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Compliance with State Water Resources Control Board Decision 1631 and Order Nos. 98-05 and 98-07

May, 2002

Los Angeles Department of Water and Power

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1. INTRODUCTION

Pursuant to State Water Resources Control Board (SWRCB) Decision 1631 and Orders No. 98-05 and 98-07 (Orders), the Los Angeles Department of Water and Power (LADWP) is to undertake certain activities in the Mono Basin to be in compliance with the terms and conditions of its water right licenses 10191 and 10192. In particular, the Orders state that LADWP is to undertake activities to restore and monitor the fisheries, stream channels, and waterfowl habitat. This summary provides an overview of all of the activities LADWP and its consultants completed during Runoff Year (RY) 2001 for compliance. The summary also provides a list of planned work/activities for RY 2002.

Runoff Year 2001 was the third full field season after the adoption of the Orders. As such, LADWP is continuing the implementation of its revised Stream and Stream Channel Restoration Plan, revised Grant Lake Operation and Management Plan, and revised Waterfowl Habitat Restoration Plan. This required, among other things, scheduling field crews and other resources, coordinating with various other agencies, and preparing work plans. LADWP completed most of the planned work/activities for compliance. Due to circumstances outside the Department's control, some activities were not completed. This report details the work/activities undertaken and the activities involving projects that the Department was not able to complete.

Figure 1. *An aerial photograph of the Mono Basin. Major streams and LADWP facilities are depicted.*

2. WORK PERFORMED DURING RUNOFF YEAR 2001

2.1 Restoration Activities

2.1.1 Streams

In 2001, LADWP undertook and completed several measures that were outlined in the Mono Basin Stream and Stream Channel Restoration Plan (1996). These included:

- Studied the feasibility of channel rewatering on Rush Creek;
- Coordinated and consulted with Caltrans on the culvert replacement project for Rush, Lee Vining, Walker, and Parker creeks at Highway 395;
- Completed a conceptual engineering and design for sediment passage facilities on Lee Vining Creek;
- Continued with the grazing moratorium;
- Continued no irrigation policy during peak flows;
- Performed approximately 70% of the construction work to rehabilitate the Rush Creek Return Ditch;
- Provided base flows, stream restoration flows, and export in accordance with the Orders; and
- Removed gravel bags from Lee Vining Creek.

Channel Rewatering (3D): LADWP staff met with Bill Trush, Darren Mierau, and John Bear of McBain and Trush to discuss rewatering the abandoned east side channel in Reach 3D on Rush Creek. McBain and Trush have analyzed the pros and cons of rewatering the abandoned channels in the Rush Creek bottomland. Dr. Trush will propose recommendations on options available for this site and other sites located on lower Rush Creek.

Culverts: LADWP staff met with Caltrans in July 2001 to discuss their construction activities associated with the project to widen Highway 395.

Sediment Bypass Study: R2 Resource Consultants Inc. (R2) has completed their analyses and conceptual design of sediment bypass systems for Lee Vining Creek and has submitted a report to LADWP. R2's report entitled "Sediment Bypass Alternatives for Lee Vining Creek" provides conceptual designs for three alternatives.

Grazing Moratorium: There was no grazing on LADWP's land in the Mono Basin during RY 2001. The grazing moratorium is still in effect and has been expanded to all lands in the Mono Basin.

Irrigation Practices: There was no irrigation by LADWP in the Mono Basin during RY 2001. All irrigation in the Mono Basin was suspended in RY 2001.

Rehabilitation of Rush Creek Return Ditch: During 2001, LADWP and DFG completed their quantitative assessment of the habitat in the Return Ditch deemed beneficial to fish. That work was completed in April enabling the LADWP to proceed in mobilizing its work force, procuring equipment and materials, and obtaining a special use permit from the US Forest Service for beginning construction work in mid July 2001. LADWP construction crews commenced work on the Return Ditch on July 16th and continued the work until October 16, 2001. Field conditions were much more complicated than expected and as such the work progressed slower than anticipated. Approximately 80 percent of the buttressing of the outside berm was completed and 100 percent of the 20 percent (approximately 1800') of the lowering and widening of the total invert was completed (LADWP and DFG agreed that to reduce impacts to the fishery LADWP would perform the work in two phases; dredge 1800' in 2001 and another 1800' in 2002. LADWP may flow test the Return Ditch in June or July 2002 to see how the ditch performs and to inspect for possible problem areas. The remaining rehabilitation work will be carried out in Fall 2002.

Figure 2. *A scraper placing screened soil adjacent to the outside of existing berm.*

Figure 3. *A sheep foot roller compactor compacting freshly laid screened soil.*

Figure 4. *Completed compacted soil. This process will have to be repeated many times.*

Figure 5. *The newly compacted berm approximately 2/3 completed.*

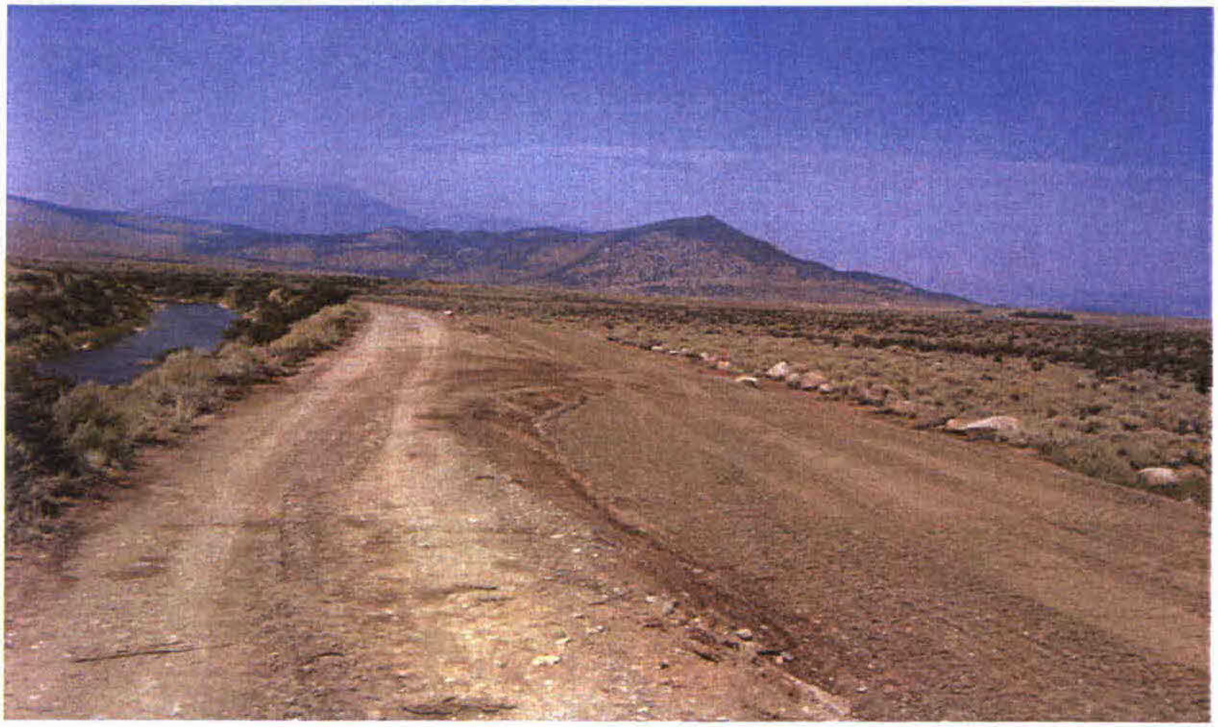


Figure 6. *Nearly completed compacted berm. Grading and dressing is still required.*

Figure 7. *Completed compacted berm after grading, dressing and seed.*

Figure 8. *Gradall removing accumulated sediment from the bottom and sides of the Return Ditch.*

Base Flows and Stream Restoration Flows: During RY 2001, Lee Vining, Walker, and Parker creeks were maintained in "flow through" conditions and met all flow requirements. Rush Creek exceeded its base flow requirements. Since the Rush Creek Return Ditch has not yet been restored to its original capacity, LADWP was only able to provide a peak flow of 162 cfs (the current maximum capacity of the Return Ditch). The peak was attained on June 11th and maintained for six days and then ramped down to the minimum base flow. Exports from the basin began on June 6th and continued until March 31, 2002. The rate of export ranged from 32 cfs to 40 cfs and the total export was approximately 15,965 acre-feet.

Removal of Bags of Spawning Gravel: LADWP staff in March opened and distributed one layer of bags (approximately 20 bags per layer) containing spawning gravel into Lee Vining Creek.

2.1.2 Waterfowl

In RY 2001, LADWP continued its waterfowl habitat monitoring and restoration program. The following is a summary of activities.

- Monitored Mono Lake elevation;
- Continued to develop a prescribed burn program; and
- Continued to monitor lake-fringing vegetation.

Mono Lake: Mono Lake elevation was monitored on a weekly basis. There was very little change in Mono Lake's elevation. The lake elevation during RY 2001 ranged from 6,383.8 on April 1, 2001 to 6,382.9 msl on March 31, 2002. The average surface area during RY 2001, based on the Pelagos Corp. 1986 bathymetric study, was approximately 71 sq. miles or 45,400 acres. The average salinity based on Jones & Stokes 1993 Mono Basin EIR was approximately 75 g/l. Salinity levels measured by UC Santa Barbara differed from the average in that the salinity levels are measured at several locations and elevations and the lake is currently meromictic.

Prescribed burn program: During RY 2001, LADWP continued development of a prescribed burn program for the Mono Basin. LADWP is working with State Parks to jointly conduct a burn with an anticipated burn in early 2003.

Vegetation transects: Vegetation transects were established at Simon Spring, Warm Spring, DeChambeau Embayment, and the deltas of Rush and Lee Vining creeks during RY 1999. No transect data was collected during RY 2001.

2.2. Monitoring

2.2.1 Stream Channel

Monitoring and Reporting: McBain and Trush during RY 2001 continued their monitoring program developed in RY 1997 and 1998 following the White and Blue book principles.

Planmap sites were established per the White and Blue books monitoring protocol. There are 3 sites on Rush Creek, 2 sites on Lee Vining Creek, 1 site on Walker Creek and 1 site on Parker Creek. A report for RY 2001 was prepared by McBain and Trush detailing the monitoring activities and requirements. The report entitled "Mono Basin Tributaries Restoration: Lee Vining, Rush, Walker, and Parker Creeks – Monitoring Activities and Results for Runoff Year 2001" is included in Section 4 of the Compliance Report.

2.2.2 Fishery

Monitoring and Reporting: Mr. Hunter continued the monitoring program developed in RY 1997 and 1998 following the White and Blue book principles. Mr. Hunter surveyed the 3 planmap sites on Rush Creek the 2 on Lee Vining Creek and each of the planmap sites on Walker and Parker creeks. A report entitled "Fisheries Monitoring Report for Rush, Lee Vining, Parker and Walker creeks 2001" is included in Section 3 of Compliance Reporting. The report details the fish population surveys and monitoring requirements.

In addition to Mr. Hunter's fish population surveys, LADWP funded the second year of a two-year creel census for Lee Vining Creek. The purpose of the creel survey was to estimate the fishing pressure brought on by the amended fishing regulation that allows a take of two fish per day per person. The results of the survey were provided to Mr. Hunter.

2.2.3 Waterfowl

Oversight of the Monitoring Program: During RY 2001, Dr. White met with the researchers responsible for collecting data in the Mono Basin. Dr. White also reviewed historical data and reports.

During RY 2001, LADWP contracted with I. K. Curtis Inc. and AirPhoto USA to provide aerial photography services to produce GIS compatible aerial photography of the Mono Basin with a scale of 1:2400 or 1 inch = 200 feet.

LADWP personnel collected hydrology data for the four streams and Mono Lake.

LADWP provided oversight to the Mono Lake Committee volunteers/interns to remove Salt Cedar plants from the Rush Creek delta. Other agencies are encouraged to participate.

2.3. Informational Meetings

The LADWP sponsored two meetings during RY 2001 for the experts and interested persons to present and discuss restoration and monitoring activities, hydrology and other issues related to the Mono Basin. The first meeting was held on May 1, 2001 in Sacramento and the second meeting was held on November 16, 2001 in Sacramento.

April Meeting: This meeting provided an opportunity for the stream monitoring experts to present their finding of RY 2001 monitoring activities and discuss their proposed RY 2001 scope of work. In addition, the preliminary RY 2001 runoff forecast was discussed.

Attendees in addition to LADWP personnel included the following: Experts – Dr. Trush, Mr. Hunter. Interested persons – Jim Canaday (SWRCB), Heidi Hopkins and Peter Vorster (MLC), Steve Parmenter (DFG), Jim Edmondson (Caltrout), and Paula Pennington and Ken Anderson (State Parks).

November Meeting: This meeting provided an opportunity for the stream monitoring experts and waterfowl experts to present and discuss their RY 2001 activities. The meeting also provided an opportunity to provide an overview of the runoff recap for 2001.

Attendees in addition to LADWP personnel included the following: Experts – Dr. Trush and Mr. Hunter. Interested persons – Jim Canaday (SWRCB), Ms. Hopkins, Greg Reis and Mr. Vorster (MLC), Paula Pennington (State Parks) and Mr. Smith (DFG).

3. ACTIVITIES PLANNED FOR RUNOFF YEAR 2002

3.1 Restoration

3.1.1 Streams

Channel Rewatering: In Reach 3D plans were developed to lower the right-side terrace to allow over bank flooding during high flows. In addition, some revegation of Jeffrey and lodgepole pines will be planted as well as some Black cottonwood and willows. The plug on Channel 8's opening will be removed to allow high flows to inundate and rewater the channel. Additional channel rewatering, as proposed in the Stream and Stream Channel Restoration Plan, are still be considered by Dr. Trush.

Revegetation: There are no plans this season for planting additional areas with Jeffrey pines on Lee Vining or Rush Creek. If the opportunity arises to plant Jeffrey pines, LADWP will coordinate with the Mono Lake Committee.

Road Closures: There are no plans this season to close roads in the floodplain of Rush Creek. The remaining roads will be left open until restoration activities are completed. There is still a need to bring in heavy equipment to some of the proposed restoration sites.

Bags of Spawning Gravel: LADWP will distribute the remaining bags of gravel into Lee Vining Creek from the bags located immediately upstream of the old diversion dam. LADWP will also remove rebar from the site.

Coordinate with Caltrans: LADWP will continue monitoring Caltrans progress on the installation of new culverts during the highway-widening project.

Return Ditch: LADWP will complete the rehabilitation of the Return Ditch in late summer early fall.

Sediment Bypass: LADWP has received a report from R2 containing conceptual engineering and drawings of three alternatives for sediment passage on Lee Vining Creek. LADWP will consider comments by interested parties then select one of the alternatives and proceed with preparing the final engineering and specifications. The work is expected to occur in fall 2003.

Permits and Approvals: LADWP will obtain all necessary permits and approvals from the Water Quality Control Board, Army Corp of Engineers, and from DFG. Environmental documents, if necessary, will be prepared to comply with the requirements of the California Environmental Quality Act.

Flows: LADWP will release flows to the four creeks based on the May 1, 2002 runoff forecast as set forth in Board Order 98-05. The runoff forecast is included in Section 2 of the Compliance Report. LADWP will attempt to provide the mandated flushing flows to Rush

Creek even though the rehabilitation to the ditch is only partially completed. McBain and Trush are currently analyzing the ramping rates and duration of flushing flows to determine if the current ramping rates are the most beneficial to the restoration of the streams. Based on their findings, LADWP may petition the State Board for modifications to decision 1631 ramping rates.

3.1.2 Waterfowl

Prescribed Burn Program: LADWP will continue to work with State Parks to design an implement a burn in early 2003.

Channel Rewatering: There are currently no plans to rewater the channels described in the waterfowl plan.

3.2 Monitoring

3.2.1 Streams

Dr. Trush will continue the monitoring program on Rush, Lee Vining, Walker, and Parker creeks.

3.2.2 Fishery

Mr. Hunter will continue the fish population monitoring program on Rush, Lee Vining, Walker, and Parker creeks.

3.2.3 Waterfowl

Expert: Dr. White will oversee the waterfowl-monitoring program.

Limnology: Dr. Jellison and Dr. Melack will continue limnological monitoring in the Mono Basin.

Waterfowl Population Surveys: Deborah House will perform the waterfowl population surveys in the Mono Basin.

Aerial photography: LADWP will conduct aerial photography of the Mono Basin in a GIS compatible format.

Hydrology: LADWP will continue to monitor the elevation of Mono Lake and to collect hydrologic data in the Mono Basin.

3.3. Informational Meetings

Bi-annual Meetings: LADWP will host two meetings with the researchers and interested parties to discuss restoration and monitoring activities in the Mono Basin. As in previous years, the meetings will be held prior to and after the field season. The first meeting has been scheduled for April 23, 2002.

4.0. PHYSICAL PROJECTS REMAINING

4.1 Streams

- Channel Rewatering on Rush Creek: No construction activities have been conducted on several channels on lower Rush Creek. The decision on whether to proceed with the original stream plan is currently being analyzed.
- Road Closures on Rush Creek: Several roads on lower Rush Creek identified for closures will remain opened until all restoration activities have been completed.
- Sediment passage on Lee Vining Creek: LADWP has received from R2 a report describing three alternatives for passing sediment at Lee Vining diversion structure. LADWP will select one of the alternatives; prepare the final engineering and specifications and begin the permitting process.
- Rehabilitation/Maintenance of Mono Gate Return Ditch: LADWP will complete the remaining sections of the berm reinforcement and the lowering and widening of the invert during RY 2002.

4.2 Waterfowl

- Channel Rewatering on Rush Creek: There are no construction activities planned for the channels on lower Rush Creek.
- Prescribed Burn Program: Discussions with State Parks are ongoing with an anticipated burn in early 2003.

Mono Basin Operations for Runoff Year 2002-2003

The May 1, 2002 Mono Basin runoff forecast for the 2002-03 Runoff Year is 99,800 acre-feet or 84% of normal[1]. This year is a "dry normal II" year, as defined by the State Water Resources Control Board (SWRCB) Order No. 98-05 year-type designations. The Operations Plan is based on the May 1st forecast.

To meet the flow requirements of the SWRCB Order No. 98-05, the LADWP intends to follow the Guidelines shown in Figure 1. The runoff forecast indicates that the LADWP will not be able to fill and spill Grant Lake during this runoff season even with augmentation from Lee Vining Creek. As such, LADWP does not intend to divert any water from Lee Vining Creek this season.

The Mono Gate Return Ditch has not yet been fully rehabilitated to its design capacity of approximately 380 cfs, consequently, LADWP will not be able to provide the minimum stream restoration flows of 250 cfs for 5 days to Rush Creek. To partially mitigate this circumstance, LADWP will instead ramp up the Return Ditch to its current maximum operating limit of 160 cfs for 5 days. Dry and Dry-Normal year stream restoration flows provide little or no benefit to the fluvial geomorphologic process however, the flows do provide some benefit to the vegetation and groundwater recharge.

LADWP anticipates exporting its full entitlement of 16,000 acre-feet at a constant rate. Exports for RY 2002 commenced on April 1st and are expected to continue through March 31, 2003.

Table 1 (attached) "Grant Lake Operations Model - Statistical Summaries" summarizes the "educated guess" of distribution of monthly flows in the Mono Basin streams and LADWP facilities for the 2002-03 Runoff Year. These flows do not represent minimum or maximum flows, or targets any kind; they merely provide a possible scenario of the flow distribution in the basin, assuming average climatic conditions subsequent to the forecast date. The actual flows will likely be different.

Figures 2 through 7 are graphs depicting data from a single similar year type and do not represent the forecasted runoff. The graphs are provided for illustration purposes only.

The values of expected magnitude and timing of the peak flows in Rush, Lee Vining, Walker and Parker creeks were generated by a predictive model, and are shown in Table 2.

Table 2

	Peak Flow Magnitude (cfs)	Timing
Rush Creek @ Damsite	168	June 2
Walker Creek above Conduit	29	June 14
Parker Creek above Conduit	42	June 18
Lee Vining Creek	212	June 5

The model uses regression analysis of historical data to predict future events. Since the actual values depend heavily on ambient temperatures that are difficult to accurately predict with any degree of certainty, it is more than likely that the values in Table 2 are not accurate. It is intended that they be used as an indicator of magnitude and timing of the peak flows. These predictions are based on the April 1, 2002 forecast, and assume average precipitation for the following six months.

On April 1, 2002, Mono Lake's water surface elevation measured 6,382.9-ft. amsl (USGS datum) and storage in Grant Lake Reservoir was 31,708 acre-feet (67% of capacity). Given the most current forecast, and the proposed operations guideline, the elevation of Mono Lake is expected to be approximately 6382.9-ft. amsl at the end of the runoff year.. This is graphically shown in Figure 8 "Mono Lake Elevation and Transition Export". The estimate is derived from modeling, and includes a number of assumptions such as normal precipitation conditions for the remainder of the year. The number is to be used as a general indicator.

Grant Lake Operations Model - Statistical Summaries

2002 Runoff Year: Dry-Normal

Daily Flows

	Lee Vin. Creek Above Intake	Walker Creek Above Conduit	Parker Creek Above Conduit	Rush Creek @ Damsite	Lee Vin. Creek Release	Lee Vin. Conduit Diver.	Lower Walker Parker Flow	Lower Rush Cr. Release	Rush C. Bottom land Flow	Grant Lake Storage	Grant Lake Outflow	Grant Lake Spill	Mono Basin Export	Owens River Abv. E. Portal	Owens River Blw. E. Portal
	cubic feet/second									ac-ft	cubic feet/second				
Start										31,708					
Min	13	1	3	30	13	0	6	44	50	28,210	64	0	20	47	84
Ave	51	6	10	67	51	0	16	50	66	32,521	72	0	22	61	100
Max	224	34	59	155	224	0	91	160	251	36,100	180	0	25	77	114
End										29,100					

Monthly Average Flows

cubic feet/second	Lee Vin. Creek Above Intake	Walker Creek Above Conduit	Parker Creek Above Conduit	Rush Creek @ Damsite	Lee Vin. Creek Release	Lee Vin. Conduit Diver.	Lower Walker Parker Flow	Lower Rush Cr. Release	Rush C. Bottom land Flow	Grant Lake Storage (1st of Month)	Grant Lake Outflow	Grant Lake Spill	Mono Basin Export	Owens River Abv. E. Portal	Owens River Blw. E. Portal
Apr	51	2	7	78	51	0	9	47	56	31,708	67	0	20	65	102
May	109	12	11	113	109	0	23	49	72	32,650	69	0	20	61	98
Jun	131	20	33	120	131	0	53	96	150	35,480	116	0	20	70	107
Jul	54	8	16	84	54	0	24	47	71	35,640	67	0	20	60	97
Aug	35	4	8	70	35	0	12	47	59	36,070	67	0	20	56	93
Sep	25	3	8	48	25	0	11	47	58	35,870	72	0	25	57	99
Oct	30	5	5	38	30	0	10	44	54	34,210	69	0	25	62	104
Nov	33	8	6	43	33	0	14	44	58	32,270	69	0	25	63	105
Dec	32	4	5	44	32	0	9	44	53	31,050	69	0	25	62	104
Jan	31	3	5	47	31	0	8	44	52	29,760	69	0	25	60	102
Feb	38	4	6	49	38	0	10	44	54	28,740	64	0	20	58	95
Mar	40	2	6	72	40	0	8	44	52	28,250	64	0	20	57	94

Monthly Total Flows

acre-feet	Lee Vin. Creek Above Intake	Walker Creek Above Conduit	Parker Creek Above Conduit	Rush Creek @ Damsite	Lee Vin. Creek Release	Lee Vin. Conduit Diver.	Lower Walker Parker Flow	Lower Rush Cr. Release	Rush C. Bottom land Flow	Grant Lake Storage (Average)	Grant Lake Outflow	Grant Lake Spill	Mono Basin Export	Owens River Abv. E. Portal	Owens River Blw. E. Portal
Apr	3,029	117	396	4,658	3,029	0	513	2,797	3,310	31,614	3,987	0	1,190	3,888	6,090
May	6,675	708	705	6,963	6,675	0	1,413	3,027	4,440	34,156	4,257	0	1,230	3,752	6,027
Jun	7,766	1,219	1,948	7,166	7,766	0	3,167	5,738	8,905	35,329	6,928	0	1,190	4,161	6,363
Jul	3,320	466	1,000	5,141	3,320	0	1,466	2,890	4,356	35,995	4,120	0	1,230	3,719	5,994
Aug	2,157	265	498	4,333	2,157	0	762	2,890	3,652	36,005	4,120	0	1,230	3,431	5,706
Sep	1,475	170	474	2,831	1,475	0	644	2,797	3,441	35,230	4,284	0	1,488	3,378	5,877
Oct	1,839	322	292	2,361	1,839	0	613	2,705	3,319	33,288	4,243	0	1,537	3,809	6,392
Nov	1,988	465	354	2,579	1,988	0	819	2,618	3,437	31,670	4,106	0	1,488	3,772	6,271
Dec	1,970	221	316	2,688	1,970	0	538	2,705	3,243	30,394	4,243	0	1,537	3,805	6,388
Jan	1,906	208	284	2,865	1,906	0	492	2,705	3,197	29,275	4,243	0	1,537	3,707	6,289
Feb	2,083	244	324	2,718	2,083	0	568	2,444	3,012	28,418	3,554	0	1,111	3,236	5,291
Mar	2,472	113	372	4,443	2,472	0	486	2,705	3,191	28,612	3,935	0	1,230	3,475	5,750
Apr-Sep	24,422	2,946	5,020	31,092	24,422	0	7,966	20,138	28,105		27,696	0	7,557	22,329	36,057
Oct-Mar	12,258	1,573	1,943	17,654	12,258	0	3,515	15,884	19,399		24,324	0	8,440	21,805	36,382
Annual Total	36,680	4,519	6,963	48,745	36,680	0	11,482	36,022	47,504		52,019	0	15,997	44,135	72,439

Table 1

MONO BASIN OPERATIONS - PLANNING GUIDELINE C

Hydrologic Year Type: Dry-Normal II
Forecasted Volume of Runoff (acre-feet): 92,207 < - ≤ 100,750

LOWER RUSH CREEK

Instream Flows:

	Apr-Sept	Oct-Mar
Flow (cfs)	47	44

Minimum base flows are those specified above or the inflow to Grant Lake reservoir, whichever is less. However, if the inflow is less than the dry year instream flow requirements, then dry year base flow requirements apply (Refer to Schedule A).

Stream Restoration Flows: 250 cfs for 5 days

- Begin ramping stream restoration flows on May 15.
- Ramping rate: 10% change ascending and descending, or 10-cfs incremental change, whichever is greater.

LEE VINING CREEK

Instream Flows:

	Apr-Sept	Oct-Mar
Flow (cfs)	54	40

Minimum base flows are those specified above or the stream flow at the point of diversion, whichever is less.

Stream Restoration Flows: Allow peak flow to pass point of diversion

- Begin ramping for stream restoration flows on May 15.
- Ramping rate: 20% change ascending and 15% change descending, or 10 cfs incremental change, whichever is greater.

Lee Vining Conduit Diversions:

- Divert flows in excess of base flows until May 15.
- Diversions may resume 7 days after the peak flow.

WALKER AND PARKER CREEKS

Instream Flows:

	Apr-Sept	Oct-Mar
Parker Creek (cfs)	9	6
Walker Creek (cfs)	6	4.5

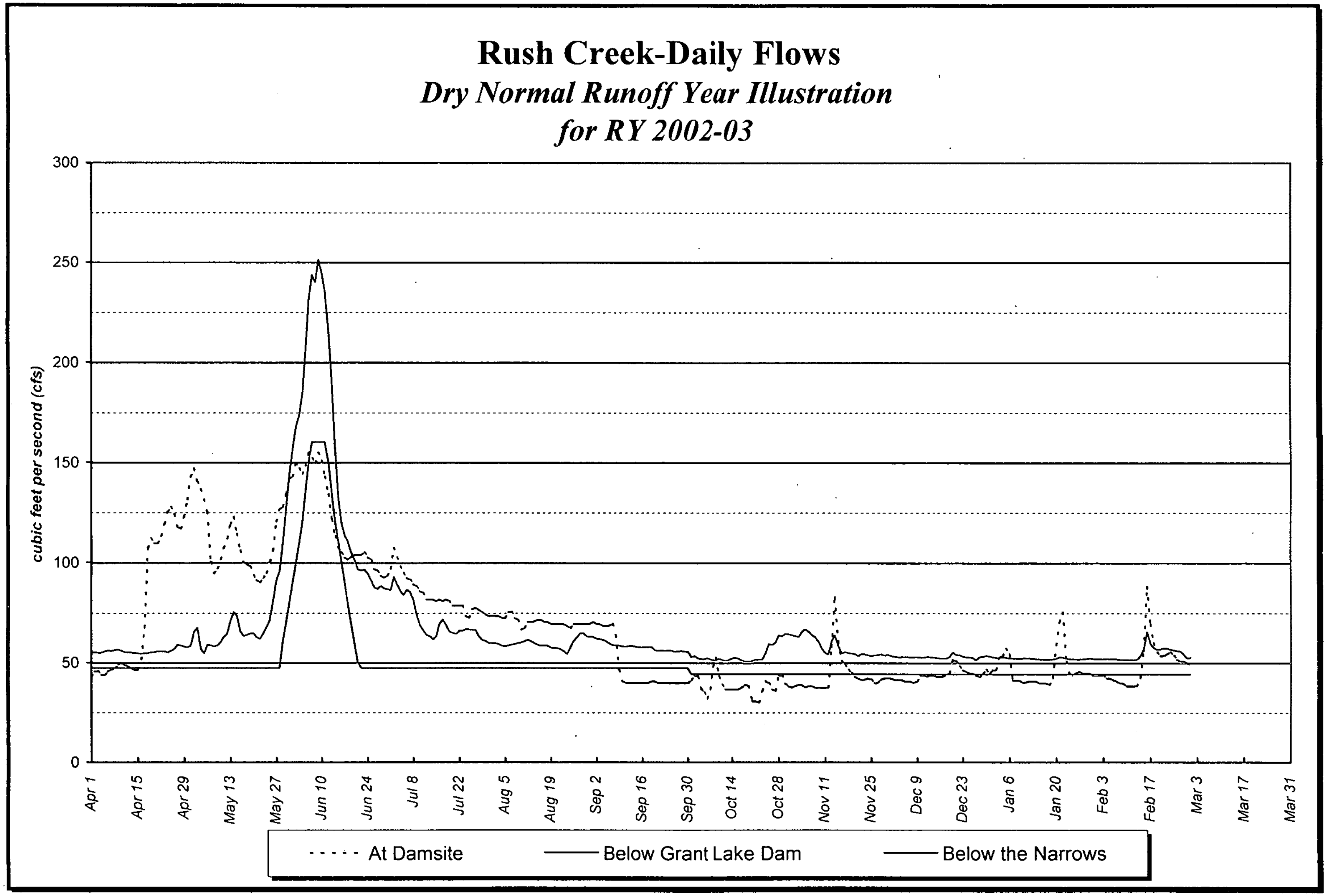
Minimum base flows are those specified above or the stream flow at the point of diversion, whichever is less.

Stream Restoration Flows: Allow peak flow to pass point of diversion

Lee Vining Conduit Diversions: None

MONO BASIN EXPORTS Maintain 22 cfs throughout the year.

Figure 1



Rush Creek-Daily Flows
Dry Normal Runoff Year Illustration
for RY 2002-03
cubic feet per second (cfs)
300
250
200
150
100
50
0
Apr 1
Apr 15
Apr 29
May 13
May 27
Jun 10
Jun 24
Jul 8
Jul 22
Aug 5
Aug 19
Sep 2
Sep 16
Sep 30
Oct 14
Oct 28
Nov 11
Nov 25
Dec 9
Dec 23
Jan 6
Jan 20
Feb 3
Feb 17
Mar 3
Mar 17
Mar 31
At Damsite
Below Grant Lake Dam
Below the Narrows

Figure 2

Forecasted Grant Lake Reservoir - Daily Inflow, Outflow, & Storage

Dry Normal Runoff Year Illustration
for RY 2002-03

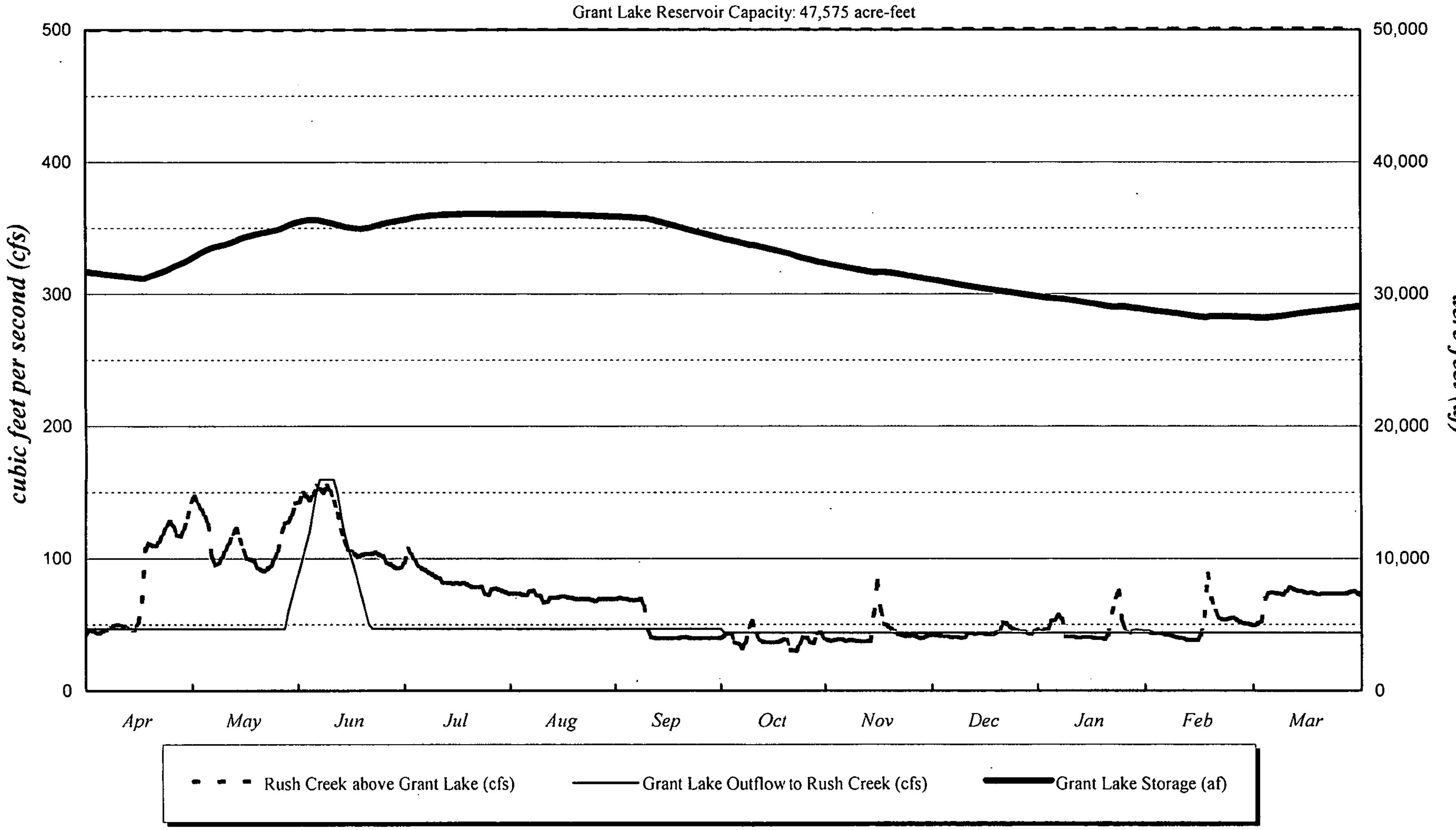
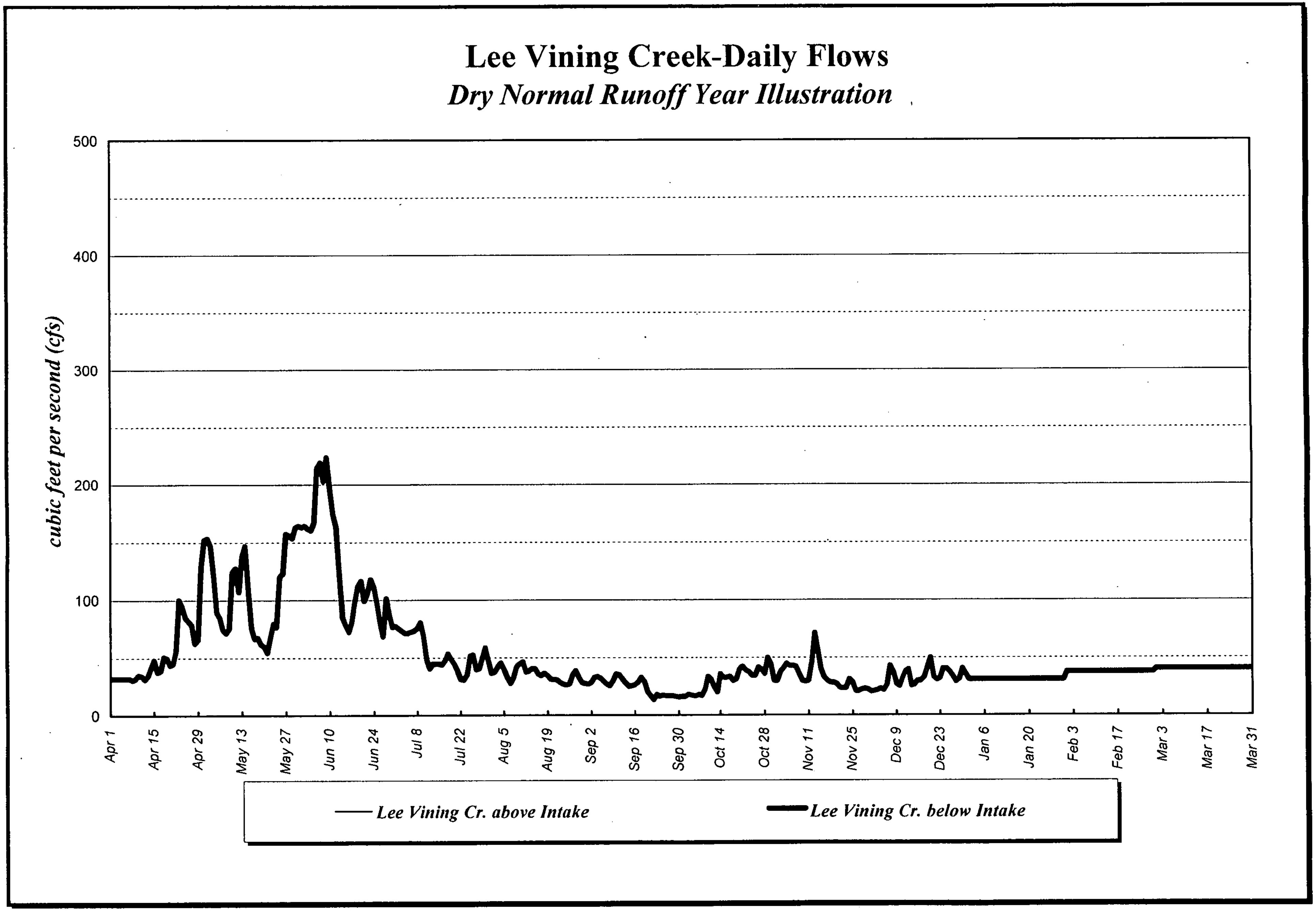


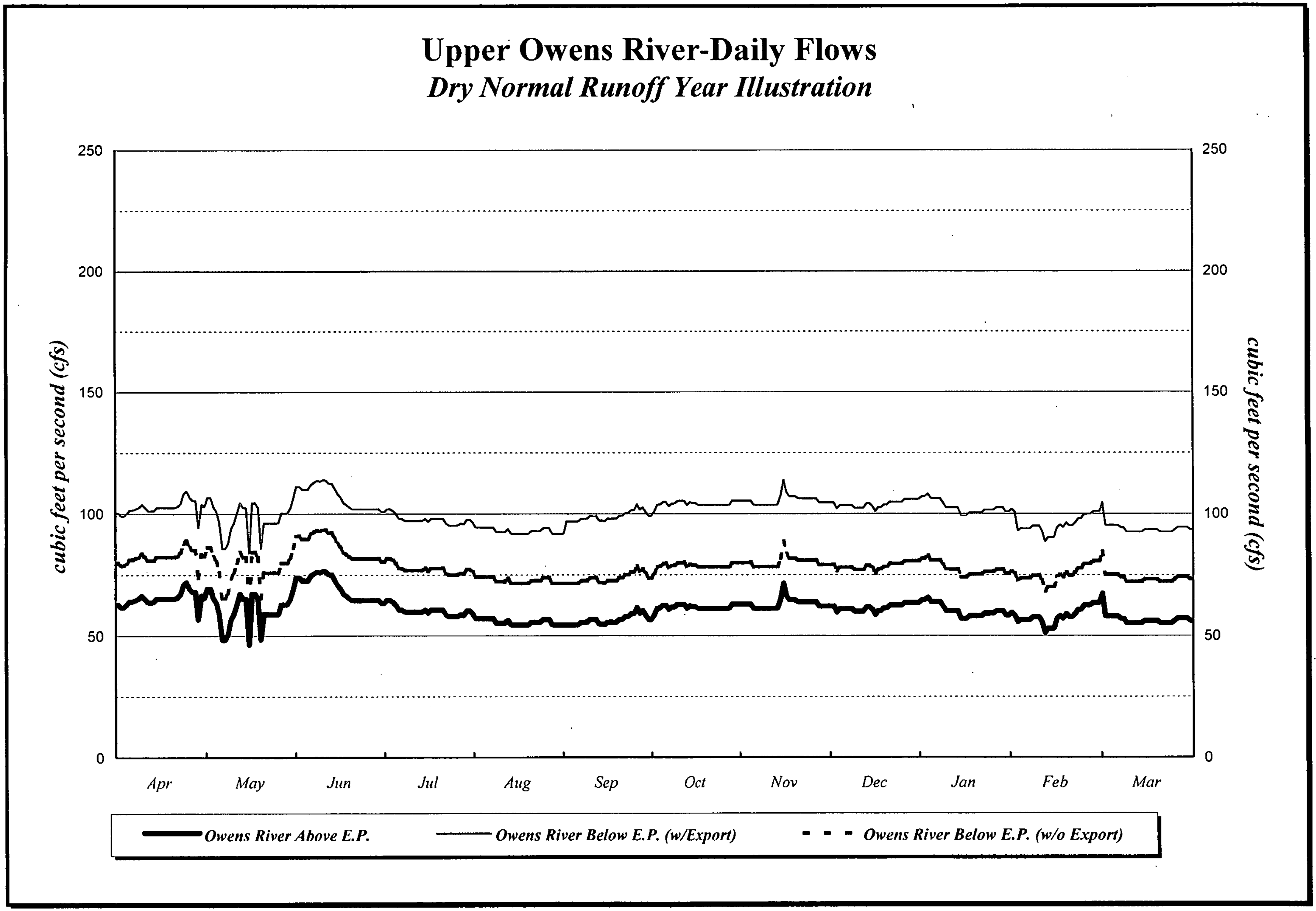
Figure 3

April, 2002



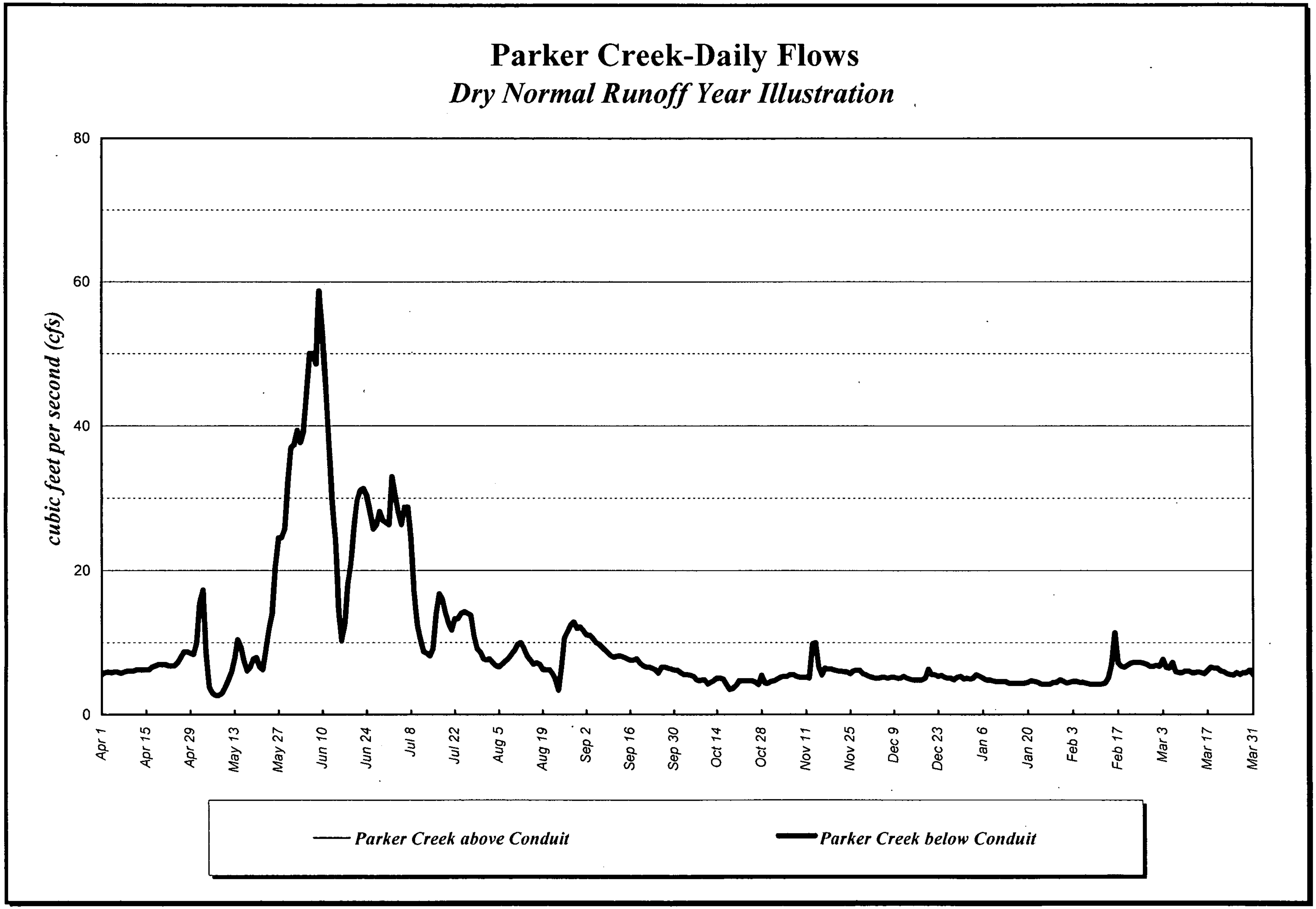
Lee Vining Creek-Daily Flows
Dry Normal Runoff Year Illustration
cubic feet per second (cfs)
500
400
300
200
100
0
Apr 1
Apr 15
Apr 29
May 13
May 27
Jun 10
Jun 24
Jul 8
Jul 22
Aug 5
Aug 19
Sep 2
Sep 16
Sep 30
Oct 14
Oct 28
Nov 11
Nov 25
Dec 9
Dec 23
Jan 6
Jan 20
Feb 3
Feb 17
Mar 3
Mar 17
Mar 31
Lee Vining Cr. above Intake
Lee Vining Cr. below Intake

