEMPERATURE (DEG-F)
65.0
60.0
55.0
50.0
45.0
40.0
35.0
1-Apr
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F


1973 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES
TEMPERATURE (DEG-F)
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55.0
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40.0
35.0
1-Apr
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
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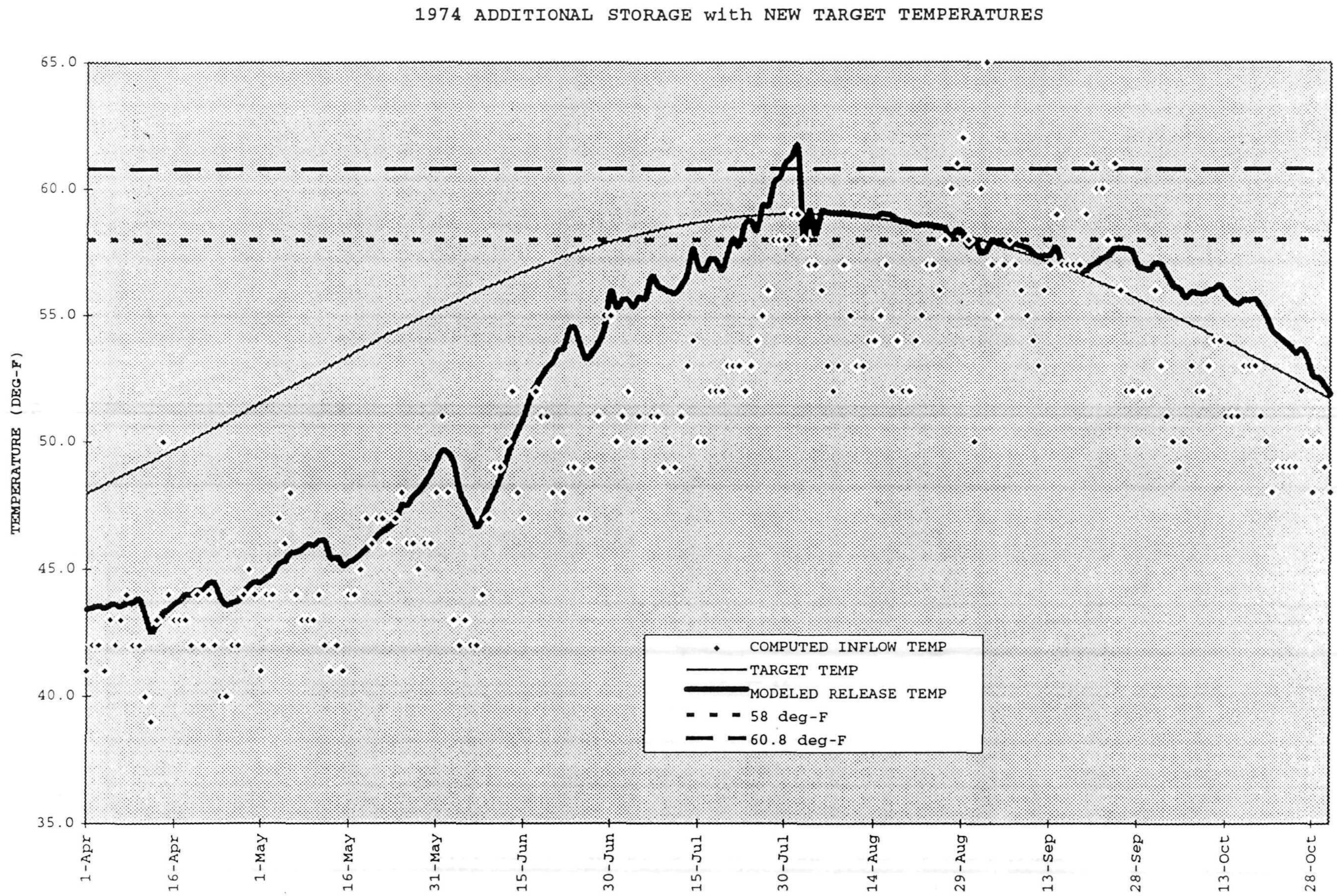
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F



1974 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES
TEMPERATURE (DEG-F)
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40.0
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1-Apr
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
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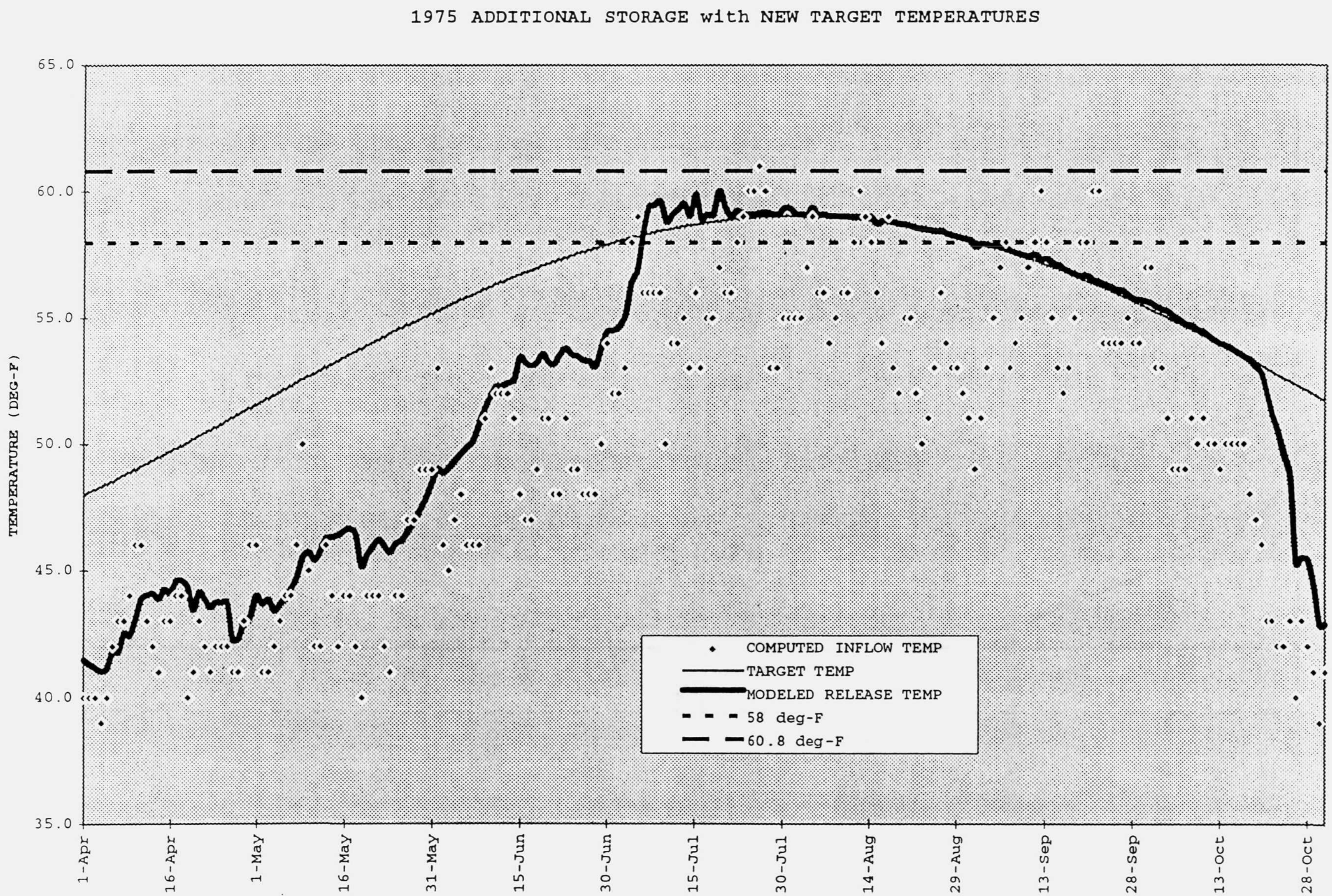
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F