Figure 4



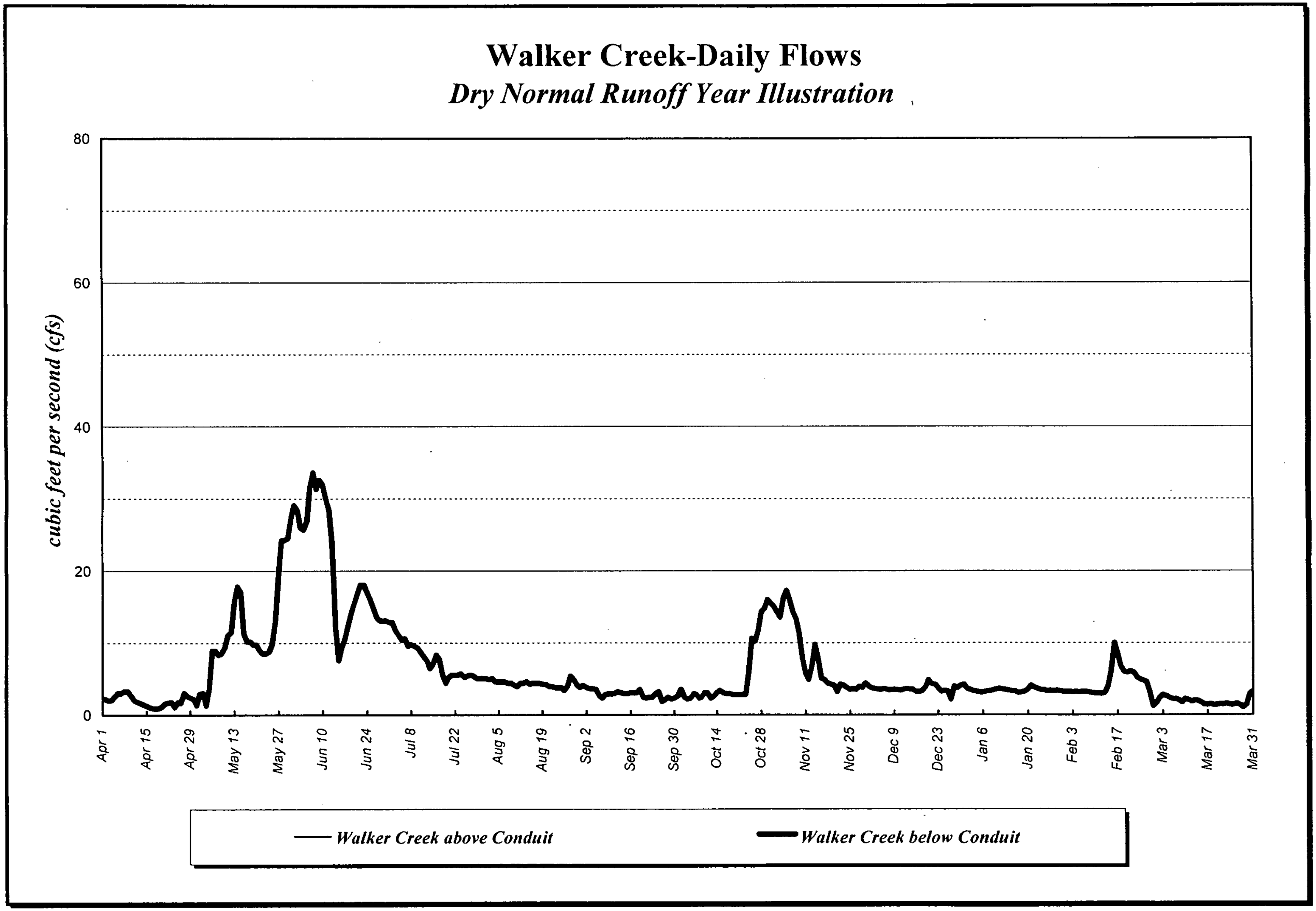
Upper Owens River-Daily Flows
Dry Normal Runoff Year Illustration
250
200
150
100
50
0
cubic feet per second (cfs)
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Owens River Above E.P.
Owens River Below E.P. (w/Export)
Owens River Below E.P. (w/o Export)

Figure 5



Parker Creek-Daily Flows
Dry Normal Runoff Year Illustration
cubic feet per second (cfs)
80
60
40
20
0
Apr 1
Apr 15
Apr 29
May 13
May 27
Jun 10
Jun 24
Jul 8
Jul 22
Aug 5
Aug 19
Sep 2
Sep 16
Sep 30
Oct 14
Oct 28
Nov 11
Nov 25
Dec 9
Dec 23
Jan 6
Jan 20
Feb 3
Feb 17
Mar 3
Mar 17
Mar 31
Parker Creek above Conduit
Parker Creek below Conduit

Figure 6

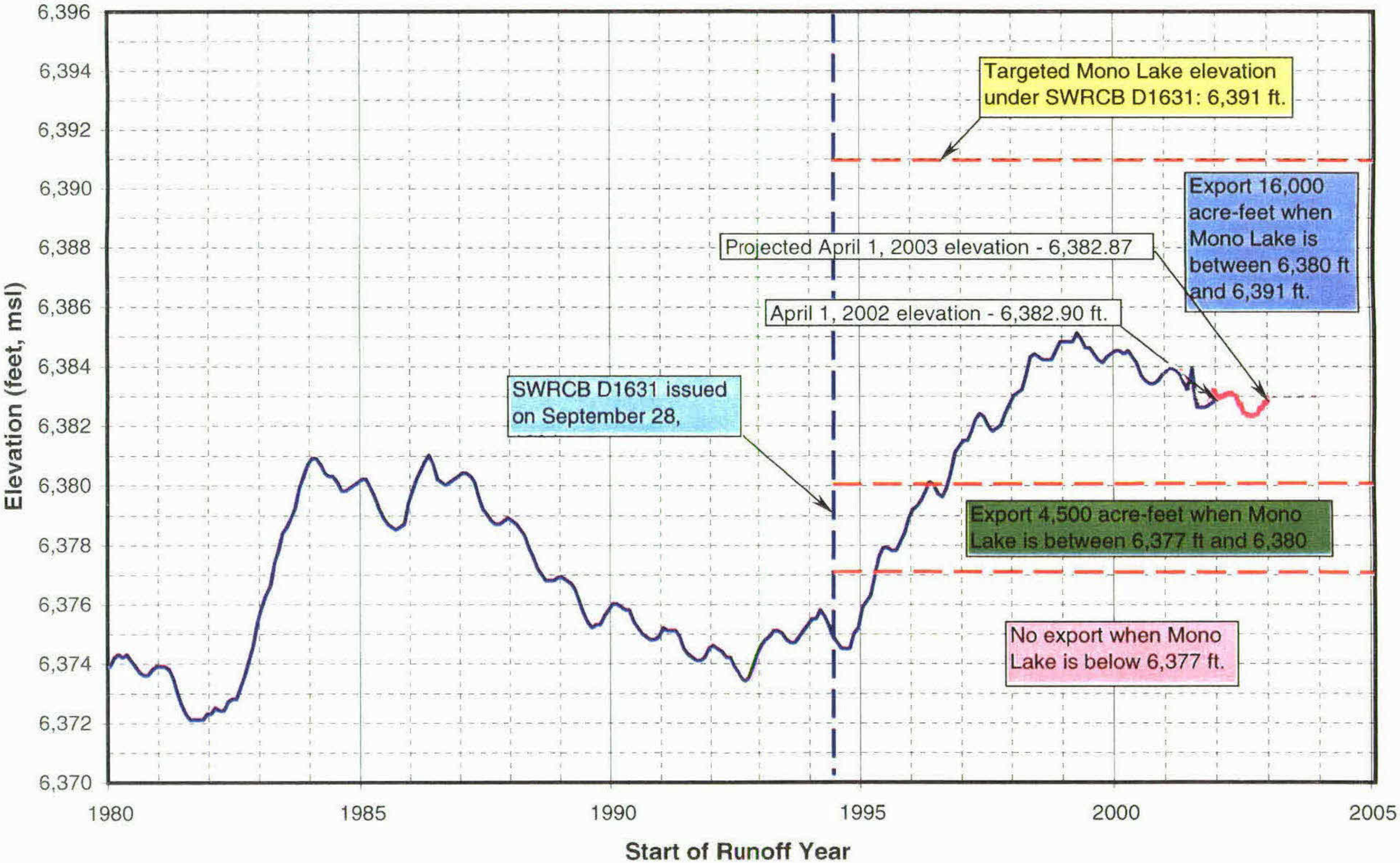


Walker Creek-Daily Flows
Dry Normal Runoff Year Illustration
80
60
40
20
0
cubic feet per second (cfs)
Apr 1
Apr 15
Apr 29
May 13
May 27
Jun 10
Jun 24
Jul 8
Jul 22
Aug 5
Aug 19
Sep 2
Sep 16
Sep 30
Oct 14
Oct 28
Nov 11
Nov 25
Dec 9
Dec 23
Jan 6
Jan 20
Feb 3
Feb 17
Mar 3
Mar 17
Mar 31
Walker Creek above Conduit
Walker Creek below Conduit

Figure 7

Mono Lake Elevation and Transition Period Exports

April 1980 - April 2005



Note: The time until the Mono Lake elevation reaches 6,391 ft is called the "Transition Period". Export rules change at the end of that interval.
*Based on Runoff Forecast Model developed in 1993.

4/12/2002 by David Neal
Mono Lake Elevation

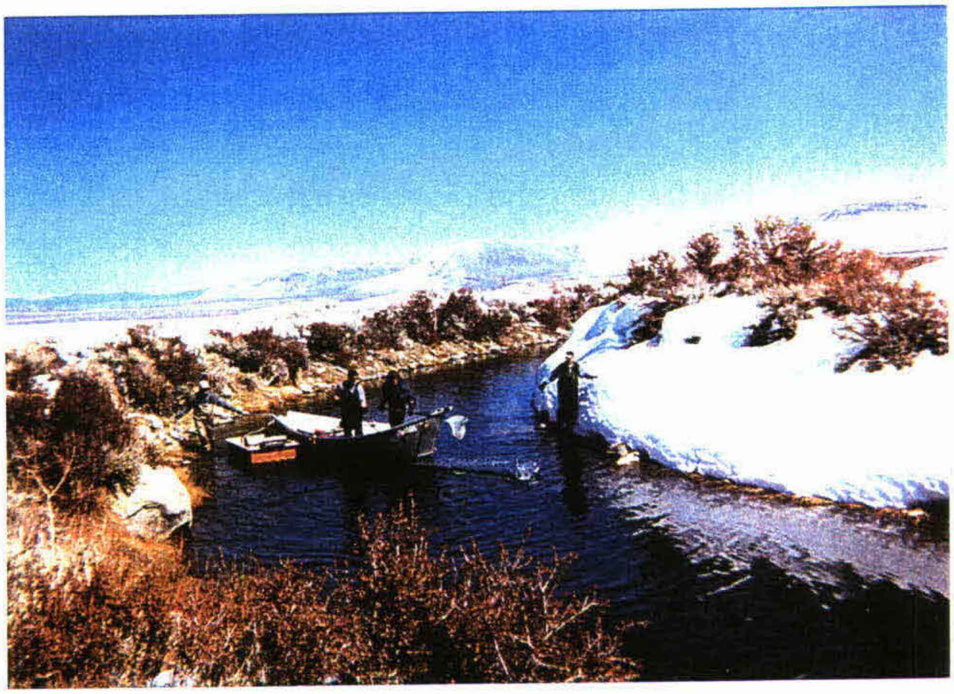
Figure 8

Fisheries Monitoring Report
For
Rush, Lee Vining, Parker and Walker creeks
2001

Prepared by: Chris Hunter
Brad Shepard
Ken Knudson
Ross Taylor
Matt Sloat
Anabel Knoche

Prepared for: Los Angeles Department of Water and Power

Date: May 1, 2002



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Executive Summary

This report presents the results of the third year of fish population monitoring for Rush, Lee Vining, Parker, and Walker creeks pursuant to State Water Resources Control Board (SWRCB) WR 98-07. We used mark-recapture electrofishing techniques to estimate trout populations in four sections of Rush Creek and two main stem sections of Lee Vining Creek. Fish population estimates for two Lee Vining Creek side channels and Parker and Walker creeks were made using electrofishing depletion methods. In addition, we electrofished Rush Creek during the spring to obtain information on fish movement and growth rates.

Densities of Age 1 and older brown trout were generally the same or higher in 2001 than in 2000, except in upper Rush and Walker creek sections. Densities of Age 1 and older rainbow trout were higher in 2001 than in 2000 in all Lee Vining Creek sections, but lower in all Rush Creek sections.

Estimates of trout standing crops were lower during 2001 than in 2000 in the Lower and Upper Rush Creek, Lower Main Lee Vining Creek and Walker Creek sections, but were higher or similar in the other sections. Densities and standing crops of trout, especially rainbows, have continued to increase in Lee Vining Creek from 1999 to 2001.

Young-of-the-year trout were extremely abundant in all sampled sections each year from1999 through 2001. This result indicated that spawning habitat is probably adequate to fully seed these streams with trout.

The population estimate of the Mono Gate One Return Ditch (MGORD) yielded almost no young of the year brown trout. This section supported 1,410 brown trout Age 1 and older of which 190 were 300 mm (12 inches) and longer.

The movement studies revealed little movement in general although a high percentage of larger fish captured in Rush Creek in the spring were recaptured in the MGORD in September.

Growth of tagged and recaptured brown trout, based on a small sample size, indicates that all brown trout weighing more than 900 g (2 pounds) lost weight during the summer of 2001, as did many brown trout weighing between 450 and 900 g (1-2 pounds).

We compared the estimated fish population data for Rush and Lee Vining creeks to the termination criteria adopted by the SWRCB. The termination criteria are:

1. Lee Vining sustained catchable brown trout averaging 8-10 inches in length.

2. Rush Creek fairly consistently produced brown trout weighing ¾ to 2 pounds. Trout averaging 13 to 14 inches were also regularly observed.

The SWRCB requires us to recommend additional quantitative termination criteria for Rush and Lee Vining creeks as well as quantitative termination criteria for Parker and Walker creeks. The lack of historical fish population data makes it very difficult to recommend reasonable quantitative termination criteria with confidence. We recommend that data collection be continued for a few more years before we attempt to define additional termination criteria. Additional data collection will also allow us to explore relationships between trout abundance and physical parameters, such as stream flows, water temperatures, and stream channel characteristics.

Study Area

The same three population estimate sample sections in Rush Creek and two in Lee Vining Creek that had been sampled during the late summers of 1999 and 2000 were again sampled from September 3 to 14, 2001 (Hunter et al. 2001; Table 1 and Figure 1). While we expressed concern in our last report (Hunter et al. 2001) that the dynamic nature of the stream channels, particularly Rush Creek, makes sample sections dynamic, we determined that we would maintain existing sample sections after a site visit with representatives from Los Angeles Department of Water and Power (LADWP). These sample sections had not changed much since 2000. However, in 2001 we added some of the middle channel in the upper portion of the Lower Rush Creek sample section because it appeared that this channel had captured some more of the flow from the north channel since 2000. Adding about 40 m of this channel changed the average wetted width slightly from 5.4 to 5.5 m. In addition, we also added 72.5 m to the bottom end of the side channel associated with the Lower Lee Vining Creek section. We also made an estimate in the Mono Gate One Return Ditch (MGORD) from the Grant Lake Outlet structure downstream about 2.23 km to the top end of a series of grade control weirs near the bottom end of the MGORD.

In addition to late summer sampling, we tagged trout in as much of Rush Creek as we could access during March 2001 to assess their movement patterns. A major spring snowstorm that deposited almost 60 cm of snow made access extremely difficult; however, we were able to sample approximately 4.7 km of the approximately 13.3 km of Rush Creek and 2.23 km of the 2.5 km length of the MGORD (Table 2). Lengths of all sections sampled during March, except the Upper Rush Section, were estimated from air photos using a GIS-based software application. All sample sites were referenced by distance (in km) downstream from the Grant Lake Outlet at the MGORD. We used these upstream reference points because with the filling of Mono Lake, the mouth of Rush Creek at Mono Lake does not represent a stable reference point. Stream flows and water temperature data are on file with LADWP and McBain and Trush consultants.

Table 1. Total length (m), average wetted width (m), and total surface area of sample sections in Rush, Lee Vining, Parker, and Walker creeks sampled from September 3 to September 14, 2001.

Section	Length (m)	Width (m)	Area (sq m)
Rush – County Road	813	6.0	4878.0
Rush - Lower	405	5.5[1/]	2227.5
Rush – Upper	430	7.4	3182.0
Rush – MGORD	2230	7.5	16725.0
Lee Vining – Lower	187	4.8	897.6
Lee Vining - Lower-B1	262[2/]	5.0	1310.0
TOTAL Lower			2207.6
Lee Vining - Upper-main	330	5.8	1914.0
Lee Vining - Upper-A4	201	4.2	844.2
TOTAL Upper			2758.2
Parker	98	2.2	215.6
Walker	100	1.8	180.0

1/ Added about 40 m of middle channel in 2001 which changed overall average wetted width from 5.4 to 5.5 m.

2/ Added 72.5 m to bottom portion of this side channel in 2001.

Table 2. Locations and lengths sections of Rush Creek sampled during March 2001.

Location	Stream km (from – to)	Length (km)
MGORD	0.0 – 2.23	2.23
Parker Road Junction	2.68 – 3.48	0.80
Upper Rush	4.51 – 4.94	0.43
Above Old Bridge	4.94 – 5.44	0.50
Old Bridge to Highway 395	5.55 – 6.00	0.45
Below Highway 395	6.00 – 6.75	0.75
Above County Road	13.08 - 14.08	1.00
Below County Road	14.50 – 15.25	0.75
TOTAL SAMPLED		6.91

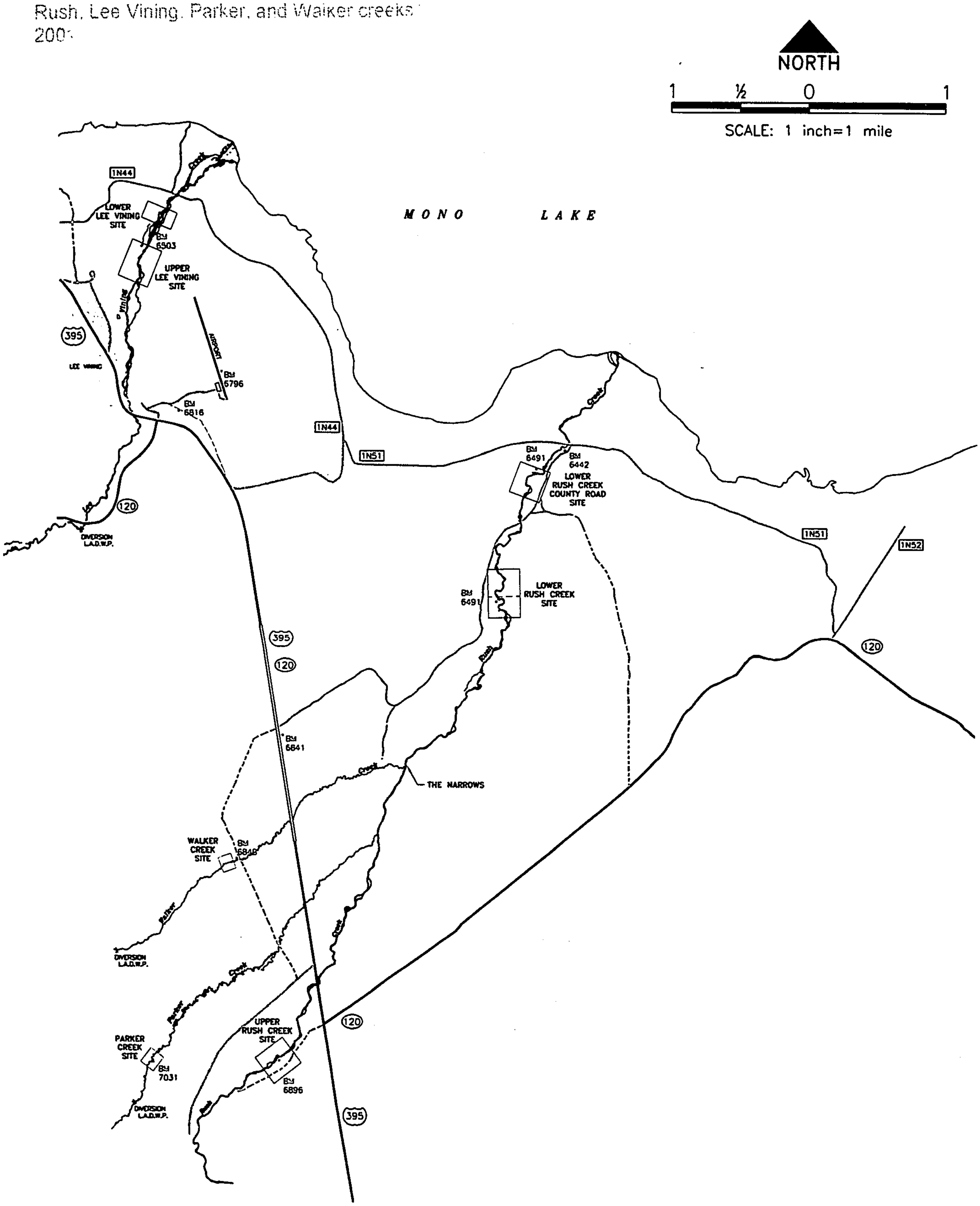

Figure 1. Map of study area showing sampling site locations (from McBain and Trush 2000).

Methods

Fish Population Estimates

During March 2001 fish were captured in main Rush Creek using a Smith-Root® BP backpack electrofisher (Model 12B) and in the MGORD using a drift boat and barge-mounted electrofishing unit (see below for description of this methodology). Water temperatures were extremely low (5 to 6 C) during all March sampling efforts and capture efficiencies were known to be relatively low. We computed the approximate number of fish captured per sampled length of stream and compared the relative catches between sample locations in the spring, but did not compare these catch rates to any other sampling period.

During the late summer (September 3 to 14, 2001) mark-recapture estimates were made in the County Road, Lower, and Upper sections of Rush Creek, most (2.23 km) of the MGORD, and the main channel portions of the Lower and Upper sections in Lee Vining Creek. For all mark-recapture estimate sections fish were captured using a Smith-Root® 2.5 GPP electrofishing system that consisted of a Honda® generator powering a variable voltage pulsator (VVP) that had a rated maximum output of 2,500 watts. This unit was set at 30 or less pulses per second to reduce risk of injury to fish and voltages were set to allow for capture of fish without harming fish. Obtaining this desired response in fish usually resulted in voltages ranging from 300 to 500 and amperes from 0.3 to 1.5. Depletion estimates were made in one sample section within each of Parker and Walker creeks and in two side-channels of Lee Vining Creek associated with the Lower and Upper sections. For depletion estimates Smith-Root® BP backpack electrofishers (Model 12B) were used to capture fish.

During mark-recapture electrofishing, the generator and VVP unit were transported downstream in a small barge for all mark-recapture sections except the MGORD. An insulated tub to transport captured fish was carried in the barge. A person operating a mobile anode and a dip netter fished each half of the stream in a downstream direction (total of two anode operators and two dip netters). All netted fish were placed in the insulated tub within the barge shortly after capture.

In the MGORD a drift boat was used to transport three crewmembers, while the electrofishing barge was attached to the drift boat. Two people wading along shore with ropes attached to the bow and stern of the drift boat guided it downstream. A mobile anode was thrown by one of the crewmembers in the drift boat. The anode was generally thrown from side to side across the channel and then downstream with a goal of either driving the fish downstream or forcing them to move into the electrical field to get around the drift boat. A spring-loaded foot switch provided power to the anode and this switch was controlled by the crewmember throwing the anode. Another crewmember netted stunned fish, while the third crewmember monitored the electrofishing equipment and another "kill switch" for safety. An insulated tub to transport captured fish was also carried in the drift boat. We made an effort to minimize fish movement downstream in the MGORD by placing three crewmembers, one with a backpack shocker and two netters, at the lower boundary of each sub-section that was sampled. Numerous fish were often captured as the two electrical fields converged. Sub-section lengths were based on the number of captured fish that could be reasonably held in the water tank.

Two backpack shockers were used in the two Lee Vining Creek side-channels, while a single backpack shocker was used in each of the Walker and Parker creek sections. At least one dip-netter per electrofisher netted fish stunned by that shocker. Another crew member served as a backup dip-netter and carried a live bucket in which all captured fish were placed immediately after capture, except in Parker and Walker creeks where one person both netted fish and transported the live bucket.

To meet the assumption of closed populations for sampling purposes, all sample sections, except the County Road Section and MGORD, were blocked at both ends prior to sampling. In the Upper and Lower Rush Creek sections and main channel portions of the Upper and Lower Lee Vining Creek sections, 12 mm mesh hardware cloth fences were installed at the upper and lower boundaries of the sections. These hardware cloth fences were installed by driving fence posts at approximately two-meter intervals through the bottom portion of the hardware cloth approximately 15 cm from its bottom edge. Rope was then strung across the top of each fence post and anchored to willows, fence posts, or trees on each bank. The hardware cloth was held vertically by wiring the top of the cloth to this rope with baling wire. These fences were installed prior to the marking run and maintained in place until after the recapture effort was completed. Fences were cleaned and checked at least once daily, and often twice daily, to ensure they remained in place and for any possible dead fish between mark and recapture sampling. For the side channel portions of the Upper and Lower Lee Vining Creek sections and the sample sections in Parker and Walker creeks 12 mm mesh block seines were placed at sample section boundaries during depletion efforts.

Block fences were not placed at the boundaries of the County Road and MGORD; however, these sections were long enough (813 and 2,230 m, respectively) that effects of movements at the ends of the sample section should have been low in proportion to the entire section. Since the upper boundary of the MGORD section was the Grant Lake outlet structure and the lower boundary was the beginning of a high gradient section of the channel where large rocks have been placed across the channel, we assumed that few, if any, fish moved into or out of this sample section either during sampling or between the mark and recapture efforts.

All captured fish were held in either an insulated tub within the barge or drift boat, a bucket carried by a crewmember, or live cars within the stream channel. All captured fish were anesthetized in a clove oil bath (Anderson et al. 1997; Taylor and Roberts 1999), measured to the nearest mm (total length), and most were weighed to the nearest gram. In the Lower Rush Creek and Lower Main Lee Vining Creek sections, all captured fish had their lower caudal fin clipped to conduct mark-recapture estimates in these sections. In the Upper Rush Creek, Upper Main Lee Vining, and the Rush Creek MGORD sections, all captured fish received an anal fin clip. In the County Road Section of Rush Creek, all captured fish received an upper caudal clip. When clipping the caudal fin a scissors was used to make a straight vertical cut from the top, or bottom, of the caudal fin approximately 1-3 mm deep at a location about 1-3 mm from the posterior edge of the fin. Population and biomass estimates were conducted according to methods presented in last year's report (Hunter et al. 2001), except age 0 fish were included in biomass estimates for all years in this report.

Length-Weight Regression

Length-weight regressions (Cone 1989) were calculated for brown trout in each section of Rush Creek by year to assess differences in length-weight relationships between sections and years. Log_{10} transformations were made on both length and weight prior to running regressions.

Use of Mono Lake Estuary by Fish from Lee Vining Creek

A cursory snorkel survey was done in the Lee Vining Creek estuary area, where Lee Vining Creek enters Mono Lake on September 9, 2001. Unfortunately, moderately high winds from the northeast created relatively large waves from Mono Lake that caused turbid conditions in both Mono Lake and lower Lee Vining Creek. These turbid conditions made fish observation extremely difficult.

Tagging Study to Assess Movement and Growth

During March 2001 fish were captured in main Rush Creek using a Smith-Root® BP backpack electrofisher (Model 12B). A drift boat and barge-mounted electrofishing unit were used in the MGORD to capture fish. Captured fish were held in live buckets and processed at approximately 100-200 m intervals in main Rush Creek and held in the drift boat in a cooler and processed at about 500 m intervals in the MGORD. All captured fish were weighed (nearest gram) and measured (nearest mm; total length) and those fish longer than 150 mm were tagged with a small, brown, numbered Floy® anchor tag. Release locations for each tag fish were recorded to the nearest 0.1 km. During September 2001 sampling all captured fish were examined for the presence of a tag. If a tag was found, the tag number code was recorded along with the length and weight information. Information from fish recaptured with tags was summarized for distance and direction they moved and difference in weight between time of tagging and time of recapture.

Evaluation of the Test Station Road Culvert to Allow Upstream Fish Passage

On March 15, 2001 the Test Station Road culvert on lower Rush Creek was surveyed to evaluate whether brown trout could move upstream through this culvert. This culvert is located approximately 1.5 km upstream of Mono Lake and is the lowermost of several stream crossings and diversion dams that may impact fish migration within the Rush Creek watershed (Figure 2).

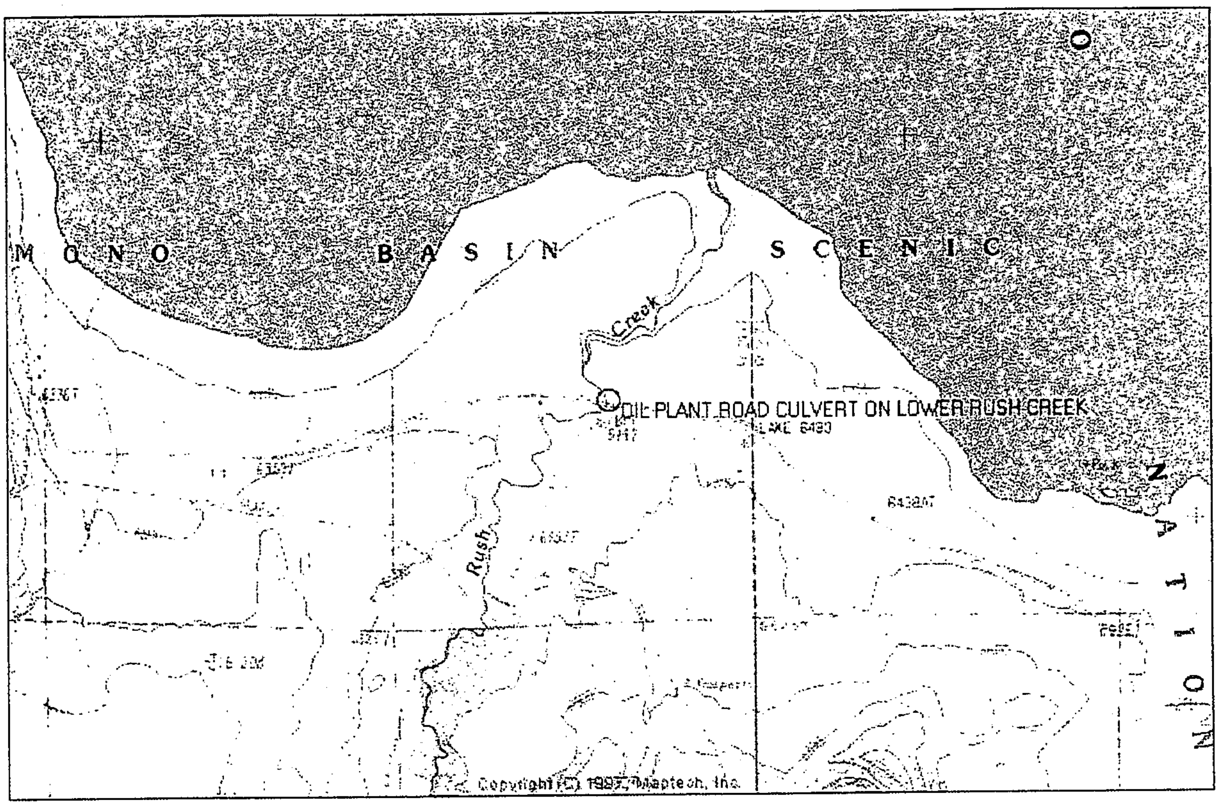

Figure 2. Map showing location of Test Plant Road culvert on lower Rush Creek.

Methods for conducting field measurements, calculating the range of migration flows, and evaluating fish passage were consistent with protocols recently developed for the California Department of Fish and Game (CDFG) *Salmonid Stream Habitat Restoration Manual* using the program FishXing (www.stream.fs.fed.us/fishxing; Taylor and Love 2002). The range of tested migration flows and criteria used to test for upstream brown trout passage were consistent with criteria recently developed by CDFG (Heise 2001). For brown trout, the low passage flow was defined as either the 90% exceedence flow or an alternate minimum flow of 3.0 cubic feet per second (cfs; while metric units are used for all measurements in this report, we report flows in cfs). The high passage flow was defined by CDFG as either the 5% exceedence flow or 30% of the two-year recurrence interval. For the Rush Creek analysis, 3.0 cfs was used for the low passage flow and the 30% of the two-year recurrence interval was used for the high passage flow.

CDFG's passage criteria also defined hydraulic conditions for the passage of non-anadromous salmonids as follows (Heise 2001): maximum average water velocity for culverts less than 18 m long of 1.2 m/s or less; minimum water depth of at least 0.2 m;

and a drop at the outlet of a culvert of 0.3 m or less. Survey elevations and culvert specifications measured in the field were entered into the FishXing program to evaluate passage at the Test Station Road culvert. Using the FishXing program, the range of flows that meet the depth, velocity, and leaping criteria for adult brown trout in the 220 – 280 mm size range were identified. The proportion of flows, within the range of tested flows, for which the model predicted that adult brown trout (220-280 mm) could pass upstream past this culvert was the metric reported for this analysis.

Results

Fish Population Abundance

Rush Creek – March 2001

A total of 18 rainbow trout and 278 brown trout were tagged in Rush Creek and 6 rainbow trout and 140 brown trout were tagged in the MGORD during March 2001. Overall catch efficiencies were relatively low for March sampling due to cold water temperatures. However, except for the MGORD, where the drift boat set-up was employed, a single backpack electrofisher with two netters was used for capturing fish. This standardized methodology allows for comparing catch rates between sections to provide an indication of the relative abundance of brown trout in different portions of Rush Creek. Catches of age 0 brown trout (< 130 mm) were highest in the sections of Upper Rush Creek, above Highway 395, and below the County Road (Figure 3). Catches of larger brown trout (> 200 mm) were highest in the MGORD, about 65 per km, and fairly constant in Rush Creek, at about 10 to 25 fish per km (Figure 3).

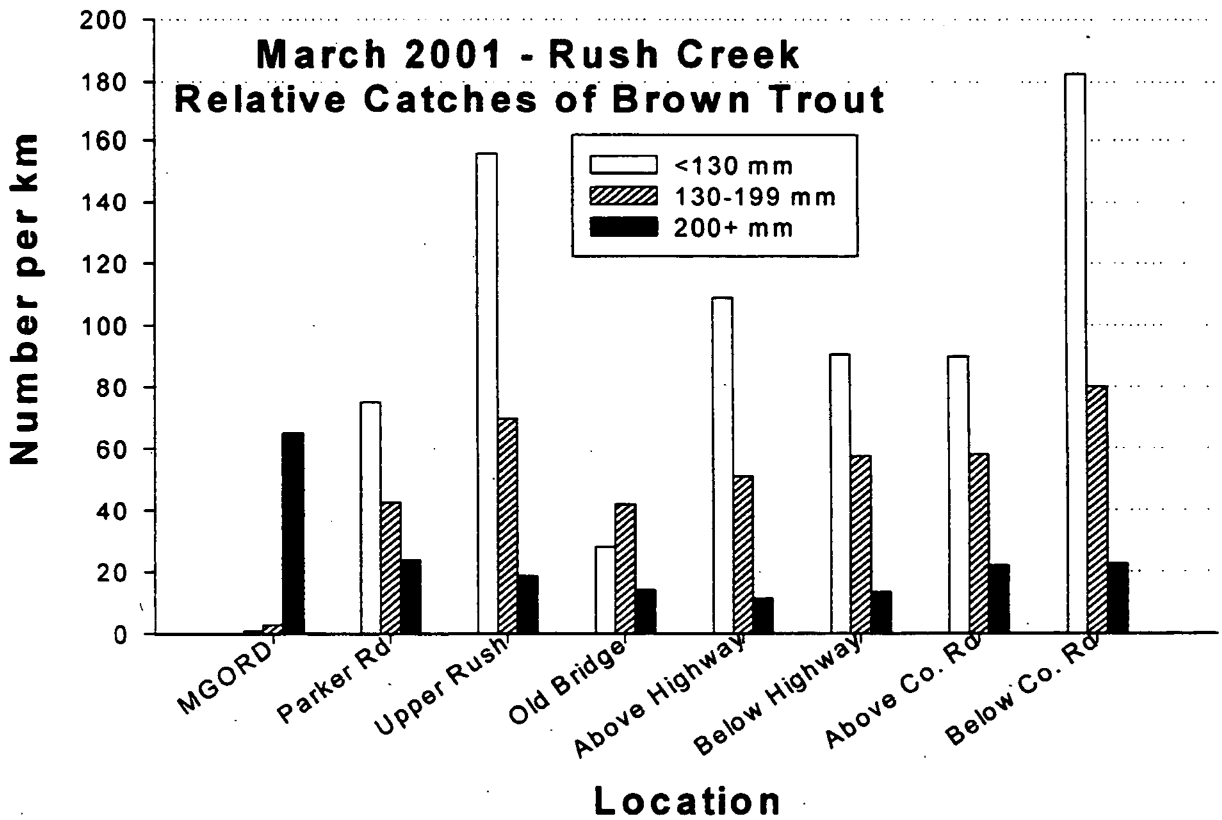

Figure 3. Relative catches of brown trout in seven portions of Rush Creek and in the MGORD during March 2001.

Rush Creek – September 2001

County Road Section

The majority of the brown trout captured in the County Road Section of Rush Creek were from 70 to 100 mm and the longest brown trout captured was just under 290 mm (Figure 4). Few rainbow trout were captured and most of these were from 150 to 240 mm with two fish from 60 to 80 mm (Figure 4). This section supported an estimated 766 age 1 and older and 1,322 age 0 brown trout (Table 3). Estimates of brown trout were relatively precise with standard deviations ranging from 5-10% of the estimates. No estimate could be made for rainbow trout age 0, but the section supported an estimated 26 rainbow trout age 1 and older.

Lower Section

Length frequencies of brown trout captured in the Lower Section were similar to the distribution observed for the County Road Section (Figure 4). About half the number of rainbow trout were captured in this section compared to the County Road Section. This section supported an estimated 300 age 1 and older and 880 age 0 brown trout (Table 3). Estimates of all size classes of brown trout were relatively precise with standard deviations ranging from 3-10% of the estimates. Again, no estimate could reliably be made for age 0 rainbow trout, but this section supported an estimated 10 age 1 and older rainbow trout (Table 3).

Upper Section

Length frequencies of brown trout captured in the Upper Section were also similar to the distribution observed for the County Road and Lower sections (Figure 4). The length frequency of rainbow trout was similar to the Lower Section, but more age 0 rainbow trout were captured in this Upper Section. The Upper Section of Rush Creek supported an estimated 365 age 1 and older and 3,453 age 0 brown trout (Table 3). This section supported an estimated 14 age 1 and older and 111 age 0 rainbow trout; however, these rainbow trout estimates were likely biased due to the low number of recaptures.

MGORD

The length frequency histogram for brown trout captured within the MGORD showed that almost no captured fish were smaller than 150 mm (Figure 4). A mode existed from 160 to about 220 mm and brown trout up to 650 mm were captured. No estimate of age 0 brown trout could be made, but this channel supported 1,410 brown trout age 1 and older with 190 of these fish 350 mm and longer and 45 of these 450 mm and longer (Table 3). Estimates of age 1 and older brown trout were precise, ranging from 3-13%. Very few rainbow trout were captured in this channel and all those captured were 230 mm and longer (Figure 4). This channel supported so few rainbow trout that no reasonable estimate of their numbers could be made.