D3-6-14


1975 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES
TEMPERATURE (DEG-F)
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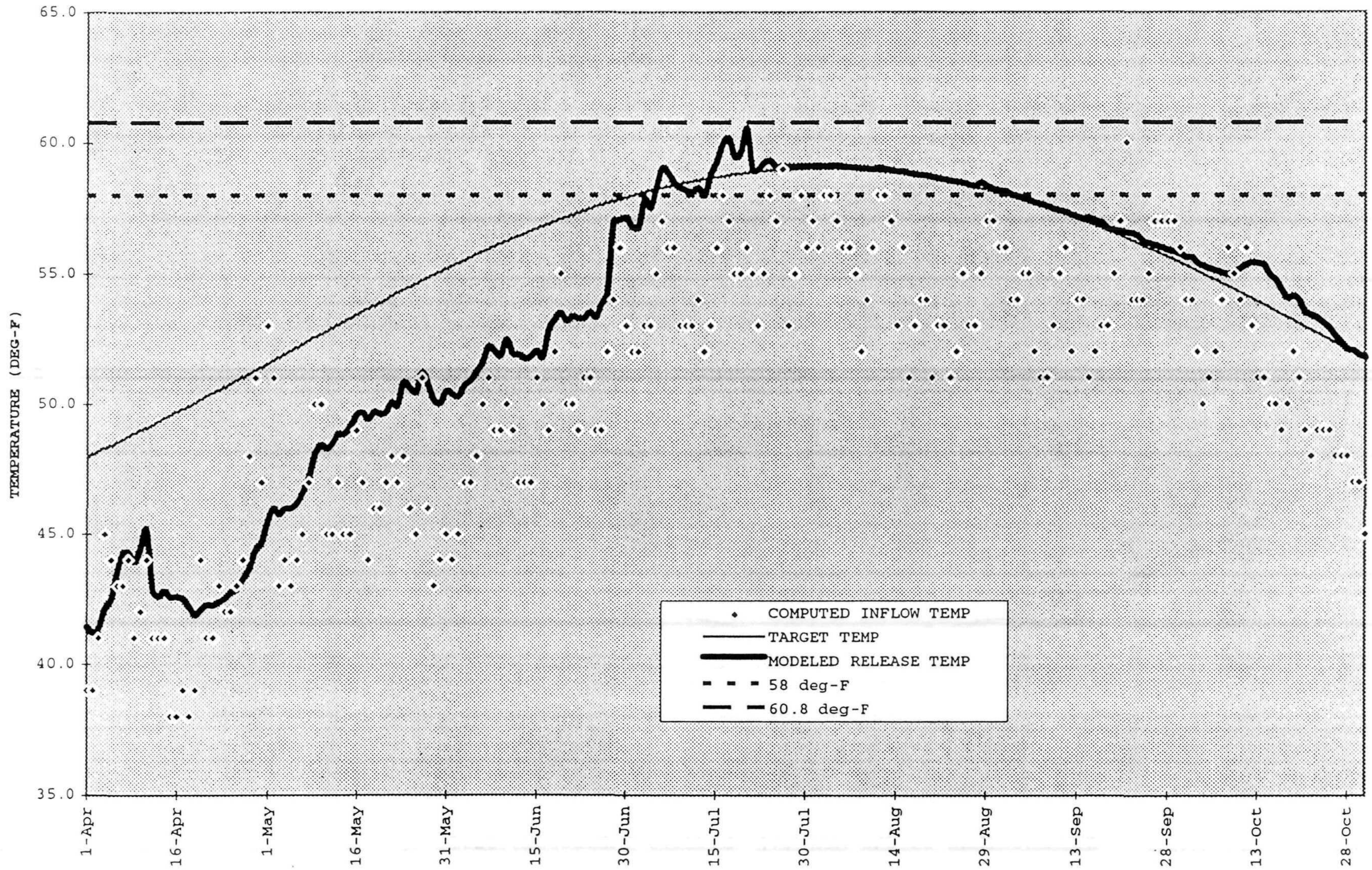
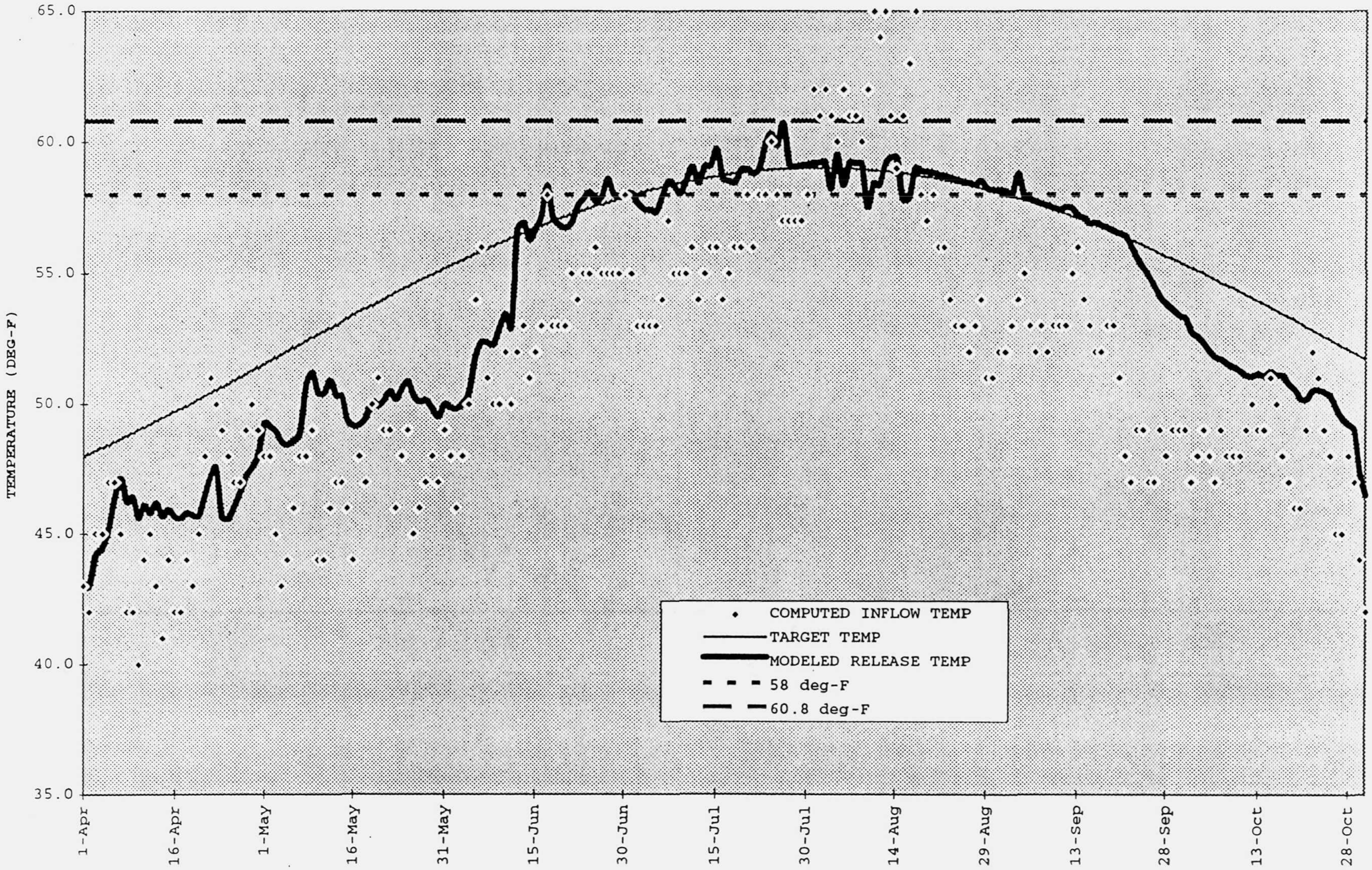
1-Apr
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F

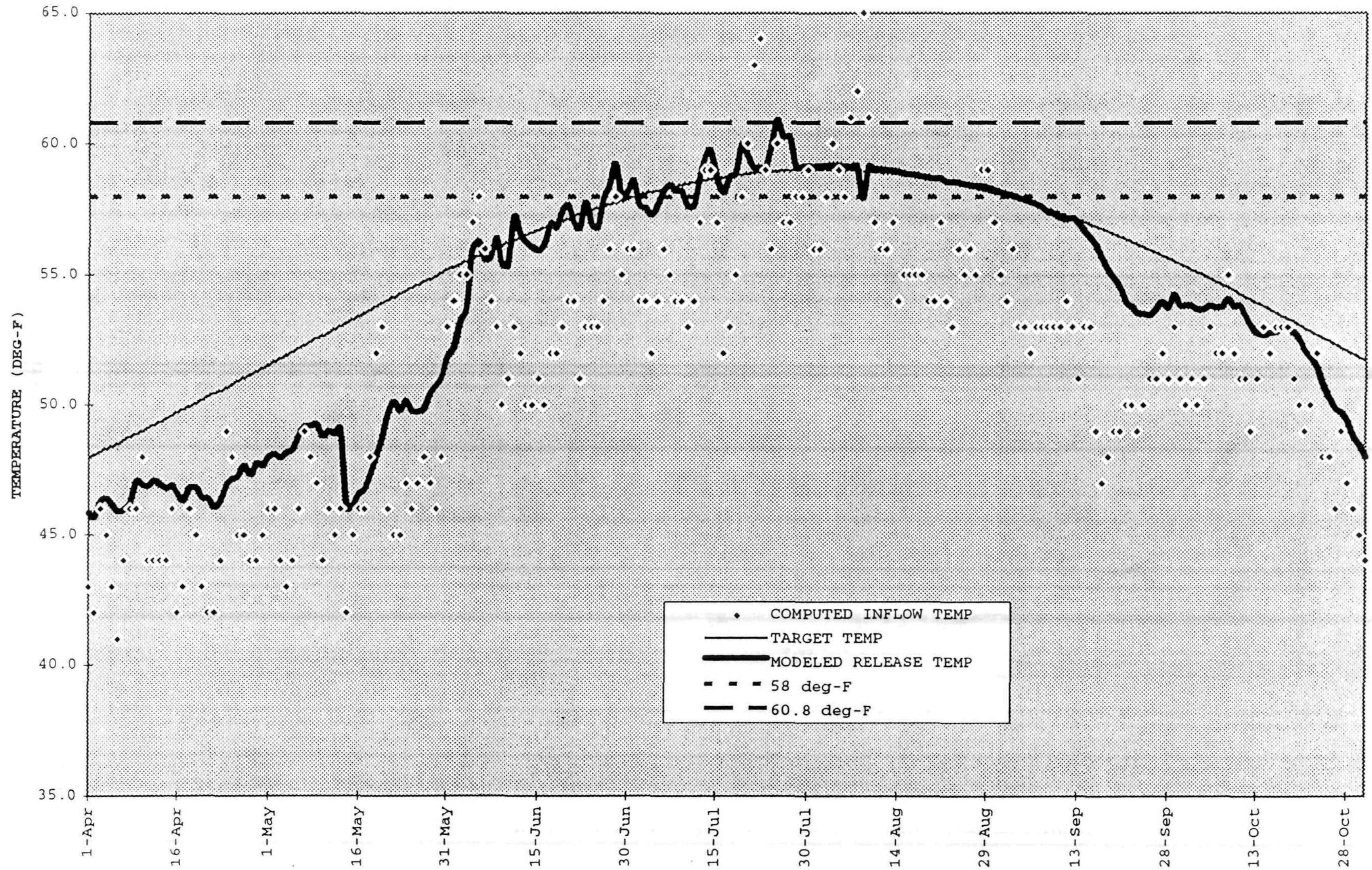
1976 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES

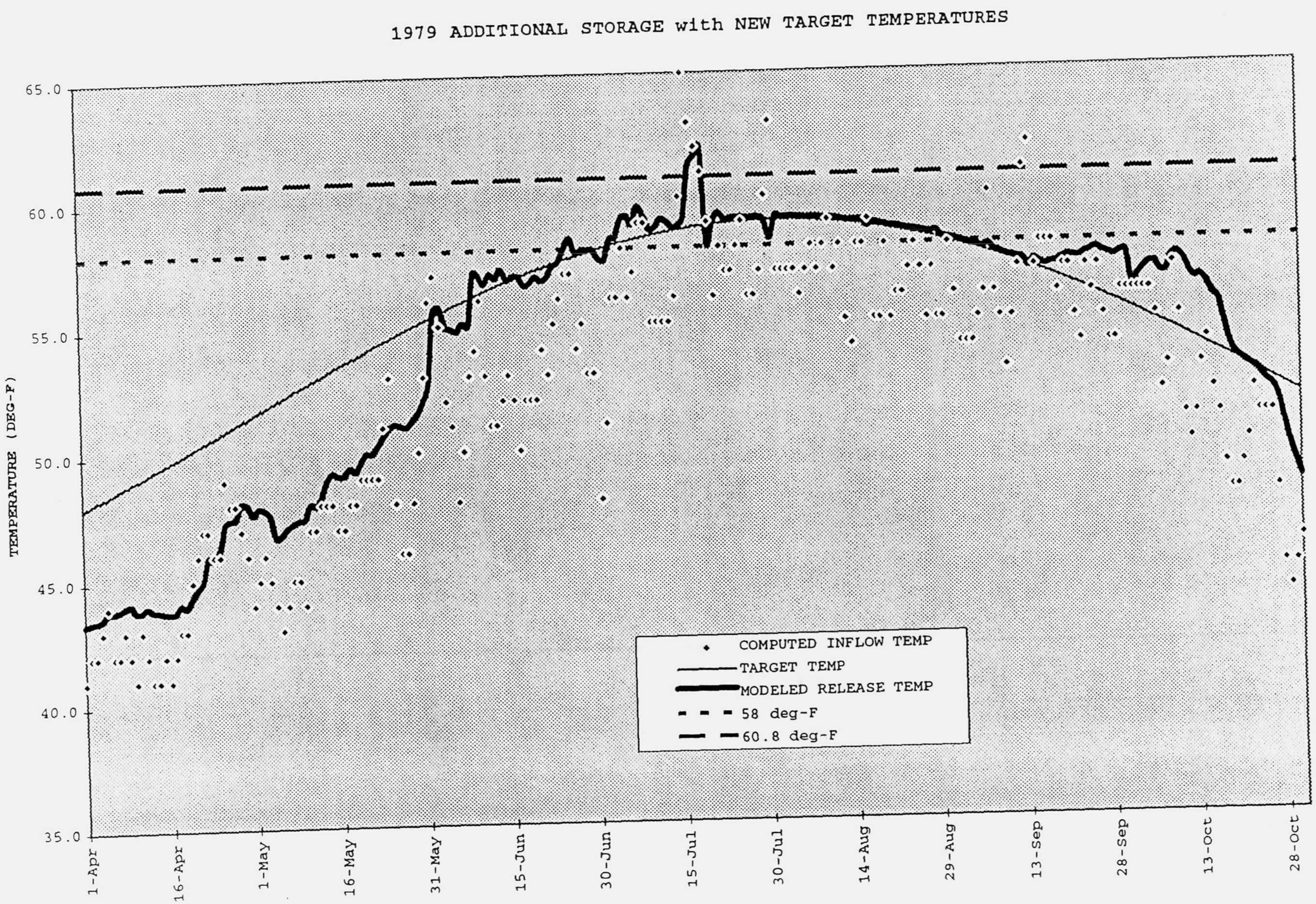


1977 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES



1978 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES





1979 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES
TEMPERATURE (DEG-F)
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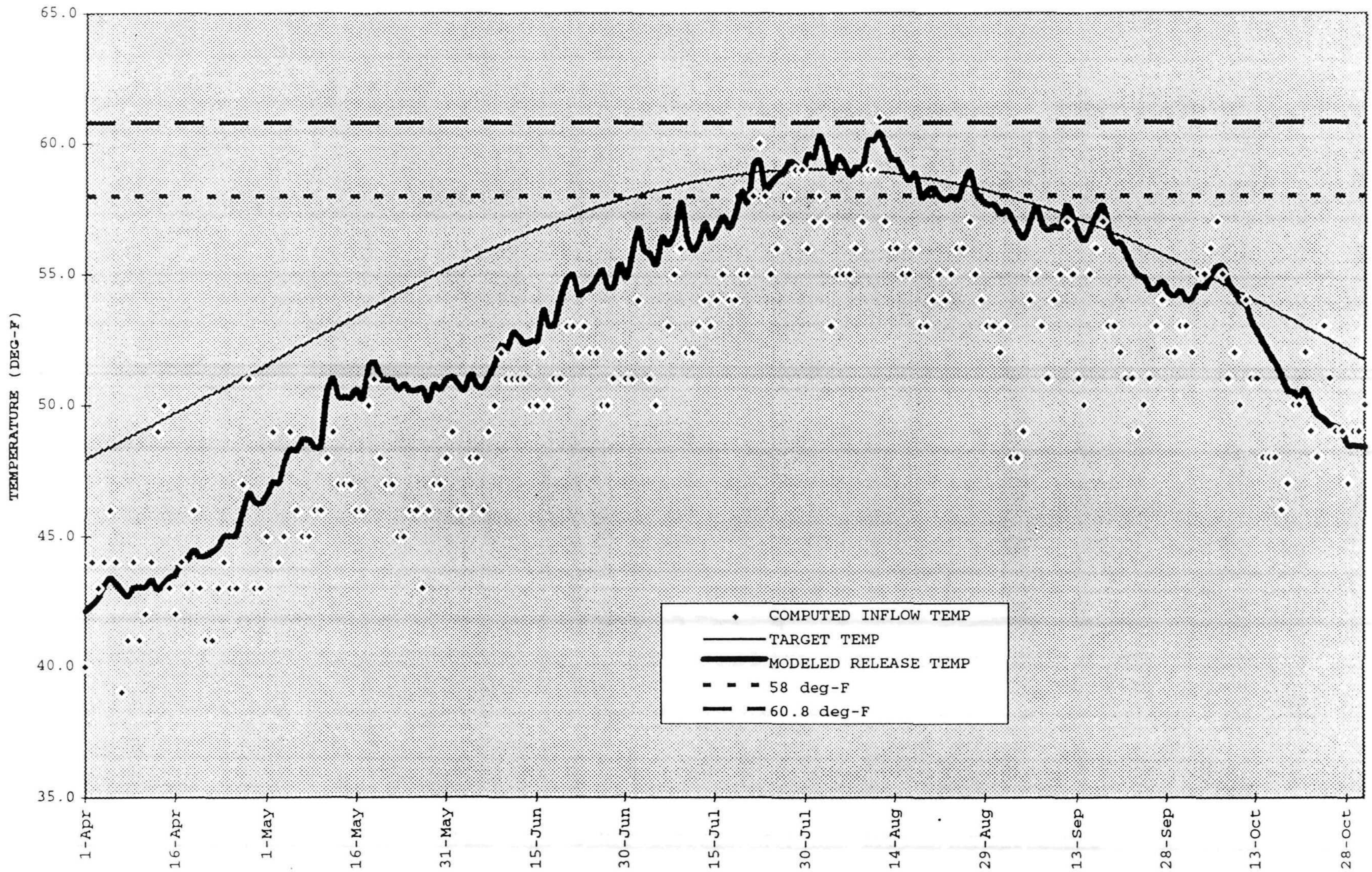
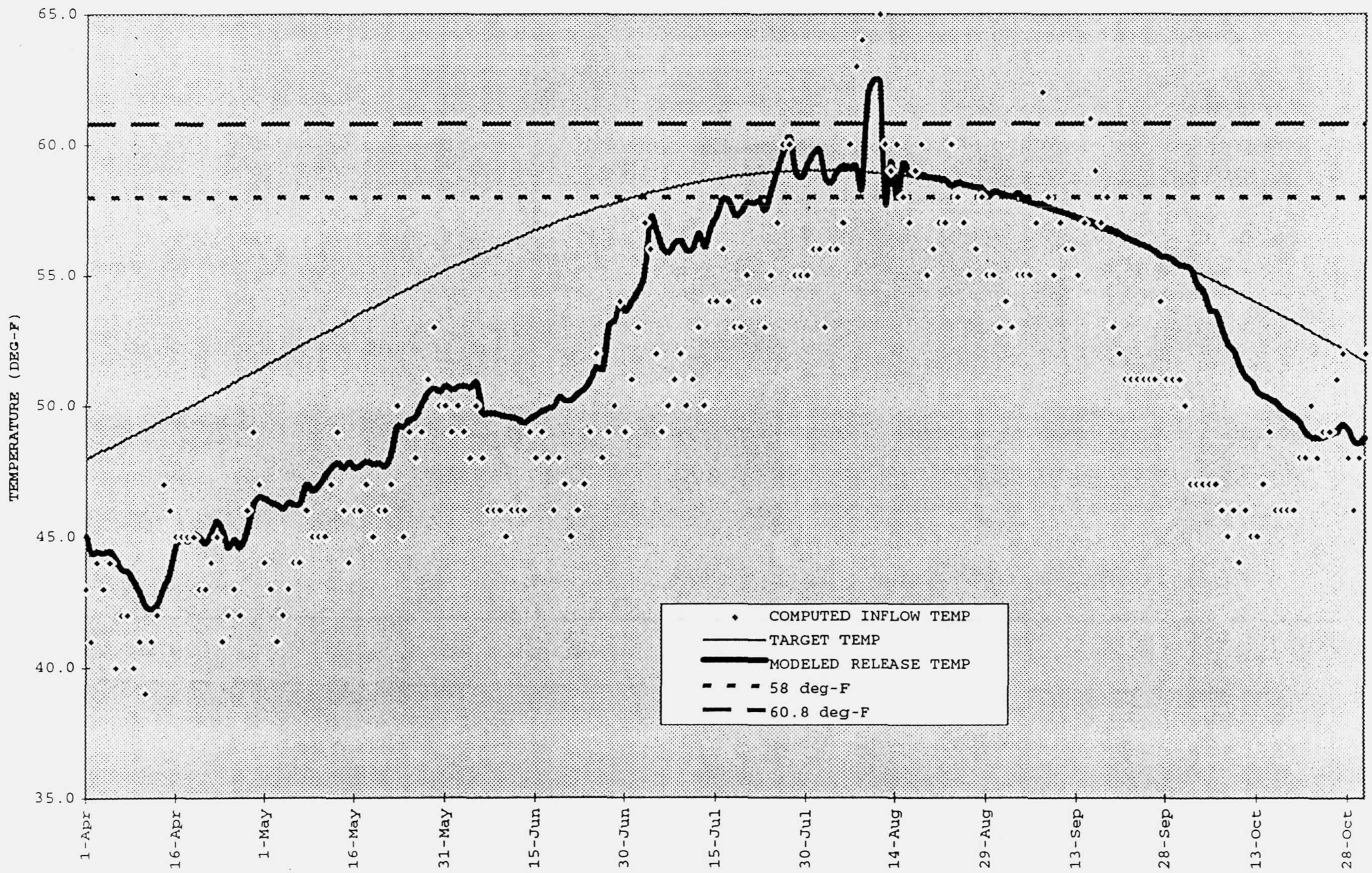
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F