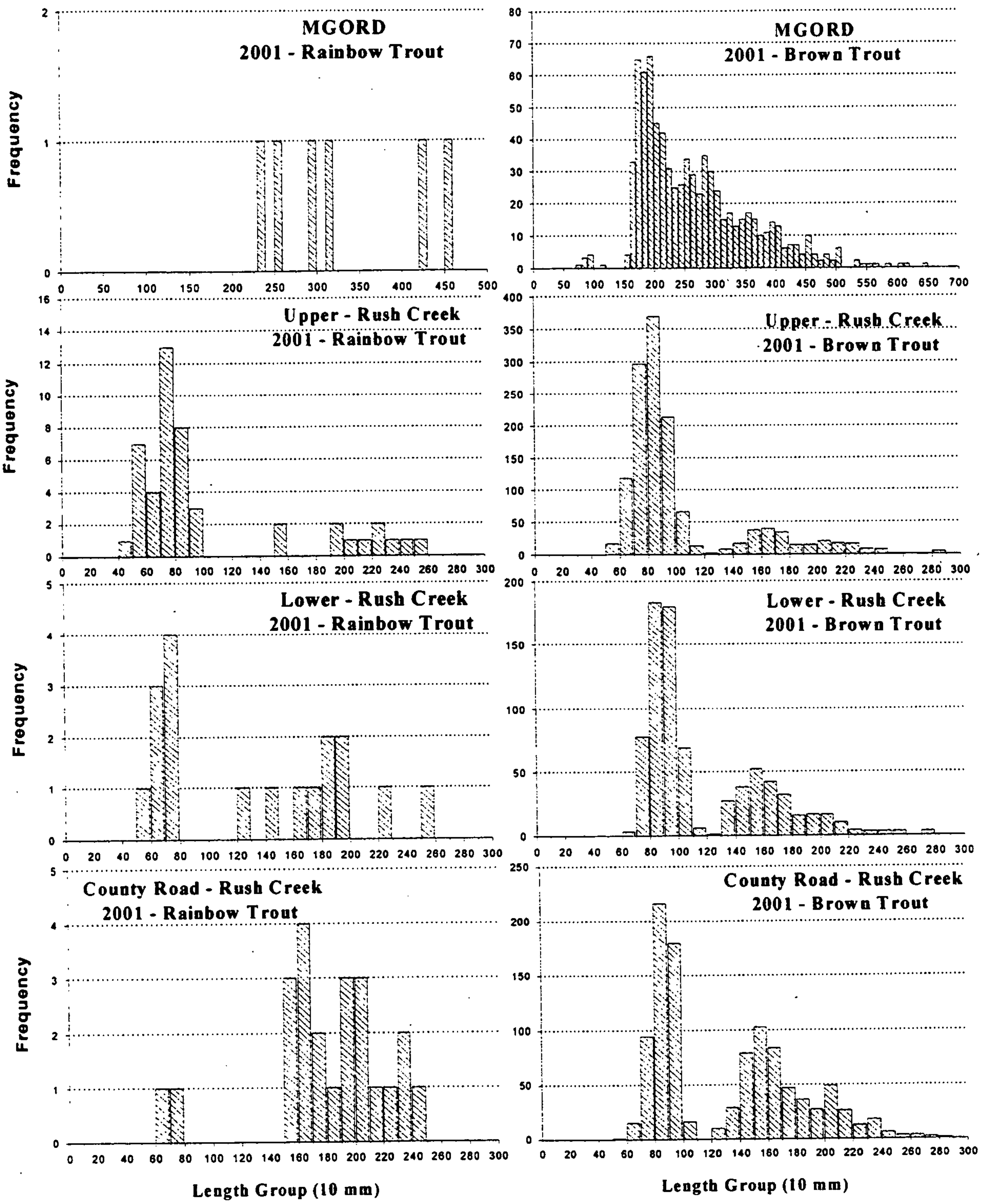

Figure 4. Length frequency histograms for rainbow (left) and brown trout (right) captured in the MGORD (top), and Upper (mid-top), Lower (mid-bottom) and County Road (bottom) sections of Rush Creek from September 3 to September 14, 2001. Note the different scales on the vertical axes.

Table 3. Mark-recapture estimates showing number of fish marked (M), number captured on recapture run (C), number recaptured on recapture run (R), number of mortalities (Morts) between mark and recapture run, estimated number, and standard deviation (S.D.) by stream section, species and length group (YOY = age 0) during September 2001. Estimator method is shown after species (LL=log likelihood; MP=modified Peterson).

Stream (Section) Species (Estimator) Length Group	Mark-Recapture				Estimated[1/] number	S.D.
	M	C	R	Morts		
Rush Creek (County Road Section)						
Brown Trout (MP)						
YOY (< 125 mm)	287	280	64	14	1308	134
125-174 mm	202	202	80	0	509	34
175 + mm	141	135	75	2	255	14
Rainbow Trout (MP)						
YOY (< 125 mm)	1	1	0	0	NP[2]	-
125 + mm	17	11	7	0	26	4
Rush Creek (Lower Section)						
Brown Trout (MP)						
YOY (< 125 mm)	279	305	101	41	839	54
125-149 mm	38	45	22	6	77	7
150 + mm	147	152	107	8	209	6
Rainbow Trout (MP)						
YOY (< 125 mm)	2	6	0	0	NP[2]	-
125 + mm	8	10	8	0	10	0
Rush Creek (Upper Section)						
Brown Trout (MP)						
YOY (< 125 mm)	514	561	84	152	3301	322
125-199 mm	71	90	32	14	258	29
200 + mm	51	51	30	7	86	6
Rainbow Trout (MP)						
YOY (< 125 mm)	17	17	2	4	107[3/]	45
150 + mm	7	6	3	1	13[3/]	3

Table 3. (Continued).

Stream (Section) Species (Estimator) Length Group	Mark-Recapture M	C	R	Morts	Estimated[1] number	S.D.
Rush Creek – MGORD						
Brown Trout (LL)						
YOY (< 125 mm)	2	7	0	0	NP[2/]	-
150-249 mm	222	233	61	4	913	45
250-349 mm	154	152	73	1	302	10
350-449 mm	78	65	39	1	144	4
450-624 mm	23	20	20	2	43	6
Rainbow Trout (MP)						
YOY (< 125 mm)	0	0	0	0	NP[2/]	-
200-499 mm	4	4	2	0	7[3/]	2
Lee Vining Creek (Lower Section – Main Channel)						
Brown Trout (MP)						
YOY (< 125 mm)	69	61	32	1	131	11
125-224 mm	52	42	28	0	78	6
225-324 mm	15	13	13	0	15	0
Rainbow Trout (MP)						
YOY (< 125 mm)	3	5	1	0	11[3/]	4
150-349 mm	9	8	6	0	12[3/]	1
Lee Vining Creek (Upper Section – Main Channel)						
Brown Trout (LL)						
YOY (< 125 mm)	37	53	14	0	136	23
125-349 mm	75	67	46	0	109	5
Rainbow Trout (LL)						
YOY (< 125 mm)	41	40	9	3	215	35
125-499 mm	41	27	23	0	68	2

1/ To arrive at a complete estimate the mortalities ("Morts") should be added to the "Estimated number".

2/ "NP" denotes that an estimate was not possible for this size group.

3/ The number of recaptured fish for these estimates were below 7, the number recommended for an unbiased modified Peterson estimate.

Lee Vining Creek

A diver did not observe any fish in the estuary portion of Mono Lake where Lee Vining Creek entered the lake; though turbid water conditions and wave action severely limited visibility. This diver saw a few trout in the first large pool in Lee Vining Creek above Mono Lake, but fish densities in this pool were not very high.

Lower Section

Similar numbers of age 0 brown trout (<125 mm) were captured in the side channel portion as were captured in the main channel portion of the Lower Section of Lee Vining Creek; however, more age 1 and older brown trout were captured in the main channel (Figure 5). Most rainbow trout, especially age 0, were captured in the side channel portion of the Lower Section (Figure 5). The main channel supported an estimated 131 age 0 and 93 age 1 and older brown trout, while the side channel supported an estimated 85 age 0 and 44 age 1 and older brown trout (Tables 3 and 4). The main channel supported an estimated 11 age 0 rainbow trout, but this was a very poor estimate, and an estimated 12 rainbow trout age 1 and older. The side channel supported an estimated 102 age 0 and 41 age 1 and older rainbow trout. An extra 72.5 m of side channel length was sampled in 2001, compared to 1999 and 2000 sampling.

Upper Section

Similar numbers of age 0 brown trout (< 125 mm) were captured in both the main and side channel portions of the Upper Section of Lee Vining Creek, while more age 1 and older brown trout were captured in the main channel (Figure 5). More age 0 rainbow trout were captured in the main channel, but more age 1 and older rainbow trout were captured in the side channel (Figure 5). Two large rainbow trout (> 350 mm) were captured in this section. One was captured in the main channel and one in the side channel. The main channel portion of the Upper Section supported an estimated 136 age 0 and 109 age 1 and older brown trout, and 218 age 0 and 68 age 1 and older rainbow trout (Table 3). The side channel portion supported an estimated 24 age 0 and 38 age 1 and older brown trout, and 13 age 0 and 54 age 1 and older rainbow trout (Table 4).

Parker Creek

Only brown trout were captured in Parker Creek and most of these were less than 100 mm (Figure 6). Parker Creek supported an estimated 132 age 0 and 27 age 1 and older brown trout (Table 4).

Walker Creek

Only brown trout were captured in Walker Creek and most were less than 120 mm (Figure 6). Walker Creek supported an estimated 73 age 0 and 30 age 1 and older brown trout (Table 4).

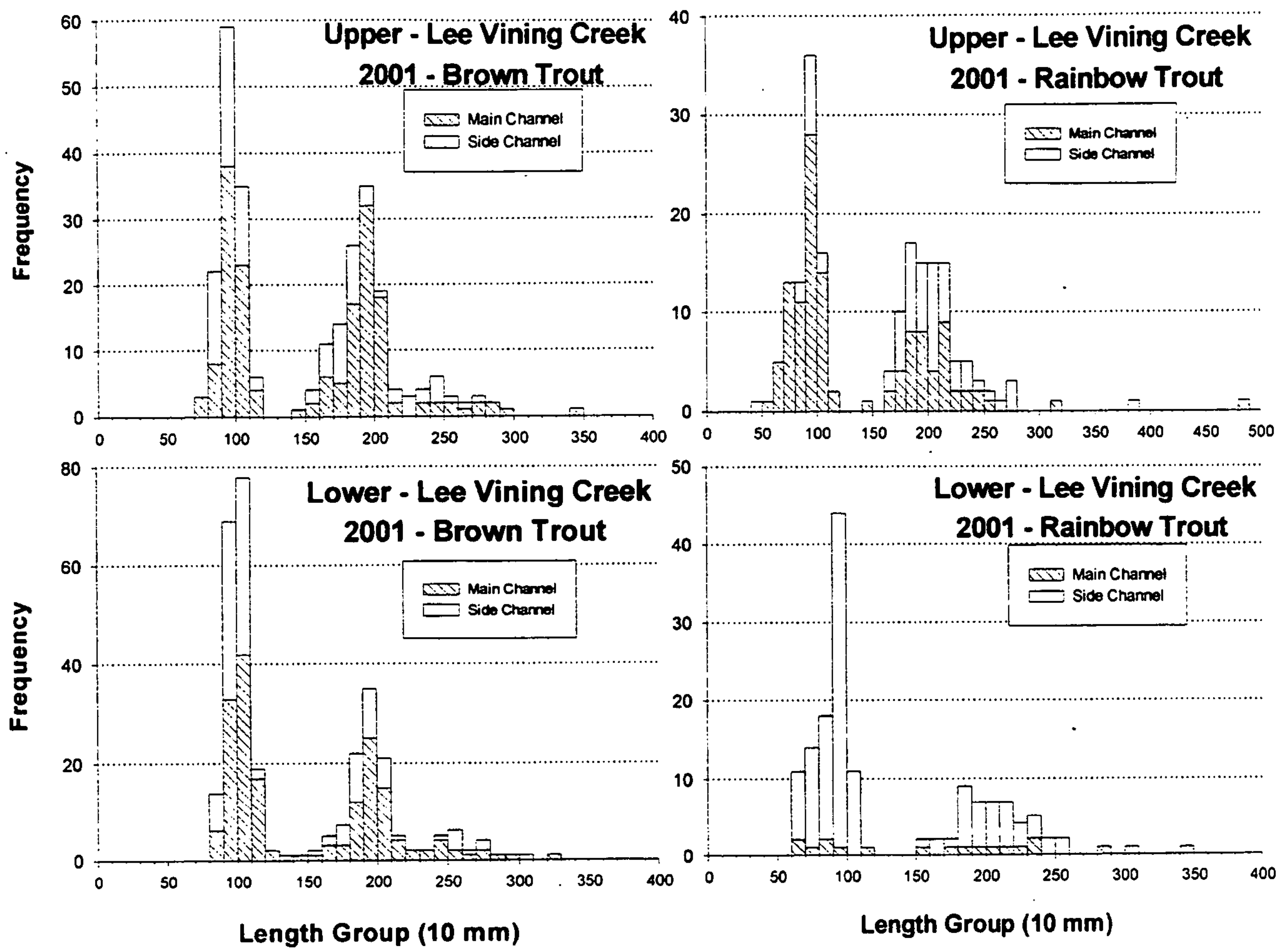

Figure 5. Length frequency histograms for brown (left) and rainbow (right) trout captured in the Upper (top) and Lower (bottom) sections of Lee Vining Creek during September 2001 showing those fish captured in the main channel (cross-hatched bars) and side channel (open bars) portions of each section. Note the different scales on the vertical axes.

Table 4. Depletion population estimates made in the side channel portions of the Lower and Upper sections of Lee Vining Creek and in Parker and Walker creeks during September 2001 showing number of fish captured on each pass, estimated number, and standard deviation (S.D.) by species and length group (YOY = age 0).

Stream (Section) Species Length Group	Number captured per pass 1	 2	 3	Estimated number	S.D.
Lee Vining Creek (Lower Side Channel)					
Brown Trout					
YOY (<125 mm)	68	14	-	85	2.7
125-199 mm	28	0	-	28	0
200 + mm	15	1	-	16	0.3
Rainbow Trout					
YOY (<125 mm)	69	23	-	102	6.6
125-199 mm	17	1	-	18	0.2
200 + mm	21	2	-	23	0.5
Lee Vining Creek (Upper Side Channel)					
Brown Trout					
YOY (<125 mm)	19	5	-	24	1.2
125-199 mm	31	0	-	31	0
200 + mm	7	0	-	7	0
Rainbow Trout					
YOY (<125 mm)	7	5	1	13	1.0
125-199 mm	17	4	2	23	0.8
200 + mm	24	5	2	31	0.7
Parker Creek					
Brown Trout					
YOY (<125 mm)	39	26	21	132	30.4
125-199 mm	15	6	1	22	0.8
200 + mm	4	0	1	5	0.4
Walker Creek					
Brown Trout					
YOY (<125 mm)	59	12	-	73	2.3
125-199 mm	16	3	-	19	0.8
200 + mm	10	1	-	11	0.3

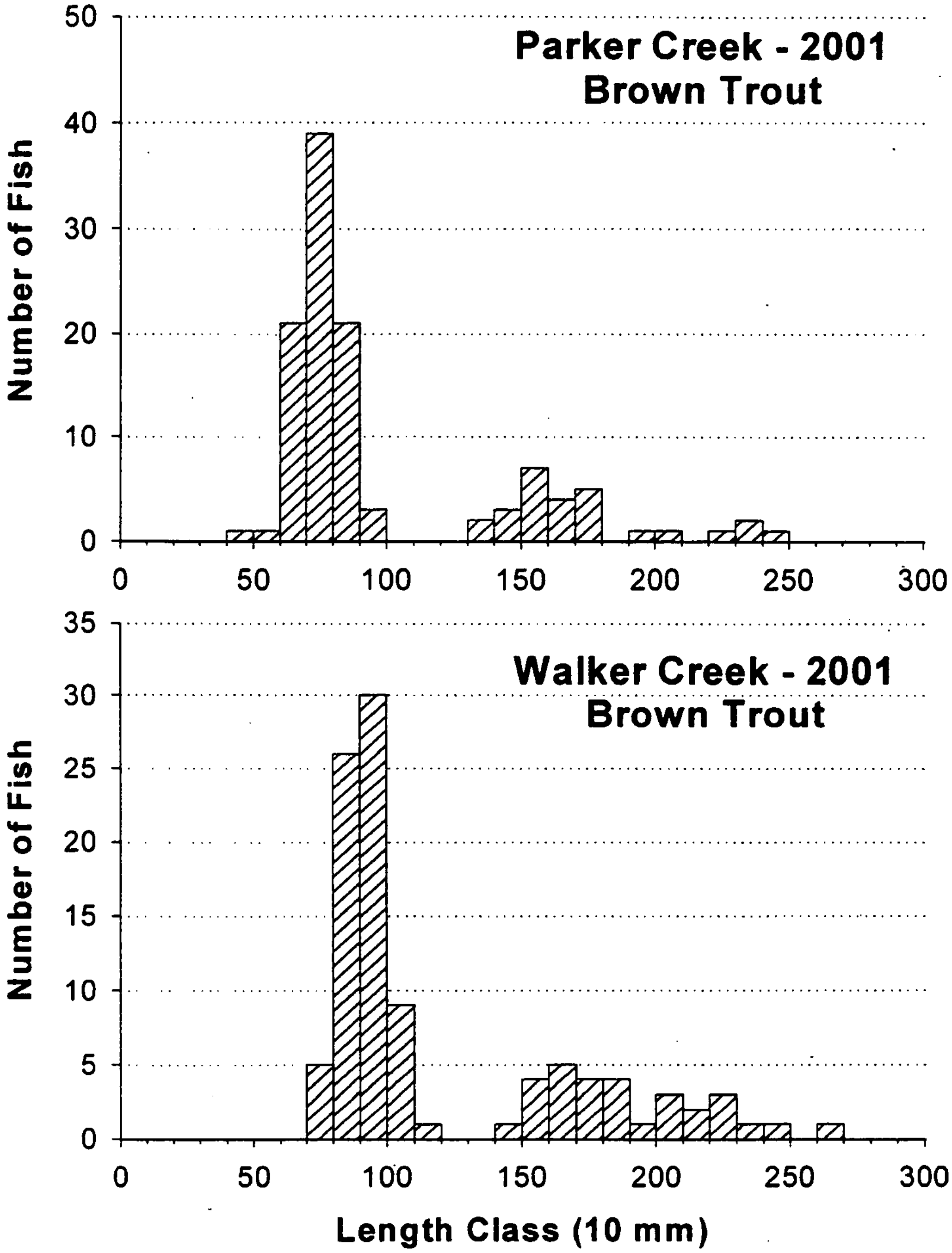

Figure 6. Length frequency histograms for brown trout captured in Parker (upper) and Walker (lower) creeks during September 2000. Note the different scales on the vertical axes.

Relative Condition of Trout

Log_{10} transformed length-weight regressions for brown trout had R^2-values over 0.98 for almost all sample events indicating that weight was strongly correlated to length (Table 5). Length-weight regressions for brown trout from Rush Creek indicated that brown trout captured during 2000 were in better condition (a fish of a certain length weighed more) than those captured during 1999 (dotted lines versus solid lines; Figure 7), but that fish captured in 2001 were in poorer condition than those captured in 2000 (dashed lines versus solid lines) and in many cases were similar in condition to fish captured in 1999. Relative weights did not change between the spring (March) and fall (September) of 2001 in either the County Road or MGORD areas, but did increase in the Upper Section of Rush Creek (Figure 8). Computation of condition factors by length group showed a similar trend as relative weights between years for brown trout 150 to 250 mm in Rush Creek, where conditions were better during 2000 than 1999, but then were poorer in 2001 (Figure 9). Condition factors for the other streams followed a similar pattern, except for Walker Creek, where condition factor increased in 2001. Condition factors were average to high, compared to condition factors for trout, with most being near 1.0 or higher.

Table 5. Regression statistics for log_{10} transformed length (L) to weight (WT) for brown trout 100 mm and longer captured in Rush Creek by sample section and year.

Section	Year	N	Equation	R^2	P
County Road	2000	412	$Log_{10}(WT) = 2.936 * Log_{10}(L) - 4.827$	0.987	< 0.01
	2001	552	$Log_{10}(WT) = 2.912 * Log_{10}(L) - 4.815$	0.979	< 0.01
Lower	1999	314	$Log_{10}(WT) = 3.027 * Log_{10}(L) - 5.078$	0.992	< 0.01
	2000	230	$Log_{10}(WT) = 2.975 * Log_{10}(L) - 4.904$	0.985	< 0.01
	2001	350	$Log_{10}(WT) = 2.975 * Log_{10}(L) - 4.939$	0.986	< 0.01
Upper	1999	279	$Log_{10}(WT) = 2.922 * Log_{10}(L) - 4.813$	0.983	< 0.01
	2000	309	$Log_{10}(WT) = 3.001 * Log_{10}(L) - 4.958$	0.981	< 0.01
	2001	335	$Log_{10}(WT) = 2.987 * Log_{10}(L) - 4.958$	0.992	<0.01
MGORD	2001	769	$Log_{10}(WT) = 2.873 * Log_{10}(L) - 4.719$	0.990	<0.01

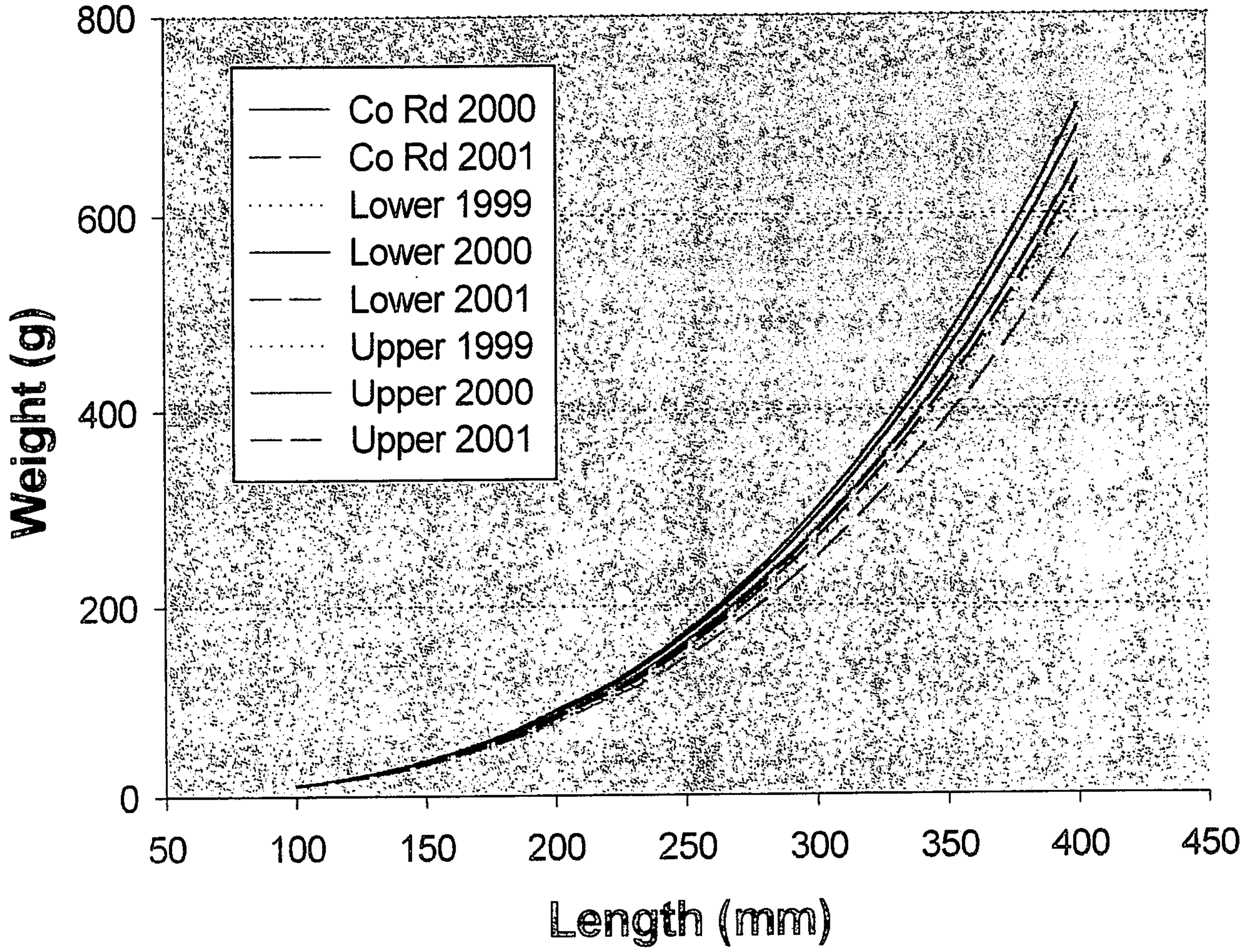

Figure 7. Length-weight regressions for brown trout captured in three sections of Rush Creek during the late summers of 1999, 2000, and 2001. Legend shows the section and year.

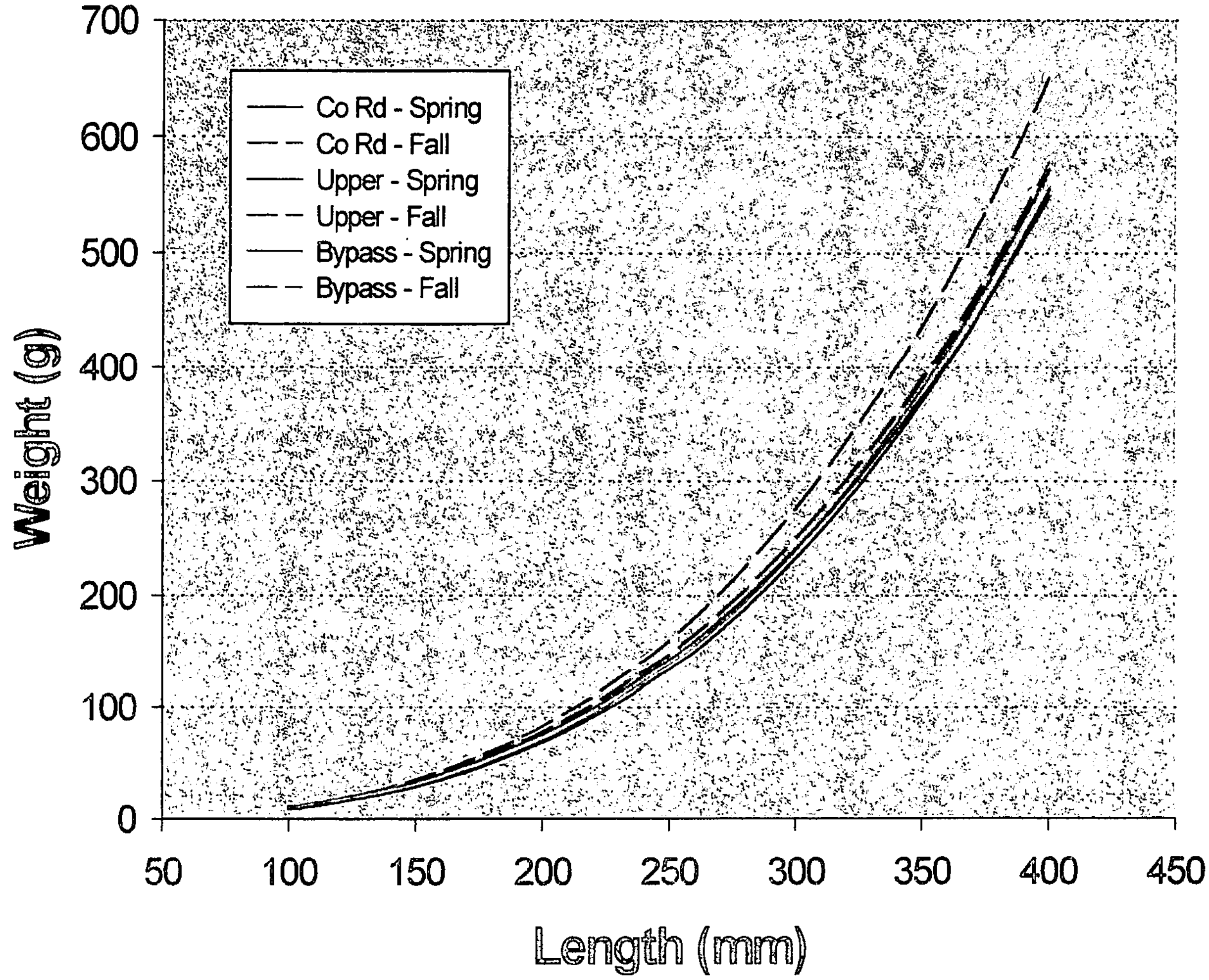

Figure 8. Length-weight regressions for brown trout 100 mm and longer captured in three sections of Rush Creek during the spring (March) and fall (September) of 2001.

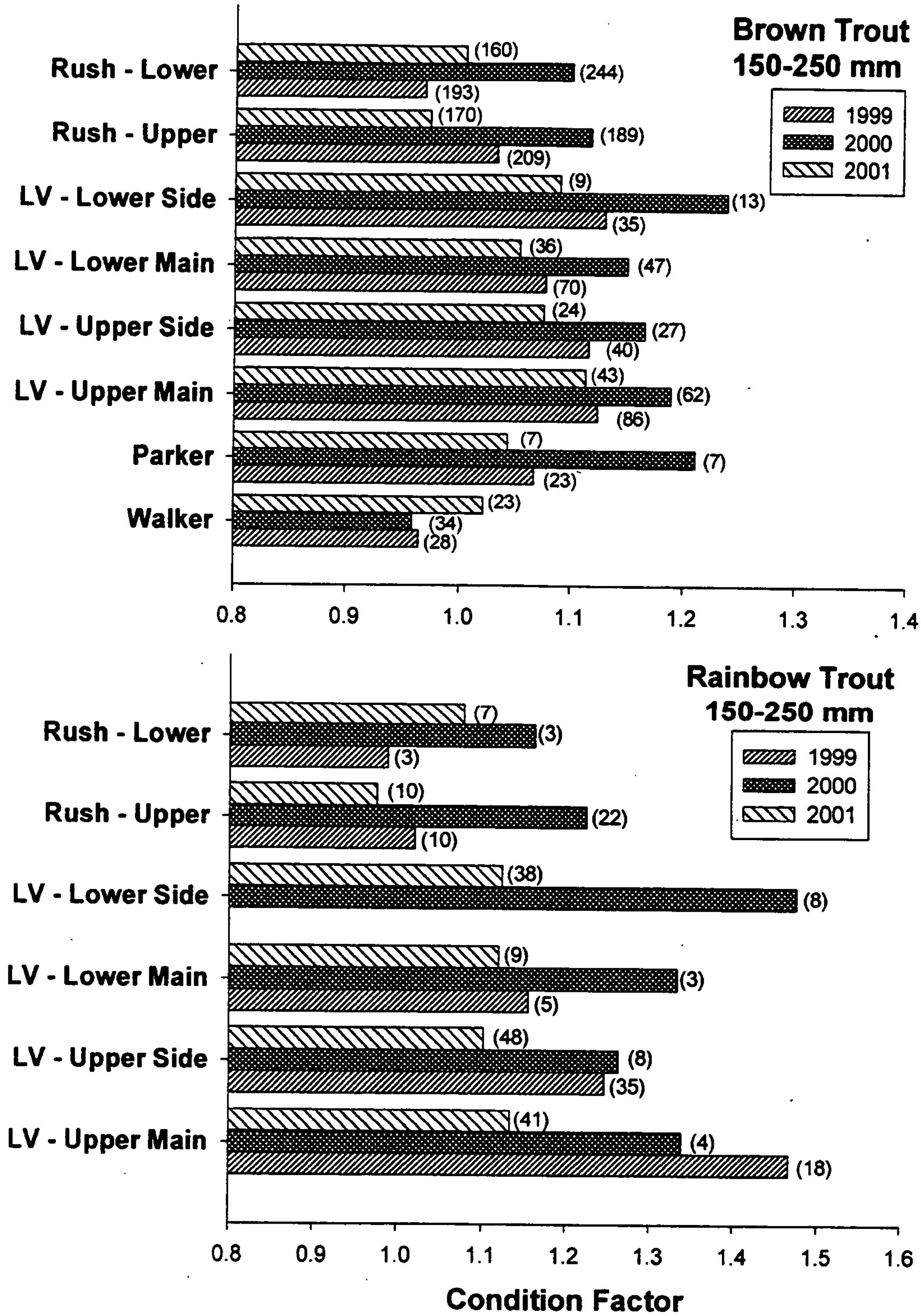

Figure 9. Condition factors for brown trout (top) and rainbow trout (bottom) 150 to 250 mm long in Mono Lake tributaries from 1999 to 2001.

Movement of Brown Trout from March to September

Fourty-one of the 140 (29%) brown trout that were tagged in the MGORD during March were recaptured in September (Table 6). Recapture rates in the MGORD were related to fish size with 56% of the largest (> 900 g) brown trout being recaptured, 33% for browns weighing between 450 and 900 g, and only 23% for those weighing less than

Table 6. Tag return information for trout by weight groups that were tagged during March 2001 and recaptured in September 2001. Locations move from the MGORD downstream into main Rush Creek in a downstream direction (Ab Upper = Above Upper Rush Section and below the MGORD; Upper = Upper Rush Section; Bl Upper = Immediately below Upper Rush Section to Highway 395; Ab Co Rd = Below Highway 395; Co Rd = Above County Road; and Bl Co Rd = Below County Road).

SPECIES	< 450 g			450-900 g			> 900 g			Total All Sizes		
Location	Mar	Sept	% Recap	Mar	Sept	% Recap	Mar	Sept	% Recap	Mar	Sept	% Recap
BROWN												
MGORD	92	21	22.8	30	10	33.3	18	10	55.6	140	41	29.2
Ab Upper	43	2[1/]	4.7	2	2[1/]	100	0	0	0	45	4	8.9
Upper	37	2	5.4	1	1[1/]	100	0	0	0	38	3	7.9
Bl Upper	68	1[1/]	1.5	0	0	0	2	0	0	70	1	1.4
Ab Co Rd	26	0	0	0	0	0	0	0	0	26	0	0
Co Rd	46	2	4.3	0	0	0	0	0	0	46	2	4.3
Bl Co Rd	62	0	0	0	0	0	0	0	0	62	0	0
Total Rush Creek	282	7	2.5	3	3	100	2	0	0	287	10	3.5
RAINBOW												
MGORD	6	0	0	0	0	0	0	0	0	6	0	0
Ab Upper	3	0	0	0	0	0	0	0	0	0	0	0
Upper	1	1	100	0	0	0	0	0	0	1	1	100
Bl Upper	6	0	0	0	0	0	0	0	0	6	0	0
Ab Co Rd	2	1[2/]	50	0	0	0	0	0	0	2	1	50
Co Rd	1	0	0	0	0	0	0	0	0	1	0	0
Bl Co Rd	5	0	0	0	0	0	0	0	0	0	0	0
Total Rush Creek	18	2	11.1	0	0	0	0	0	0	18	2	11.1

[1/] These fish were recaptured in the MGORD.

[2/] These fish were recaptured in the Lower Rush Section.

450 g. In the Rush Creek channel below the MGORD, 10 out of 287 (4%) of the brown trout tagged during March were recaptured during September. Six of these tagged fish, including three that weighed between 450 and 900 g, were recaptured in the MGORD. Five of the ten large (> 340 g or > 320 mm) brown trout that were tagged in Rush Creek during March were recaptured in the MGORD during September. All tagged rainbow trout weighed less than 450 g. Of the six rainbow trout that were tagged in the MGORD, none were recaptured in September (Table 6). Two of the 18 (11%) rainbow trout tagged during March in the Rush Creek channel were recaptured in September. This compares to a 2.5% recapture rate for brown trout of a similar size (Table 6).

A total of 25 brown trout that weighed less than 450 g were recaptured in the MGORD in September (Appendix A-1). Four of these browns immigrated into the MGORD from downstream sites in main Rush Creek up into the MGORD, traveling distances ranging from 1.58 to 4.07 km. The other 21 recaptured brown trout in this weight group were also tagged in the MGORD, and most were recaptured slightly downstream of their March locations. Twelve of these fish were recaptured more than 0.15 km downstream of their March sites, compared to only two that were captured more than 0.15 km upstream. The remaining fish less than 450 g were tagged and recaptured in main Rush Creek. Two of these fish, tag numbers 343 and 239, were rainbow trout. One of these rainbows was recaptured 0.65 km upstream of where it was tagged. The other rainbow trout and the four brown trout were recaptured in essentially the same locations in Rush Creek during both March and September.

Two brown trout weighing between 450 and 900 g emigrated from Rush Creek upstream into the MGORD between March and September, traveling 1.58 and 3.30 km upstream (Appendix A-2). An additional 20 brown trout in this weight range were tagged and recaptured in the bypass channel. Most (all but two) of the brown trout in this weight range were also recaptured downstream of their March locations, similar to movements observed for the smaller (< 450 g) brown trout. However, more of these medium-sized brown trout moved further downstream (0.20 to 0.34 km) from their tagging sites than did the smaller fish (Appendix A-1 versus A-2). An equal number of the largest brown trout (> 900 g) were recaptured upstream and downstream from where they were tagged, with half of these large fish being recaptured within 0.15 km of their March tagging locations (Appendix A-3).

All, but one, of the recaptured trout that weighed less than 450 g at its time of tagging in the MGORD increased their weight between March and September 2001 (Appendix A-1). Growth rates for these smaller browns varied from –1.1 to 4.6 g/week, with half of the fish growing less than 2.0 g/week (Appendix A-1). Individual growth rates for the smallest (< 300 g) of these brown trout in the MGORD, ranged from 1.3 to 3.8 g/week, with the majority ranging from 2.0 to 3.0 g/week. Growth rates for the two smaller (< 450 g) brown trout that were tagged and recaptured in the Upper Rush electrofishing section (tag numbers 327 and 344) were 2.4 and 3.0 g/week, similar to MGORD growth rates. The two smaller brown trout that were tagged and recaptured in the County Road section (tag numbers 257 and 262) had lower growth rates (0.9 and 1.2 g/week) than any of the similar-sized individuals in the MGORD or upper Rush Creek areas.

Growth rates for medium-sized (450 – 900 g) brown trout were evenly split between positive and negative values, with individual growth rates for this weight group ranging from –6.6 to 2.5 g/week (Appendix A-2). Interestingly, all of the brown trout heavier than 900 g tagged in the MGORD lost weight between March and September 2001 (Appendix A-3. Weight differences for these large fish indicated they lost from 2 to almost 12 g/week.

Evaluation of the Test Station Road Culvert to Allow Upstream Fish Passage

The Test Station Road crossing consisted of a 12 m long corrugated, steel-plated, pipe-arch culvert that is 4.6 m wide by 3.1 m tall. The culvert floor was set at a slope of 1.1% and the culvert structure has concrete wing walls at both the inlet and outlet. The corrugation dimensions of the culvert were 15 cm wide by 5 cm deep. The corrugations' dimensions affect the roughness of the culvert floor, influencing water depths and velocities. Generally the deeper the corrugations, the deeper and slower is the flow through the culvert. Larger corrugations also create regions of slower velocities along the culvert's walls that fish can utilize for successful upstream migration. The culvert has a 4.6 m long concrete apron sloped at 1.7% on its downstream, or outlet side, that drops about 9 cm into a large pool (Figure 10).

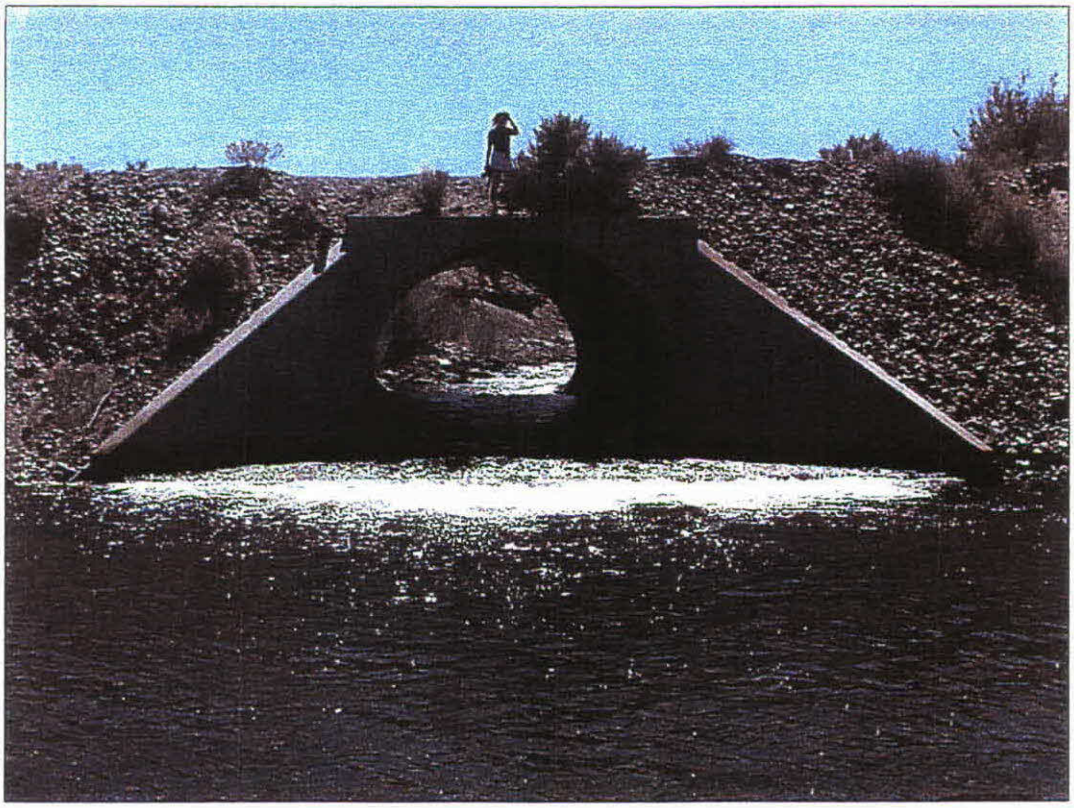

Figure 10. Outlet side of the Test Station Road culvert on lower Rush Creek.

The low passage flow was set at 3.0 cfs, while the high passage flow was set at 30% of the two-recurrence interval discharge. The two-year recurrence interval (impaired flow) on Rush Creek below the dam at Grant Lake is 198 cfs (Hasencamp 1994). Because no long-term gauged discharge information was available for the entire Rush Creek watershed, the 198 cfs was used, but should be considered an underestimate of the actual two-year discharge at the Test Station Road crossing. McBain and Trush established a gauge in November of 2001 at the Test Station Road culvert; however, at least 10 years of gauged data is recommended for generating migration flow values (Taylor and Love 2002). Thirty percent of 198 cfs is equal to approximately 60 cfs.

One of the limitations of FishXing is modeling hydraulics through culverts comprised of a composite of materials, such as the Test Station Road culvert, which consists of 40 feet of corrugated pipe and 15 feet of a smooth, concrete apron. The passage evaluation was conducted as if the culvert were split into two sections: a 4.6 m long concrete box culvert at a 1.7% slope and then a 12 m long corrugated pipe-arch set at a slope of 1.1%.

FishXing determined that adult brown trout could move upstream through the corrugated pipe-arch at approximately 63% of the range of migration flows (3 to 60 cfs). The model predicted that adult brown trout could pass through the culvert at flows between 10 and 47 cfs. The culvert lacks adequate depth for migration at flows less than 10 cfs, while at flows over 47 cfs water velocities that exceed the fish's swimming ability would prevent upstream movement. FishXing also determined that the concrete apron is a barrier due to a lack of depth at all migration flows and is also a velocity barrier between 40 and 60 cfs. Predicted velocities over this apron were nearly 6.5 ft/s at 60 cfs.

Discussion

Reliability of Estimates

For all estimates, except the County Road and MGORD estimates, we believe we met all assumptions, including closure of populations to emigration and immigration because block fences were maintained and stayed in place between mark and recapture runs. Since no block fences were deployed at the boundaries of the County Road or MGORD sections of Rush Creek, movement of fish into and out of these sections between mark and recapture efforts may have affected these estimates. However, the relatively long length of these sections (over 800 m for County Road and over 2,200 m for the MGORD) should have reduced this effect. In addition, the lower boundary of the MGORD was located immediately above a relatively steep drop and the upper boundary was at the Grant Lake outlet structure making it unlikely that much fish movement into or out of this section occurred between the marking and recapture events.

Estimate and Standing Crop Comparisons

Densities (number per hectare) of age 1 and older brown trout were generally the same or higher in 2001 than in 2000, except in the Upper Rush and Walker Creek sections (Figure 11). We note that standard errors for some estimates were extremely low and either do not show up on the graph, or were actually estimated as zero, due to extremely high capture efficiencies (see Table 3). The 2000 mark-recapture estimate in the Upper Rush Creek section may have been an over-estimate due to movement of fish into and out of the section between the mark and recapture events as discussed in last year's report (Hunter et al. 2001). The Rush Creek, Lower Main Channel of Lee Vining Creek, Parker Creek, and Walker Creek sections supported similar densities of age 1 and older brown trout, from 1,000 to 1,500 per hectare, during 2001. Densities of age 1 and older rainbow trout were higher in 2001 in all Lee Vining Creek sections, but lower in all Rush Creek sections (Figure 12).

Estimates of trout standing crops (kg/hectare) were lower during 2001 than during 2000 in the Lower and Upper Rush Creek, Lower Main Lee Vining Creek, and Walker Creek sections, but were higher or similar in the other sections (Figure 13). Densities and biomass of trout, especially rainbows, have continued to increase in Lee Vining Creek from 1999 to 2001.

Sampling has indicated that age 0 trout, especially brown trout, have been extremely abundant (2,000 to 14,000 per hectare); however, the abundance of age 0 brown trout declined from 2000 to 2001 in all Rush Creek sections and main channel sections of Lee Vining Creek (Figure 14). Estimates of age 0 brown trout increased in both Parker and Walker creeks in 2001, compared to 2000. The high relative abundance of age 0 trout indicates that spawning habitat is probably adequate for fully seeding these streams with trout.

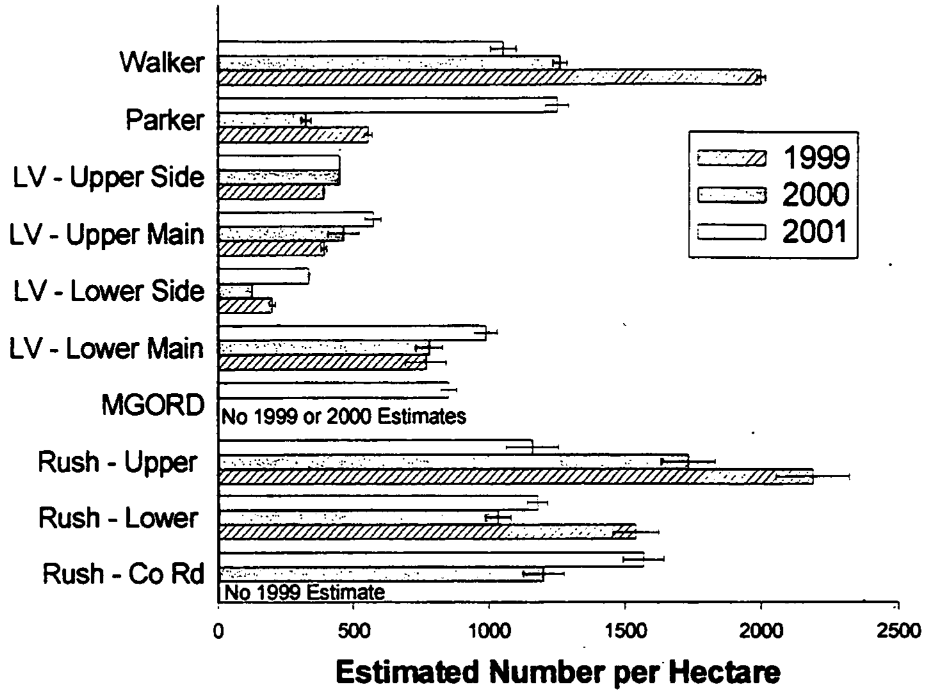

Figure 11. Estimated number (standard errors shown as capped horizontal lines) of age 1 and older brown trout per hectare in sections of Rush and Lee Vining creeks during September 1999, 2000, and 2001.

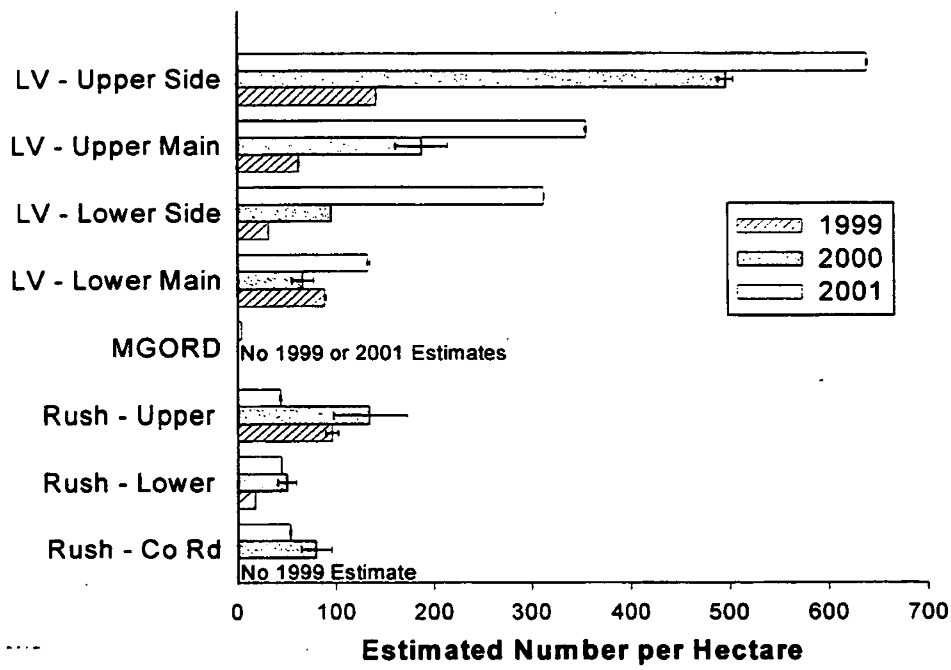

Figure 12. Estimated number (standard errors shown as capped horizontal lines) of age and older rainbow trout per hectare in sections of Rush and Lee Vining creeks during September 1999, 2000, and 2001.

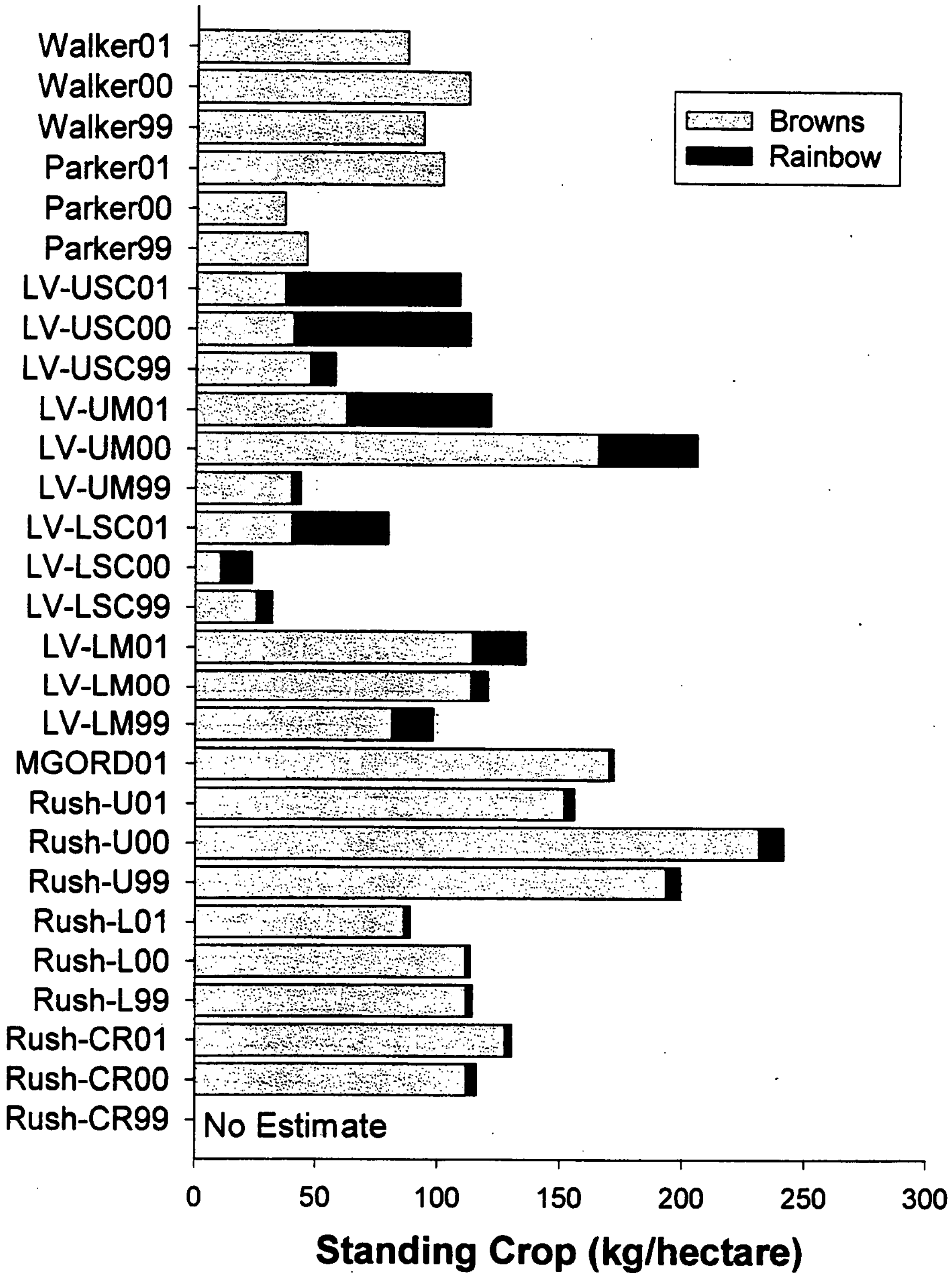

Figure 13. Standing crop (kg/hectare) of age 1 and older brown and rainbow trout in selected Mono Lake tributaries in 1999, 2000, and 2001. Vertical axis shows stream (LV = Lee Vining), section (U = Upper, L = Lower, SC = side channel, M = main channel, CR = County Road, and MGORD), and year.

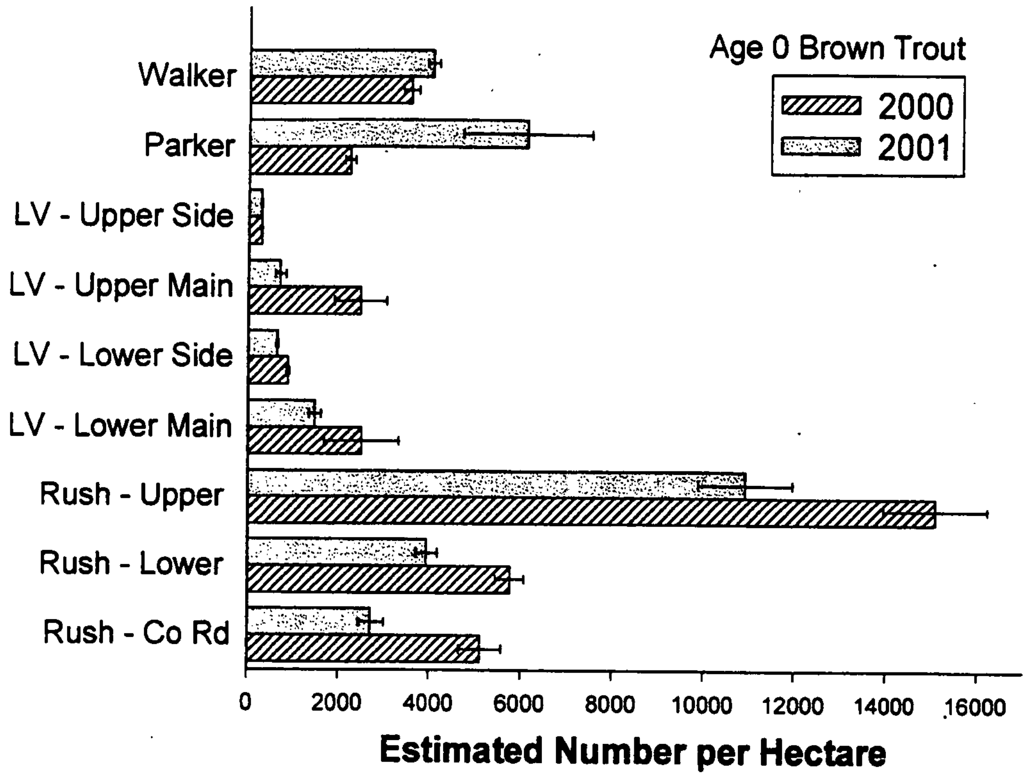

Figure 14. Estimated number (standard errors shown as capped horizontal lines) of age 0 brown trout per hectare in sections of Rush and Lee Vining creeks during September 2000 and 2001.

Habitat Selection Literature Review

Since the termination criteria concentrates on the abundance of larger "catchable" trout (">8 inches [203 mm] with some 13 to 15 inches [330 to 381 mm]") we feel a discussion of factors that probably influence these streams' capacity to support larger (> 200 mm) trout is warranted. Habitat is important in determining stream carrying capacity and population density in young brown trout (Heggenes et al. 1999). Habitat selection changes as young brown trout grow. Small trout (less than 7 cm) are abundant in the shallow swift stream areas (less than 20 - 30 cm depths, 10 - 50 cm/sec velocities) with cobble substrates, while larger trout have increasingly strong preferences for deep-slow stream areas, particularly pools. Kocik and Taylor (1996) evaluated habitat use of juvenile brown trout by snorkeling. They found that age 0 brown trout occupied stream margins soon after emergence, using cover provided by aquatic vegetation growing on silt and sand substrates. By summer and fall, brown trout had moved into deeper water and used more diverse cover types. Maki-Petays et al. (1999) assessed habitat suitability for brown trout fry using summer and winter habitat preference curves for water velocity, depth and substrate. They concluded that in boreal areas, winter presents a 'bottleneck' period for juvenile salmonids and stressed the importance of using winter habitat curves when habitat-hydraulic models are applied to areas with severe winter conditions.

Heggenes et. al. (1999) considered water depth as the most important habitat variable for brown trout. In an earlier work they illustrated that brown trout have a strong preference for slow water velocities, a trait they believed brown trout used to maximize energy-intake using a sit-and-wait strategy of feeding on drifting insects (Heggenes et al. 1995). Brown trout generally seek deeper water associated with cover as they grow (Blades and Vincent 1969; Heggenes 1988; Kocik and Taylor 1996). Hayes and Jowett (1994) found that brown trout in three New Zealand rivers preferred water that was 100 cm deep (67 - 86 cm was most commonly used) and optimal focal point water velocities (19 - 28 cm/s) were lower than mean velocities. They found that depth and mean velocity consistently explained habitat selection (accounting for 33 - 85% of deviances in a logistic regression model). Shirvell and Dungey (1983) found that adult brown trout (mean fork length of 42 cm) preferred a mean depth of 65 cm and mean velocity of 26.7 cm/sec at feeding locations within six diverse New Zealand rivers. They also found no significant differences in these preferences between rivers. Näslund et al. (1998) reported that adult brown trout grew and survived better in pool habitats than in riffle habitats of Swedish streams. Lewis (1969) found that cover was the most important variable that affected densities of brown trout and populations of brown trout were most stable in deep-slow pool habitats with extensive cover. Quinn and Kwak (2000) found that both brown and rainbow trout occupied the deepest habitats available in the White River, Arkansas below Beaver Dam.

Lewis (1969) found that surface area, water volume, depth, current velocity, and cover accounted for 70 to 78% of the variation in numbers of rainbow and brown trout over 175 mm in Little Prickly Pear Creek, Montana. Newman and Waters (1989) found that trout densities and standing stocks differed significantly among eight continuous sampling sections along South Branch Creek, a limestone stream in southeastern Minnesota. These differences were relatively consistent between 3 years of study and were regulated by habitat differences between sections. Jutila et al. (1999) investigated the influence of environmental factors on the density and biomass of stocked brown trout in a stream in western Finland. Multivariate regression analysis showed that 69% of the variation in the population density of brown trout juveniles was determined by five variables: 1) mean water depth, 2) abundance of pools, 3) stony bottom substrates ranging in size from 2 - 10 cm in diameter, 4) undercut banks and 5) percentage of shading by trees. Correspondingly, 57% of the variation in biomass was determined by 3 variables: 1) mean water depth; 2) abundance of pools and 3) benthic vegetation. Conversely, Beard and Carline (1991) did not find any correlation between brown trout densities and depth, pool area, cover, or substrate in a limestone spring creek of Pennsylvania, but did find a strong correlation with redd (spawning site) density. They concluded that juvenile brown trout did not disperse widely from natal areas and that local population density was a function of spawning habitat availability.

Cunjak and Power (1986) described winter habitat use of brook and brown trout in an Ontario River and found that age 1 and older brown trout occupied deeper water during the winter than during the summer with mean focal point depths at two different sites of 43 and 59 cm during the summer and 53 and 76 cm during the winter. Cunjak and Power also found that brown trout generally preferred deeper water than brook trout and that both species preferred positions beneath cover. They also found that brown and brook trout aggregated beneath cover in the winter, but saw no evidence of gregarious behavior during the summer.

Habitat preferences may change diurnally as well as seasonally. Clapp et al. (1990) found that large (> 400 mm) radio-tagged brown trout in a Michigan stream typically selected deep (> 30 cm), slow (< 10 cm/s) water habitats that had heavy log cover during daytime hours. Summer daytime feeding habitat of brown trout is characterized by a narrow selection of slow snout water velocities (Heggenes et al. 1999). In winter, Heggenes et al. (1999) found a diurnal pattern in behavior. Brown trout sought out shelter within interstitial spaces in the substrate during the daylight, but during night held positions on or close to the substrate in slower flowing stream areas. Coarse substrate providing cover was deemed an important habitat factor during daylight at low water temperatures, while slow flowing water was important during night (Heggenes and Dokk 2001). Hubert et al. (1994) investigated diurnal shifts in habitat use by age 0 brown trout during June and July in a low gradient, Wyoming stream. They reported that young brown trout were found predominately in locations with slow water velocities in stream margins and backwater pool habitat. They observed them in slower water, closer to the stream edge at night than during the day.

Rainbow trout have also been shown to change their use of habitat, using deeper and faster water, as they grow (Baltz et al. 1991). Baltz et al. (1991) also showed that rainbow trout used different microhabitats during different seasons throughout the year. Lewis (1969) suggested that current velocity was the most important variable influencing rainbow trout in Little Prickly Pear Creek, Montana. Li et al. (1994) found that biomass of rainbow trout was negatively correlated with solar radiation and positively correlated with stream discharge and water depth in streams of the John Day basin in Oregon.

Movement of Brown Trout

While studying brown trout in the southern Appalachian Chattanooga River, Burnnell et al (1998) found that 268 to 446 mm fish moved up to 0.08 km during a twenty-four hour period, with the largest brown trout (>375 mm) having the widest diel ranges. During fish movement studies on a Michigan stream, Clapp et al (1990) found that large brown trout (> 400 mm) used as many as four specific home sites during the spring-summer period and the average distance between these home sites was 0.39 km. Of the 20 brown trout longer than 375 mm that were tagged and recaptured in the MGORD, 17 or 85% were recaptured within 0.34 km of their spring tagging sites. This suggests that the majority of large brown trout in the MGORD probably occupied their same specific home sites between March and September. However, this tagging effort was not designed to investigate movements of fish between microhabitat units within the MGORD. Rather, it was done to preliminarily evaluate whether trout were moving between the MGORD and main Rush Creek, and to gather some preliminary growth rate information.

Movement of brown trout from Rush Creek into the MGORD was clearly documented. Six 202 to 406 mm browns tagged in Rush Creek moved 1.58 to 4.07 km upstream into the MGORD between March and September 2001, and five of these migratory fish weighed more than 340 g. Since only ten fish that were tagged in Rush Creek upstream of the Highway 395 bridge weighed more than 340 g, 50% of the largest brown trout tagged in the upper six kilometers of Rush Creek in March were recaptured in the MGORD during September. It is not unusual for stream-dwelling brown trout to seasonally move more than 15 kilometers, the approximate distance between the MGORD and Mono Lake. Meyers et al (1992) found that large brown trout (>400 mm) in a Wisconsin stream system moved between 8 and 20 km in the spring and fall. Clapp et al (1990) noted seasonal movements of up to 33 km by large brown trout.

Five of the six trout that were both tagged and recaptured in main Rush Creek were recaptured in the same locations as they had been tagged. The fish that we documented as moving was a 218 mm rainbow trout that moved 0.65 km upstream. The low recapture rate (4%) for trout tagged in Rush Creek downstream of the MGORD can be partially explained by the fact that only about one-third of the stream.sections where fish were tagged were re-sampled during September. This low recapture rate could also suggest that greater movement and/or higher mortality rates occurred in the brown trout populations in main Rush Creek, compared to the MGORD.

Our preliminary tagging/movement surveys stress the need to enhance or maintain fish passage or connectivity throughout the Rush Creek and Lee Vining drainages, at least below existing LADWP dams. To maintain connectivity road crossings and other human structures should not impede the upstream or downstream movement of fish.

Preliminary growth information (g/wk) from tagged fish also provided some useful insights. For example, growth rates for brown trout in the County Road section appeared to be noticeably less than for similar-sized browns in the upper Rush section and the MGORD. These results are very preliminary, however, since only two brown trout, or 4.3% of the fish that were tagged, were recaptured in this section. Our preliminary data also indicated that many brown trout weighing more than one pound, as well as all brown trout weighing more than two pounds, lost weight during the spring and summer of 2001. This finding could help refine long-term termination criteria for Rush Creek, particularly regarding the maximum weight of brown trout that the stream can be expected to consistently produce.

Methods Evaluation

The 1999 Fisheries Monitoring Report for Rush, Lee Vining, Parker and Walker creeks recommended changes to the fish population estimation methods described in the White book prepared by the Los Angeles Department of Water and Power (LADWP, 1997). These changes included conducting mark-recapture electrofishing estimates in all three sections in Rush Creek and the two main channel sample sections in Lee Vining Creek. Due to the large size of Rush Creek it was also recommended that a larger generator and electrofishing unit be used to increase sampling efficiencies.

All of the recommended methods changes were implemented in 2000 and 2001. We believe that these new methods improved our ability to estimate populations, and we believe that increasing our efforts to maintain block nets in 2001 was effective at preventing fish movement into or out of our sample sections between mark and recapture events.

Spring Use of the MGORD and Rush Creek

Last year (Hunter et al. 2001) we hypothesized that thick beds of elodea in the Rush MGORD would die during the winter, forcing most of the larger brown trout to migrate out of this MGORD to seek cover in the main creek. Our sampling in March 2001 found the elodea did not experience a die-off during the winter of 2000-2001 and densities of trout in this MGORD were high in March 2001. Since air temperature data indicates that the winter of 2000-2001 was near normal, or colder than normal (Figure 15), we suspect that conditions in the MGROD that we observed in March 2001 were typical of early spring conditions.

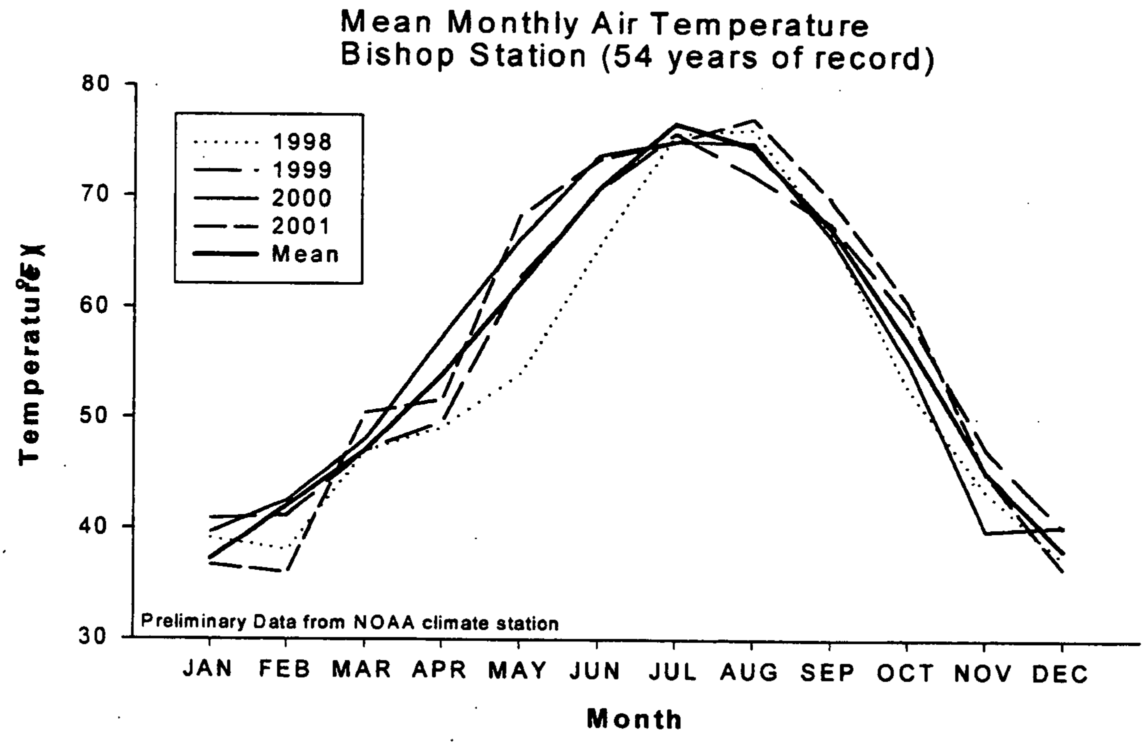

Figure 15. Mean monthly air temperatures (°F) and means for the 54-year period of record at Bishop, California from preliminary NOAA climate data (http://www.wrcc.dri.edu/summary/climsmnca.html).

We also conducted reconnaissance level electrofishing sampling of much of Rush Creek to determine relative abundance of the young-of-the-year following the winter. We hypothesized that harsh winter conditions might lead to relatively low survival of age 0 brown trout. While we don't advocate comparing relative catches of age 0 brown trout between Fall 2000 and March 2001 due to differences in capture efficiencies, we believe that comparing the proportion of age 0 to total catch of brown trout in the first pass will provide some insight. We found that age 0 brown trout made up over 15% of catch in the MGORD in September 2000, but made up only slightly over 1% in March 2001. Age 0 brown trout made up about 80% of the catch in Upper Rush in September 2000, but only 64% in March 2001, and made up about 65% in the County Road area in September 2000, but only about 53% in March 2001. While these proportions suggest some declines, these were not dramatic declines and suggest lower winter mortality than observed in other studies (Maciolek and Needham 1951; Hunt 1969; Whitworth and Strange 1983; Smith and Griffith 1994; Meyer and Griffith 1997; Solazzi et al. 2000). It was interesting to see the more dramatic decline in the MGORD, where very high densities of large brown trout may be preying on smaller trout.

Test Station Road Culvert Fish Passage

Although FishXing predicted that the Test Station Road pipe-arch culvert was passable to migrating adult brown trout at about 63% of the tested flows, the downstream apron of this culvert most likely prevents fish from successfully moving upstream into the culvert at any flow. Water depths at varying flows were difficult to model over the concrete apron because of its unconfined nature. Modeled velocities for the 15-foot length of the apron also failed to account for water acceleration as flows exited the pipe-arch onto the concrete apron, thus velocities over the apron were most likely underestimated. For example, at a discharge of 37 cfs, FishXing predicted average velocities ranging from 4.50 ft/s to 5.63 ft/s – depending on location along the apron. On November 11, 2000 employees of McBain and Trush measured velocities on the apron with a Price AA meter at 6/10ths depths while Rush Creek was flowing at 37 cfs. Velocities of 11.5, 12.1, 12.2, 12.2 ft/s were measured at four locations equally distributed across the width of the apron. The average velocity was 12.0 feet per second. Depths and velocities were fairly uniform across the entire width of the apron.

Tag return data during 2001 did not document any upstream movement of trout from below to above this culvert, since none of the 62 fish tagged downstream of Test Station Road in March were recaptured in September within the County Road sampling reach (located immediately upstream of Test Station Road). In many watersheds, numerous crossings often exist which cumulatively prevent fish from freely migrating to and from preferred (and often critical) rearing, foraging, and spawning habitats. Recent research regarding watershed restoration considers the identification, prioritization, and treatment of migration barriers to restore ecological connectivity for salmonids a vital step towards recovering depressed populations (Roni et al. 2002).

Data collected by McBain and Trush during July and August of 1999 documented maximum water temperatures in lower Rush Creek below the Test Station Road that regularly exceeded 69 to 70° F. While the assessment for this culvert identified it as a likely barrier to upstream movements by brown trout, we are unsure what the implications of this barrier are to the brown trout population in Rush Creek. The relatively high water temperatures recorded in lower Rush Creek could lead to slower growth by trout in this portion of the stream. We recommend continued assessment of the potential consequences of this fish barrier on brown trout in Rush Creek.

Termination Criteria

The agreed upon termination criterion for Lee Vining Creek is to sustain a fishery for brown trout that average 8-10 inches in length with some trout reaching 13 to 15 inches. For trout 200 mm (~ 8 inches) and longer, we estimated that the Lower Main Channel of Lee Vining Creek supported 15 brown and less than 12 rainbow trout (14 trout/100 m of channel); the Upper Main Channel supported an estimated 38 brown and 38 rainbow trout (23 trout/100 m); the Lower Side Channel supported 16 brown and 23 rainbow trout (15 trout/100 m); and the Upper Side Channel supported 7 brown and 31 rainbow trout (19 trout/100 m) during 2001. We captured only five trout that exceeded 330 mm (~13 inches) during 2001 sampling of Lee Vining Creek. One 389 mm rainbow trout was captured in the Upper Side (A-4) Channel, one 489 mm rainbow and two larger brown trout (335 and 344 mm) were captured in the Upper Main Channel, and one 343 mm rainbow trout was captured in the Lower Main Channel. None of these larger rainbow trout were identified as being of hatchery origin, based on observed fin erosion. We do not believe these results indicate that the stream is meeting the termination criterion.

The agreed upon termination criterion for Rush Creek states that Rush Creek fairly consistently produced brown trout weighing 0.75 to 2 pounds. Trout averaging 13 to 14 inches (330 to 355 mm) were also allegedly observed on a regular basis prior to the dewatering of this stream. We captured two brown trout in main Rush Creek during 2001 that met this criterion, a 338 mm brown trout captured in the County Road Section and a 358 mm brown that was captured in the Upper Section. However, 235 trout exceeding 330 mm (4 rainbow and 231 browns), of which 177 were longer than 355 mm (4 rainbow and 173 browns), were collected in the MGORD during September 2001 (Figure 2).

Recommended Termination Criteria

Our 2000 report noted that there is virtually no data available that provides an accurate picture of the trout populations that these streams supported on a self-sustaining basis prior to 1941 (Hunter et al. 2000). We recommended that additional fish population data be collected from these streams for several years until we have a suitable amount of data upon which to base additional quantitative termination criteria (Hunter et al. 2000 and 2001). This continues to be our recommendation. We also believe that obtaining at least six, and preferably ten, years of continuous fish abundance information will allow us to assess potential relationships between fish populations and physical habitat components, such as flows, physical habitat parameters, and water temperatures.

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We would like to thank Los Angeles Water Power for their continued support of this project, especially Steve McBain and Dave Martin. Dave Martin of LADWP has provided technical support and field help. Kelly Cashman, Kevin Peterson, Gary Hoopen, Helen Stroud, and numerous others assisted with fish sampling efforts. The owners and staff of the Latte Da and Mobile Station in Lee Vining, and June Lake Resort at June Lake have consistently provided good lodging, good food, and good conversation. The Mono Lake Committee assisted with copying field data sheets. McBain and Trush Consultants provided maps, water temperature information, and completed physical surveys of sample sites. Darren Mierau of McBain and Trush assisted with fieldwork and logistic support during 1999 and 2000.

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Appendix A
Tag Return Information

Appendix A-1. Tag return information for brown trout that weighed less than 450 g at time of tagging showing tag number (Tag No.), tagging and recapture location, distance moved (km), weight and length at time of tagging and recapture and net change in weight and length, and estimated growth per week in grams and millimeters. Tag numbers 239 and 343 were put in rainbow trout. Locations move from the MGORD downstream into main Rush Creek in a downstream direction (Ab Upper = Above Upper Rush Section and below the MGORD; Upper = Upper Rush Section; Bl Upper = Immediately below Upper Rush Section to Highway 395; Ab Co Road = Below Highway 395; and Co Road = Above County Road).

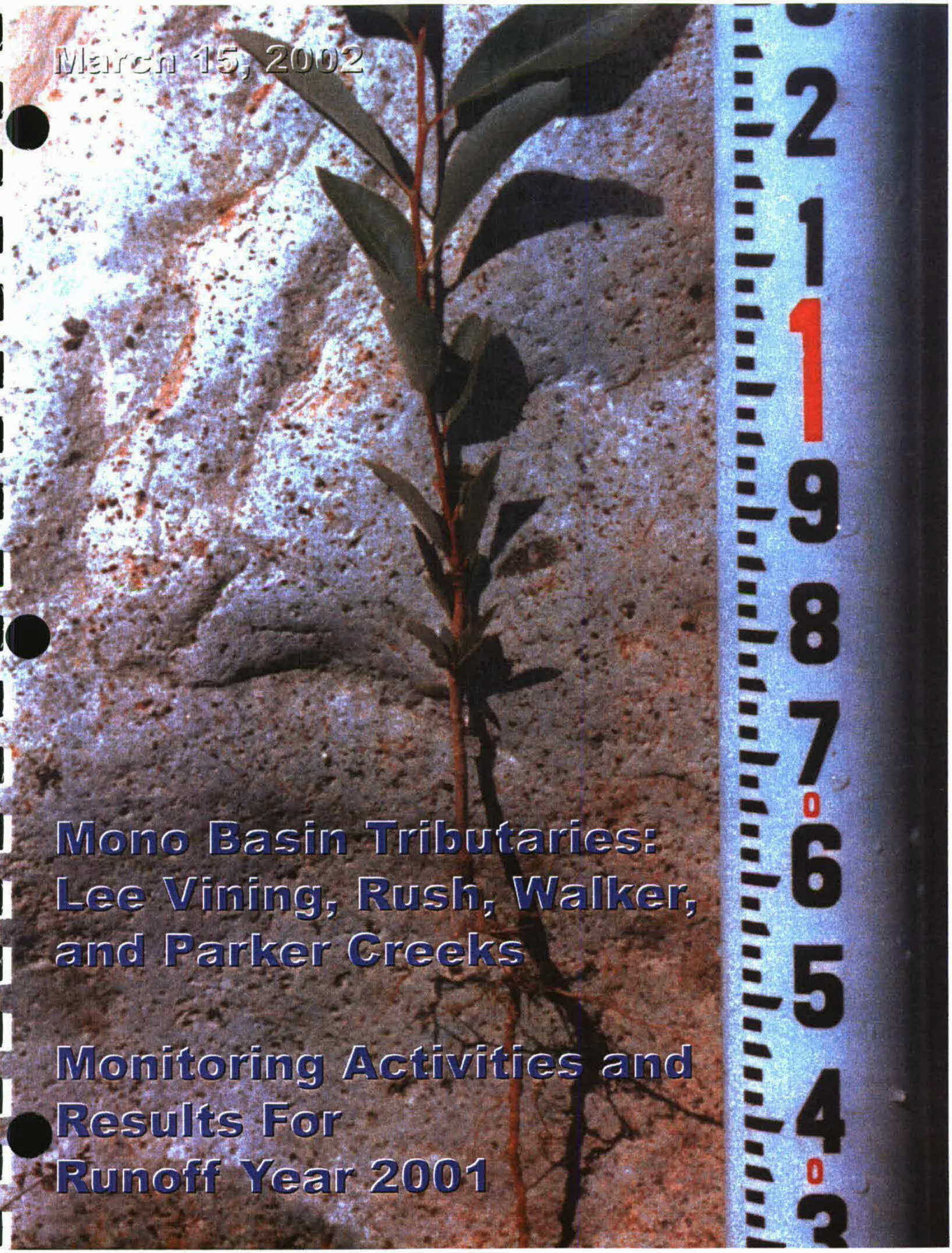
Tag	Location		Dist. (km)	Weight (gr)			Growth	Length (mm)			Growth
No.	March	Sept	Moved	March	Sept	Change	(g/wk)	March	Sept	Change	(mm/wk)
440	MGORD	MGORD	-0.16	85	165	80	3.2	206	257	51	2.0
511	MGORD	MGORD	-0.18	85	145	60	2.4	197	245	48	1.9
439	MGORD	MGORD	-0.02	85	141	56	2.2	209	237	28	1.1
442	MGORD	MGORD	-0.16	86	119	33	1.3	202	234	32	1.3
426	**Ab. Upper**	MGORD	1.58	89	143	54	2.1	222	252	30	1.2
588	MGORD	MGORD	0.08	103	176	73	2.9	230	262	32	1.3
408	MGORD	MGORD	-0.27	116	192	76	3.0	231	273	46	1.8
558	MGORD	MGORD	-0.13	122	177	55	2.2	227	251	24	1.0
576	MGORD	MGORD	-0.34	150	208	58	2.3	249	276	27	1.1
563	MGORD	MGORD	0.01	151	248	97	3.8	257	282	25	1.0
586	MGORD	MGORD	0.50	158	233	75	3.0	263	297	34	1.3
566	MGORD	MGORD	-0.27	206	263	57	2.3	297	305	8	0.3
410	MGORD	MGORD	-0.27	211	261	50	2.0	282	281	-1	0.0
419	MGORD	MGORD	0.08	279	320	41	1.6	321	325	4	0.2
493	MGORD	MGORD	0.10	285	345	60	2.4	313	336	23	0.9
522	MGORD	MGORD	-0.20	285	402	117	4.6	331	345	14	0.6
548	**Ab. Upper**	MGORD	2.04	304	355	51	2.0	335	342	7	0.3
577	MGORD	MGORD	0.08	305	327	22	0.9	311	309	-2	-0.1
430	MGORD	MGORD	-0.16	316	339	23	1.0	331	346	15	0.6
584	MGORD	MGORD	-0.20	317	422	105	4.2	345	350	5	0.2
308	**Bl. Upper**	MGORD	4.07	322	331	9	0.4	358	361	3	0.1
574	MGORD	MGORD	-0.34	325	434	109	4.3	342	342	0	0.0
420	MGORD	MGORD	0.08	400	447	47	1.9	355	360	5	0.2
521	MGORD	MGORD	-0.20	406	448	42	1.7	358	364	6	0.2
550	**Ab. Upper**	MGORD	2.74	438	409	-29	-1.1	376	377	1	0.0
327	Upper	Upper	0.00	45	121	76	3.0	172	229	57	2.3
[redacted]	Upper	Upper	0.00	52	108	56	2.2	183	224	41	1.6
262	Co. Road	Co. Road	0.00	63	94	31	1.2	184	214	30	1.2
257	Co. Road	Co. Road	0.00	77	100	23	0.9	208	224	16	0.6
[redacted]	**Ab. Co. Road**	Lower	0.65	100	165	65	2.6	218	258	40	1.6
344	Upper	Upper	0.00	216	277	61	2.4	284	307	23	0.9

Appendix A-2. Tag return information for brown trout that weighed 450 to 900 g at time of tagging showing tag number (Tag No.), tagging and recapture location, distance moved (km), weight and length at time of tagging and recapture and net change in weight and length, and estimated growth per week in grams and millimeters. Locations move from the MGORD downstream into main Rush Creek in a downstream direction (Ab Upper = Above Upper Rush Section and below the MGORD and Upper = Upper Rush Section).

Tag	Location		Dist. (km)	Weight (gr)			Growth	Length (mm)			Growth
No.	March	Sept	Moved	March	Sept	Change	(g/wk)	March	Sept	Change	(mm/wk)
561	MGORD	MGORD	-0.27	468	449	-19	-0.8	392	379	-13	-0.5
552	MGORD	MGORD	-0.27	479	538	59	2.3	387	387	0	0.0
415	MGORD	MGORD	-0.06	524	587	63	2.5	394	387	-7	-0.2
471	MGORD	MGORD	-0.20	527	558	31	1.3	401	403	2	0.1
339	Upper	MGORD	3.30	557	539	-18	-0.7	402	404	2	0.1
538	Ab. Upper	MGORD	1.58	579	599	20	0.8	406	408	2	0.1
431	MGORD	MGORD	-0.16	625	598	-27	-1.1	398	408	10	0.4
580	MGORD	MGORD	0.50	627	671	44	1.7	407	410	3	0.1
523	MGORD	MGORD	-0.34	639	621	-18	-0.7	410	407	-3	-0.1
414	MGORD	MGORD	0.50	696	529	-167	-6.6	424	406	-18	-0.7
560	MGORD	MGORD	-0.27	760	771	11	0.4	431	423	-8	-0.3
518	MGORD	MGORD	-0.34	843	762	-81	-3.2	463	458	-5	-0.2

Appendix A-3. Tag return information for brown trout that weighed more than 900 g at time of tagging showing tag number (Tag No.), tagging and recapture location, distance moved (km), weight and length at time of tagging and recapture and net change in weight and length, and estimated growth per week in grams and millimeters.