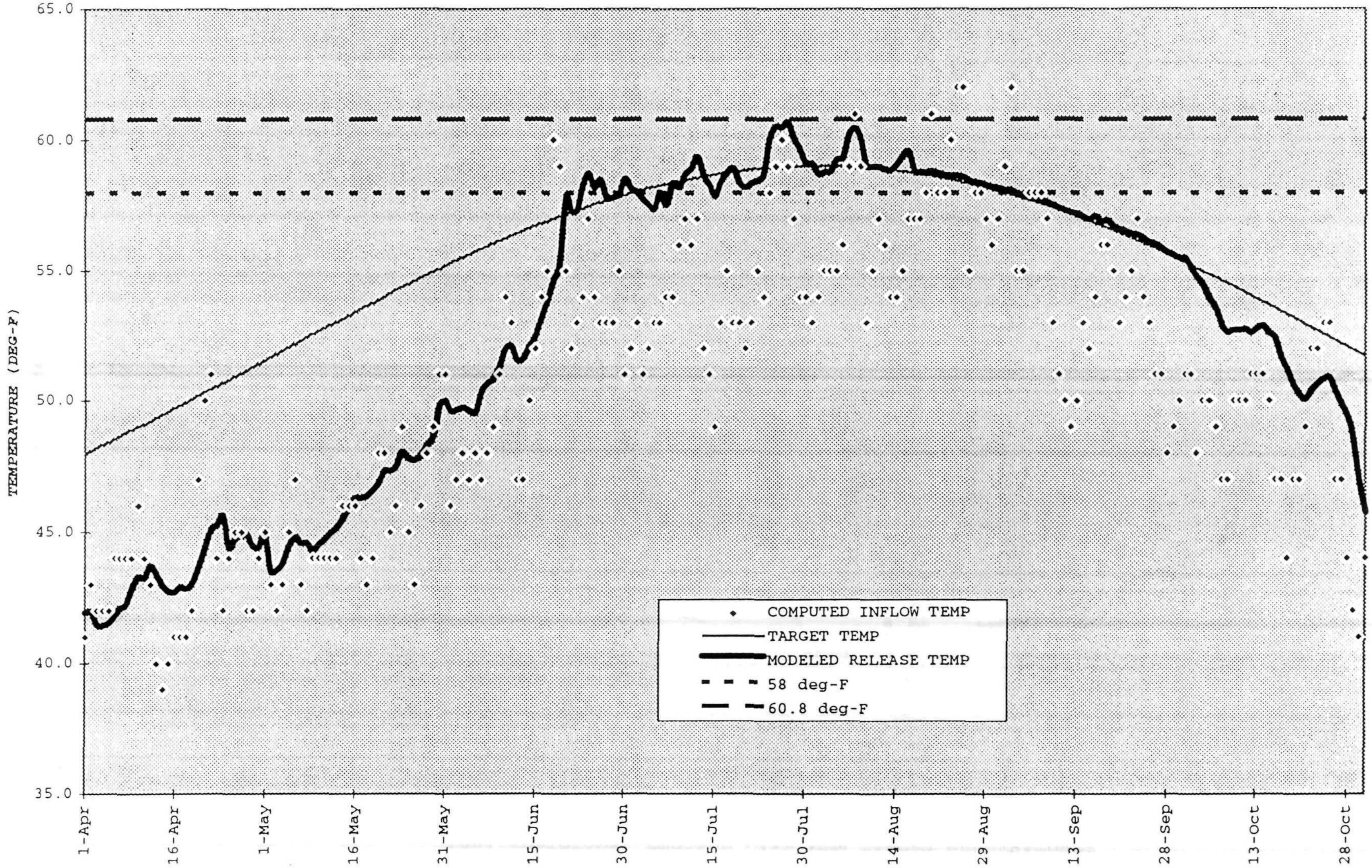
1980 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES



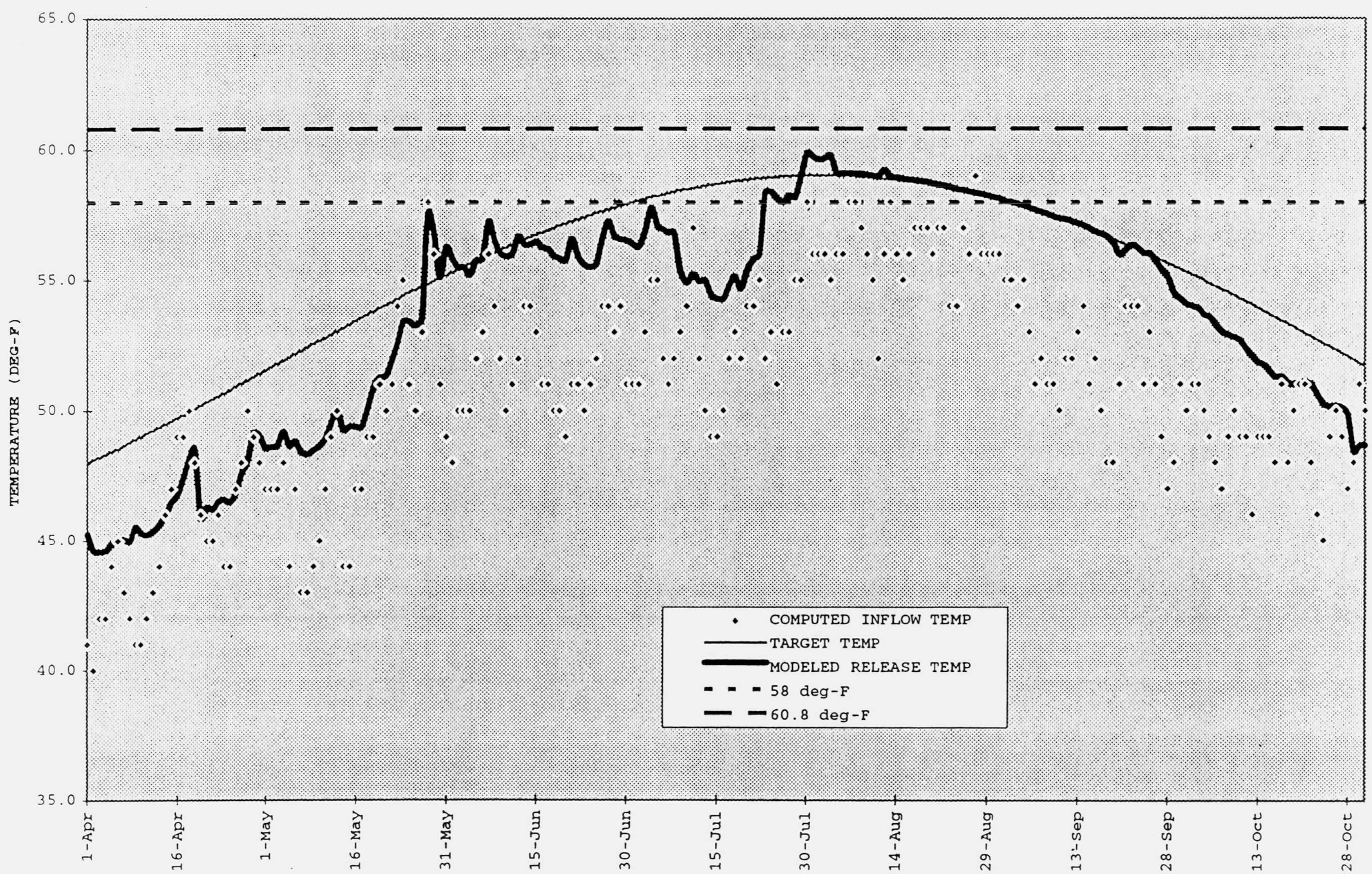
1981 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES

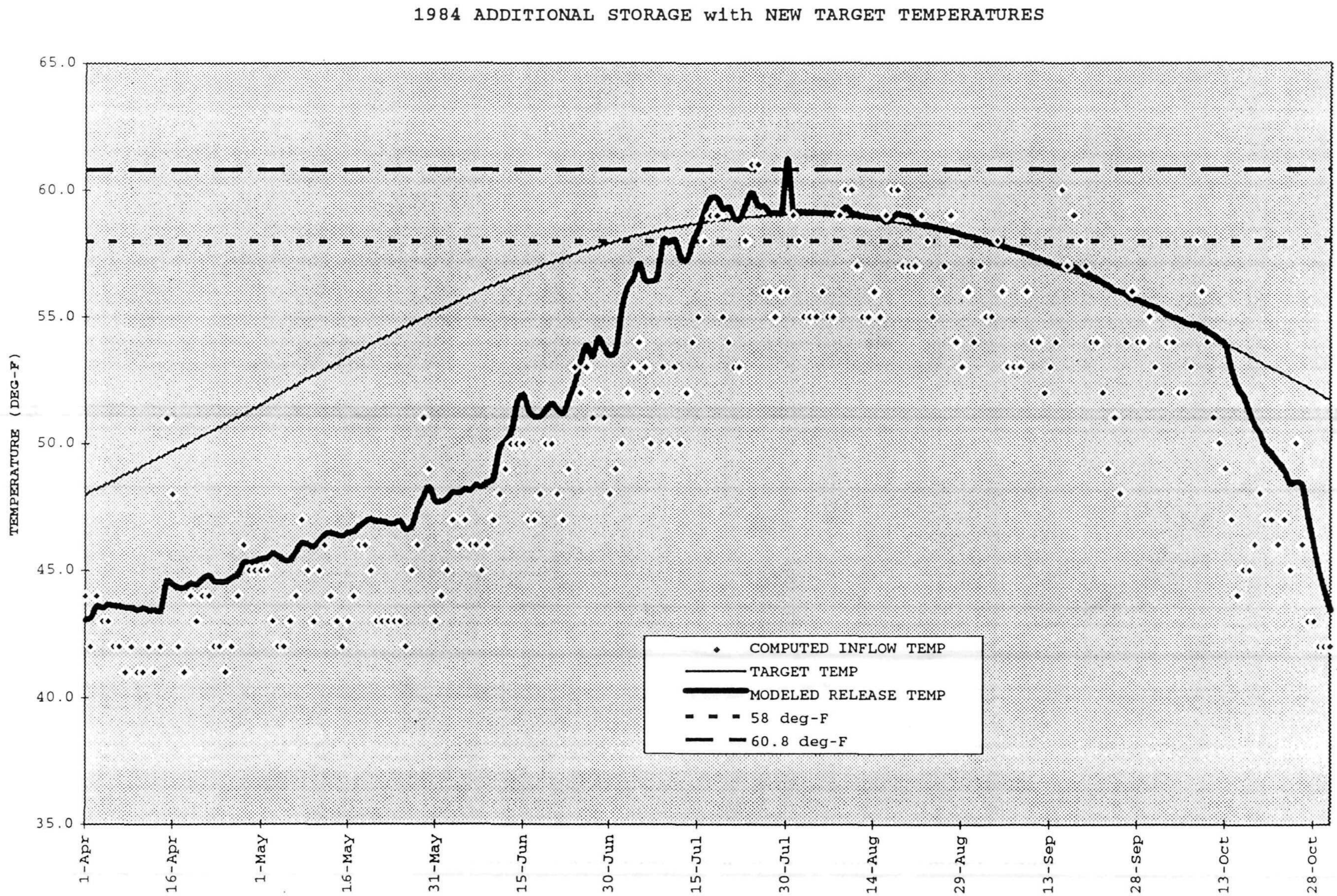


1982 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES



1983 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES





1984 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES
TEMPERATURE (DEG-F)
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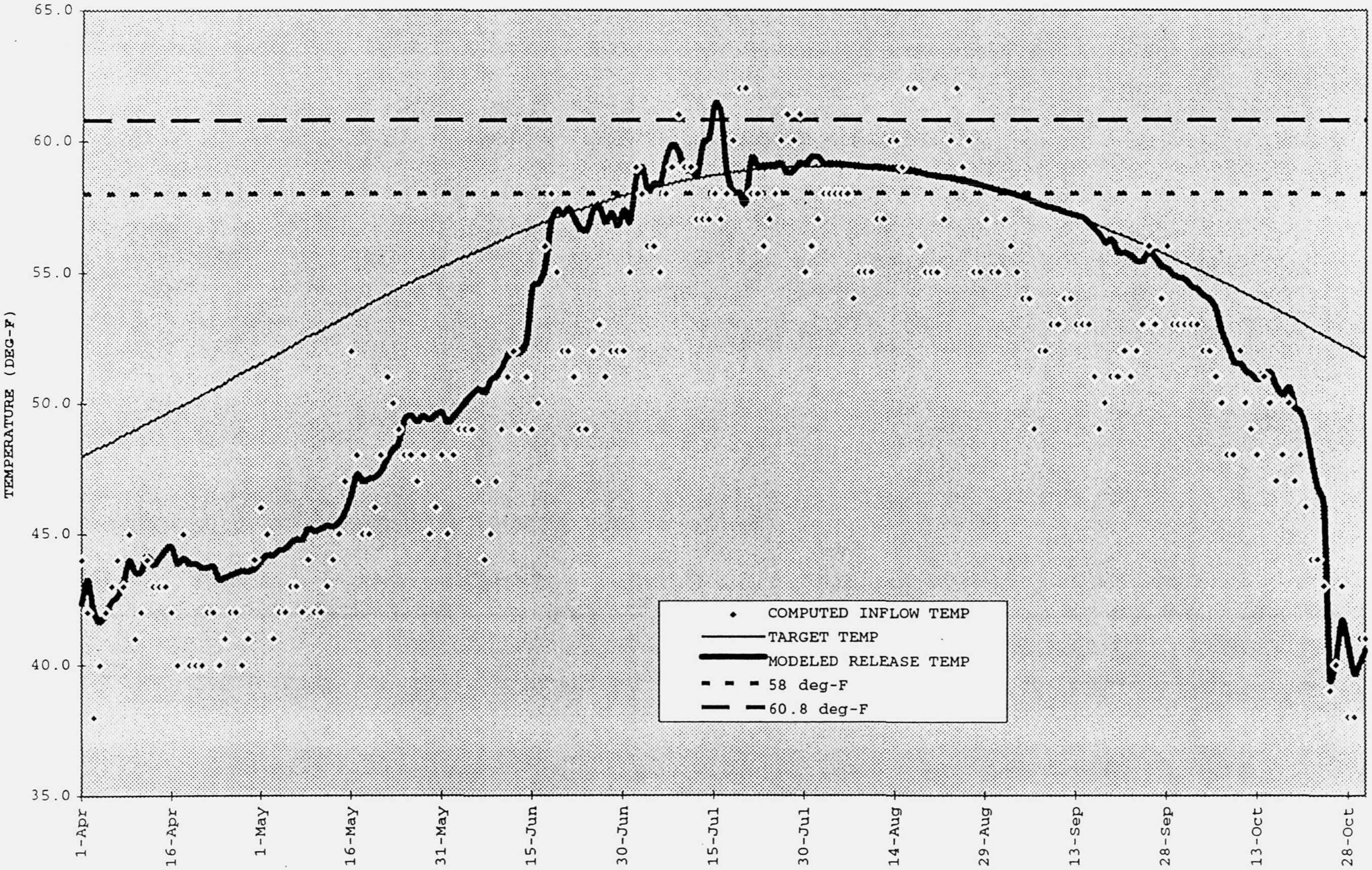
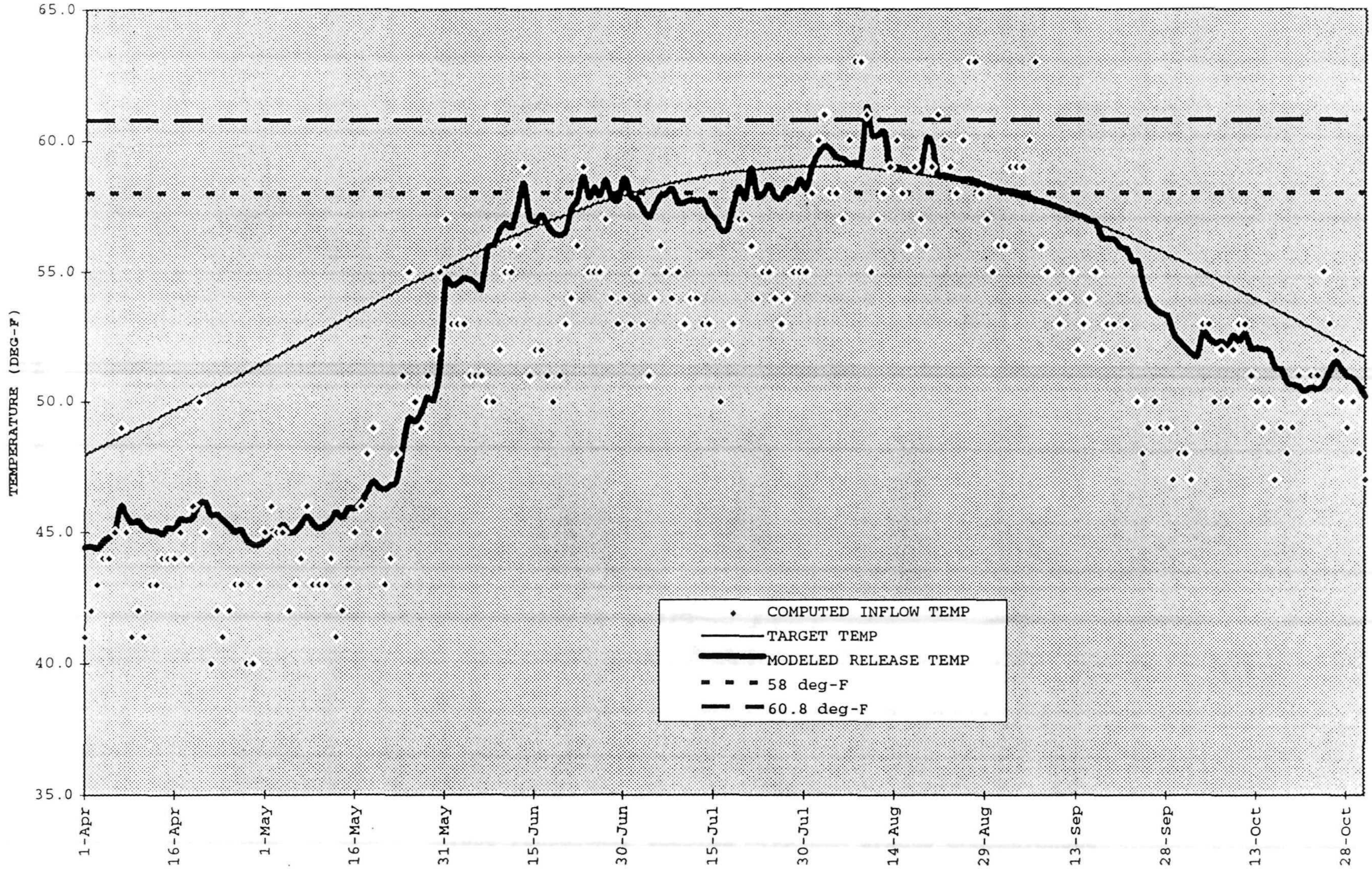
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F