Tag	Location		Dist. (km)	Weight (gr)			Growth	Length (mm)			Growth
No.	March	Sept	Moved	March	Sept	Change	(g/wk)	March	Sept	Change	(mm/wk)
595	MGORD	MGORD	1.11	1002	935	-67	-2.6	475	463	-12	-0.5
445	MGORD	MGORD	-0.02	1016	861	-155	-6.1	462	453	-9	-0.4
444	MGORD	MGORD	-0.02	1185	1015	-170	-6.7	503	503	0	0.0
551	MGORD	MGORD	-0.27	1217	1165	-52	-2.1	487	472	-15	-0.6
594	MGORD	MGORD	0.13	1273	1105	-168	-6.6	490	486	-4	-0.2
413	MGORD	MGORD	0.27	1278	NM	NC	NC	508	455	-53	-2.1
421	MGORD	MGORD	0.08	1296	1181	-115	-4.6	498	478	-20	-0.8
566	MGORD	MGORD	-0.27	1628	1431	-197	-8.4	561	531	-30	-1.2
520	MGORD	MGORD	-0.34	1630	1335	-295	-11.7	579	587	8	0.3
416	MGORD	MGORD	0.08	>2000	>2000	NC	NC	583	416	-167	-6.6



March 15, 2002

Mono Basin Tributaries: Lee Vining, Rush, Walker, and Parker Creeks

Monitoring Activities and Results For Runoff Year 2001

Mono Basin Tributaries: Lee Vining, Rush, Walker, and Parker Creeks

Monitoring Activities and Results for Runoff Year 2001

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Pursuant to State Water Resource Control Board Decision 1631

March 15, 2002

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1 MONITORING ACTIVITIES AND RESULTS FOR RUNOFF YEAR 2001

1.1 Introduction

This report summarizes the fifth consecutive year of stream monitoring in the Mono Basin for compliance with the SWRCB Orders 98-05 and 98-07. Data collection began in 1997 with selection and establishment of study reaches on Rush and Lee Vining Creeks, and later on Parker and Walker Creeks (Figure 1). Our monitoring has focused on three established monitoring sites on Rush Creek, two sites on Lee Vining Creek, and one site each on Parker and Walker Creeks. In addition to previously established and reported monitoring activities at these sites, our monitoring was expanded considerably in Runoff Year 2001 (RY 2001) (April 1, 2001 to March 31, 2002). Additional work included:

- corridor-wide data collection of riparian vegetation,
- assistance with design and installation of a permanent streamflow gaging station on lower Rush Creek,
- acquisition of historical and contemporary aerial photography sets,
- survey and preliminary design of the Rush Creek 3D Floodplain Restoration Project
- presentations of Mono Basin monitoring activities at workshops and conferences.

Our monitoring activities for RY 2001 are presented in a manner similar to the last two runoff seasons, with discussion of the hydrologic year and presentation of data and results of our field monitoring, then followed with more detailed descriptions of other activities and projects. This year we report the status of our bed mobility experiments, describe installation of the gaging station on Lower Rush Creek, present field and analytical methods used in riparian studies, and finally, discuss preliminary designs for three restoration projects to be implemented in RY 2002. These projects include opening the entrance to the 8-Channel in Lower Rush Creek, restoring the 3D Channel floodplain, and implementing a pilot planting project on the right bank floodplain of Rush Creek below the Narrows. We conclude this report with a summary of our proposed monitoring activities for the coming RY 2002 field season.

1.2 Aerial Photography and Orthorectification

For many of the geomorphic and riparian mapping exercises, orthorectified base maps are necessary to accurately digitize and compare results year-to-year. In the past year, we worked on gathering aerial photos sets and supporting topographic and horizontal and vertical control data. The photo sets archived in our offices and their status are summarized in Table 1.

This past year we focused on completing one small-scale aerial photo set that had the most comprehensive topographic and control data. The 1991 aerial photo set used for photogrammetry of Rush, Lee Vining, Walker, and Parker creeks fulfilled these criteria. We recreated the digital terrain model using the 1991 contours and provided these data to Aerial Photomapping Services in Clovis, California who had archived the original aerial photo negatives and control for the photogrammetry. They will be providing a digital set of orthorectified 1991 photos and control data. Using these and other data as a base, we will orthorectify other historic and contemporary aerial photo sets.

Additionally, film diapositives of 1929-30 aerial photos were acquired from the Fairchild Aerial Photo Collection in Whittier, California. These photos have been scanned at high resolution and will be orthorectified. This completed set of photos will allow us to accurately digitize the pre-1941 riparian and channel conditions and to compare with contemporary conditions.

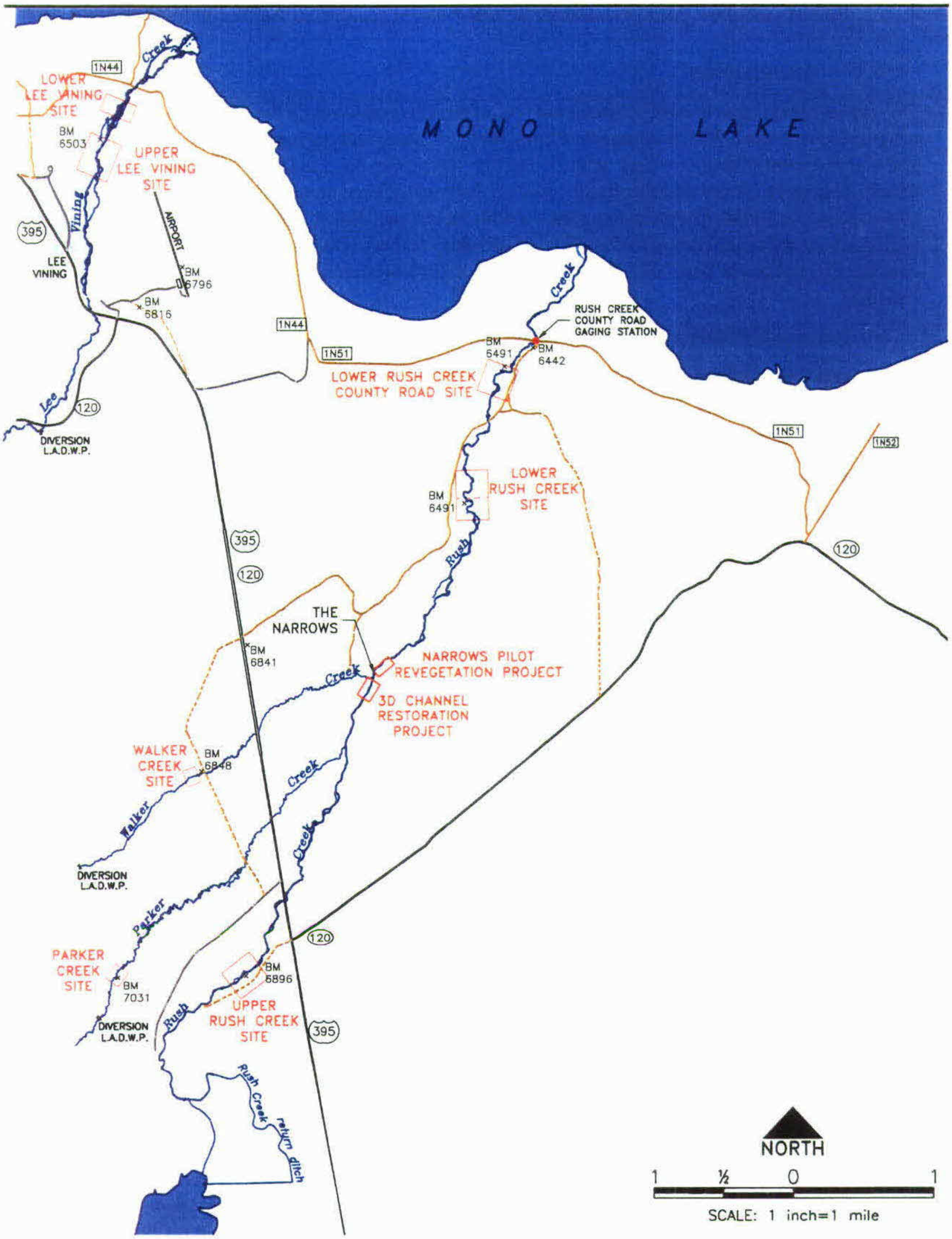


Figure 1. Map of the Mono Basin tributaries and established study sites.

Table 1. Inventory and status of aerial photographs archived at McBain & Trush.

DATE	DESCRIPTION	SOURCE	FORMAT	COLOR	SCALE/ RESOLUTION	GEO-CORRECTED
1929/30*	Rush, Lee Vining, Parker, Walker Creeks	Fairchild Collection	Contact print (film diapositive)	B/W	1 in = 1000 ft	No
			Digital (tif)	B/W	1 ft / pixel	Pending
1954*	SW Mono Basin	Fairchild Collection	Photoindex (film diapositive)	B/W	1 in = 3333 ft	No
1981	Rush Creek	LADWP	Xerox enlargement of contact print	Color	~1 in = 100 ft	No
1987	Rush, Lee Vining Creeks	LADWP	Xerox copy of contact print	Color	1 in = 200 ft	No
1990	Rush, Lee Vining, Parker, Walker Creeks	LADWP	Xerox enlargement of contact print	Color	~1 in = 200 ft	No
			Pending (need complete set of originals)	Color	0.25 ft / pixel	Pending
1992*	Lee Vining 7 ½ minute digital orthophotoquad	USGS	Digital (tif)	B/W	8 ft / pixel	Yes
1991*	Rush, Lee Vining, Parker, Walker Creeks	Aerial Photomapping Services	Contact prints	B/W	1 in = 500 ft	No
			Digital (tif)	B/W	0.25 ft / pixel	Yes
1993/94	Sections of Rush, Lee Vining, Walker Creeks	LADWP	Xerox copy of rubbersheeted mosaic	Color	1 in = 100 ft	Yes
1999	Rush, Lee Vining, Parker, Walker Creeks	I.K. Curtis	Contact prints	Color	1 in = 300 ft	No
			Digital (tif)	Color	Various (to be rescanned at 0.25 ft/pixel)	Study sites only, complete set pending

1.3 Hydrology

Annual Hydrographs

The 2001 Runoff Year was the second consecutive year of below average runoff conditions in the Mono Basin. The snowmelt peak flows occurred earlier in the season than during wetter years. Peak flows generally receded quickly. The annual hydrographs (Figures 2-4) show the runoff patterns for Rush, Lee Vining, Parker, and Walker Creeks. The total unimpaired yield for Rush Creek (Rush Creek Runoff) was 48,700 acre feet (af), of which approximately 38,300 af (79%) was released downstream of Grant Lake to Mono Lake. The total unimpaired yield for Lee Vining Creek was 32,700 af, of which approximately 31,000 af (95%) flowed past Lee Vining Creek Intake to Mono Lake.

Rush Creek unimpaired flows (Rush Creek Runoff) peaked substantially higher than the flows observed in our study sites downstream of Grant Lake; the unimpaired peak discharge was 491 cfs on May 26, 2001. Because of the below average runoff conditions and despite limited flow augmentation from Lee Vining Creek, Grant Lake was unable to spill and the Rush Creek Return Ditch delivered a peak discharge of 162 cfs to the upper Rush Creek reach on June 11, 2001. Lower Rush Creek (below the Narrows) experienced a slightly higher peak discharge of 202 cfs. The 162 and 202 cfs peaks in the upper and lower Rush Creek study reaches were the smallest snowmelt peaks since the 100/133 cfs peak of 1994.

In Lee Vining Creek, spring snowmelt peaked at 201 cfs on May 17, 2001. The same peak was recorded above and below the Intake, because no diversions from Lee Vining Creek occurred during the snowmelt peak. Similar to Rush Creek, the Lee Vining Creek peak was the smallest snowmelt flood since the 125 cfs peak of 1994. Parker and Walker Creeks had moderate sized snowmelt peaks of 56 and 42 cfs, respectively, each larger than the prior two years' peak flows. Prior to the Lee Vining Creek snowmelt peak on May 17, 2002, approximately 1,700 af were diverted from Lee Vining Creek to Grant Lake, to increase the possibility of filling Grant Lake and causing a spill.

Peak discharge at the LA DWP gaging stations and at each of our study sites are summarized in Table 2 for WY 1997 to 2002 (corresponding to our contemporary monitoring period).

Synoptic Streamflow gaging

During RY 2001, we continued collecting discharge measurements at several locations within the study sites. The purpose of this "synoptic streamflow gaging" was first to establish the proportion of total flow in the split-channel sections of reaches, then track this flow proportion from year-to-year to determine if a particular channel is capturing a larger or smaller proportion of the total flow. This approach is applied to determine flows in the Lower Rush main channel and 10-Channel in the planmapped reach, as well as in Upper Lee Vining Creek main channel, A-4 and B-1 channels (Table 3). We also surveyed water surface elevations at all cross sections to develop stage-discharge rating curves and hydraulic geometry relationships at each cross section. These data are not presented in this report, but are available on request.

Discharge measurements were routinely collected at the following sites:

- Upper Rush Creek Study Site at XS 1+05
- Lower Rush Creek Study Site at the 10-Channel piezometer station;
- Lower Rush Creek Study Site at XS –9+82
- Lower Rush Creek Study Site in the 10-Return Channel (only occasionally);
- Rush Creek County Road Culvert, approximately 300 ft downstream of the culvert;
- Upper Lee Vining Study Site Main Channel at XS 3+45

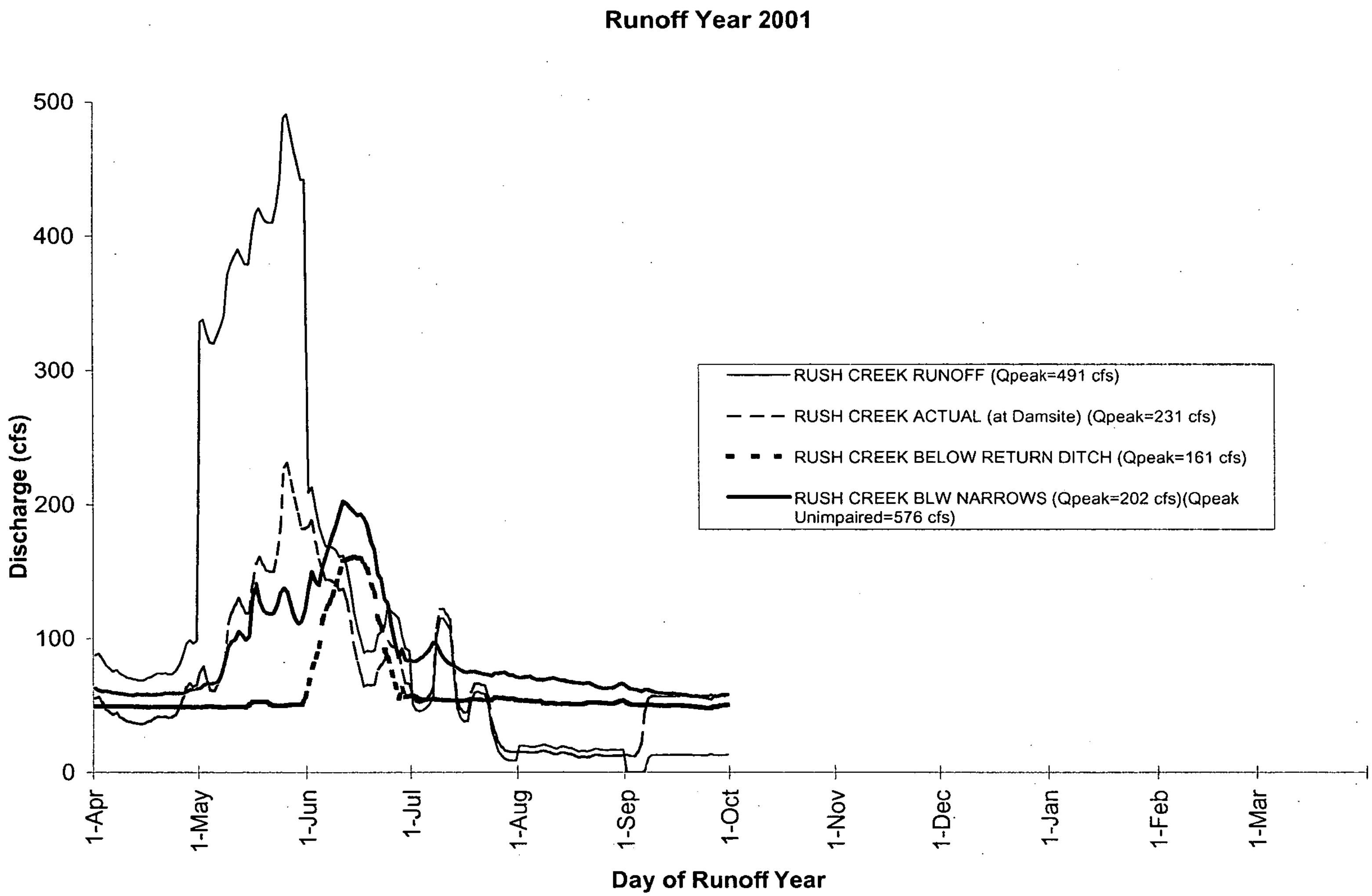


Figure 2. Rush Creek annual hydrograph for Runoff Year 2001. The unimpaired peak flow of 491 cfs (Rush Creek Runoff) occurred on May 26, 2001. The peak regulated flows of 162 cfs (Rush Creek below Return Ditch) and 202 cfs (below the Narrows), corresponding to our upper and lower Rush Creek study sites, both occurred on June 11, 2001.

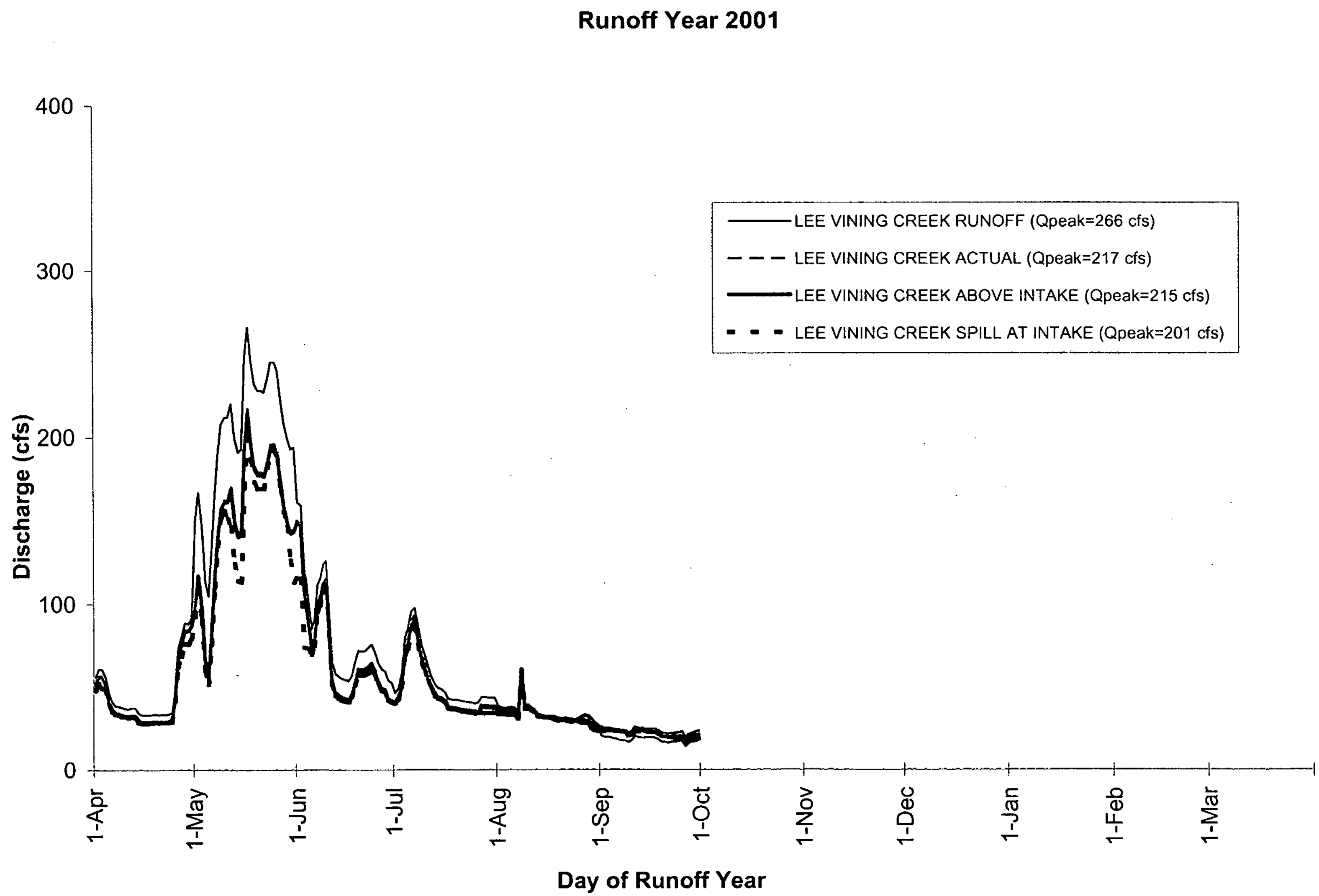


Figure 3. Lee Vining Creek annual hydrograph for Runoff Year 2001. The unimpaired peak flow of 266 cfs (Lee Vining Creek Runoff) occurred on May 17, 2001. The peak regulated flow (Lee Vining Creek spill at Intake) of 201 cfs occurred on the same day, May 17, 2001.

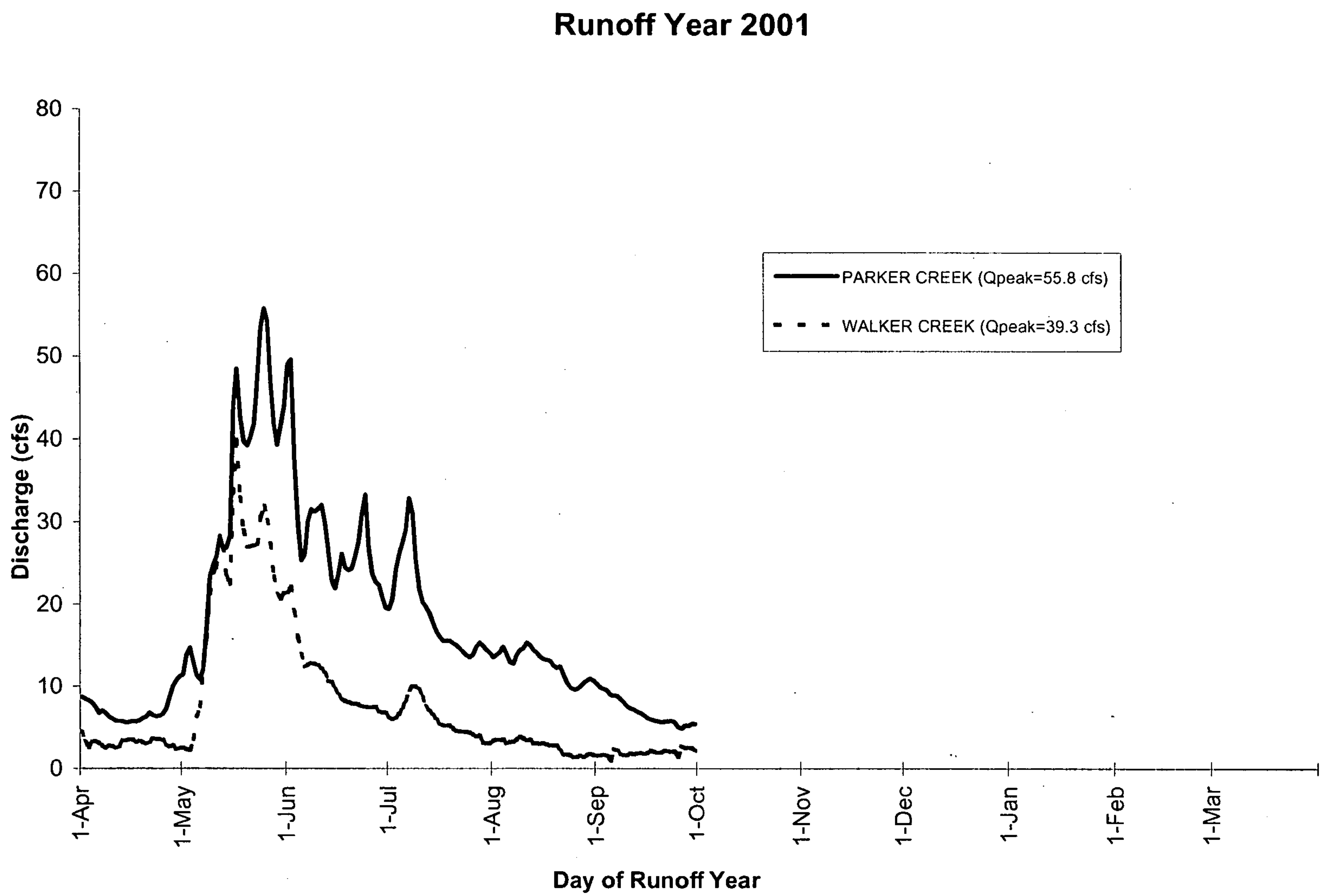


Figure 4. Parker and Walker annual hydrograph for Runoff Year 2001. Unimpaired peak discharges of 56 cfs (Parker) and 42 cfs (Walker) occurred on May 26 and May 16, 2001, respectively.

Table 2. Summary of peak flow discharges for Rush, Lee Vining, Parker, and Walker Creeks for gaged and ungaged sites (synthesized by addition of gaged sites) reported by LA DWP, and the corresponding peak flow in primary and secondary channels within our established study sites. Peak flows for stations bracketed [ ] were obtained from the linear regression relationships developed from our synoptic streamflow gaging, and are not necessarily measured flow peaks.

Station	1997 Peak Daily Average (Instantaneous) [4]	Peak Date	1998 Peak Daily Average (Instantaneous)	Peak Date	1999 Peak Daily Average (Instantaneous)	Peak Date	2000 Peak Daily Average (Instantaneous)	Peak Date	2001 Peak Daily Average (Instantaneous)	Peak Date
Rush Creek Runoff [1]	411	31-May-98	601	22-Jul-98	405	30-Jun-99	502	20-Jun-00	491	26-May-01
Rush Creek at Damsite (5013)	211 (216)	31-May-98	495 (519)	22-Jul-98	222 (266)	2-Jul-99	372 (381)	20-Jun-00	231 ( )	26-May-01
Rush Creek blw Return Ditch	175	18-May-98	538	23-Jul-98	201	10-Jul-99	204	30-Jun-00	162	11-Jun-01
Rush Creek blw Narrows (unimpaired) [2]	467	1-Jun-98	718	22-Jul-98	463	1-Jul-99	582	20-Jun-00	576	25-May-01
Rush Creek blw Narrows (actual) [3]	233	20-May-98	635	24-Jul-98	247	11-Jul-99	284	1-Jul-00	202	11-Jun-01
[Lower Rush Creek Main Channel in Study Site]	147	20-May-98	396	24-Jul-98	155	11-Jul-99	161 (178)	1-Jul-00	128	11-Jun-01
[Lower Rush Creek 10-Channel]	89	20-May-98	259	24-Jul-98	95	11-Jul-99	99 (111)	1-Jul-00	76	11-Jun-01
Lee Vining Creek above Intake (5008)	378 (404)	31-May-98	419 (451)	9-Jul-98	285 (288)	19-Jul-99	264 (293)	28-May-00	201 ( )	17-May-01
Lee Vining Creek at Intake (5009)	354 (399)	31-May-98	391 (391)	9-Jul-98	274 ( )	19-Jul-99	258 (288)	28-May-00	201 ( )	17-May-01
[Upper Lee Vining Creek Mainstem]	245	31-May-98	270	9-Jul-98	190	19-Jul-99	179	28-May-00	140	17-May-01
[Upper Lee Vining Creek A-4 Channel]	126	31-May-98	140	9-Jul-98	96	19-Jul-99	90	28-May-00	69	17-May-01
[Upper Lee Vining Creek B-1 Channel]	159	31-May-98	176	9-Jul-98	122	19-Jul-99	115	28-May-00	89	17-May-01
[Lower Lee Vining Creek Main Channel]	195	31-May-98	215	9-Jul-98	152	19-Jul-99	143	28-May-00	112	17-May-01
[Lower Lee Vining Creek B-1 Channel]	159	31-May-98	176	9-Jul-98	122	19-Jul-99	115	28-May-00	89	17-May-01
Parker Creek (5003)	48	20-Jun-98	72	9-Jul-98	52	24-Jun-99	49 (52.4)	25-Jun-00	56 ( )	26-May-01
Walker Creek (5002)	34	1-Jun-98	47	21-Jul-98	30	29-May-99	31 (32.3)	28-May-00	42 ( )	16-May-01

[1] Computed natural flows, assuming no flow regulation;
[2] Computed by adding Rush Creek Runoff+Parker+Walker;
[3] Computed by adding RCBRD+Parker+Walker;
[4] Only gauged stations provide instantaneous peak discharges; stations that are calculated provide only the maximum daily average discharge;

Table 3(a). Measured flow proportions in split channels of Rush Creek and Lee Vining Creek study sites.

Date	Rush Creek blw Narrows (cfs)	Main Channel in Study Reach		10 Channel		10-Return Channel	Main Channel at XS -9+82	County Rd Culve
		MEASURED FLOW PROPORTIONS						
	blw Narrows	Q (cfs)	% of total Q	Q (cfs)	% of total Q	Q (cfs)	Q (cfs)	
4-Jun-98	67	42	65%	23	35%	6	**65**	
3-Jul-98	321	198	61%	127	39%	73	**325**	
13-Sep-98	117	100	74%	35	26%	11	**135**	
6-May-99	54	42	80%	10	20%	7	**52**	
4-Jun-99	87	57	76%	18	24%	19	**75**	
27-Jul-99	105	72	63%	41	37%	2	**113**	
7-Oct-99	58	24	54%	21	46%	15	**45**	
14-Jun-00	109	54	60%	36	40%		**90**	
4-Nov-00	49	19	50%	18	50%		**37**	37
10-May-01	97	57	66%	29	34%		**87**	85
3-Jun-01	253.4	70	60%	47	40%		**117**	122
4-Jun-01	229.6	68	60%	45	40%		**113**	97
5-Jun-01	215.2	77	60%	51	40%		**128**	128
6-Jun-01	207.3	78	61%	51	39%	30	**129**	124
7-Jun-01	211.6	83	60%	55	40%		**138**	133

Table 3(b). Measured flow proportions in split channels of Rush Creek and Lee Vining Creek study sites.

		MEASURED FLOW PROPORTIONS						
Date	***Lee Vining Creek at Intake (cfs)***	***Mainstem above B Connector***		***A4 Channel***		***B1 Channel***		***Measured Total***
	Q TOTAL (cfs)	Q (cfs)	% of total Q	Q (cfs)	% of total Q	Q (cfs)	% of total Q	Q TOTAL (cfs)
05-Jun-98	115	76	69%	35	31%	51	46%	**110**
18-Jun-98	274	161	62%	99	38%	126	49%	**260**
11-Sep-98	76	56	68%	26	32%	38	47%	**82**
06-May-99	45	25	79%	7	21%	14	45%	**32**
04-Jun-99	180	142	71%	59	29%	76	38%	**201**
26-Jul-99	64	48	75%	16	25%	29	44%	**65**
08-Oct-99	27	19	73%	7	27%	12	48%	**26**
01-Jun-00	166	127	71%	52	29%	68	38%	**179**
02-Jun-00	170	127	70%	55	30%	72	40%	**182**
11-May-01	151	105	68%	50	32%	66	43%	**155**
22-May-01	169	129	70%	56	30%	76	41%	**185**
07-Jun-01	95	72	72%	28	28%	43	43%	**100**

- Upper Lee Vining Study Site B-Connector channel at the staff plate
- Upper Lee Vining Study Site B-1 Channel at XS 6+08

Discharge data collected during the past four field seasons were plotted with the total "gaged flow" reported by LA DWP to determine a linear relationship between discharge reported at the gaging sites and the proportion of flow in the sub-channels. A linear regression would then allow prediction of the discharge in the split channel sections, and therefore at many of our cross sections and experimental sites within the study reaches. The linear regressions were quite good for all the sites, ranging from r^2 values of 0.94 to 0.98 (Figures 5-8). Peak flows reported in Table 2 at un-gaged study sites were determined using these linear relationships.

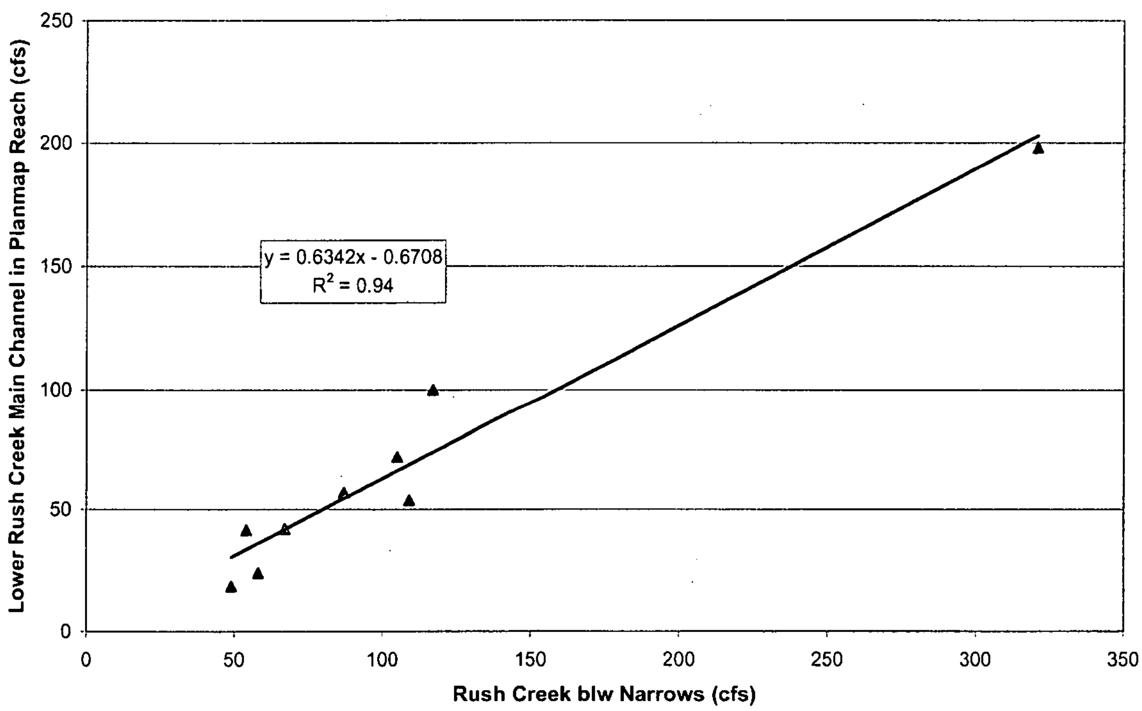


Figure 5. Linear relationship between measured flows in the Lower Rush Creek study site Main Channel (proportion of flow in planmapped reach) and flows reported by LA DWP 'below Narrows'.

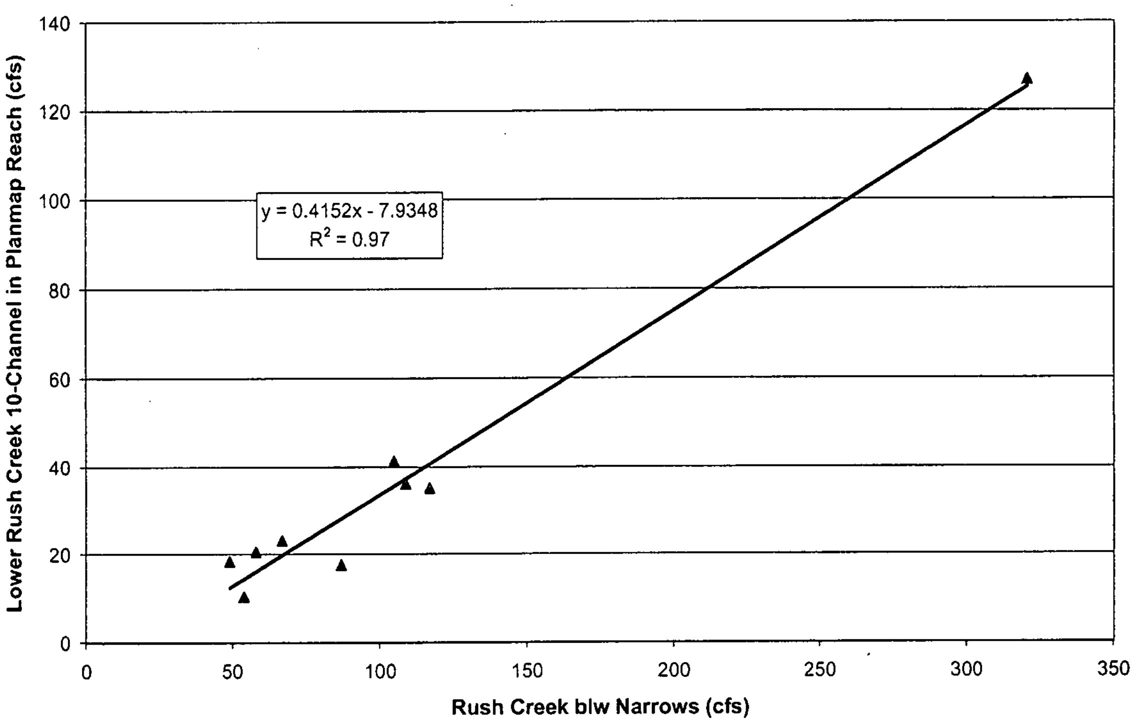


Figure 6. Linear relationship between measured flows in the Lower Rush Creek study site 10-Channel and flows reported by LA DWP 'below Narrows'.

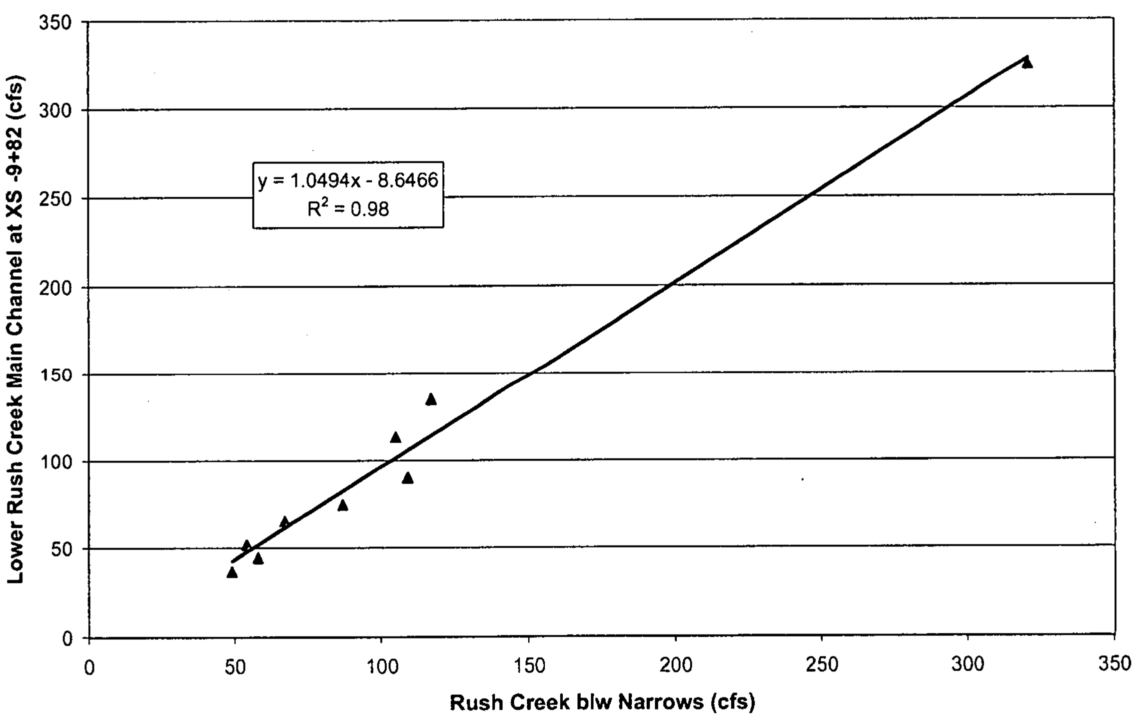


Figure 7. Linear relationship between measured flows in Lower Rush Creek study site at XS –9+82 (total Rush Creek flow) and flow reported by LA DWP 'below Narrows'.

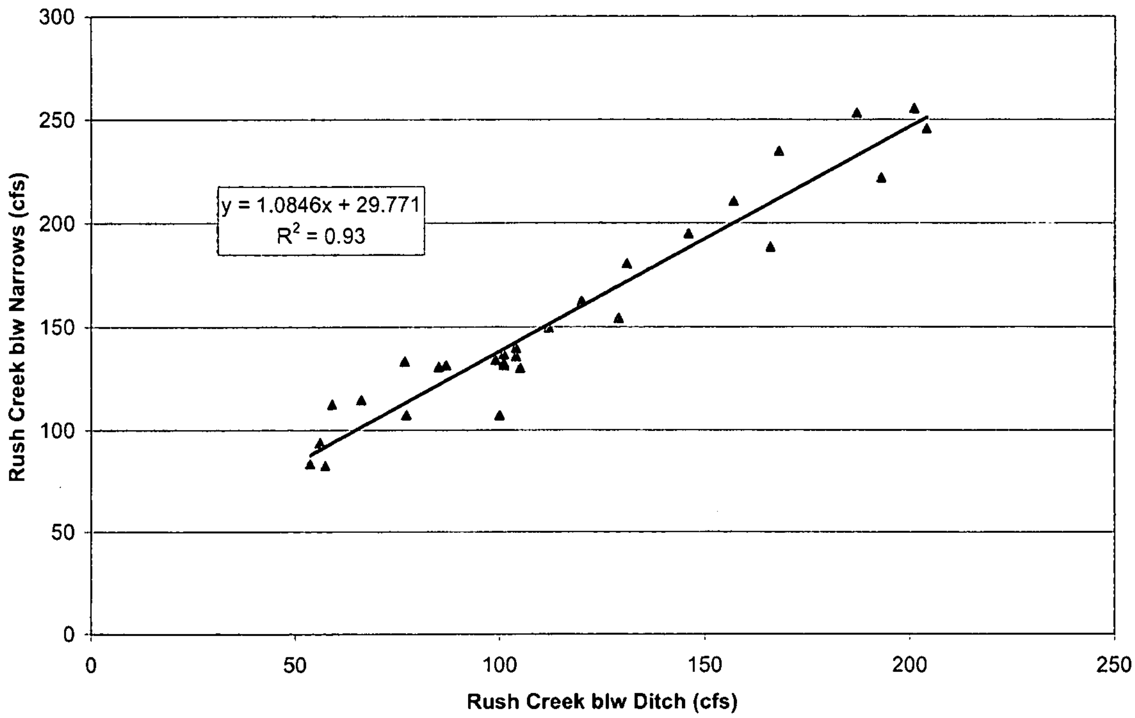


Figure 8. Linear relationship between flows reported by LA DWP for Rush Creek "below Return Ditch' and 'below Narrows'. Only non-base flows were plotted, to allow extrapolations of flood recurrence interval values reported by Hassencamp (1994) to lower Rush Creek sites.

1.4 Cross Section Surveys

Following the RY2001 snowmelt runoff, field crews visited all study sites to evaluate the extent of geomorphic changes resulting from the snowmelt peak. Based on observations at each cross section, nine cross sections were resurveyed (of 44 total cross sections on Rush and Lee Vining Creeks), while other cross sections were not. Because of the low peak flow magnitudes, most surveying was concentrated within the bankfull channel; floodplain and terrace areas were not inundated and thus were not re-surveyed.

Most changes to cross section morphology were relatively minor. At the lower Rush Creek site, main channel XS's 7+25 and 7+70 continued to evolve as the channel migrates laterally into the left bank and rebuilds the right bank point bar. The lower Rush Creek 10-Channel continues to be dynamic, both at the upstream 10-Channel entrance as well as at the entrance to the 10-Return Channel (Figure 9). In the upper Rush Creek site, resurvey of the relatively mobile pool tail XS 1+05 in 2001 (Figure 10), showed the lack of change in the upper Rush Creek reach in response to the peak 162 cfs event. Similar lack of change was observed in the Rush Creek County Road site.

In Lee Vining Creek, three cross sections were resurveyed and showed only subtle changes in cross section morphology. Parker and Walker Creek study sites were not monitored in RY 2001, other than temperature data collection.

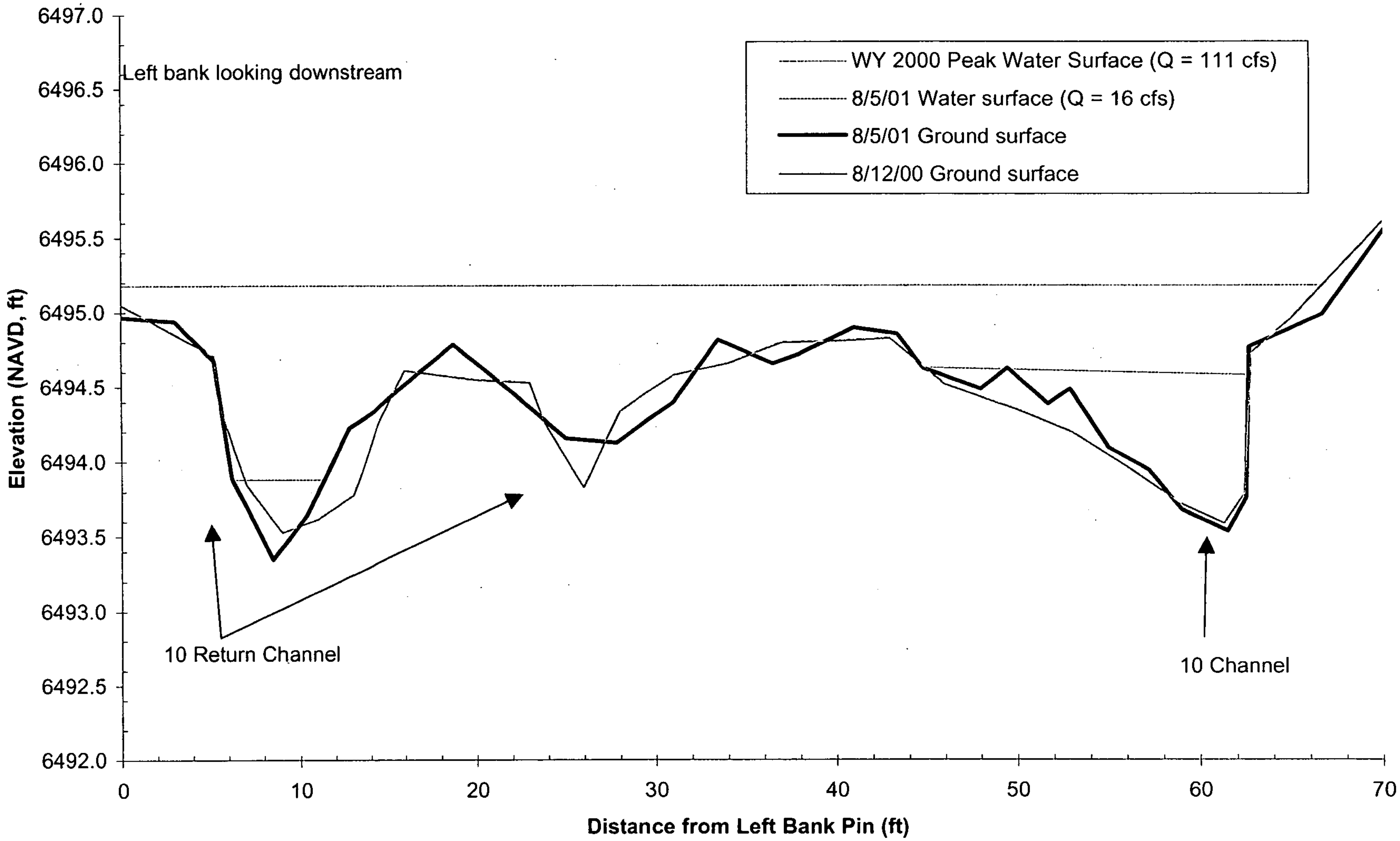


Figure 9. Lower Rush Creek 10-Channel XS 0+50. This cross section traverses the point of flow divergence into the 10-Channel and the 10-Return Channel (that returns back to the main channel in the planmapped reach). This channel location is dynamic and critically important, as it determines the volume of flow in the main channel of the planmapped reach.

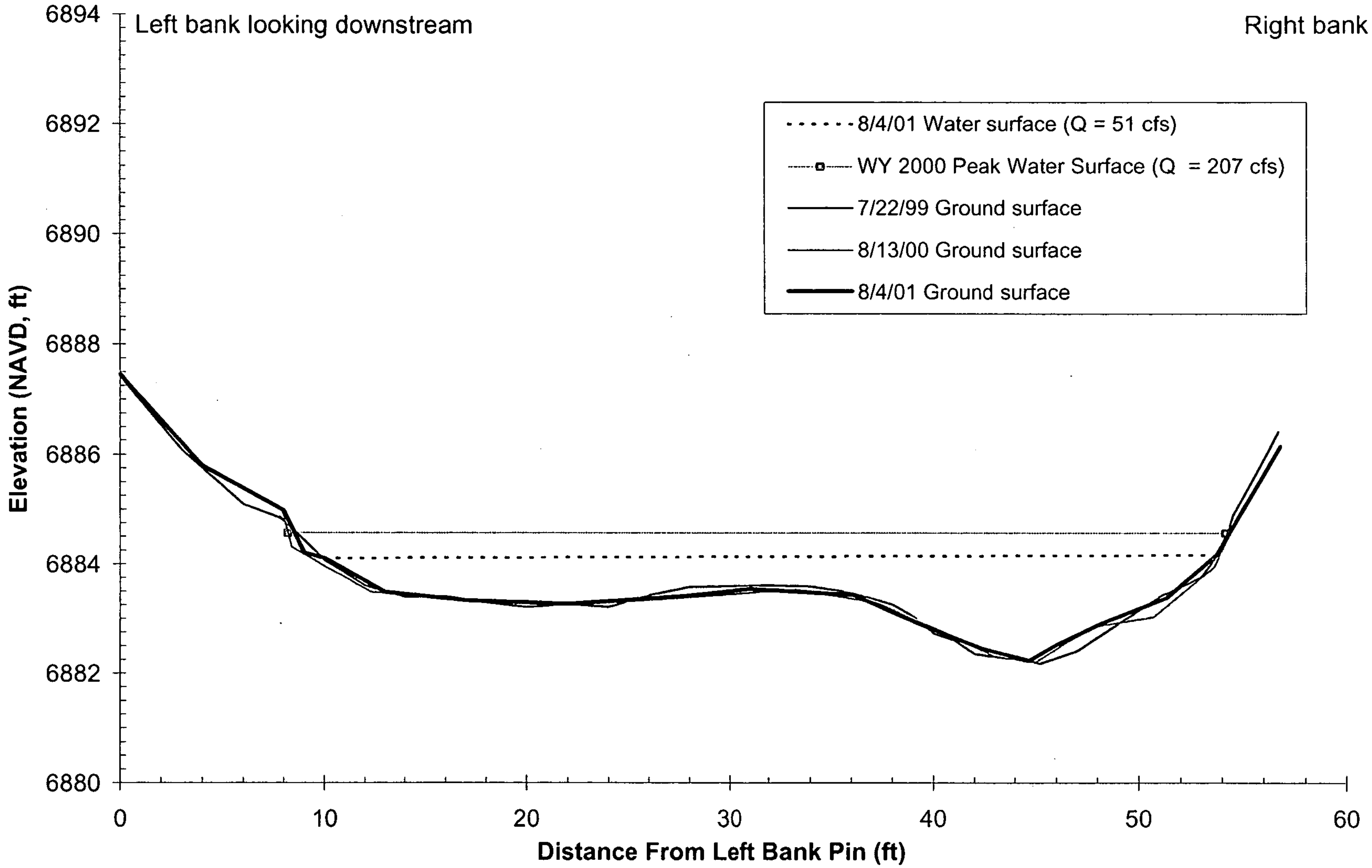


Figure 10. Upper Rush Creek XS 1+05. This cross section traverses the pool tail at the lower end of our study reach, below the constructed root-wad pool. Very little geomorphic activity occurred in this reach in RY 2001 as a result of the 162 cfs peak flow.

1.5 Longitudinal Profile Surveys

No additional longitudinal profiles were surveyed in RY 2001, due to the low runoff conditions and lack of significant channel changes. The White Book: List of Monitoring Activities and Data Gathering Protocols recommends surveying thalweg/width profiles during each year with normal year or greater peak flows. This condition was not achieved in RY 2001.

1.6 Planmapping

No additional planmapping occurred in our study sites in RY 2001. The White Book: List of Monitoring Activities and Data Gathering Protocols recommends planmapping every five years, or during the first wet year since the last survey. Depending on late-winter/spring precipitation conditions, planmapping may be repeated in the 2002 field season, to update termination criteria.

The upper Lee Vining Creek Main/A4 channel split was mapped in RY 2001 using Total-Station survey equipment (Figure 11). The purpose of this survey was to establish baseline topography for later comparisons of channel changes in this critical area that controls the proportion of flow into the upper Lee Vining Main and A-4 Channels.

1.7 Water Temperature Monitoring

We continued collecting water temperature data during RY 2001 at all six sites previously reported, which are:

- Rush Creek in the Return Ditch
- Rush Creek at the Narrows
- Rush Creek at County Road
- Lee Vining Creek in the Upper B-1 Channel
- Parker Creek at Study Site
- Walker Creek at Study Site

Hourly temperature data were compiled from October 1999 to present for these six sites. Data are not presented here, but are available upon request.

2 BED MOBILITY AND SCOUR EXPERIMENTS

As described in our WY 1999 monitoring report, *tracer* rocks are used to empirically document channel bed surface mobility on different alluvial features (e.g., riffles, point bars, pool tails, etc.). Although channel bed surface mobility can be modeled in hydraulically simple reaches (see "Channelbed Mobility" discussion in McBain and Trush, 2000), documenting bed surface mobility thresholds with empirical data allows us to directly measure incipient motion conditions in a range of hydraulic settings. The goal of our tracer rock experiments is to document bed surface mobility resulting from a broad range of high flow events so that our results bracket the range of peak flows that generates incipient mobility of each size class of tracer rock and type of alluvial feature. Theoretically, enough monitoring events will provide sufficient data points to capture this flow range, as illustrated conceptually in Figure 12.

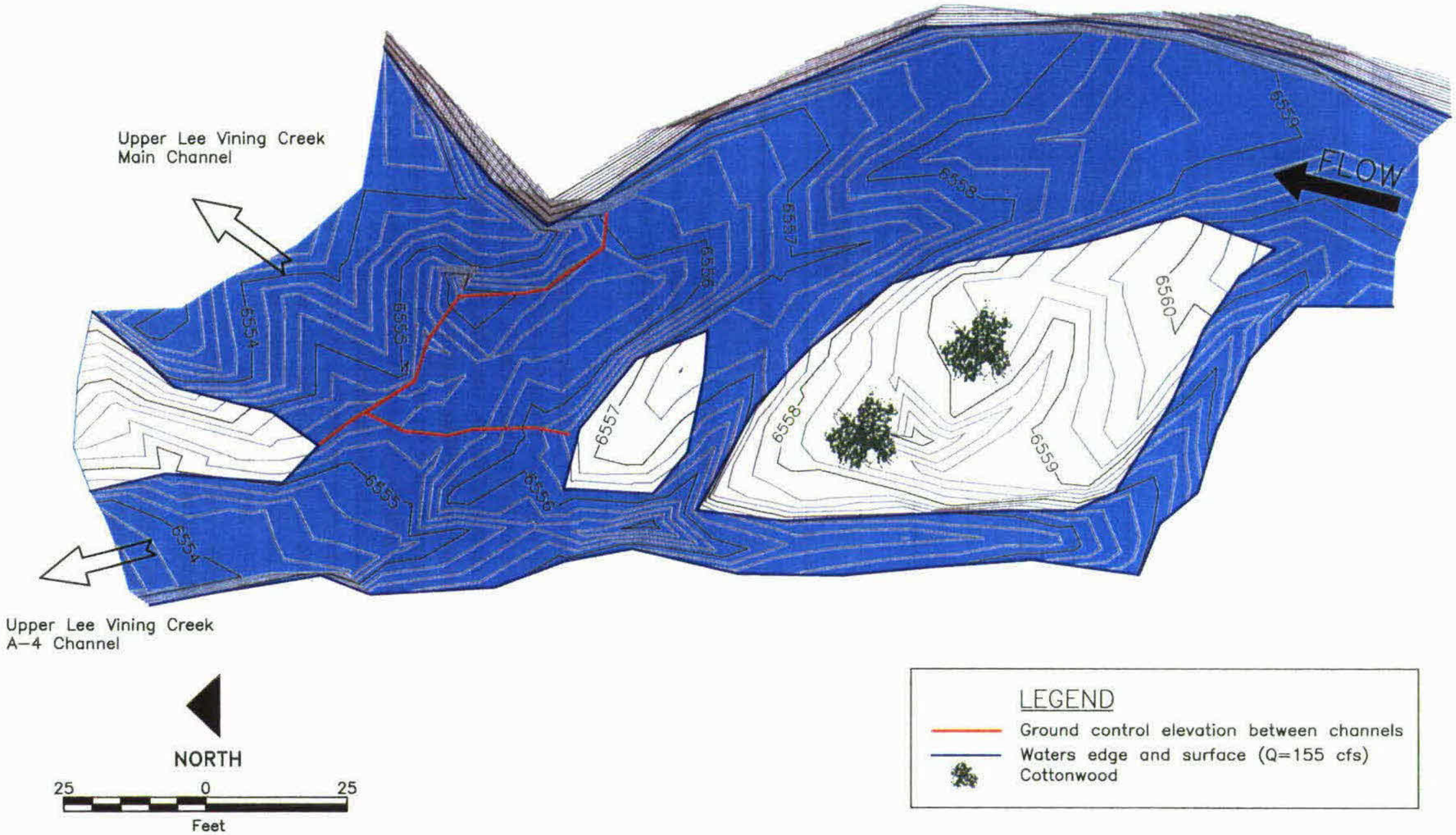


Figure 11. Total-Station survey of the upper Lee Vining Creek mainstem and A-4 channel split. This survey was conducted to establish baseline topographic conditions to which to compare future changes.

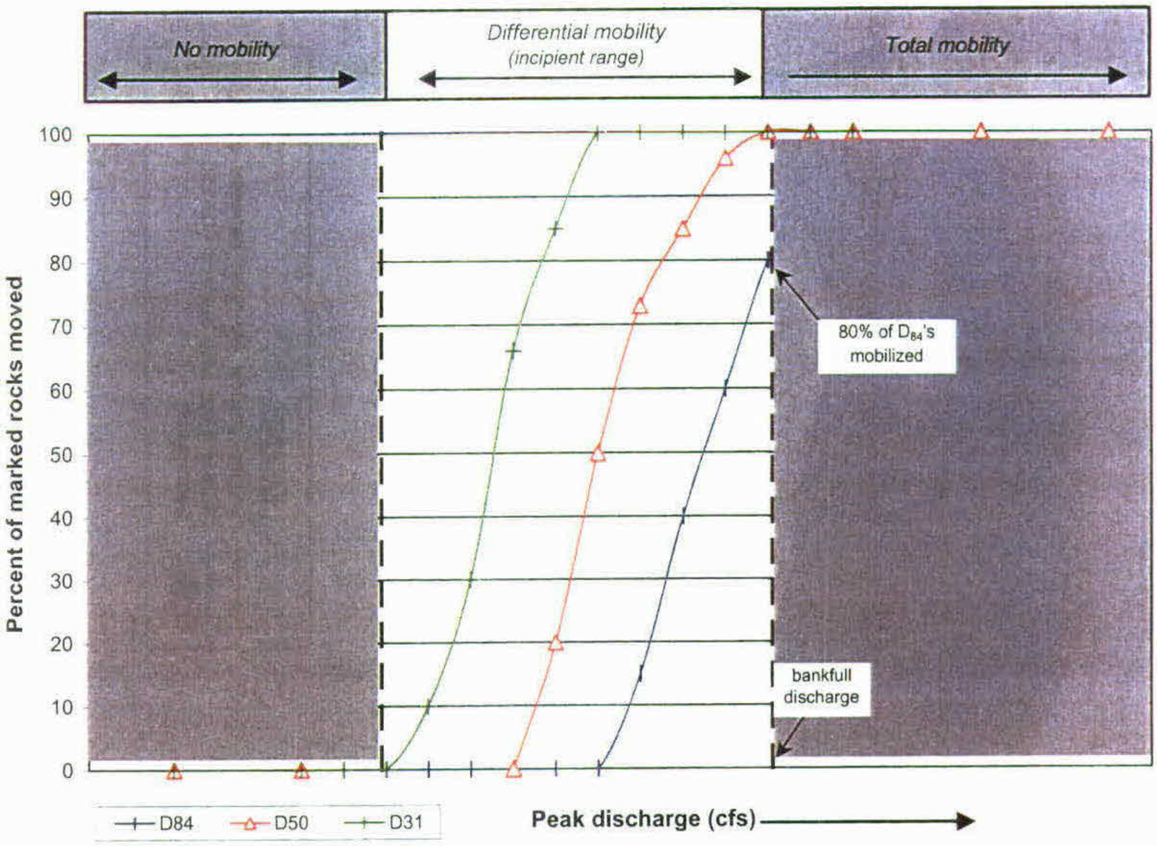


Figure 12. Idealized distribution of tracer rock mobility over a range of peak flows at a given alluvial feature. Each point represents a peak flow event mobilizing a percentage of tracer rocks. The range of differential mobility varies by alluvial feature. Complete bed mobilization will be considered when 80% mobilization of the D84 occurs.

As discussed in our WY 1999 monitoring report, significant mobilization of the D_{84} population (i.e., >80%) in many alluvial channels occurs close to the bankfull discharge. Assuming that the D_{84} represents the framework grain size for the bed surface – that is, the alluvial matrix of bed surface particles is held by the grain-to-grain contact of the D_{84} particles (Church et al. 1987; Bunte and Abt 2001), we hypothesize that significant bed mobilization occurs at, or very near, the bankfull discharge. To understand what range of flows are responsible for mobilizing the bed surface at our study sites, and to use this flow range to develop channel maintenance flow recommendations for post-restoration regulated conditions, we want to bracket the incipient mobility range at all our monitoring cross sections. Once the incipient range is bracketed, we can then (1) estimate the average bed shear stress, τ_b, at both ends of the range, (2) estimate the dimensionless critical shear stress, τ^*_{ci}, at both ends of the incipient range, (3) back-calculate discharge from the dimensionless critical shear stress, τ^*_{ci}, at both ends of the incipient range, then (4) compare this range of discharges to estimates of bankfull discharge from flood frequency analyses or other derivations. These calculations would then provide an important theoretical check to our empirical data.

Mobilization thresholds have not been equal throughout the channel. Although more uniform portions of the channel such as riffles and pool tails may mobilize near the bankfull discharge, other alluvial features such as alternate bars or higher elevation developing floodplains require greater flows to mobilize their surfaces. For example, we previously hypothesized that alternate bars would require a 5- to 10-year flood for mobilization. The combined result of our modeled flow estimates and our empirical observations will provide estimated flow ranges capable of mobilizing the channel bed surface based on the different types of alluvial feature (e.g., riffle, pool tail, bars).

2.1 Tracer Rock Methods

We continued bed mobility experiments at cross sections and other selected locations during the WY 2001 peak flows. As with previous monitoring years, we reset all tracer rock and scour core experiments prior to the onset of the snowmelt runoff. The tracer rocks were repainted when necessary (or new tracer rocks were painted and placed if they could not be recovered downstream) and placed in the channel. Tracer rock particle sizes were based primarily on data from pebble counts updated at each cross section during the 2000 field season. Scour cores were also monitored. Following high flows, the scour core location was revisited to document scour and redeposition depths. Each core was relocated, the surface layer was removed to expose the painted tracer rock, and the core was replenished with freshly-painted tracer gravels to the level of the surrounding substrate.

Following the peak spring snowmelt floods, we examined each tracer rock and scour core experiment to observe tracer rock movement and scour depth. Rocks were assumed to have moved if they were farther than one foot from the original cross section location. Tracer rocks relocated downstream were measured for their particle size and the distance moved. Scour and redeposition were measured by resurveying both bed surface and scour core gravel elevations.

2.2 Tracer Rock Results

2.2.1 Rush Creek

Our tracer rock experiments target the discrete range of high flows that begin to mobilize sediment particles on the channel bed surface. These flow thresholds are important signals to the onset of geomorphic processes of sediment transport, scour and deposition, particle sorting, etc. On Rush Creek, tracer rock results ranged from no rock movement at stations having rock sets placed out of the low-water channel (point bars and floodplain surfaces), to moderate rock movement within the active channel (riffles and pool-tail features). Table 4 summarizes results for all Rush Creek cross sections.

In RY 2000 monitoring report (McBain and Trush 2000), XS -9+82 at the Lower Rush Creek study site was described as a good example of surface particle mobilization for RY 2000. This cross section is located below the return of the 10 Channel and therefore receives the entire peak discharge. The tracer rock set at XS -9+82 is placed on a lateral bar developing in-channel. The cross section has relatively good channel confinement, and has been developing a more complex channel cross section in successive years (Figure 13). In response to this year's peak discharge of 202 cfs, no D_{84}'s moved, no D_{50}'s moved, and five D_{31}'s moved (38%). These results illustrate that the RY 2001 snowmelt peak magnitude did not achieve targeted thresholds for bed mobility at this location. In last year's monitoring report, we also cited the "in-channel" tracer rock facies at XS 7+70 as a good example of bed surface mobility. Results from this year's monitoring are consistent with those from XS -9+82 indicating that the RY 2001 peak discharge did not reach thresholds for mobilizing the bed surface at lower Rush Creek sites.

In the Upper Rush Creek site, with peak flow of 162 cfs, few tracer rocks were mobilized. We continued our second year of monitoring tracer rocks at the Rush Creek County Road site XS 15+19, and the results were similar to results from the Lower Rush Creek sites. None of the D_{84}'s moved, 3 D_{50}'s moved (25%), and 7 D_{31}'s (58%) moved downstream (compared with last year's results of 8%, 58%, and 75%, respectively). In summary, the RY 2001 peak discharge on Rush Creek was not a significant event for mobilizing the bed surface of most alluvial features.

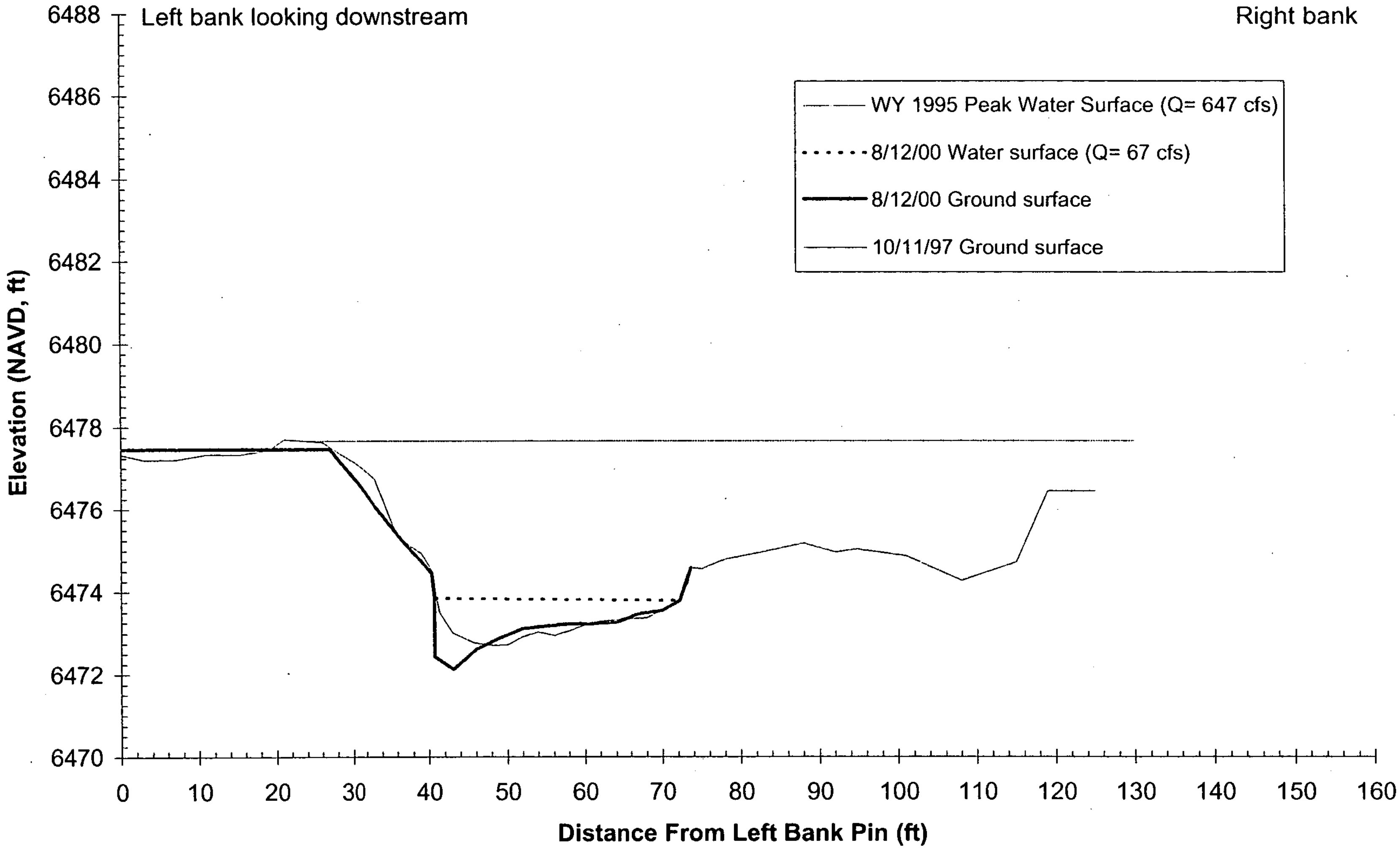


Figure 13. Lower Rush Creek XS -9+82

Table 4. Results of Tracer Rock experiments in Rush Creek for RY 2001.

LOWER RUSH CREEK PEAK DISCHARGE = 202 cfs on June 11, 2001

REACH	CHANNEL	CROSS SECTION	PARTICLE SIZE (mm)	PARTICLE SIZE CLASS	NUMBER OF TRACER ROCKS PLACED	PEAK DISCHARGE AT CROSS SECTION (CFS)	NUMBER OF TRACER ROCKS MOBILIZED	PERCENT OF TRACER ROCKS MOBILIZED	GEOMORPHIC UNIT	NOTES
LOWER	MAIN	-9+82 (H)	125	D_{84}	13	202	0	0%	Riffle	
			63	D_{50}	13	202	0	0%	Riffle	
			44	D_{31}	13	202	5	38%	Riffle	
		rocks placed at stations 46, 48, ...70.								
		-5+07 (D)	110	D_{84}	10	202	0	0%	Riffle	
			52	D_{50}	10	202	0	0%	Riffle	
			36	D_{31}	10	202	2	20%	Riffle	
		rocks placed at stations 75, 77.5, ...105.								
		4+08	56	D_{84}	10	128	0	0%	Point Bar	major deposition on this pool-tail
			35	D_{50}	10	128	0	0%	Point Bar	buried
			28	D_{31}	10	128	1	10%	Point Bar	buried
		rocks placed at stations 140,142,144,...152								
		7+25	99	D_{84}	10	128	2	20%	Lower Point Bar	rocks in the middle are on medial bar
			53	D_{50}	10	128	5	50%	Lower Point Bar	developing as extension to the lateral bar
			40	D_{31}	10	128	6	60%	Lower Point Bar	
		Facies II rocks placed at stations 23, 27, ...37.								
		7+25	43	D_{84}	10	128	0	0%	Upper Point Bar	
			26	D_{50}	10	128	0	0%	Upper Point Bar	
			19	D_{31}	10	128	0	0%	Upper Point Bar	
		Facies I rocks placed at stations 50, 52, ...62								
		7+70	99	D_{84}	10	128	0	0%	Channel Bed	
			53	D_{50}	10	128	2	20%	Channel Bed	
			40	D_{31}	10	128	5	50%	Channel Bed	
		Facies II rocks placed at stations 26, 28, ...38.								
		7+70	43	D_{84}	10	128	0	0%	Point Bar	
			26	D_{50}	10	128	0	0%	Point Bar	
			19	D_{31}	10	128	0	0%	Point Bar	
		Facies I rocks placed at stations 50, 52, ...62								
		10+10	78	D_{84}	16	128	0	0%	Pool Tail	
			46	D_{50}	16	128	6	38%	Pool Tail	many rocks buried on XS; more deposition than scour here.
			28	D_{31}	16	128	10	63%	Pool Tail	
		rocks placed at stations 20.5, 21.5....35.5								
	10-Channel	10B	108	D_{84}	12	76	1	8%	Channel Bed	no movement in channel
			64	D_{50}	12	76	0	0%	Channel Bed	floodplain continues to develop
			44	D_{31}	12	76	2	17%	Channel Bed	
		rocks placed at stations 18, 19, 20, ...29								

Table 4. continued.

UPPER RUSH CREEK PEAK DISCHARGE = 162 cfs on June 11, 2001

REACH	CHANNEL	CROSS SECTION	PARTICLE SIZE (mm)	PARTICLE SIZE CLASS	NUMBER OF TRACER ROCKS PLACED	PEAK DISCHARGE AT CROSS SECTION (CFS)	NUMBER OF TRACER ROCKS MOBILIZED	PERCENT OF TRACER ROCKS MOBILIZED	GEOMORPHIC UNIT	NOTES
UPPER	Main	0+74 (A)	132	D_{84}	17	162	0	0%	Riffle	No movement
			65	D_{50}	17	162	0	0%	Riffle	
			38	D_{31}	17	162	0	0%	Riffle	
			26	D_{16}	17	162	0	0%	Riffle	
		rocks placed at stations 50, 52, ...82.								
		5+45 (B)	122	D_{84}	10	162	1	10%	Riffle	
			75	D_{50}	10	162	2	20%	Riffle	
			62	D_{31}	10	162	2	20%	Riffle	
			49	D_{16}				0%	Riffle	
		rocks placed at stations 20, 21.5, 23, 24....30								
		9+40	88	D_{84}	8	162	0	0%	Pool Tail	
			46	D_{50}	8	162	0	0%	Pool Tail	
			29	D_{31}	8	162	0	0%	Pool Tail	
			18	D_{16}	8	162	0	0%	Pool Tail	
		rocks placed at stations 30, 32, ...42.								
		11+68							Riffle	
				SITE ABANDONED						
		six large boulders were painted and placed on cross section at stations 10, 12, ...20 with assorted "b" diameter sizes.								
		12+95 (C)	140	D_{84}	10	162	0	0%	Pool Tail	
			77	D_{50}	10	162	0	0%	Pool Tail	
			53	D_{31}	10	162	0	0%	Pool Tail	
		rocks placed at stations 11, 14, ... 35								

RUSH CREEK COUNTY ROAD PEAK DISCHARGE = 202 cfs on June 11, 2001

REACH	CHANNEL	CROSS SECTION	PARTICLE SIZE (mm)	PARTICLE SIZE CLASS	NUMBER OF TRACER ROCKS PLACED	PEAK DISCHARGE AT CROSS SECTION (CFS)	NUMBER OF TRACER ROCKS MOBILIZED	PERCENT OF TRACER ROCKS MOBILIZED	GEOMORPHIC UNIT	NOTES
County Rd	County Rd	15+19	185	D_{84}	12	202	0	0%	Low Gradient Riffle	
			71	D_{50}	12	202	2	17%	Low Gradient Riffle	
			40	D_{31}	12	202	7	58%	Low Gradient Riffle	
		rocks placed at stations 11, 14, ... 35								
		6+85	185	D_{84}	10	202	0	0%	Lower Point Bar	
			71	D_{50}	10	202	0	0%	Lower Point Bar	
			40	D_{31}	10	202	0	0%	Lower Point Bar	
		rocks placed at stations 11, 14, ... 35								

the upstream end of the Upper Rush Creek study reach (Table 6). During RY 2001, peak flows were lower (162/202 cfs), and as a result we recorded no scour at the XS 12+95 scour cores. The maximum recorded scour for Rush Creek scour cores in RY 2001 was 0.29 ft, recorded in a lee deposit at Upper Rush Creek XS 5+45. Overall, results were generally consistent for most scour cores; where scour was recorded, it was generally less than the scour recorded in RY 2000.

2.4.2 Lee Vining Creek

In Lee Vining Creek, the RY 2001 peak flow was 201 cfs. Similar to Rush Creek, scour was minimal at all cross section stations (Table 7). The maximum scour was 0.44 ft, recorded in a fine gravel point bar deposit at XS 10+44 (51% of the total scour core depth). All other scour cores recorded generally less than 0.1 ft of scour.

2.5 Future monitoring needs

2.5.1 Tracer Rocks

Of the 15 tracer rock monitoring sites on Rush Creek and 12 on Lee Vining Creek, six have captured the incipient range on Rush Creek and none have on Lee Vining Creek. However, one additional site on Rush Creek and five sites on Lee Vining Creek are close to capturing the incipient range, having documented flows responsible for moving at least 50% of the D_{84}'s. Although this is close to the 80% total tracer rock mobilization threshold for alluvial channels, additional monitoring is needed to estimate the upper end discharge for these sites, as well as to continue building the data set for those sites that are not so close to having their incipient range documented.

A good example of where our monitoring has successfully captured the incipient range is at XS 7+70 on the Lower Rush Creek mainstem. Tracer rock monitoring has occurred over a peak flow range of 65 to 387 cfs, with 80% mobilization of the D_{84} occurring at approximately 195 cfs (Figure 14). This 195 cfs peak discharge at XS 7+70 translates to approximately 310 cfs for 'Rush Creek below the Narrows' and approximately 260 cfs for 'Rush Creek below Return Ditch'. Conversely, our tracer rock monitoring on the right bank point bar at Upper Rush Creek XS 9+40 (mainstem) has yet to document mobilization of any tracer rock size. Tracer rock monitoring at this cross section has occurred over a peak flow range of 55 to 205 cfs, and it is clear that higher peak flows are needed to mobilize the bed at this site. Because the incipient range had yet to be completely documented at 9 sites on Rush creek and at 12 sites on Lee Vining Creek, we will continue to monitor tracer rock movement in response to peak flow events at all monitoring sites.

2.5.2 Scour Cores

On Rush Creek, of the 10 sites with scour core experiments in place, only a few sites have collected data over a sufficient range of peak flows to establish a strong relationship between discharge and scour depth/redeposition. Data for Lower Rush Creek XS 0+86 (the right bank point bar just upstream of the abandoned "million-dollar bend") and XS 7+70 (the right bank developing floodplain at the valley-wide cross section) are presented here as contrasting examples of scour core locations that have captured a range of scour during the past four years of experimentation, and locations that have experienced minor or no scour (Figure 15). The XS 0+86 scour core site is located at the low water edge within the active channel and scoured approximately 0.21 ft at 396 cfs in 1998, whereas XS 7+70 is on a higher elevation developing floodplain surface and showed only minor scour (0.03 ft) during the same event. On Lee Vining Creek, five sites have scour core experiments, none of which have collected enough data to develop strong relationships between discharge and scour depth.

Table 5. Results of Tracer Rock experiments in Lee Vining Creek for RY 2001.

PEAK DISCHARGE = 201 cfs on May 17, 2001

REACH	CHANNEL	CROSS SECTION	PARTICLE SIZE (mm)	PARTICLE SIZE CLASS	NUMBER OF TRACER ROCKS PLACED	PEAK DISCHARGE AT CROSS SECTION (CFS)	NUMBER OF TRACER ROCKS MOBILIZED	PERCENT OF TRACER ROCKS MOBILIZED	GEOMORPHIC UNIT	NOTES
UPPER	MAIN	3+45	210	D_{84}	15	140	1	7%	Riffle	0.5 to 3 ft
			104	D_{50}	15	140	2	13%	Riffle	both moved 2 ft
			84	D_{31}	15	140	3	20%	Riffle	o.5 to 2 ft
		rocks placed at stations 56, 58, ...84.								NOT MUCH SIGNIFICANT MOVEMENT
		6+61	175	D_{84}	12	140	0	0%	Point Bar	site did not get inundated
			95	D_{50}	12	140	0	0%	Point Bar	
			66	D_{31}	12	140	0	0%	Point Bar	
		rocks placed at stations 38, 40, 42,...60								
		9+31	144	D_{84}	12	140	0	0%	Medial Bar	
			77	D_{50}	12	140	0	0%	Medial Bar	
			54	D_{31}	12	140	2	17%	Medial Bar	estimated 10 to 20 ft movement of rocks in thalv
		rocks placed at stations 58, 61, 64, ...106 [12 sets]								ONLY 3 STATIONS IN CHANNEL OTHER STAT
		9+31	144	D_{84}	11	140	2	18%	High Gradient Riffle	1-2 ft
			77	D_{50}	11	140	3	27%	High Gradient Riffle	1-12 ft
			54	D_{31}	11	140	6	55%	High Gradient Riffle	1-3 ft, some unrecovered
		rocks placed at stations 109.5, 111, 112.5, 114, 115.5,....124.5								very high gradient riffle
		13+92	256	D_{84}	11	140	0	0%	Riffle	
			95	D_{50}	11	140	1	9%	Riffle	3 ft
			58	D_{31}	11	140	2	18%	Riffle	1-3 fr
		rocks placed at stations 44, 46, ...64								D84's are quite large; moderate to low gradient
	A4	4+04	165	D_{84}	10	69	0	0%	Medial Bar	
			112	D_{50}	10	69	2	20%	Medial Bar	
			90	D_{31}	10	69	0	0%	Medial Bar	
		rocks placed at stations 16, 19, 22, ...43.								Not much really happening here
		5+15	160	D_{84}	10	69	0	0%	Point Bar	
			60	D_{50}	10	69	0	0%	Point Bar	
			35	D_{31}	10	69	1	10%	Point Bar	likey buried
		rocks placed at stations 44, 47, ...65.								This site is extremely depositional, I.e., the bar i
		6+80	250	D_{84}	8	69	0	0%	Riffle	
			115	D_{50}	8	69	0	0%	Riffle	
			86	D_{31}	8	69	0	0%	Riffle	
		rocks placed at stations 12.5, 14.5, 16.5, 18.5, 21.5, 24.5 (stn 12.5 missing D31)								No movement
	B1	06+08	240	D_{84}	8	89	0	0%	Riffle	
			125	D_{50}	8	89	1	13%	Riffle	
			81	D_{31}	8	89	0	0%	Riffle	
		rocks placed at stations 24, 26, 28, 30, 32, 34, 36, 38								This XS has changed due to deposition of LWD

PEAK DISCHARGE = 201 cfs on May 17, 2001

REACH	CHANNEL	CROSS SECTION	PARTICLE SIZE (mm)	PARTICLE SIZE CLASS	NUMBER OF TRACER ROCKS PLACED	PEAK DISCHARGE AT CROSS SECTION (CFS)	NUMBER OF TRACER ROCKS MOBILIZED	PERCENT OF TRACER ROCKS MOBILIZED	GEOMORPHIC UNIT	NOTES
LOWER	MAIN	01+15	205	D_{84}	10	112	0	0%	Riffle	
			106	D_{50}	10	112	0	0%	Riffle	
			65	D_{31}	10	112	2	20%	Riffle	
		rocks placed at stations 18, 20, 23, 26, 29, 32, 35.								
	B1	01+80	153	D_{84}	10	89	2	20%	Riffle	
			74	D_{50}	10	89	2	20%	Riffle	
			54	D_{31}	10	89	5	50%	Riffle	
		rocks placed at stations 14, 15 ...23								
	B1	00+87	98	D_{84}	10	89	1	10%	Point Bar	
			56	D_{50}	10	89	1	10%	Point Bar	
			40	D_{31}	10	89	2	20%	Point Bar	
		rocks placed at stations 25, 26.5, 28, 29.5, 31, 32.5, 34, 35.5, 37, 38.5, 40, 41.5.								

Data collection should continue at all previously established sites during the next several years, particularly during runoff years with average and above runoff conditions. Additional data points that record some degree of scour will improve the linear regression relationships between discharge and depth of scour, as well as strengthen our conclusions from those data.

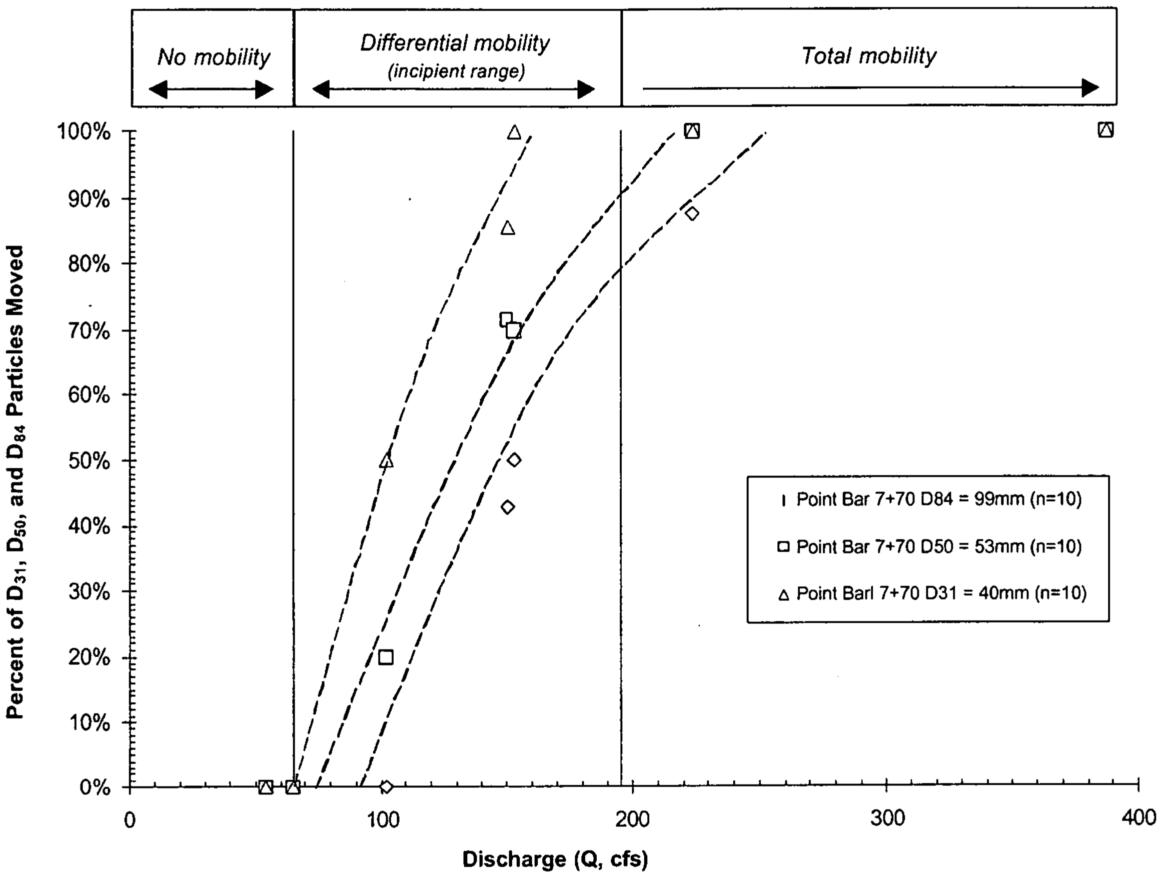


Figure 14. Distribution of tracer rock mobility over a range of peak flows at XS 7+70, Lower Rush Creek mainstem. Each point represents a peak flow event mobilizing a percentage of tracer rocks. The mobilization range falls between approximately 65 and 195 cfs, and complete bed mobilization is considered to have occurred at approximately 195 cfs when 80% mobilization of the D84 occurred.