D3-6-24

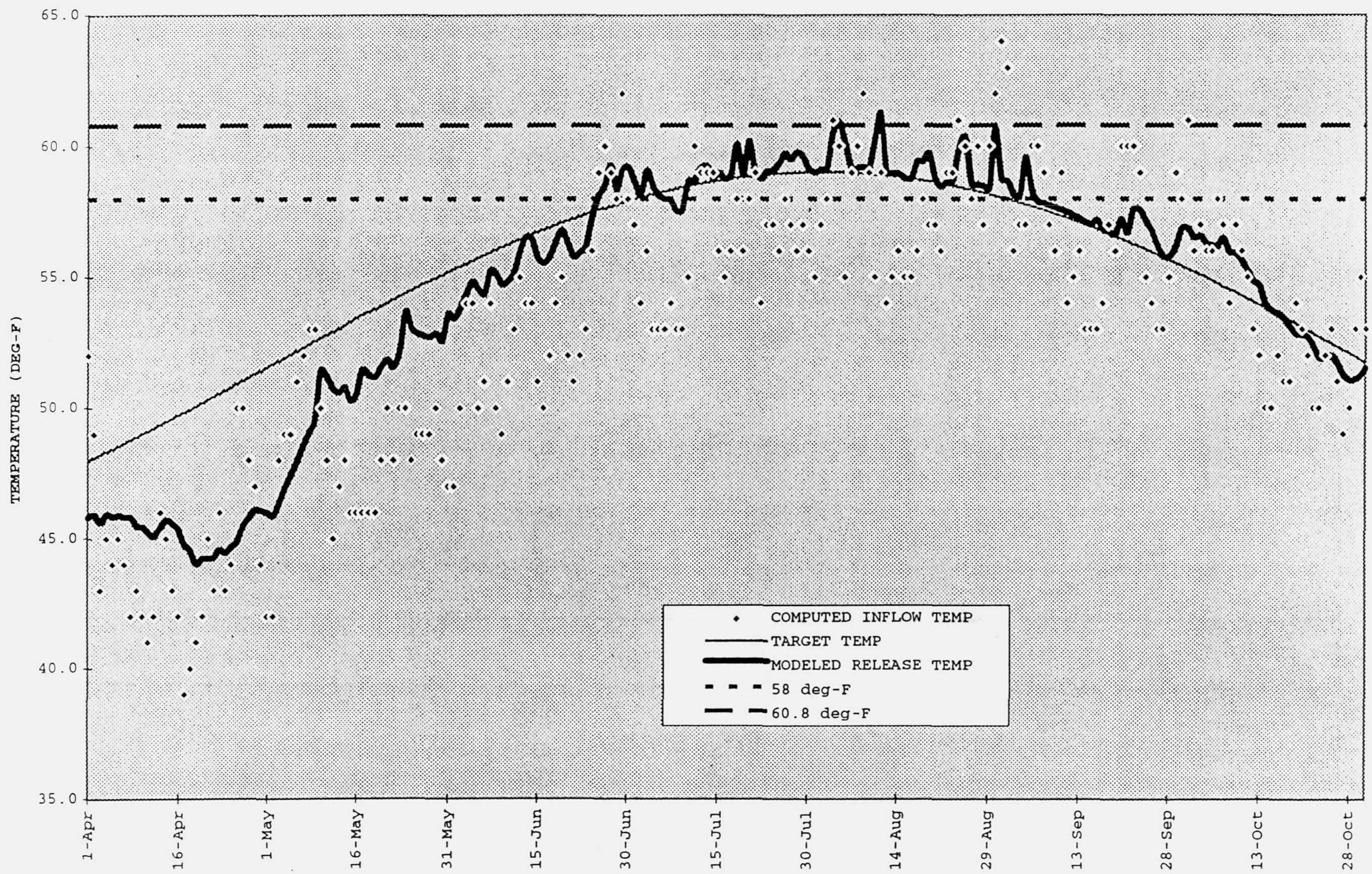
1985 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES

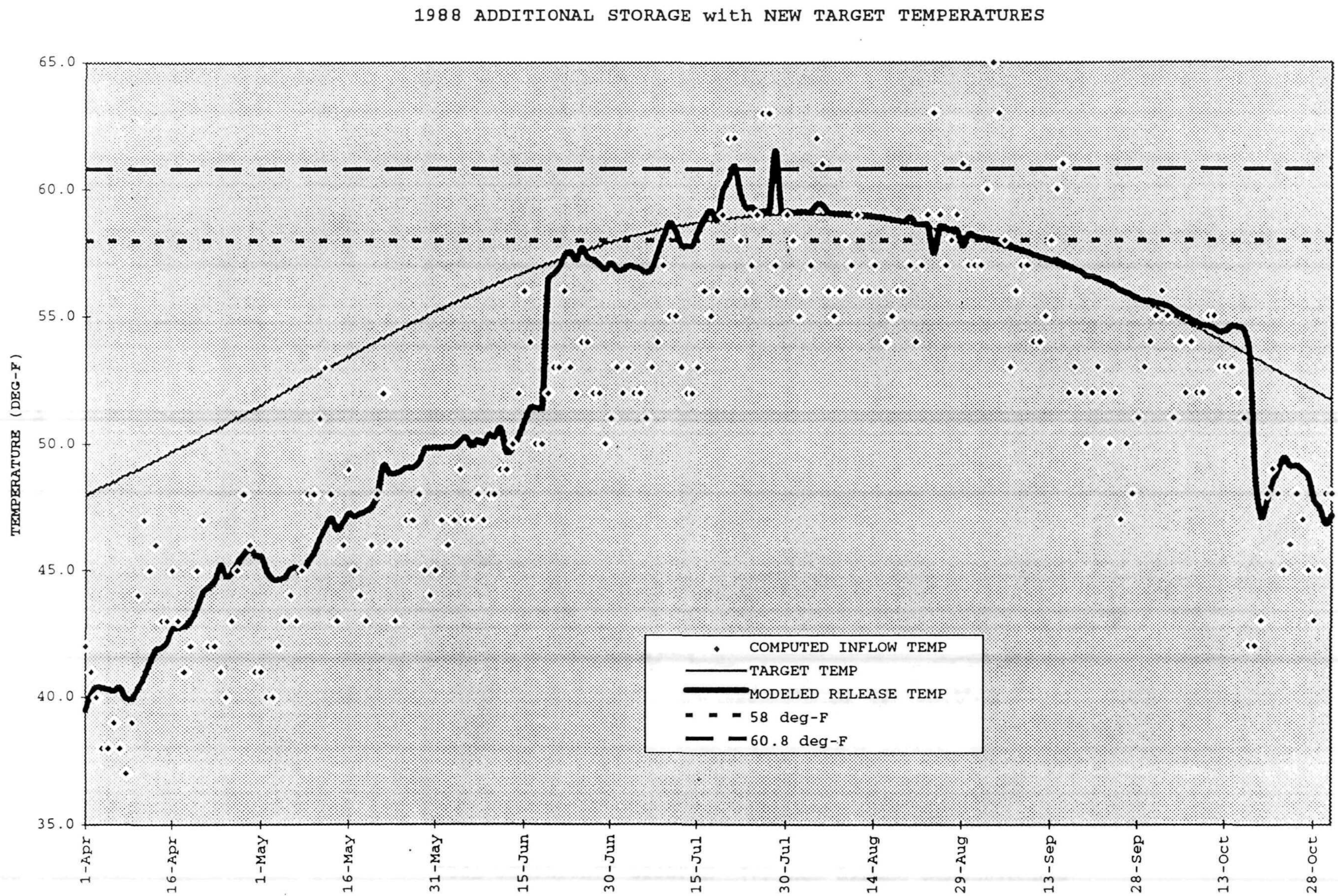


1986 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES



1987 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES




1988 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES
TEMPERATURE (DEG-F)
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16-May
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13-Sep
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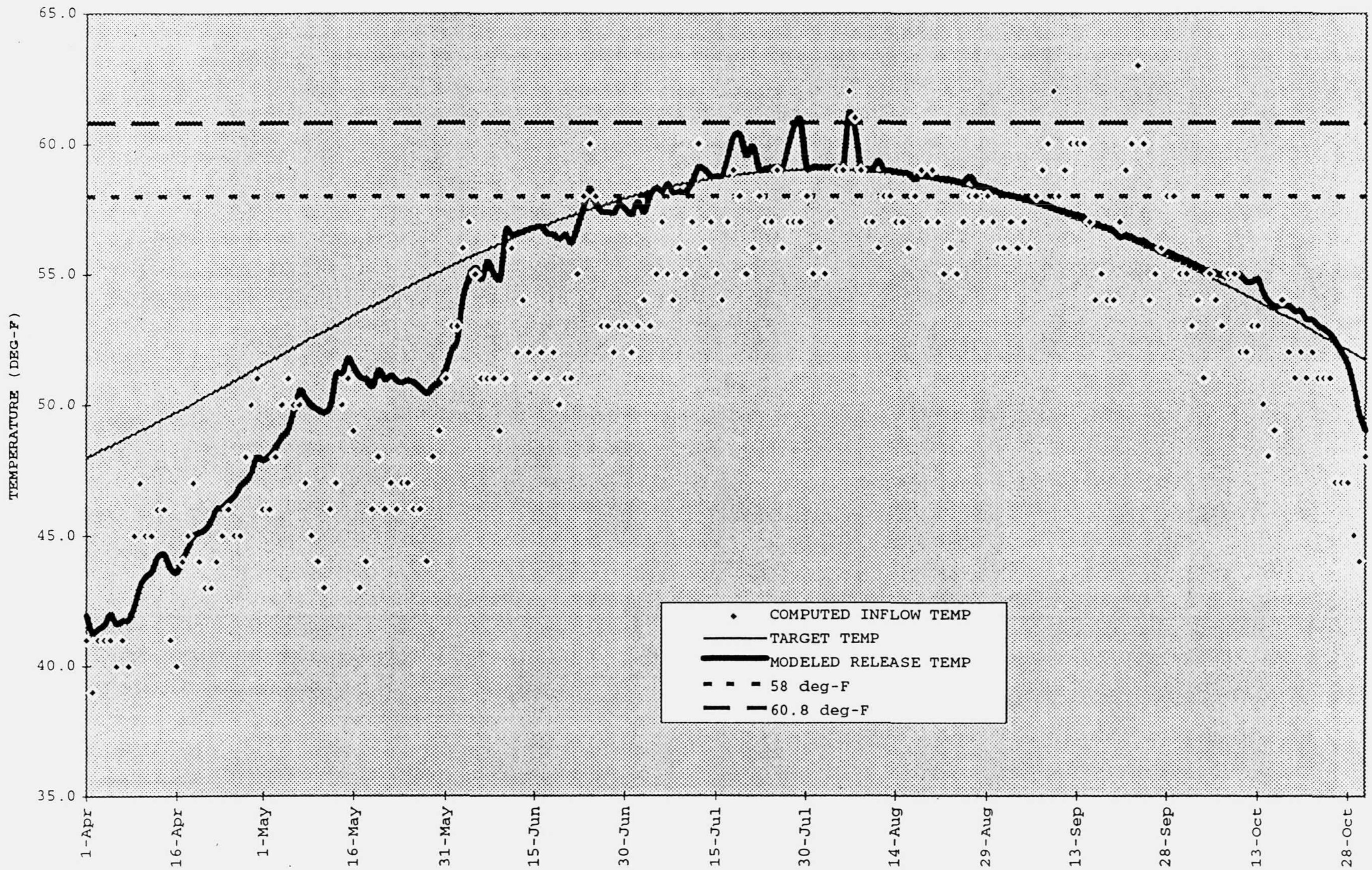
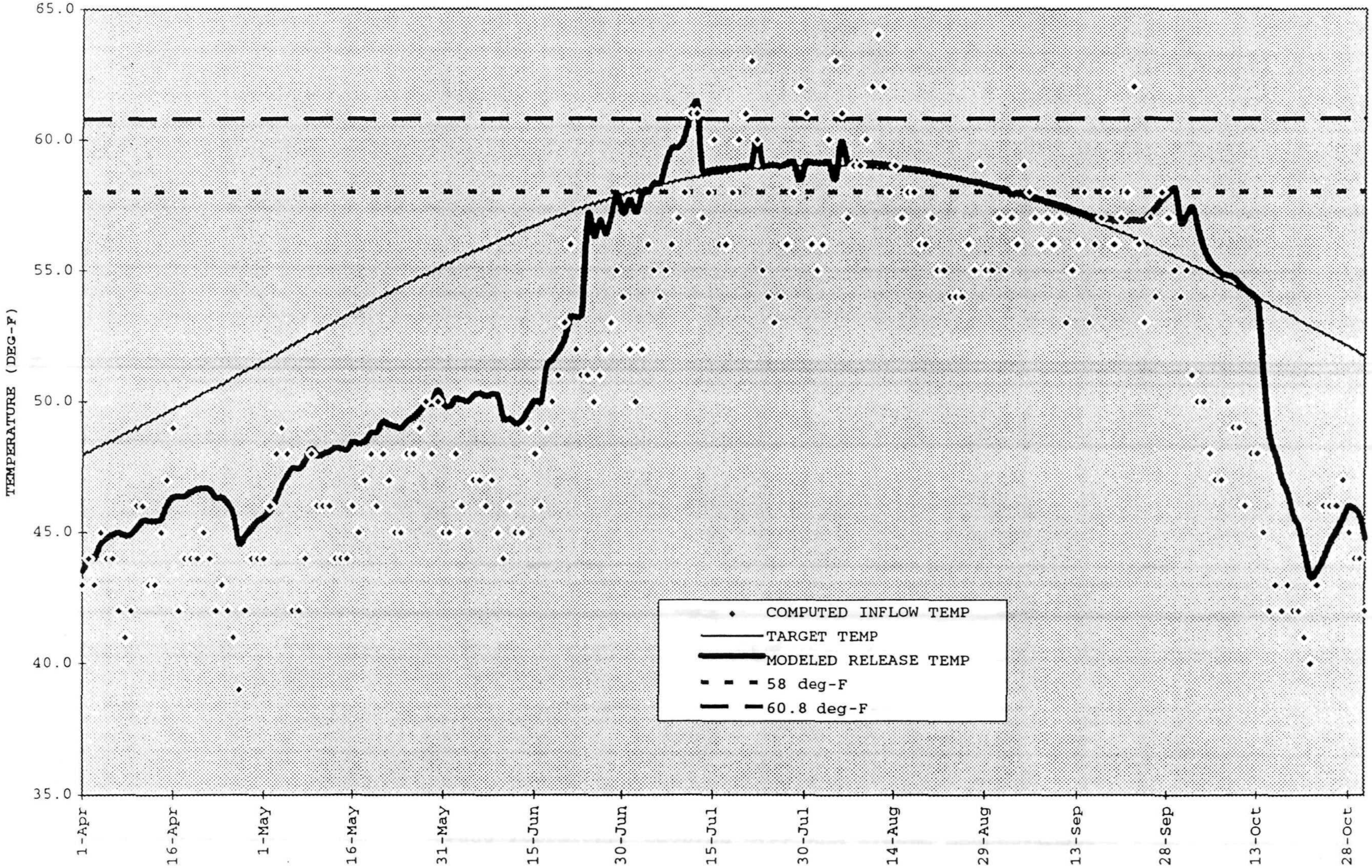
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F

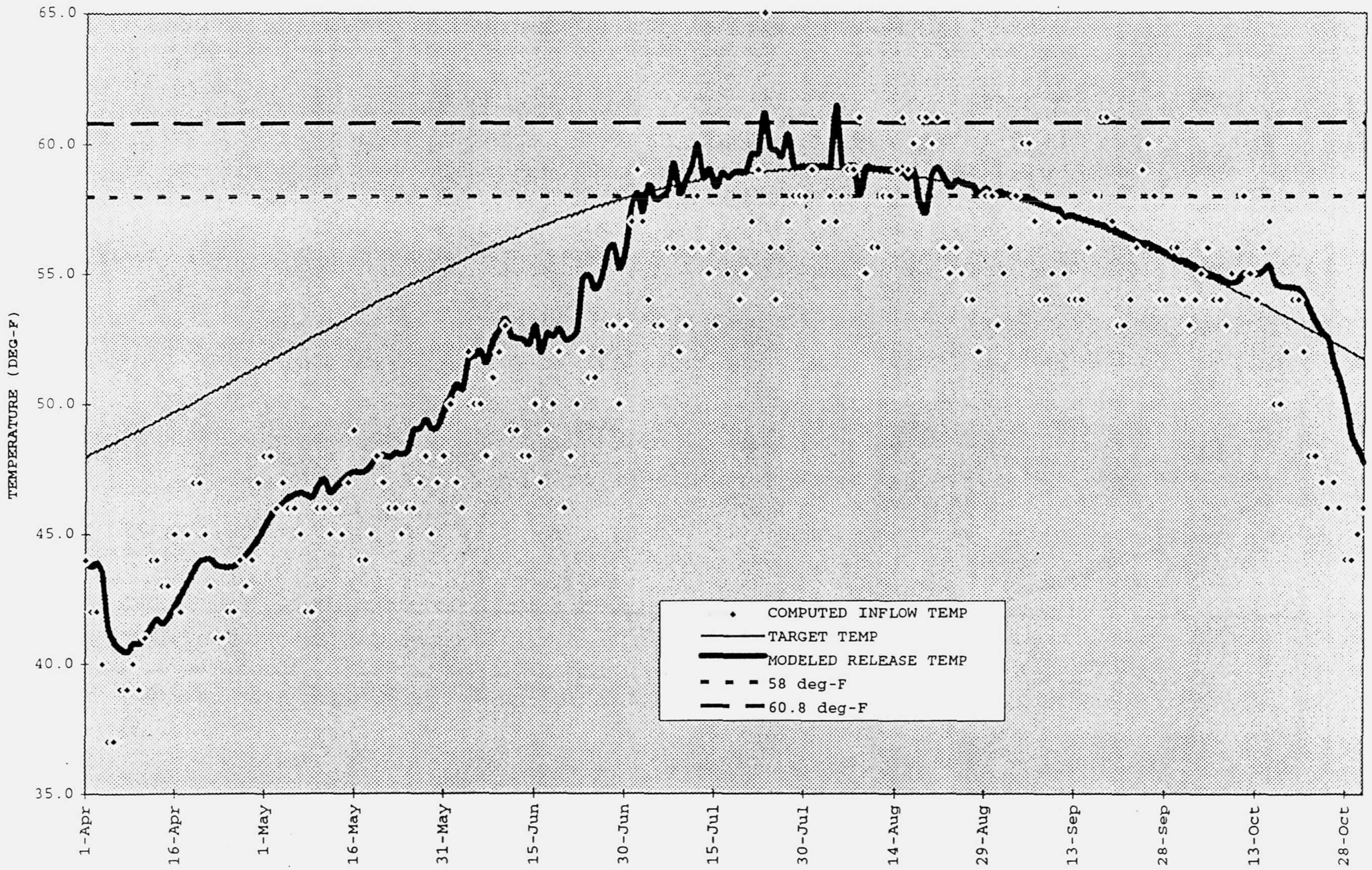
1989 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES

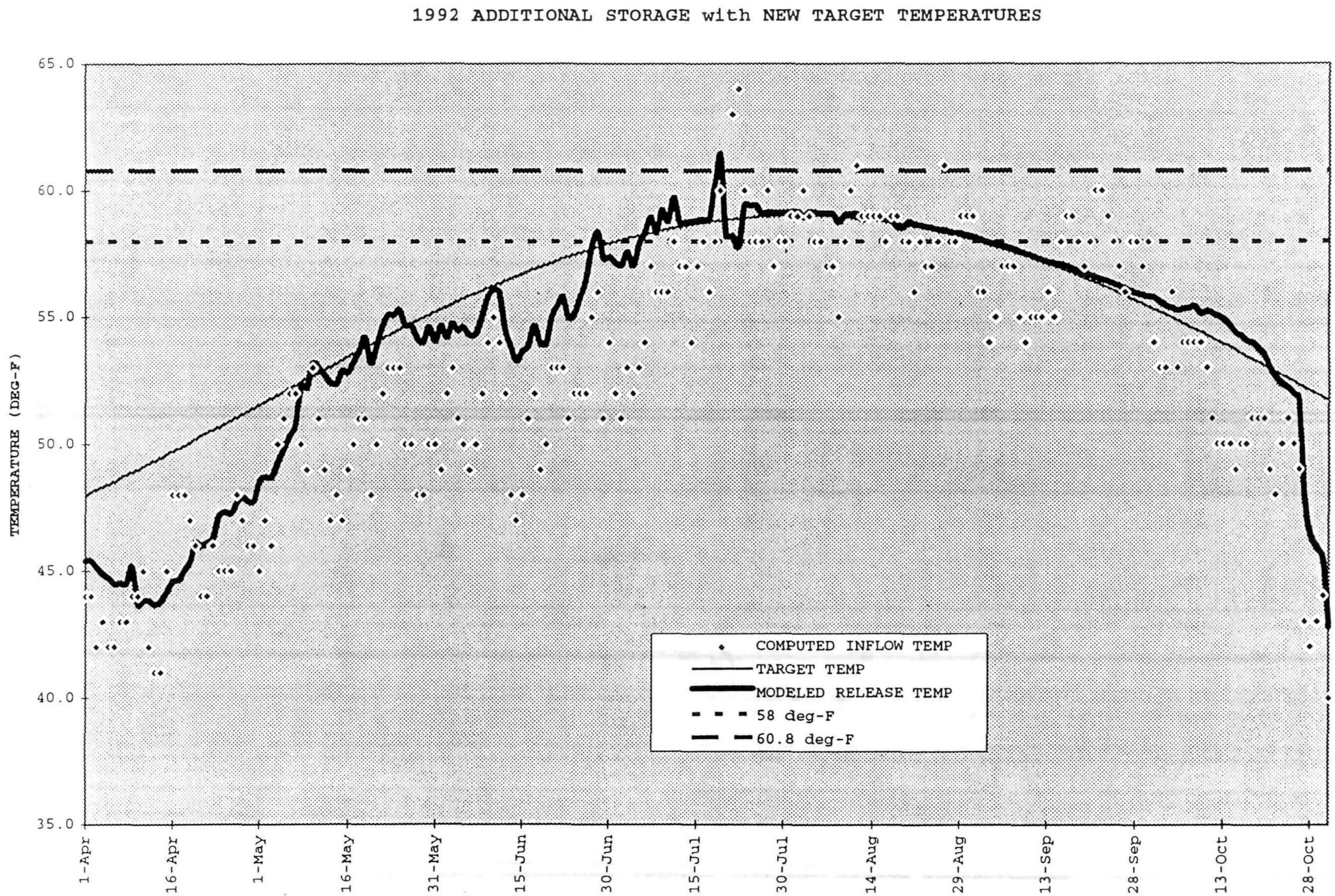


1990 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES



1991 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES




1992 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES
TEMPERATURE (DEG-F)
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16-May
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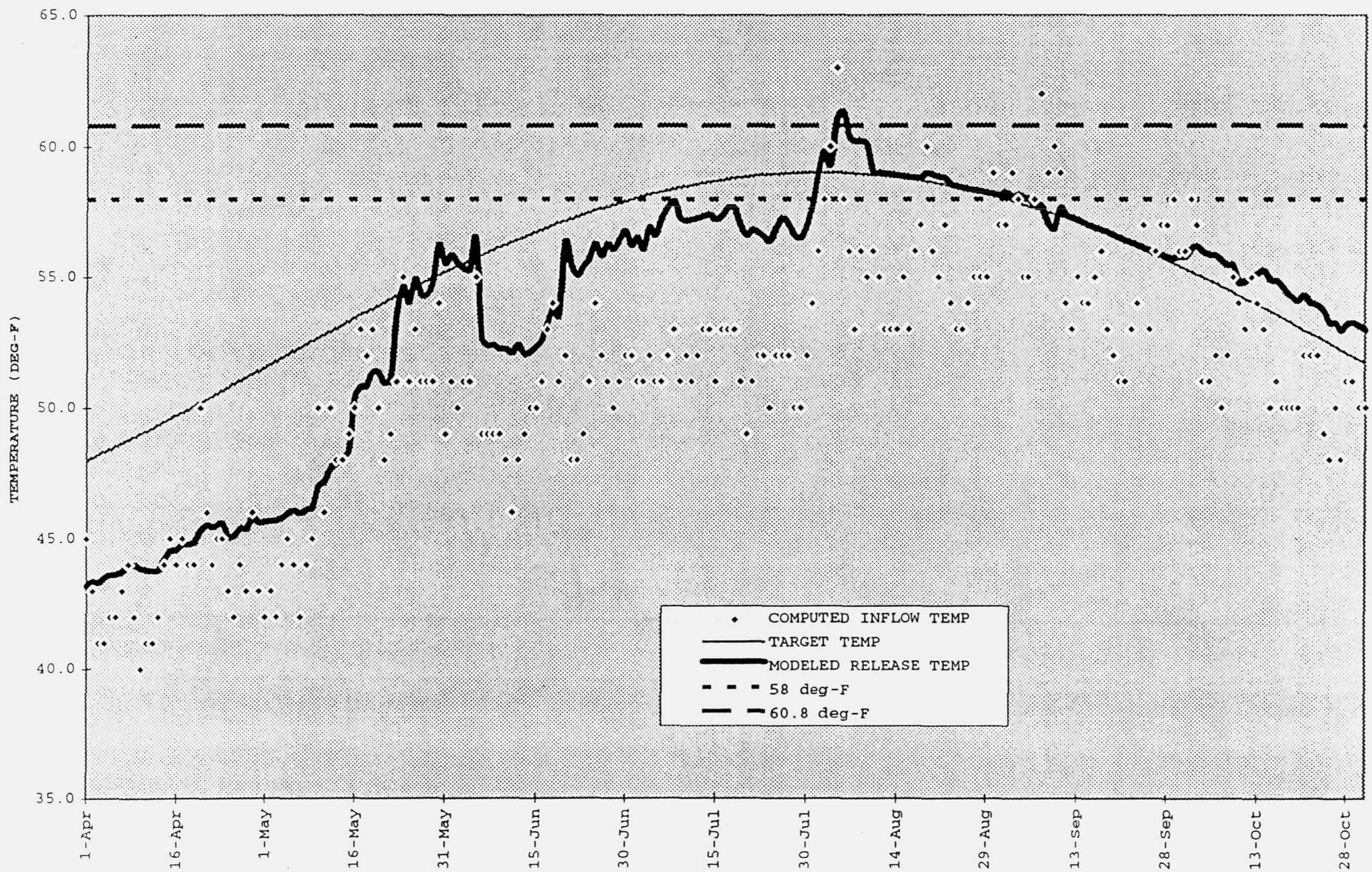
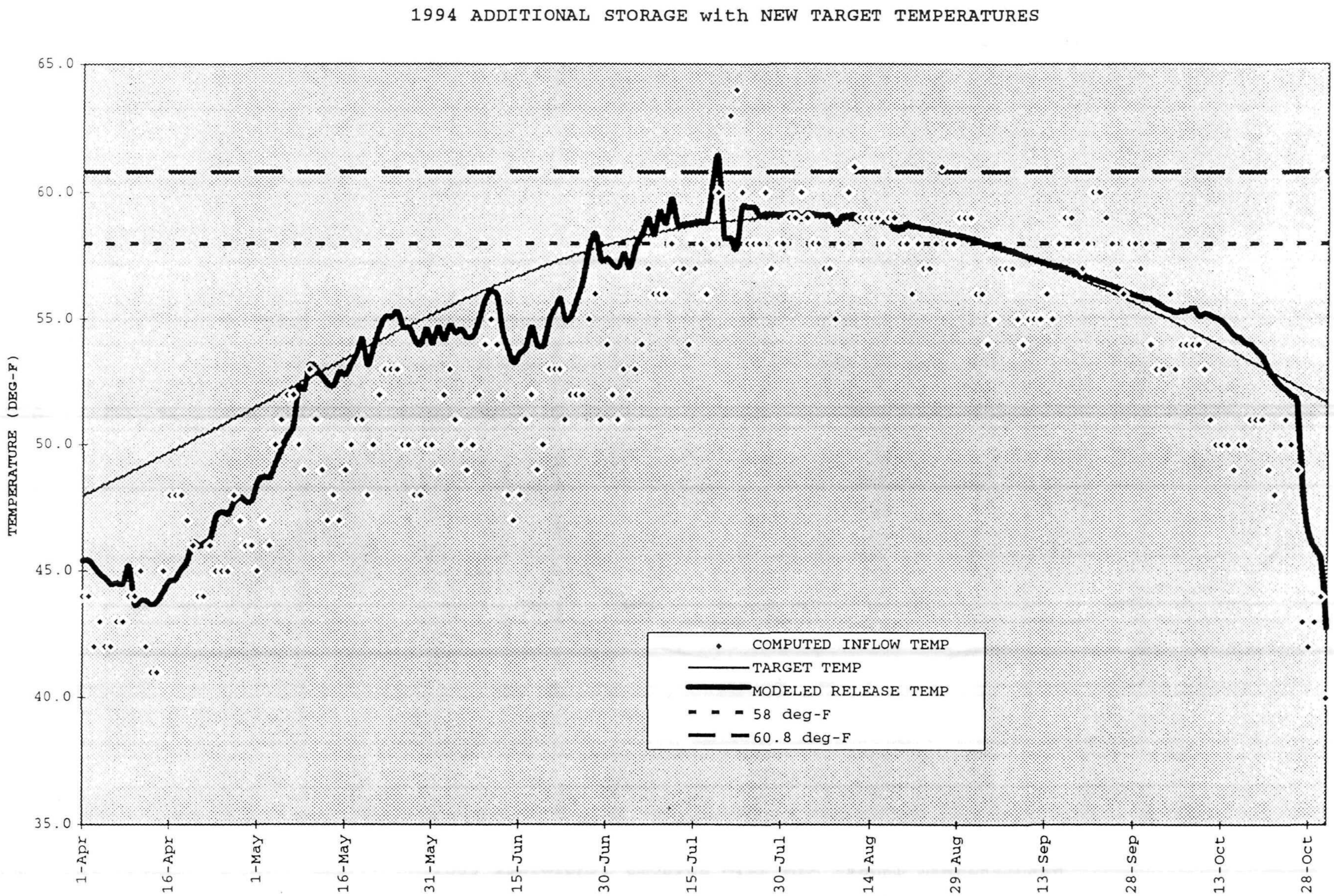
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F

1993 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES




1994 ADDITIONAL STORAGE with NEW TARGET TEMPERATURES
TEMPERATURE (DEG-F)
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35.0
1-Apr
16-Apr
1-May
16-May
31-May
15-Jun
30-Jun
15-Jul
30-Jul
14-Aug
29-Aug
13-Sep
28-Sep
13-Oct
28-Oct
COMPUTED INFLOW TEMP
TARGET TEMP
MODELED RELEASE TEMP
58 deg-F
60.8 deg-F

SECTION 7 REFERENCES

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