3 TERMINATION CRITERIA

SWRCB Order 98-08 establishes seven termination criteria for determining when the stream monitoring program shall end (reviewed by McBain and Trush 2000). Given the low peak discharges in RY 2001, we expected no significant occurrence of fluvial processes capable of affecting the geomorphic termination criteria. The summer 2001 field data for channelbed scour and mobility corroborate this finding (presented in this annual report), as do the cross sectional surveys indicating no significant change in floodplain aggradation or in planform morphology. Vegetation field surveys, for assessing the riparian vegetation termination criteria, were completed in RY 2001. An analysis of these data will be completed and summarized in the next annual report (2002) including a quantitative comparison to the riparian termination criteria. Chris Hunter addresses the termination criteria for fish.

4.1 Gaging Station Description

The gaging station was constructed on November 14-15, 2001. We planned to house the pressure transducer and signal cable in a conduit inside the culvert itself, then extend the orifice out of the culvert, up the concrete abutment, and into the enclosure that houses the electronic equipment. However, water velocities inside the culvert were too high to install the pressure transducer. The pressure transducer was therefore installed in the plunge pool below the culvert (similar to our initial plan) rather than inside the culvert.

The enclosure that houses the electronic equipment (gage house) sits just above the downstream right bank concrete backwall abutment of the Test Station Road culvert. The gage house consists of a 2 ft x 2 ft x 2 ft steel box with a hinged locking lid. The box is made of $^{3}/_{16}$ inch thick steel and is bolted to a 30 inch square concrete pad. A 2 inch diameter galvanized pipe serves as a conduit for the electronic equipment. The pipe protrudes from the side of the pad and runs down the culvert backwall, then follows the wingwall and projects four feet down into the water (Figure 16). All segments of pipe were affixed to the concrete walls using anchor bolts and pipe brackets.

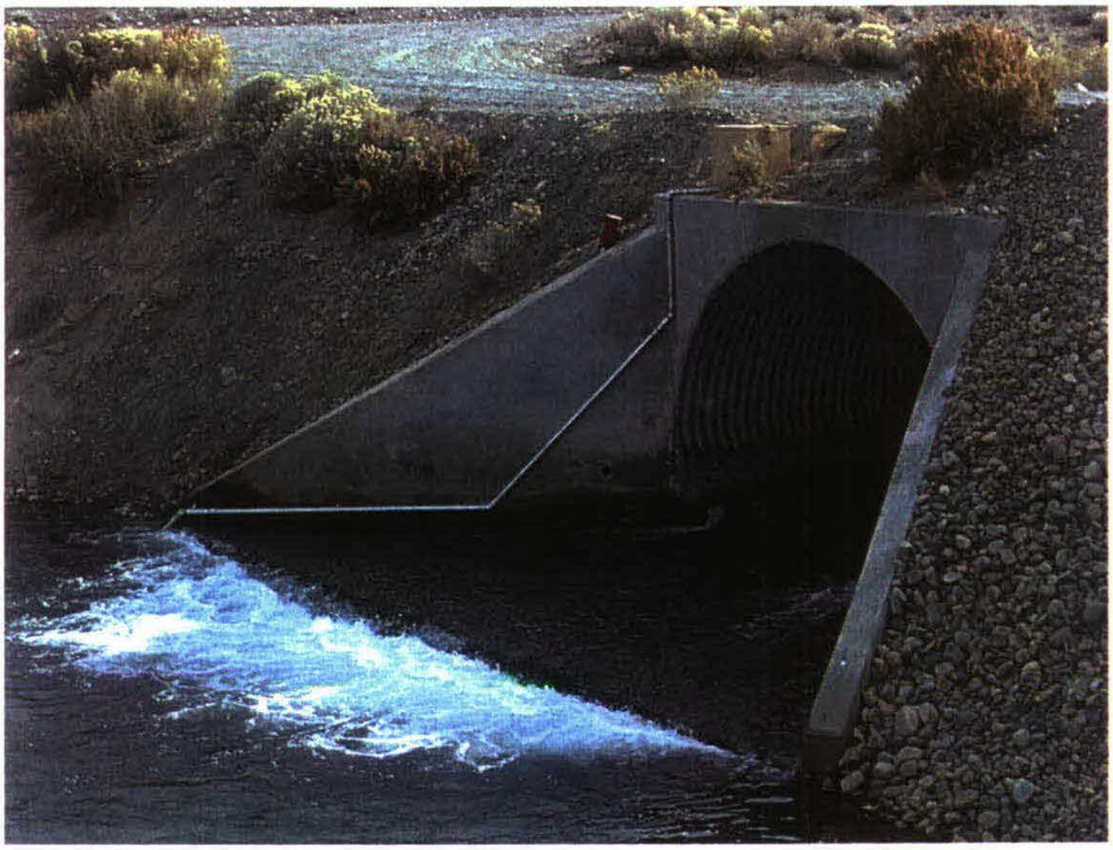


Figure 16. Photograph showing the completed gaging station. The transducer housing extends from the gage house to the top of the culvert backwall, extends along the culvert backwall and wingwall, and projects four feet into the water where the pressure transducer is housed in a perforated end piece. Discharge shown is approximately 43 cfs.

Table 6. Results of Scour Core experiments in Rush Creek for RY 2001.

Reach	Channel	Cross Section	Year	Peak discharge in channel (cfs)	Core #	Scour depth (ft)	Redeposition depth (ft)	D84 (mm)	Relative scour depth (dsc/D84)	Depth of scour core (thickness of tracer gravels when core installed) (feet)	Percent core scoured	Geomorphic feature	Notes
LOWER	MAIN	00+86	1998	396	1	0.00	0.00	50	0.00	0.64	0%	Upper point bar / floodplain	Q is peak daily average. D84 from 1997 pool tail count.
					2	0.03	0.00	50	0.18	0.67	4%	Middle of point bar	D84 from 1997 pool tail count.
					3	0.21	1.14	50	1.28	0.60	35%	Point bar within low water channel	D84 from 1997 pool tail count.
					4	0.30	0.77	50	1.83	0.55	55%	Point bar within low water channel	D84 from 1997 pool tail count.
			1999	155	1	0.01	0.00	50	0.06	0.64	2%	Upper point bar / floodplain	Q is peak daily average. No pebble count data post-1998. Use 1998 D84 size.
					2	0.03	0.00	50	0.18	0.67	4%	Middle of point bar	D84 from 1997 pool tail count.
					3	0.00	0.00	50	0.00	0.60	0%	Point bar within low water channel	D84 from 1997 pool tail count.
					4	-	-			0.55		Point bar within low water channel	Core #4 believed to be completely scoured.
			2000	178	1	0.01	0.00	50	0.06	0.64	2%	Upper point bar / floodplain	Q is instantaneous peak. No pebble count data post-1998. Use 1998 D84 size.
					2	0.01	0.00	50	0.06	0.67	1%	Middle of point bar	D84 from 1997 pool tail count.
					3	0.05	0.00	50	0.30	0.60	8%	Point bar within low water channel	D84 from 1997 pool tail count.
					4	-	-			0.55		Point bar within low water channel	Core believed to be completely scoured in 1998.
					5	0.00	0.00	50	0.00	0.92	0%	Pool tail	D84 from 1997 pool tail count.
			2001	128	1	0.00	0.00	50	0.00	0.64	0%	Upper point bar / floodplain	Q is peak daily average. No pebble count data post-1998. Use 1998 D84 size.
					2	0.00	0.00	50	0.00	0.67	0%	Middle of point bar	D84 from 1997 pool tail count.
					3	0.00	0.00	50	0.00	0.60	0%	Point bar within low water channel	D84 from 1997 pool tail count.
					4	-	-			0.55		Point bar within low water channel	Core #4 believed to be completely scoured in 1998.
					5	0.00	0.00	50	0.00	0.92	0%	Pool Tail	D84 from 1997 pool tail count.
LOWER	MAIN	03+30	1998	396	1	0.47	0.31	42	3.41	0.64	73%	Pool tail at low flow, transverse bar at high flow	Q is peak daily average. D84 from 1997.
					2	>0.55	>0.55	42	3.99	0.50	100%	Pool tail at low flow, transverse bar at high flow	Scour and relative scour depths are minimums. D84 from 1997.
					3	>0.75	>0.50	42	5.44	0.64	100%	Pool tail at low flow, transverse bar at high flow	Scour and relative scour depths are minimums. D84 from 1997.
			1999	155	1	0.05	0.14	42	0.36	0.64	8%	Pool tail at low flow, transverse bar at high flow	Q is peak daily average. D84 from 1997.
					2	0.14	0.14	42	1.02	0.50	28%	Pool tail at low flow, transverse bar at high flow	Q is peak daily average. D84 from 1997.
					3	-	-	42	-	0.64		Not surveyed; assume completely scoured.	Q is peak daily average. D84 from 1997.
			2000	178	1	0.00	0.03	42	0.00	0.64	0%	Pool tail at low flow, transverse bar at high flow	Q is instantaneous peak. D84 from 1997.
					2	0.00	0.00	42	0.00	0.50	0%	Pool tail at low flow, transverse bar at high flow	Q is instantaneous peak. D84 from 1997.
					3	-	-	42	-	0.64		Not surveyed in 1999; assume completely scoured.	Q is instantaneous peak. D84 from 1997.
			2001	128	1	0.18	0.00	42	1.31	0.64	28%	Pool tail at low flow, transverse bar at high flow	Q is peak daily average. D84 from 1997.
					2	0.00	0.02	42	0.00	0.50	0%	Pool tail at low flow, transverse bar at high flow	Q is peak daily average. D84 from 1997.
					3	-	-	42	-	0.64		Not surveyed in 1999; assume completely scoured.	Q is peak daily average. D84 from 1997.
LOWER	MAIN	04+08	1998	396	1	>0.46	>0.46	56	2.50	0.46	100%	Low-gradient riffle	Q is peak daily average. Scour and relative scour depths are minimums. D84 from 1997.
					2	>0.67	>0.67	56	3.65	0.67	100%	Low-gradient riffle	Scour and relative scour depths are minimums. D84 from 197.
			1999	155	1	0.17	0.20	56	0.93	0.46	37%	Low-gradient riffle	Q is peak daily average. D84 from 1997.
					2	0.13	0.00	56	0.71	0.67	19%	Low-gradient riffle	D84 from 1997.
			2000	178	1	0.00	0.00	75	0.00	0.46	0%	Low-gradient riffle	Q is instantaneous peak. D84 from 2000.
					2	0.00	0.00	75	0.00	0.67	0%	Low-gradient riffle	D84 from 2000.
			2001	128	1	0.02	0.12	75	0.08	0.46	4%	Low-gradient riffle	Q is peak daily average. D84 from 2000.
					2	0.00	0.00	75	0.00	0.67	0%	Low-gradient riffle	D84 from 2000.
LOWER	MAIN	05+49	1998	396	1	0.34	0.56	69	1.50	0.65	52%	Riffle (transverse bar), within low water channel	Q is peak daily average. D84 from 1998.
					2	0.37	0.47	69	1.63	0.53	70%	Riffle (transverse bar), within low water channel	D84 from 1998.
					3	0.43	0.53	69	1.90	0.53	81%	Riffle (transverse bar), within low water channel	D84 from 1998.
					4	0.04	0.04	69	0.18	0.57	7%	Riffle (transverse bar), within low water channel	D84 from 1998.
			1999	155	1	0.13	0.06	69	0.57	0.65	20%	Riffle (transverse bar), within low water channel	Q is peak daily average. D84 is from 1998.
					2	0.11	0.11	69	0.49	0.53	21%	Riffle (transverse bar), within low water channel	D84 is from 1998.
					3	0.00	0.33	69	0.00	0.53	0%	Riffle (transverse bar), within low water channel	D84 is from 1998.
					4	0.19	0.20	69	0.84	0.67	28%	Riffle (transverse bar), within low water channel	D84 is from 1998.
			2000	178	1	0.06	0.09	69	0.27	0.65	9%	Riffle (transverse bar), within low water channel	Q is instantaneous peak. D84 is from 1998.
					2	0.07	0.19	69	0.31	0.53	13%	Riffle (transverse bar), within low water channel	D84 is from 1998.
					3	0.00	0.14	69	0.00	0.53	0%	Riffle (transverse bar), within low water channel	D84 is from 1998.
					4	0.04	0.00	69	0.18	0.67	6%	Riffle (transverse bar), within low water channel	D84 is from 1998.
			2001	128	1	0.00	0.10	69	0.00	0.65	0%	Riffle (transverse bar), within low water channel	Q is peak daily average.
					2	0.00	0.17	69	0.00	0.53	0%	Riffle (transverse bar), within low water channel	D84 is from 1998.
					3	0.00	0.00	69	0.00	0.53	0%	Riffle (transverse bar), within low water channel	D84 is from 1998.
					4	0.00	0.00	69	0.00	0.67	0%	Riffle (transverse bar), within low water channel	D84 is from 1998.
LOWER	MAIN	07+25	1998	396	1	0.00	0.00	43	0.00	0.73	0%	Upper point bar / floodplain	Q is peak daily average. D84 is from 1997 XS 7+70 Facies I.
			1999	155	1	0.01	0.00	43	0.07	0.73	1%	Upper point bar / floodplain	Q is peak daily average. D84 is from 1997 XS 7+70 Facies I.

Table 7. Results of Scour Core experiments in Lee Vining Creek for RY 2001.

Reach	Channel	Cross Section	Year	Peak discharge in channel (cfs)	Core #	Scour depth (ft)	Redeposition depth (ft)	D84 (mm)	Relative scour depth (dsc/D84)	Depth of scour core (thickness of tracer gravels when core installed) (feet)	Percent core scoured	Geomorphic feature	Notes
LOWER	B-1	00+87	1999	122	1	0.10	0.04	113	0.27	0.97	10%	Point bar, pea gravels	Q is peak average daily.
			2000	115	1	0.05	0.04	113	0.13	0.97	5%	Point bar, pea gravels	Q is peak average daily. No post-1999 pebble count data found.
			2001	89	1	0.00	0.04	113	0.00	0.97	0%	Point bar, pea gravels	Q is peak average daily. No post-1999 pebble count data found.
LOWER	MAIN	3+57	1999	152	1	-	-	-	-	-			Core not relocated following 1999 flows; site subsequently abandoned due to trout spawning.
LOWER	MAIN	1+15	1998	215	1	0.01	0.00	238	0.01	1.19	1%	Side channel	Q is peak average daily. No 1997 pebble count data; use 1999 D84.
					2	0.01	0.00	238	0.01	1.43	1%	Side channel	Q is peak average daily. No 1997 pebble count data; use 1999 D84.
			1999	152	1	0.00	0.00	238	0.00	1.19	0%	Side channel	Q is peak average daily.
					2	0.01	0.00	238	0.01	1.43	1%	Side channel	Q is peak average daily.
UPPER	MAIN	13+92	1998	270	1	0.00	0.11	256	0.00	0.67	0%	Eddy deposit, coarse sand	Q is peak average daily.
					2	0.20	0.19	256	0.24	0.57	35%	Eddy deposit, medium gravels	Q is peak average daily.
			1999	190	1	0.08	0.13	256	0.10	0.67	12%	Eddy deposit, coarse sand	Q is peak average daily. No 1999 pebble count; use 1997 data.
					2	0.05	0.21	256	0.06	0.57	9%	Eddy deposit, medium gravels	Q is peak average daily. No 1999 pebble count; use 1997 data.
			2000	179	1	0.04	0.11	307	0.04	0.67	6%	Eddy deposit, coarse sand	Q is peak average daily.
					2	0.00	0.07	307	0.00	0.57	0%	Eddy deposit, medium gravels	Q is peak average daily.
			2001	140	1	0.03	0.12	307	0.03	0.67	4%	Eddy deposit, coarse sand	Q is peak average daily. No 2001 pebble count; use 2000.
					2	0.01	0.12	307	0.01	0.57	2%	Eddy deposit, medium gravels	Q is peak average daily. No 2001 pebble count; use 2000.
UPPER	MAIN	10+44	1999	270	1	0.27	0.06			0.86	31%	Eddy deposit - spawning gravels	Q is peak average daily. No pebble count data found.
					2	0.18	0.00			1.18	15%	Eddy deposit - exposed bar	Q is peak average daily. No pebble count data found.
			2000	190	1	0.24	0.00			0.86	28%	Eddy deposit - spawning gravels	Q is peak average daily. No pebble count data found.
					2	0.08	0.37			1.18	7%	Eddy deposit - exposed bar	Q is peak average daily. No pebble count data found.
			2001	179	1	0.44	0.09			0.86	51%	Eddy deposit - spawning gravels	2001 survey data is suspect for both cores (scour only; redeposition is good). Q is peak daily average.
					2	0.00	0.10			1.18	0%	Eddy deposit - exposed bar	
UPPER	MAIN	03+73	1998	270	1	0.00	0.04	210	0.00	0.36	0%	Point bar - pea gravels	Q is peak average daily. No post-1997 pebble count data found. Use 1997 measurement.
					2	0.57	0.05	210	0.83	0.57	100%	Point bar - pea gravels	Q is peak average daily. No post-1997 pebble count data found. Use 1997 measurement.
			1999	190	1	0.30	0.00	210	0.44	0.36	83%	Point bar - pea gravels	Q is peak average daily. No post-1997 pebble count data found. Use 1997 measurement.
					2	0.30	0.17	210	0.44	0.57	53%	Point bar - pea gravels	Q is peak average daily. No post-1997 pebble count data found. Use 1997 measurement.
			2000	179	1	0.00	0.00	210	0.00	0.36	0%	Point bar - pea gravels	Q is peak average daily. No post-1997 pebble count data found. Use 1997 measurement.
					2	0.00	0.15	210	0.00	0.57	0%	Point bar - pea gravels	Q is peak average daily. No post-1997 pebble count data found. Use 1997 measurement.
			2001	140	1	0.12	0.00	210	0.17	0.36	33%	Point bar - pea gravels	Q is peak average daily. No post-1997 pebble count data found. Use 1997 measurement.
					2	0.12	0.18	210	0.17	0.57	21%	Point bar - pea gravels	Q is peak average daily. No post-1997 pebble count data found. Use 1997 measurement.

The signal cable that transmits stage readings from the pressure transducer to the datalogger runs inside the transducer housing and into the gage house. The signal cable houses the wiring for the pressure transducer as well as a ventilation tube. Because the transducer depends on atmospheric pressure, a closed-vent system was installed so that both faces of the pressure sensor are exposed to atmospheric pressure. This ensures that changes in atmospheric pressure are experienced on both sides of the pressure sensor, thereby maintaining an even-pressure environment for accurate stage readings. Inside the gage house, the vent tube connects to a closed breather vent system. The closed vent system is located inside the gage house adjacent to the datalogger. The remaining wiring in the signal cable connects the pressure transducer to the datalogger.

Stage data from the pressure transducer is collected using a Stevens AxSys Datalogger. The datalogger is powered by a 12 volt rechargeable battery set to record water stage at 15-minute intervals. We tested the datalogger and verified the pressure transducer calibration in our office prior to the field installation. Data collected by the datalogger are stored in memory until it is downloaded.

4.2 Gaging Station Operations

LA DWP operates and maintains the gaging station. McBain and Trush will provide assistance whenever visiting the site, including measuring discharge and reading the staff plates, measuring depth of water in the culvert, and checking the stage reading on the datalogger. We began measuring streamflow discharge following the installation of our temporary gaging station, to establish a stage-discharge rating curve. To-date, we have made 10 measurements at the site and have constructed a rating curve based on these measurements. In addition to our direct discharge measurements, we began developing an indirect stage-discharge relationship by measuring the depth of water flowing in the culvert in the field and computing discharge through the culvert based on the slope-area method. This method has not shown a strong relationship to our discharge measurements, and this effort has been discontinued.

5 RIPARIAN VEGETATION MONITORING

During RY 2001 we completed the fieldwork for the riparian vegetation portion of the SWRCB compliance monitoring. The data analysis is in progress, and will be presented in our RY 2002 report. In this report, we present the field sampling methods and data analysis protocols. The RY 2001 riparian vegetation monitoring activities used the original Blue and White Book protocols as a basis for describing composition and structure of riparian plant stands. The White Book defines monitoring activities within each discipline (e.g., fisheries, geomorphology and plant ecology). The Blue Book describes field techniques and data analysis protocols, listing in detail different methods employed within each of the monitoring activities.

5.1 Background

Sediment supply, channel slope, and a variable streamflow regime interact to create and maintain alluvial channel morphology. Changes in these variables often trigger perceptible changes in channel form (Lane 1955). Through these hydrologic and geomorphic processes, an alluvial channel creates different surfaces, which we define as geomorphic units. Examples of different geomorphic units include gravel bars, floodplains, and terraces. With each successive increase in ground surface elevation due to successive depositional events, a geomorphic unit is inundated less frequently and the groundwater table becomes deeper. Plant species possess different inundation tolerances and regeneration requirements, which determine their establishment and survival success. This is especially true for riparian plant species. Each geomorphic unit within the riparian corridors will manifest characteristic vegetation patterns based on that unit's proximity to groundwater, substrate quality, and inundation pattern.

Vegetation is "all the plant species in a region, and the way they are arranged." Vegetation appears as a mosaic of numerous, definable plant stand types (Saywer and Keeler-Wolf 1995). The dominant canopy plant species defines the stand type, such that if there is a shift in species dominance, there is also a corresponding shift in stand type. Plant stands are the smallest vegetation *units* studied.

In the Mono Basin, contemporary riparian vegetation patterns have resulted from decades of flow impairment, followed by years of rewatering and recovery. Native vegetation in the basin is composed of desert as well as riparian plant stands. The goal of riparian vegetation monitoring in the Mono Basin is to assess vegetation recovery, detect changes in stand area, stand species composition, age, and canopy structure, and then relate these changes to independent variables such as climate, hydrologic regime, proximity to channel and groundwater, and substrate quality.

5.1.1 Sampling Design

Riparian vegetation and geomorphic units were mapped within the riparian corridors of four tributaries to Mono Lake (Rush, Lee Vining, Parker, Walker). These maps were presented in our RY 2000 Report (McBain and Trush 2000). We used low altitude aerial photographs in the field (1 inch=175 ft), mapped 24 plant stand types and grouped them into four general types: aquatic, riparian, transition, and desert (Table 8).

During summer 2001, we completed the field component of the riparian vegetation monitoring with intensive vegetation sampling within the entire riparian corridors of Rush Creek and Lee Vining Creek. This work included (1) sampling *plant stand composition* with numerous (n=168) nested frequency transects with locations randomly selected within the riparian corridors, and (2) quantifying *plant stand structure* along valley-wide band transects within our established study sites on Lee Vining Creek (n=2) and Rush Creek (n=3).

Riparian vegetation recovery monitoring encompassed the riparian corridors of creeks, but did not extend to the headwaters. Monitoring began at the lake and extended to Highway 395 or LA DWP intake structures. The riparian corridor includes the land adjacent to the streams with sufficient amounts of groundwater in (excess of local precipitation) to allow vegetation growth (Warner and Hendrix 1984, McBain and Trush 2000). The extent of groundwater influence defines the riparian corridor and the lateral extent of monitoring. On Lee Vining Creek and Rush Creek (and Parker and Walker downstream of Hwy 395), the riparian corridor extends from valley toe-slope to toe-slope. Above Hwy 395, Walker and Parker Creeks have no definable valley borders or groundwater measurements to determine corridor width. For these streams, the riparian corridor was defined as the zone in which vegetation influences the aquatic system (~100 meters). The longitudinal extent of riparian vegetation monitoring along the four tributaries:

- began at the Grant Lake spillway and extended to Mono Lake for Rush Creek,
- began below highway 395 and extended to Mono Lake for Lee Vining Creek and
- began at the Lee Vining Creek Conduit for Parker and Walker Creeks and extended to their respective confluences with Rush Creek.

Ideally, vegetation mapping should occur during the fall of one season and the stand description data should be collected the following spring and summer. Due to logistical difficulties for our initial sampling, however, riparian vegetation was mapped in the fall 1999, but sampled in the summer 2001. Stand composition sampling occurred at the peak of the flowering season to include as many species as possible. Structural data were collected later to emphasize the location, age, and size of woody plants. Sampling dates are presented in Table 9.

Table 8. Vegetation stand types mapped within the riparian corridors of Rush and Lee Vining Creeks.

MCBAIN & TRUSH (2000) PLANT STAND TYPES (ADAPTED FROM SAWYER 1994)	MCBAIN & TRUSH (2000) COARSE SCALE COVER TYPE	JONES & STOKES (1993) FINE SCALE VEGETATION COVER TYPE	JONES & STOKES (1993) COARSE SCALE VEGETATION COVER TYPE	NDDB DATA BASE/HOLLAND TYPE
1) Aquatic Vegetation	Aquatic	N/A	Aquatic vegetation	Montane Freshwater Marsh (52340 in part)
2) Bitterbrush	Desert	Decadent bitterbrush scrub	Great Basin scrub	Great Basin Mixed Scrub (35100)
		Mature bitterbrush scrub		
		Establishing bitterbrush scrub		
3) Black cottonwood	Riparian	Decadent cottonwood-willow	Mature floodplain vegetation	Montane Black Cottonwood Forest (61530)
		Mature cottonwood-willow		
		Establishing cottonwood-willow		
4) Buffaloberry	Transistion	Decadent mixed riparian scrub	Mature floodplain vegetation	Great Basin Mixed Scrub (35100)
		Mature mixed riparian scrub		
		Establishing mixed riparian scrub		
5) Cattail	Aquatic	N/A	Aquatic vegetation	Montane Freshwater Marsh (52340 in part)
6) Ephedra	Desert	N/A	Great Basin scrub	Great Basin Mixed Scrub (35100)
7) Great Basin grassland	Riparian	Mixed riparian meadow	Wet meadow	Great Basin Grasslands (43000 in part)
		Pasture		
8) Jeffery pine	Riparian	Decadent conifer-broadleaf	Mature floodplain vegetation	Jeffery Pine Forest (85100)
		Mature conifer-broadleaf		
		Establishing conifer-broadleaf		
9) Lupine	Riparian	Sparsely vegetated floodplain	N/A	Great Basin Grasslands (43000 in part)
10) Mixed desert rose	Transition	Decadent mixed riparian scrub	Mature floodplain vegetation	Great Basin Mixed Scrub (35100)
		Mature mixed riparian scrub		
		Establishing mixed riparian scrub		
11) Mixed riparian rose	Transition	Decadent willow scrub	Mature floodplain vegetation	Southern Willow Scrub (63320 in part)
		Mature willow scrub		
		Establishing willow scrub		
12) Mixed willow	Riparian	Decadent willow scrub	Mature floodplain vegetation	Southern Willow Scrub (63320 in part)
		Mature willow scrub		
		Establishing willow scrub		
13) Mountain mahogany	Desert	Decadent mixed riparian scrub	N/A	Semi-Desert Chaparral (37400 in part)
		Mature mixed riparian scrub		
		Establishing mixed riparian scrub		
14) Narrowleaf willow	Riparian	Decadent willow scrub	Mature floodplain vegetation	Southern Willow Scrub (63320 in part)
		Mature willow scrub		
		Establishing willow scrub		
15) Quaking aspen	Riparian	Decadent aspen	Mature floodplain vegetation	Aspen Riparian Forest (61520)
		Mature aspen		
		Establishing aspen		
		Establishing rabbitbrush scrub		

Table 9. Stand composition and structure sampling dates for RY 2001

SITE	Stand Composition Sampling	Stand Structure Sampling
LEE VINING CREEK	24 May 2001 to 7 June 20001	18 June 2001 to 27 July 2001
RUSH CREEK	18 July to 23 July 2001 and 19 June to 26 June 2001	18 June 2001 to 27 July 2001

Data will be used for the following analyses:

- Species composition changes within mapped plant stands (from nested frequency transects)
- Scorecard rating of stand quality, similar to Weixelman (et al. 1999) (from nested frequency transects)
- Current vegetation layers (% tree, % shrub) occupied for dominant stands (from nested frequency transects)
- Species and stand types related to discharge and geomorphology (from band transects)
- Characterize the stand species, age, and size structure (from band transects)
- Document woody riparian species establishment ranges (from band transects)

5.2 Mapping Methods

The primary objective of riparian vegetation mapping is to delineate plant stand boundaries within the riparian corridors for comparing riparian acreage values to previous measurements and pre-established termination criteria. Beginning in 1999 and occurring every five years, changes in vegetative cover and geomorphic unit area within the riparian corridor will be quantified via air photo analysis. A vegetation scientist will map individual plant stands and geomorphic units within the riparian corridors on low altitude orthorectified aerial photographs enlarged to at least a scale of 1:1800. This scale was used for mapping 1999 vegetation, and provides good resolution for vegetation mapping.

Plant stands and geomorphic units were mapped *in the field*. Individual plant stands were defined based on the dominant plant species in the canopy. Geomorphic units were defined by distinct changes in ground surface elevations. We defined fifteen different geomorphic unit types (Table 10). Of these fifteen geomorphic units, eight types were alluvially influence in the recent past (<200 yrs). Geomorphic units and stand perimeters can be outlined on Mylar overlaying the aerial photos, or directly on laminated copies of air photos (Figure 17). The mapped stands were labeled using the dominant plant species found in the canopy. Geomorphic units were numbered sequentially starting with the wetted channel as unit-0. Mapped plant stands were no smaller than 9m^2 (3x3 meters), the smallest geomorphic unit was approximately the same size. Following the field mapping component, geomorphic units and plant stands were digitized and entered into GIS-compatible software. The following information was collected from the maps:

- areal extent of all plant stand types, and
- the geomorphic units affiliated with each plant stand.

The GIS database will be updated and queried with each subsequent monitoring event to detect changes in the areal extent of different stand types and affiliated geomorphic units.

Table10. Geomorphic units mapped in RY1999 within Lee Vining and Rush creek riparian corridors.

Geomorphic Unit Number	Geomorphic Unit Name	Common Plant Stands Associated with Geomorphic Units	Description
0	Stream Channel	aquatic/emergent	active channel
1	Point, Transverse, and Medial Bars	Lupine	These active deposits may be mobilized frequently mobilized (< 10 year events) by smaller floods, and abandoned by incision during higher floods (<10 year events)
2	Floodplain	Lupine, mixed willow	Deposition is widespread across these surfaces during smaller events occasional scour by large floods; active floodplains
3	Low Terrace	Black cottonwood, mixed willow, yellow willow, narrowleaf willow, rose, Great Basin grassland	Channel incision, sediment plugging, and migration during 1995-97 floods scoured and abandoned these surfaces
4	Middle Terrace	Black cottonwood, narrowleaf willow, bitterbrush, rabbitbrush	Channel incision, sediment plugging, and migration during 1967-69 floods scoured and abandoned these surfaces
5	High Terrace, Pre 1941 Floodplain	Black cottonwood, mixed willow, yellow willow, narrowleaf willow, rose, buffalo berry, sage, bitterbrush	Active depositional surfaces prior to streamflow diversion
6	Pre-1941 Low Terrace	Sagebrush, bitterbrush, mixed willow	Cause for incision and abandonment unknown, presumed to be lake lowering related, potentially a floodplain prior to the end of the little Ice Age in 1850. Remnant willow stands indicate its hydrologic connectivity to streamflow prior to diversion
7	Pre-1941 Middle Terrace	Sagebrush, bitterbrush	Cause for incision and abandonment unknown, presumed to be climatically related
8	Pre-1941 High Terrace/ Climatic Low Terrace	Sagebrush, bitterbrush	Cause for incision and abandonment unknown, presumed to be climatically related
9	Climatic Middle Terrace	Sagebrush, bitterbrush	Cause for incision and abandonment unknown, presumed to be climatically related
10	Climatic High Terrace	Sagebrush, bitterbrush	Cause for incision and abandonment unknown, presumed to be climatically related
11	Tioga Age Glacial Till	Sagebrush, bitterbrush	Stream incision through these deposits occurred following the recession of Glaciers at the end of the last Ice Age
18	Cut Bank	open	Cut banks are result of channel migration and was mapped in association with geomorphic units 2-9
19	Human Disturbance	open	These sufaces are found throughout riparian corridors and are typicaly associated with parking areas and mining activites
21	Arroyo	Bitterbrush	Seasonal flow through these channels

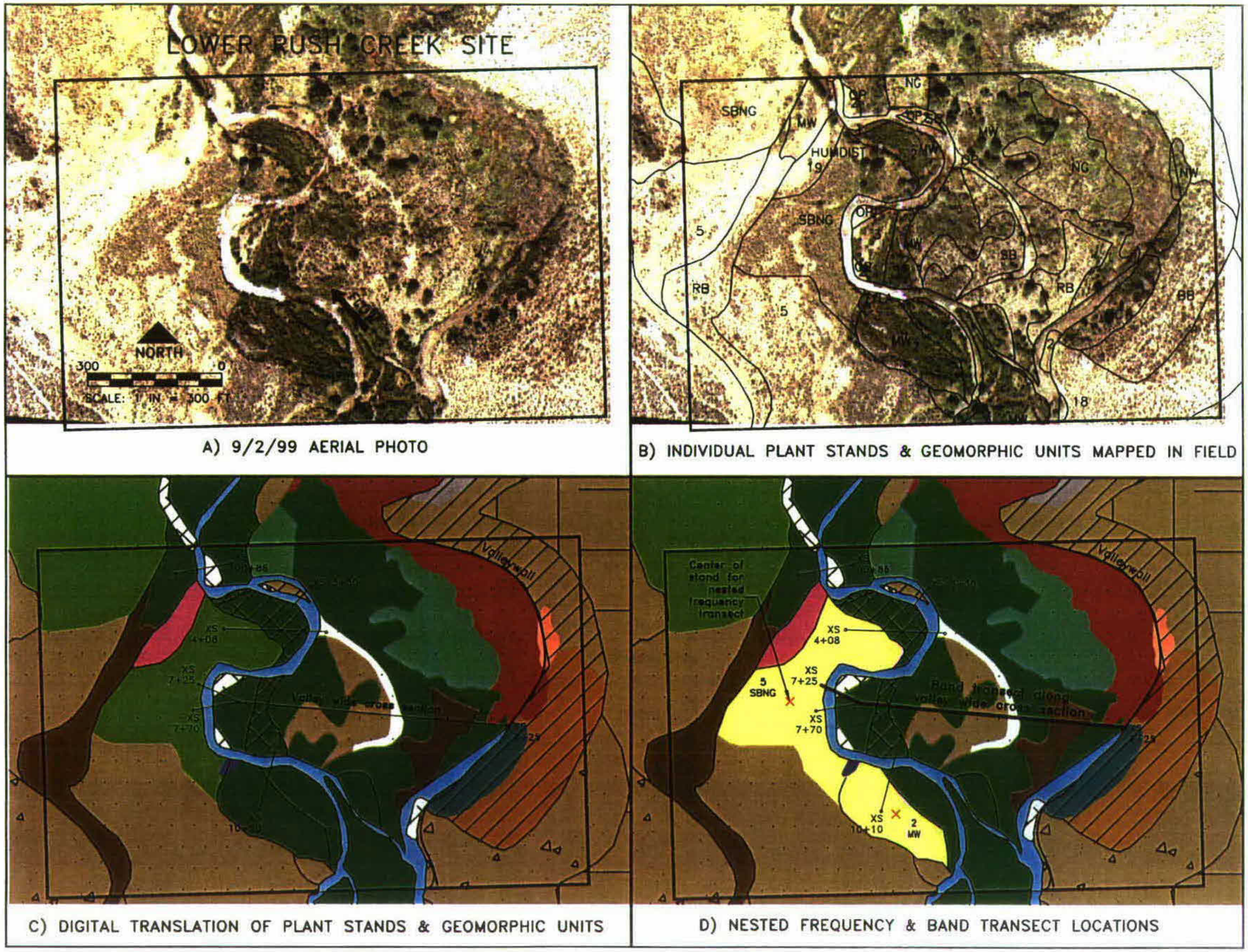


Figure 17. Example of geomorphic unit mapping conducted in Rush and Lee Vining Creeks.

5.3 Nested Frequency Transect Methods

Plant species composition within plant stands, and the area covered by terraces, floodplains, and active channel deposits, will change as the riparian corridor recovers. Plant stands affiliated with discrete geomorphic units were sampled in the Rush and Lee Vining creek riparian corridors using a nested frequency transect method (Figure 18). This method establishes permanent transects, then samples plant composition within three quadrats nested within a 1-meter by 1-meter frame along a 15 m transect (Figure 18). These permanent transects were initially randomly selected from geomorphic units 1 through 8 within the riparian corridors mapped in 1999 and established in the field in 2001. Monitoring change in species frequency within the smallest quadrats is a precise way to evaluate composition change.

5.3.1 Objectives

The specific objectives of the nested frequency sampling are:

- Quantify species composition and structure (stand characteristics) within the most frequently occurring stands on different geomorphic units within the riparian corridor;
- Compare current stand characteristics to potential natural characteristics, quantified using reference stands;
- Employ a method that minimizes sampler bias and errors during and between sampling periods.

The nested frequency transect work has three components: stand type selection, field sampling, and data analysis. These components are described below.

5.3.1 Stand type selection

Nested frequency transects were randomly selected from plant stands mapped in the fall of 1999. Although randomly selected before the first sampling, these transects were permanently monumented as permanent sampling locations for all subsequent monitoring. Selected plant stands were stratified by the geomorphic unit. Sampling all stands on all geomorphic units would be cumbersome and unnecessary. We identified the stand types that covered the most area, and focused on these stand types. Nested frequency transects will be sampled every five years starting in 2000.

We focused on the stand types that covered the most area on any given geomorphic unit within the riparian corridor. Within each of eight alluvial geomorphic units identified, we randomly selected three stands of each stand type, which, in combination with other stand types or by themselves, made up at least 80% of the vegetative cover on each geomorphic unit. For example, geomorphic unit 2 (floodplains) in Rush Creek, had four stand types comprise 84% of the total vegetative cover (Table 11). From each of these four stand types, we then randomly selected three stands for placement of nested frequency transects. The selected stand was color-coded and the center point identified Figure 18). Within the Lee Vining Creek corridor, we randomly selected 93 plant stands for nested frequency sampling; on Rush Creek 75 plant stands were selected. A complete set of maps was developed and laminated for field use in locating the nested frequency transect monuments.

5.3.2 Field Sampling

During the 2001 field season, plant stands randomly selected for nested frequency transects were located in the field. Transects 15 meters in length were placed in the center of the stand parallel to the stream flow (Figure 18). Transect endpoints were monumented with a piece of ½-inch rebar and marked with 1-inch aluminum tags stamped with the transect name and the bearing from magnetic

Table 11. Stand types mapped on geomorphic unit 2 (active floodplains) within the Rush Creek riparian corridor. Bolded stand types in combination make up over 80% of the total cover on this geomorphic surface.

Stand Types Growing on Geomorphic Unit 2	*Area (Acres)*	*Percent Of Total Cover*	*Stand Types In Bold Cumulative Percent Of Total Cover*
Aquatic Vegetation	0.935	6%	
Black Cottonwood	0.475	3%	
Cattail	0.011	0%	
Great Basin Grassland	**1.618**	**10%**	**10%**
Lupine	0.424	3%	
Mixed Willow	**6.836**	**44%**	**54%**
Narrowleaf Willow	**3.546**	**23%**	**77%**
Shiny Willow	0.008	0%	
Rabbitbrush	0.005	0%	
Rose	0.271	2%	
Sagebrush	0.417	3%	
Yellow Willow	**1.014**	**7%**	**84%**
Total	15.561	100%	84%

north to the other endpoint. A metric measuring tape was strung between transect endpoints, with the zero station at the downstream end. Transects were sampled using three quadrats nested within one frame. The largest quadrat measures 1-meter by 1-meter ($1m^2$), with ½ m^2 and ¼ m^2 nested quadrats. The quadrat frame was placed on the streamward side of the tape with the smallest quadrat (¼ m^2) at the downstream end (Figure 18).

We documented species presence within each quadrat and vegetation layer. Plant species composition is important to understanding species structure and abundance. However, the layering of vegetation and the complexity of these layers compose habitat roughness, or stand structure, and is equally important. Plants generally possess a genetically determined range of attributes, such as maximum attainable height (e.g., sagebrush rarely grow taller than 1 meter). Initially height is a function of age. However, growth rates to reach maximum attainable heights are often variable and may be suppressed. In addition to species richness (presence/absence), the plant height structure within each stand was described using three broad vegetation layers: tree, shrub, and herb (Figure 19). Plants within each quadrat were tallied within one of these three different vegetation layers based on height. A plant was tallied in the herb layer if it was shorter than 1.5 meters, in the shrub layer if it grew between 1.5 and 5 meters, and in the tree layer if taller than 5 meters. A plant could occupy any individual layer or combination of layers.

5.3.3 Data Analysis

Two types of frequency analyses will be applied to the data (Grieg-Smith 1983, Bonham 1989, Kent and Coker 1993, Elzinga et al 1998). Simple frequency is the count of rooted plant species within each quadrat without regard to plant height; plants must be rooted within the quadrat to be counted. Layered frequency is an expanded analysis that considers different vegetation layers within each quadrat; plants need not be rooted within the quadrat frame to be sampled. Simple frequency is a better measure of species density, while layered frequency is a better measure of species cover and a coarse measure of stand structure (Grieg-Smith 1983). The analysis can be combined, because analyzing the species occurrence in the herb vegetation layer would essentially provide the same

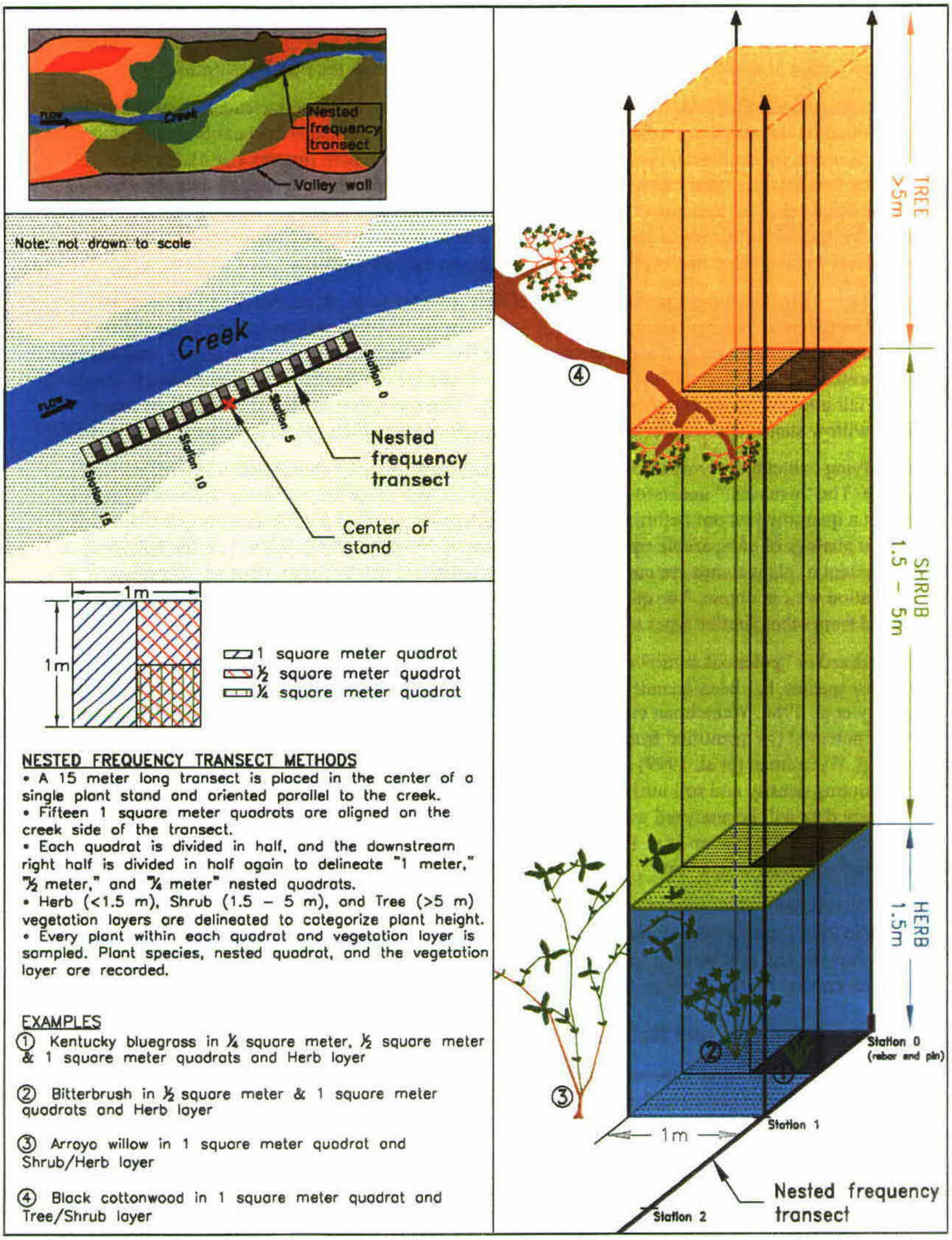


Figure 18. Illustration of the riparian vegetation "nested frequency transect" sampling procedure used within randomly selected plant stands along Rush and Lee Vining Creeks.

results as a simple frequency analysis. A bonus from collecting species presence/absence data within vegetation layers is that for each sampled species, we can assess the percentage of vegetation layers occupied within a stand type, within a geomorphic unit, and within the riparian corridor.

Riparian stands should prefer to grow on geomorphic units close to the active stream channel or near springs/shallow ground water tables. Transitional stands and desert stands may exhibit no geomorphic unit preference. Environmental conditions on geomorphic units where riparian stands "recover" influences the understory, or associated species in the stand, potentially making species composition within riparian stands another measure of recovery. For example, riparian stands growing on floodplains and high water channels (i.e., lower in elevation to the wetted channel) should contain more obligate and facultative wetland plant species than stands growing on the low terrace.

An analysis using algorithms included in the pcORD software (e.g., W.M. Post and J.D. Shepard's method) will cluster similar stands together. These clusters will be based on species composition in different vegetation layers, and stand location on different geomorphic units. The cluster analysis will be presented as a dendrogram. For example, based on species composition, all mixed willow stands should fall into one major branch of the dendrogram. The one major branch should fork because mixed willow stands could differ due to growing conditions found on the different geomorphic units.

Quantifying contemporary riparian stand structure and comparing to pre-diversion conditions is not feasible. The 'historical" understory components and canopy cover are extremely difficult to recreate without a quantified record before large-scale alterations occurred to the riparian ecosystems, or else remnant analogs of comparable riparian stands within the diverted tributaries (i.e., reference stands). Areal extent of plant stands are currently the best quantifiable pre-diversion riparian vegetation information we can obtain. The quality, or structural attributes, of currently growing stands must be inferred from other similar types of stands in the Eastern Sierra.

An idealized or "potential natural community" (PNC), developed from a multivariate analysis of indicator species, has been quantified in the literature for many of the plant stand types we mapped (Mosely et al. 1986, Weixelman et al. 1999). The PNC therefore provides a basis for comparing a stand's potential (as quantified from reference stands sampled elsewhere) to the actual conditions we sampled. Weixelman (et al. 1999) quantified plant stand similarity to the potential natural community using rooting density and soil infiltration, in addition to species composition. The collected nested frequency data will be analyzed using the list plant species for each potential natural community type taken from Weixelman et al. (1999). The potential natural community and sampled stands are compared and rated with a "low", "moderate", or "high" degree of similarity.

Currently no useful PNC exists for rose and black cottonwood dominated stands in the Eastern Sierra (Zamudio 2000). However, a potential natural community was developed for black cottonwood in central Nevada and will be used for comparing black cottonwood stands sampled along Lee Vining and Rush creeks. No comparison will be made for rose dominated stands.

5.4 Band Transect Methods

The objectives of the band transect sampling differ from the nested frequency transects. In addition to simply describing the plant stand composition (nested frequency transects), the band transects monitor riparian vegetation structural changes, woody plant recruitment and species distribution along band transects, and relates these changes to channel morphology, annual flow regimes, and plant physiology and ecology. Band transects will be monitored every five years during riparian vegetation inventories. With recovery, there should be an increase in physical and age structural diversity within the riparian corridor. Structural diversity should reflect structure on similar, less disturbed streams regionally, however, no reference stands currently exist.

Specific objectives of band transect sampling are:

- Document the bank location of riparian woody plant initiation, establishment and mortality in our geomorphic study sites (planmapped reaches)
- Document current riparian hardwood demographics within discrete vegetation layers and model reaches correlating these demographics with distance from, and elevation above, the wetted stream channel.
- Assess riparian woody plant recruitment patterns on the different geomorphic units, and the tendency of each woody riparian species to establish in discrete locations along the stream bank.
- Relate initiation and establishment patterns to inter- and intra-annual streamflow variations (e.g., magnitude, timing, duration, frequency, and rate of change), woody riparian plant physiology, and phenology.

5.4.1 Band transect location selection

Valley wide cross sections (and therefore band transects) are in the general vicinity of piezometers (where possible), with one valley wide cross section in each study site on Lee Vining and Rush Creeks. Each valley wide cross section encompasses a range of geomorphic units and stand types, and extends from valley toe-slope to toe-slope (Figure 19). Band transects therefore bisect terraces, floodplains, point bars, and the active channel (but not necessarily all the types of geomorphic units mapped). The range of geomorphic units intersected allows vegetation structure to be evaluated in a geomorphic and hydrologic context.

Intensive study reaches presumably are exemplary of stream morphology and recovery potential and the band transects attempt to encapsulate this. Assessing how woody riparian plant initiation and establishment (i.e., recruitment) relates to model conditions provides insight into the streamflows patterns important to the development and maintenance of the riparian corridor. Band transect sampling is not intended to be statistically extrapolated throughout the Mono Basin, but is intended to tell the story of how riparian vegetation interacts with geomorphic and hydrologic processes among our study sites. Each valley wide cross section was monumented and surveyed, with water surface elevations surveyed over a wide range of discharges.

The proximity of our band transects to previously surveyed geomorphic cross sections and the piezometer stations is critical to our evaluations; valley wide cross sections have fully developed hydraulic geometries, two with surveys dating from 1995. In addition, collection of groundwater data will allow us to assess whether recovering vegetation influences the groundwater depth or vice versa and potentially provide insight into mechanisms that create favorable environments for the clonal spread of some riparian plant species (e.g., Wood's rose encroachment onto terraces).

5.4.2 Vegetation sampling

Band transect sampling follows standard sampling methods (Bonham 1989, Kent and Coker 1992). Band widths were selected based on the frequency and size of plant species, and the potential to include woody riparian plants growing in the tree, shrub, or herb vegetation layers. For example, woody riparian plants shorter than 1.5m (usually seedlings) frequently occur as dense patches. Consequently, band width does not have to be large to sample a sufficient number of plants to describe the spatial variation, density, age, and size structure of these shorter plants. Sample size and the number of measurements needed to address the variation in hardwood size along the transect were considered when determining band width.

Three bands of different width (1, 5, and 10 meters) were nested within the band transect, with the band transect centered on the valley-wide cross section (Figure 19). Woody riparian plant species located within nested bands were recorded. For example, woody riparian plants within the "tree" vegetation layer (i.e., all plants 5 meters and taller) were measured within a 10 meter wide band extending 5 meters to each side of the cross section. The field teams recorded the cross section station where plant stand boundaries changed, and assigned cover estimates to plant species (using a Daubenmire scale [Bonham 1989, Daubenmire 1959]) within each stand type. Within each stand type intersected along the band transect, we listed herbaceous and woody desert plants and measured woody riparian plants. We measured (1) all isolated riparian woody plants greater than 5 meters tall rooted within the 10 meter band, (2) riparian woody plants between 1.5 and 5 meters tall rooted within the 5 meter band, and (3) woody riparian plants less than 1.5 meters tall or those woody riparian plants in a thicket (defined as >100 stems/m^2) rooted within the 1 meter band (Figure 19).

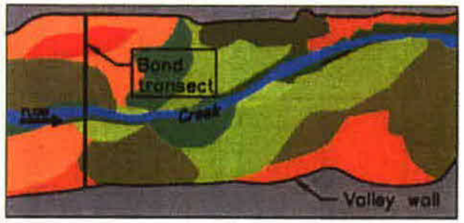
Specific woody riparian plant measures included species, the rooting location, height and root collar diameter, and age estimates. If the woody plant was shrub, field teams documented height of longest stem, age estimate of longest stem, basal area of stem mass, stem number (if less than 20) and/or height and root collar diameter. The limit of noticeable soil moisture along the cross section was noted.

Observed plant habit (tree shrub or herb), tree diameter, and basal area were parameters used to indicate structural diversity. Wherever possible plant age estimates were taken concurrently with structural measurements (either by counting terminal bud scale scars). Tree diameter and basal area were selected because they are easily repeated through time with minimum sampler bias. Plant habit was selected because different wildlife species are associated with different plant habits. In addition, tree diameter was related to tree height, crown area and volume (i.e., the principal components of structural diversity).

5.4.3 Analyses for RY 2002

We are preparing maps of riparian woody species locations and stand types along each valley wide cross section. Woody plant rooting locations and the boundaries of each patch type will be overlain on the cross section. Proximity and rooting location of riparian species relative to the primary and secondary stream channels will be evaluated. Groundwater measurements plotted on the cross section will be evaluated relative to streamflow and riparian hardwood species locations. We will assess whether stand types exhibit preference in the bank locations where they establish. Stand boundaries must be "normalized" for comparison between band transects by converting patch boundary transitions to an inundation frequency.

A plant species list will be prepared of all plant species present within each stand type intersected by the valley wide cross section/band transect. Species will be listed in order of area covered, starting with the dominant species found in the patch. The plant list prepared from band transect sampling should support results from the corridor wide stand description sampling (nested frequency sampling), but not replace them. Percent cover within each stand type and within the herb, shrub and tree vegetation layers (% cover/m^2 or % cover/hectare) will be used to evaluate vegetative cover that each patch type and plant species provide within valley walls along the band transect.



BAND TRANSECT SAMPLING METHOD

- Transects located in planmap reaches.
- Transects perpendicular to flow and extends valley toe to valley toe on the valley wide cross sections.
- All species of plants identified within the 10 meter band.
- All woody riparian plants less than 1.5 meters in height within the 1 meter band are identified (species), located (station and distance/direction from transect) and measured (age, height, and root collar diameter). Plant stand boundary intersections are identified.
- All woody riparian plants 1.5 meters to 5 meters in height within the 5 meter band are identified, located and measured.
- All woody riparian plants greater than 5 meters in height within the 10 meter band are identified, located and measured.

EXAMPLES

① Black cottonwood seedling at transect station 140
located 0.19 meter downstream of transect
age = less than 1 year
height = 0.63 meter
root collar diameter = 0.12 centimeters

② Narrowleaf willow at transect station 125
located 1.22 meters upstream of transect
number of stems = 15
age = 6 years
height = 2.33 meters
basal area = 1 square meter

③ Black cottonwood at transect station 190
located 3.79 meters downstream of transect
age = 23 years
height = 25 meters
root collar diameter = 75 centimeters

④ Jeffery pine at transect station 220
located 2.33 meter downstream of transect
age = 22 years
height = 5 meters
root collar diameter = 150 centimeters

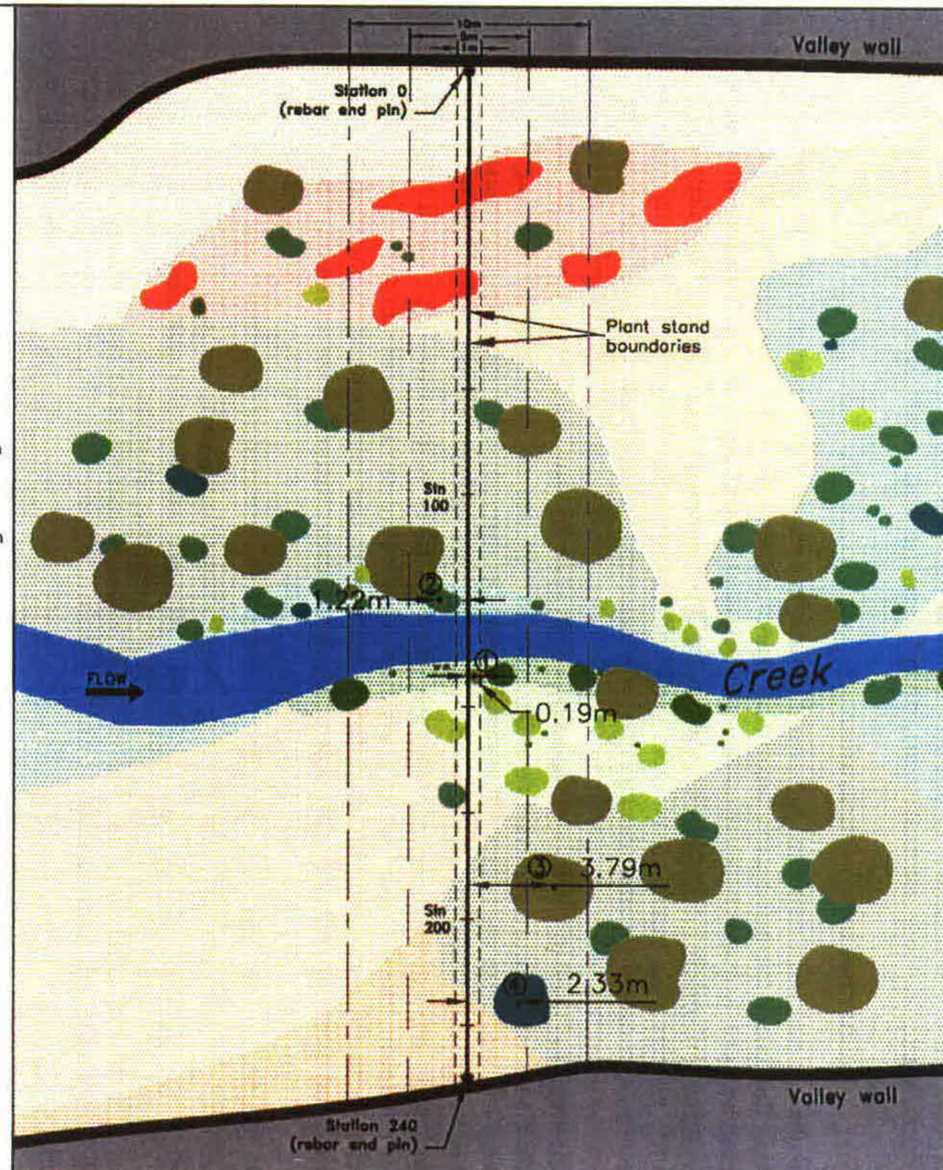


Figure 19. Illustration of the "band transect" riparian vegetation sampling procedure used along valley-wide cross sections on Rush and Lee Vining Creeks.

6 CHANNEL CONSTRUCTION AND REVEGETATION PROJECTS

Three projects are recommended for implementation in RY 2002: the "8-Channel Invert Excavation", the "Rush Creek 3D Floodplain Restoration Project", and the "Narrows Pilot Revegetation Project."

6.1 8-Channel Invert Excavation

The 8-channel on Rush Creek once provided flow conveyance to a major portion of the bottomland's left bank floodplain. We recommend that the 8 channel's entrance, now plugged with coarse bed material, be partially excavated to allow access of snowmelt floods only. This excavation will require removing approximately 2.5 ft of coarse cobbles for 200 ft at the entrance (Figure 20). A dense row of woody riparian trees along the mainstem's left bank and spanning the 8-channel entrance provides protection from stream capture. This spring's snowmelt runoff (optimistically at least 380 cfs as the peak flow) should provide the opportunity to empirically develop a stage discharge relationship at the entrance required to establish the excavation depth. The primary purpose for opening the 8-channel entrance is to encourage groundwater recharge in the left bottomland's floodplain to encourage self-recovery of the riparian vegetation. Prior, during, and after spring runoff, groundwater elevation will be monitored at several floodplain locations to establish a pre-runoff baseline and seasonal trend. We are particularly interested in documenting a long-term effect on groundwater elevation caused by a single spring runoff event, i.e., How long does the effect on groundwater elevation of a single runoff event last? Excavation of the side channel entrance should be completed by early-fall. No manipulation of the side channel morphology is planned, only configuring the entrance for high flows.

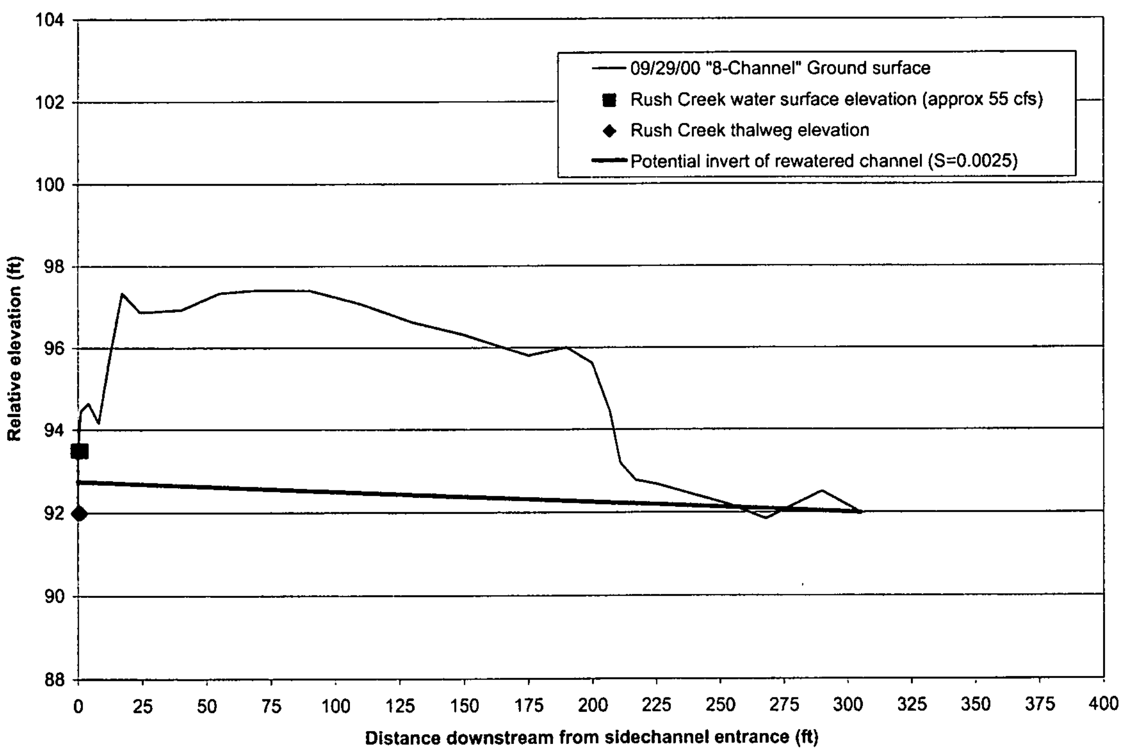


Figure 20. Longitudinal thalweg profile through the entrance to the 8-Channel of Lower Rush Creek.

6.2 Rush Creek 3D Floodplain Restoration Project

The State Water Board Order 98-05 stated:

"The abandoned east side channel in Reach 3D, extending from elevation 6639 to 6614, will be re-watered. The channel will be restored as the main channel and only 5 cfs will be allowed to flow down the present main channel when flows in Rush Creek are 47 cfs as measured at the Mono Gate Return Ditch."

In September 2001, McBain and Trush developed and presented five alternative design options during a field tour of the site. Potential benefits were weighed against potential adverse impacts of relocating the main channel to the abandoned east side channel. Based on our field observations and numerous discussions, McBain and Trush have recommended a variation of Design Option-3, which involves leaving the channel in its present location, lowering the elevation of the right bank floodplain to allow approximately 250 cfs to inundate this floodplain, then re-vegetating portions of this surface with native vegetation. A draft Technical Memorandum titled **"Rush Creek "3D" Floodplain Restoration Project Description, Conceptual Design, and Project Implementation Plan"** was completed and presented to LA DWP March 5, 2002. This draft conceptual design is presented here.

6.2.1 Rush Creek "3D" Floodplain Existing Conditions

The Rush Creek 3D Floodplain Restoration project area extends from the "Narrows" 1,375 feet upstream to the eastern extent of Desert Aggregates plant operations (Figure 1). This project area includes floodplains on the right and left banks extending from the channel and terminating at the base of the surrounding high terraces (valley wall). The left bank floodplain is a relatively narrow strip approximately 100 ft wide along the channel margin. The right bank floodplain extends approximately 350 ft to the base of the valley wall. The total project area is approximately 10 acres.

The right bank floodplain is the focus of the project. This gravel/cobble surface is nearly devoid of riparian vegetation, and the floodplain elevation is generally too high to allow contemporary high flows to inundate and encourage fine sediment deposition and natural revegetation. This "perched" floodplain condition resulted from extensive coarse sediment deposition on top of the historic floodplain during extremely large floods, facilitated by the lack of riparian vegetation and by the backwater caused by the "Narrows" knickpoint.

The contemporary bankfull channel through this reach has a slope of 1.8%. Finer-grained deposits are sparse within the channel. The channel is straight and incised within banks composed of coarse cobbles resistant to bank erosion under the present flow regime. This unnaturally confined condition increases velocity and shear stress, facilitates scouring of the channel bed, and thus prevents sand and gravel from depositing within the bankfull channel. Modeling current channel conditions using HEC-RAS indicated that flows must exceed 500 to 1,000 cfs to begin inundating the right bank floodplain. The left bank is inundated at the mouth of Walker Creek with Rush Creek flows exceeding 350 cfs; the remaining left bank floodplain was not inundated at any modeled flow (up to 1,500 cfs).

Riparian growth is limited primarily to a few sparse cottonwoods scattered across the right bank floodplain and a thin corridor of willows intermittent along the channel banks. A small stand of thick willows exists on the right bank at the upstream extent of the project; willow and cottonwood grow at the mouth of Walker Creek.

6.2.2 Proposed Restoration Alternative: Scalped Floodplain

The proposed restoration project would remove up to approximately 30,000 yd^3 of coarse gravel and cobble material from the historic floodplain surface, replenish portions of the floodplain with fine sediment, and revegetate the floodplain with native riparian and conifer species in selected areas.

Lowering the elevation would allow the floodplain to inundate at a more contemporary bankfull discharge, projected at approximately 250 cfs.

6.2.3 Project Objectives

- re-grade the right bank floodplain to an elevation that allows inundation during moderate magnitude floods (approximately 250 cfs and greater);
- raise the groundwater elevation across the floodplain to restore native riparian vegetation;
- revegetate the floodplain with native flora to jumpstart natural regeneration of vegetation;
- reduce channel confinement to encourage fluvial geomorphic processes such as bank erosion, lateral channel migration, fine sediment storage, and scouring of pools;
- re-create topographic heterogeneity within the bankfull channel and across the floodplain, to increase and improve habitat complexity.

6.2.4 Project Design

The Conceptual Restoration Designs (Figures 21 and 22) were developed collaboratively by McBain and Trush and LA DWP, and resulted from several field visits and site evaluations. McBain and Trush have surveyed the site, using topographic control established by LA DWP surveyors, to develop the existing topography, and will provide project design topography and grading plans to be implemented by Desert Aggregates and LA DWP construction crews.

6.2.5 Project Implementation

The proposed project will be implemented in four phases within a total period of approximately 6-8 months. The earthworks phases (I-III) will be completed in late-summer/fall of 2002, and the revegetation phase (IV) will be implemented in spring 2003. Monitoring will occur for at least 1 to 3 years following completion of the project. The following task descriptions reference Figures 21 and 22:

I. LA DWP surveying crews, assisted by McBain and Trush, will provide construction "stake-out" of the 10 acre site. Desert Aggregates Mining Co. will initiate the earthworks phase by removing approximately 25,000 to 30,000 yd^3 of coarse sediment material from the surface of the 3D Channel floodplain. This material is composed primarily of coarse gravel and cobble contained within a matrix of finer gravel and sand, and constitutes the majority of the excavation work. Where possible, existing riparian vegetation will be preserved; "save" vegetation will be clearly demarcated in the field with flagging. Several mature black cottonwood trees will be preserved at the site. Several lower elevation backwater depressions and lateral scour channels will be preserved in their present condition.

II. After sediment removal by Desert Aggregates, LA DWP construction crews will complete the earthworks phase by adding and shaping the topographic diversity to the floodplain surface to encourage natural vegetation regeneration and to restore some habitat complexity. This will be accomplished by removing small volumes of additional sediment at selected locations, and stockpiling this material for eventual removal by Desert Aggregates. Phase II will create swales on the floodplain that are inundated frequently (every 1-2 years). Fine silt sediment provided by Desert Aggregates will be added onto the floodplain surface in selected areas to facilitate floodplain soil formation, water retention, and vegetation regrowth. Limited vegetation removal will be necessary along the channel banks to allow the floodplain elevation to be lowered. As much of this vegetation as possible will be stockpiled and preserved, then replanted once the earthworks phase is complete.

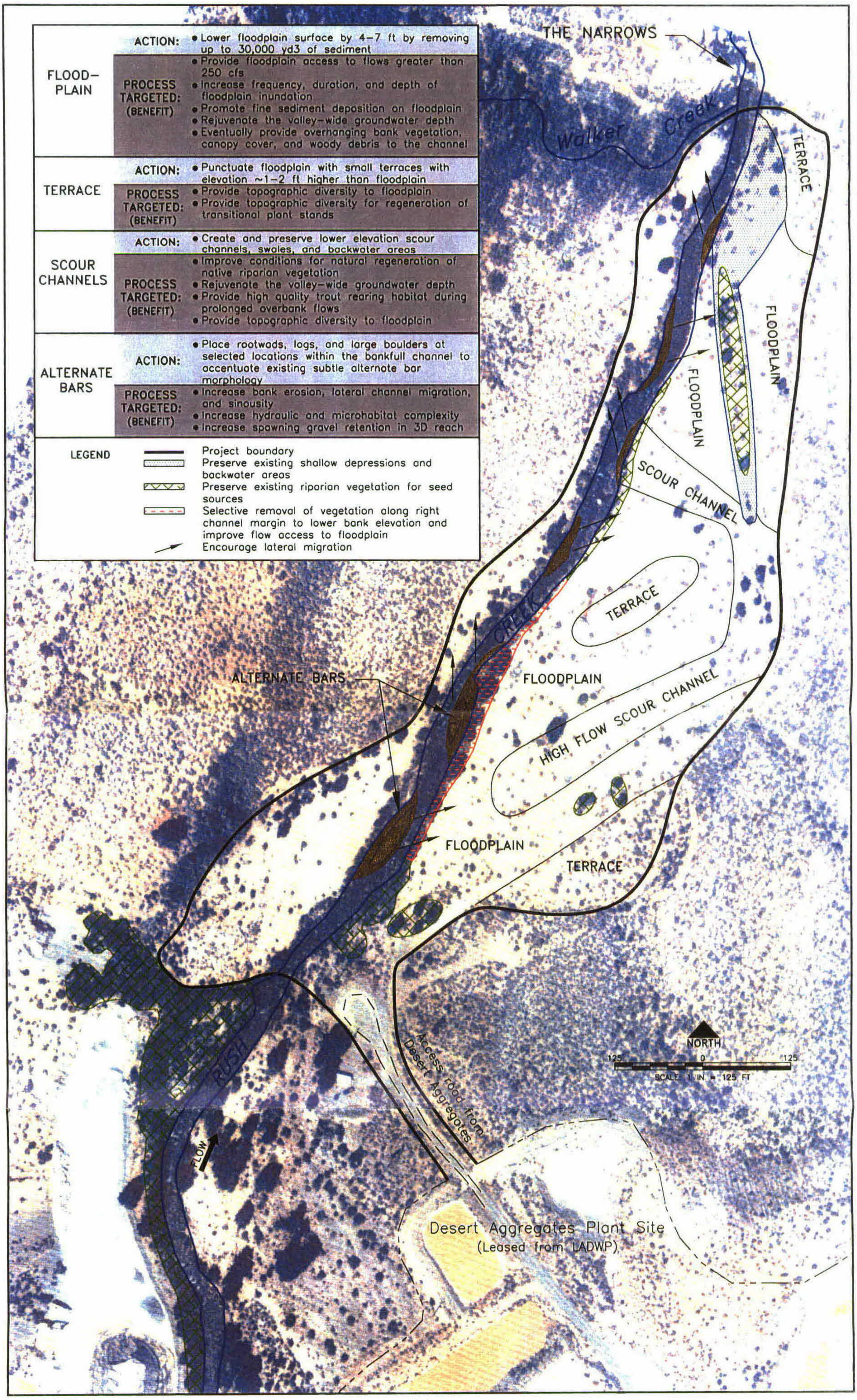


Figure 21. Conceptual restoration design for the Rush Creek 3D Floodplain Restoration Project

Figure 22. Conceptual riparian revegetation design for the Rush Creek 3D Floodplain Restoration Project

monitored to evaluate the effect of annual floodplain inundation on groundwater. The channel along the 3D floodplain will be habitat mapped to document post-construction habitat conditions and to compare future conditions. Tracer rock and scour core experiments may be employed to monitor channel bed mobility.

6.3 Rush Creek Narrows Pilot Revegetation Project

Since restoration efforts in the early 1990's, past revegetation efforts have consisted of planting lodgepole pine (*Pinus contorta* ssp. *murryana)*, Jeffery pine, willows, and black cottonwood. Planting success has been previously quantified in terms of survival/mortality only. The Rush Creek Narrows Pilot Revegetation Project is located along the right bank of Rush Creek just downstream of the Narrows, and proposes to demonstrate and quantify physical factors that contribute to successful Jeffery pine, lodgepole pine, and black cottonwood plantings. Additionally this pilot planting project will experiment with remote irrigation techniques. A pilot planting should be completed during RY 2002 at this site.

6.3.1 Soil moisture investigation

We dug four test pits along the valley wall through coarse sand and small gravel at the Narrows pilot planting site, to investigate soil moisture conditions and determine the potential for plant survival at this site. The ground surface, location of visible soil moisture and the test pit bottom were all surveyed including three ground surface points near the test pits that represent the highest ground surface elevations near the test pits (Table 13). We dug the first test pit 0.5 ft deeper than the Rush Creek main channel water surface elevation, and did not intersected groundwater. Based on our test pit observations, we conclude that the stream is "losing" water in this reach (i.e., the groundwater elevation is lower than the water surface elevation in the stream channel). Generally, measured soil moisture limits were all within 0.5 ft of the ground surface where test pits were dug, suggesting that late spring soil moisture was sufficient to support plant growth.

6.3.2 Pilot Planting Design

Three replicate planting sites are planned for the pilot planting in May/June 2002; one planting site at test pit locations 1, 3, and 4 (Figure 23). One 45 ft by 20 ft planting site is arranged into treatment areas consisting of 18 Jeffery pine, 6 black cottonwoods, and 4 soil moisture sampling stations total. Each irrigation treatment area has three trees planted and irrigated similarly. Trees within irrigation treatment areas are planted at 5 ft on center, and treatment areas are separated by 10 ft. Specific treatments are: planting trees with Driwater, planting trees with water polymers, and planting trees without any water provision (the control). Each treatment area is repeated twice within a planting site.

The irrigation needs of planted trees during the summer months is unknown, and because this site is remote, hand watering or an irrigation system is impartial. Irrigation affects root length and mass. Unfortunately the methods available for measuring irrigation effectiveness are either very coarse, or require destructively sampling the soil column. Two of the soil moisture sampling stations will be destructively sampled using a bucket auger with soil moisture content measured with a gravimetric analysis. Two of the soil moisture sampling stations will consist of gypsum blocks placed in 1 ft increments below the ground surface with soil moisture measured in electric conductivity. Both methods have limitations. Irrigation effectiveness will be compared between methods.

The successes and failures of this pilot planting will be extrapolated to other restoration activities planed for the diverted tributaries (e.g., the 3D Floodplain Project). Mortality monitoring will occur in the late fall to quantify first year success/failure rate.

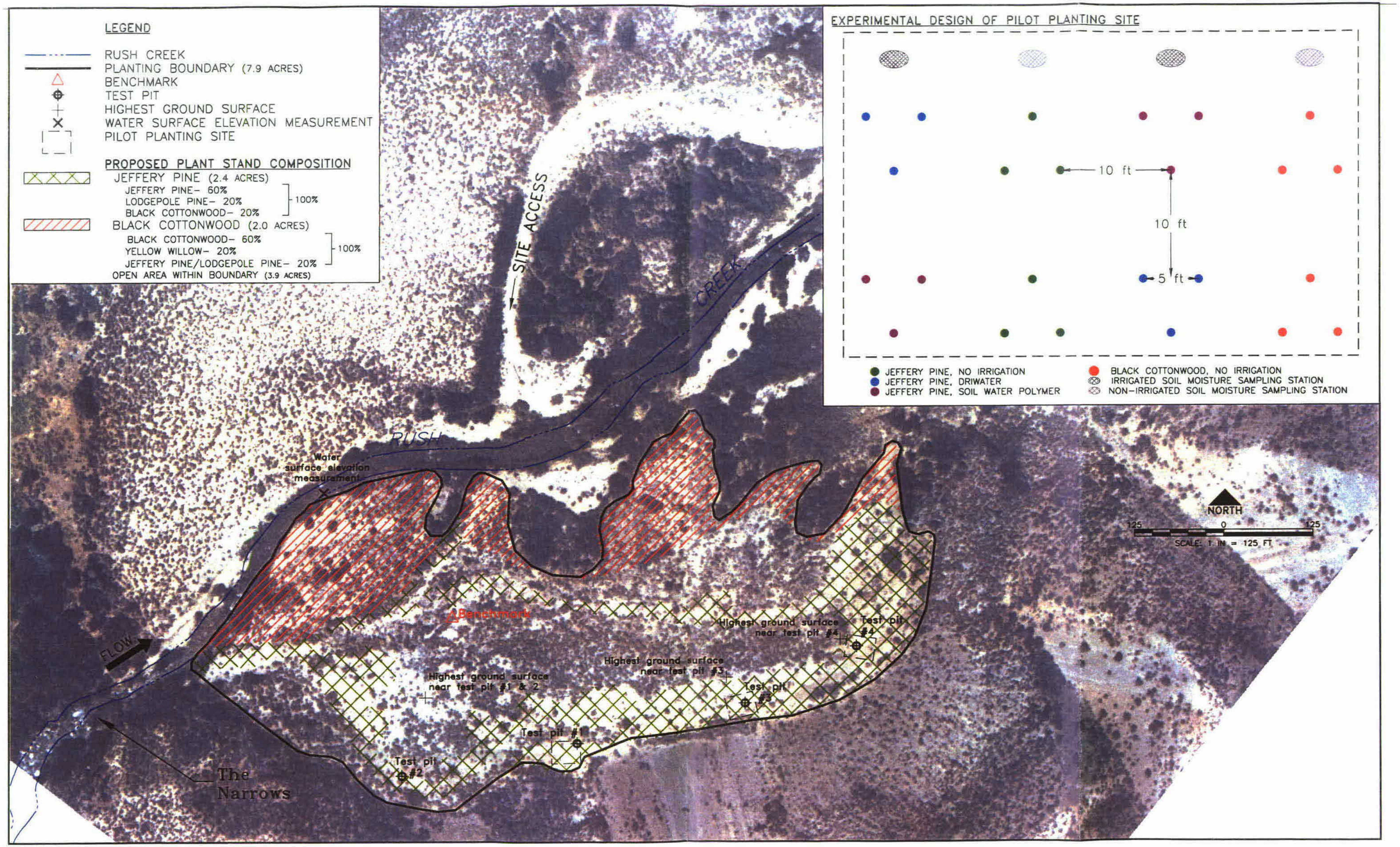


Figure 23. Proposed pilot revegetation project at the Rush Creek Narrows site.

Table 13. Results of the May 2001 soil moisture evaluation at the pilot planting site downstream of the Narrows (Figure 22). All elevations are relative to a benchmark with a 100 ft arbitrary datum assigned. Test pits 3 and 4 were dug downstream of the location where the stream's water surface elevation was surveyed.

	Test Pit #1	Test Pit #2	Test Pit #3	Test Pit #4
The height difference of the maximum ground surface elevation near test pit and the stream's water surface elevation; indicates the maximum potential distance to groundwater.	8.54 ft	8.54 ft	N/A	N/A
The height difference of the maximum ground surface elevation near test pit and the elevation of visible soil moisture; indicates the maximum potential distance to usable water in the soil column.	6.30 ft	3.01 ft	1.81 ft	2.35 ft
The height difference of the test pit ground surface elevation and the stream water surface elevation; indicates the minimum potential distance to groundwater.	2.58 ft	6.13 ft	N/A	N/A
The height difference of the test pit ground surface elevation and the elevation of visible soil moisture; indicates minimum potential distance to usable water in the soil column.	0.34 ft	0.60 ft	0.41 ft	0.46 ft
The height difference of the stream water surface elevation and the elevation of visible soil moisture; indicates the potential capillary fringe.	-2.24 ft	-5.53 ft	N/A	N/A

7 RUNOFF YEAR 2002 MONITORING SEASON

The first quarter of Water Year 2002 (Oct-Dec 2001) showed promise as an average or above-average water year. However, due to dry conditions during the early months of 2002, the initial above-average precipitation conditions appear to have shifted to drier conditions and the March-1 forecast was quite low, at approximately 76% of Normal (LA DWP, personal communication).

Our upcoming monitoring season activities (spring-fall 2002) are somewhat contingent upon receiving at least average or higher snowmelt runoff conditions to collect streamflow and bed mobility data that extend and complement data collected during the past 5 years. Following our monitoring activities during the last two years with another season monitoring below average conditions would be impractical.

The following monitoring activities are presented by category of our Scope of Work:

7.1 MONO-1: Aerial Photography

We will complete the orthorectification of the 1929-30 aerial photo set for pre-1941 riparian area estimates and channel locations; locate, scan and orthorectify the 1993 aerial photo set to re-digitize the earlier riparian inventory and channel locations; and scan and orthorectify the 1999 aerial photo set for contemporary riparian and geomorphic mapping. These and other photos will also be printed and enlarged for mapping and field use as needed.

7.2 MONO-2: Channelbed Monitoring, Streamflow Gaging, Stream Channel Dynamics

Assuming average or higher runoff conditions, we will collect the following "routine" data during RY 2002:

- discharge measurements at established metering sites and water surface elevations at cross sections, at a range of flows to improve flow proportion and stage-discharge relationships;
- cross section and longitudinal profile surveys in established study sites, including thalweg profiles from (1) 10-Channel Return down to the Ford or to County Road site; (2) through the entire 10-Channel reach, (3) Lee Vining Creek upper B-1 Channel from 06+08 down to lower B-1 reach;
- bed mobility and scour experiments at established sites;
- water surface slope and hydraulic geometry relationships at selected cross section sites for bedload transport modeling;
- finish planmapping on Parker Creek;
- continue monitoring water surface stage and hydraulic geometry relationships at selected side channel entrances, including the 8-Channel and 4bii channel;
- survey cross sections and water surface elevations at the 8-Channel entrance to determine appropriate elevation for excavation;
- fill in data gaps for historic channel confinement, roughness, and channel geometry
- produce digital panoramic photo-mosaics at selected flows for study sites, and continue photo monitoring at established photopoints;
- During spring and summer 2002, we will focus data collection on floodplain inundation and sediment depositional processes;

7.3 MONO-3: Lower Rush Creek Gaging Station

- continue discharge measurements at the Rush Creek County Road gaging station for rating curve development;

7.4 MONO-4: Riparian Investigations

Complete Vegetation Analyses

- report on status of riparian vegetation
- make predictions that can be tested during the next round of monitoring
- suggest changes in sampling procedures related to the Blue and White Books

Re-map the 1929 Riparian Corridor

- map and classify riparian vegetation growing within the riparian corridors of Lee Vining, Rush, Parker and Walker creeks, using orthorectified 1929 photos;
- Logically define the riparian corridor within Lee Vining and Rush creeks
- Evaluate the termination criteria based on the results from the new analysis

7.5 MONO-5: Channel Design and Construction

- During spring 2002, McBain and Trush staff will implement the Narrows Pilot Revegetation project, as described in Section 6.3 of this Report
- During fall 2002, McBain and Trush staff will assist LA DWP crews in survey stake-out and construction supervision for the Rush Creek 3D Floodplain Restoration Project, as described in Section 6.2 of this Report.
- During fall 2002, McBain and Trush staff will be available to assist LA DWP crews in construction supervision during excavation of the 8-Channel Entrance; McBain and Trush will provide elevational design criteria for excavating to depths appropriate for inundation targets;

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Mono Lake Waterfowl Restoration Project
Compliance Checklist
2001

Hydrology	**Attachment 1**
Mono Lake Elevation	☑
Walker Creek Flows	☑
Parker Creek Flows	☑
Lee Vining Creek Flows	☑
Rush Creek Flows	☑
Mono Basin Exports	☑
Limnology	**Attachment 2**
Meteorology	☑
Physicochemical Variables	☑
Primary Producers	☑
Secondary Producers	☑
Ornithology	**Attachment 3**
Population Surveys	☑
Aerial Photography	☑
Time Activity Budget	☑
Vegetation	**Required 2005**

Brian White
Waterfowl Coordinator

Mono Lake Elevations 2001*

Date		Elevation		Date		Elevation
JAN				AUG		
4		6383.0		2		6383.1
11		6383.0		9		6383.1
23		6383.1		17		6382.9
FEB				23		6382.8
2		6383.1		30		6382.8
15		6383.2		SEP		
22		6383.2		6		6382.7
MAR				13		6382.6
2		6383.3		20		6382.5
15		6383.4		OCT		
22		6383.4		4		6382.4
APR				11		6382.3
5		6383.4		18		6382.3
14		6383.4		25		6382.2
27		6383.5		NOV		
MAY				1		6382.2
9		6383.5		8		6382.2
17		6383.5		15		6382.1
24		6383.6		22		6382.1
31		6383.6		29		6382.2
JUN				DEC		
7		6383.5		5		6382.2
14		6383.5		13		6382.2
21		6383.5		28		6382.2

* LADWP Datum

November 7, 2001

To Enclosed Distribution List:

Update on Mono Basin Operations During 2001-02 Runoff Year

This year's runoff for the Mono Basin (Figure 1) could be termed "typical" with no significant events occurring. The peaks on all four creeks occurred earlier than forecasted and the magnitudes for all four creeks were higher than forecasted.

The following is a summary of LADWP's operations to date in the Mono Basin for the 2001-02 runoff year:

- Mono Basin Exports: Exports were suspended on March 31st to facilitate a Grant Lake spill, and were curtailed until it was determined that it was imminent that a spill would not occur. Exports were resumed on June 6th at an average flow rate of 30 cfs (Figure 2). The exports will continue through the remainder of the runoff year, and are expected to conclude in late March 2002. The flow rate will most likely be adjusted to provide LADWP its allowable maximum export of 16,000 acre-feet.

- Walker Creek: There were no diversions for export during the year. The creek experienced only one peak. The peak occurred on May 16th with a magnitude of 42 cfs (average daily). The peak exceeded the forecasted magnitude of 24 cfs (Figure 3).

- Parker Creek: There were no diversions for export during the year. The creek experienced three peaks. The first peak occurred May 17th with a magnitude of 49 cfs (average daily), the second peak occurred on May 26th with a magnitude of 56 cfs, and the third peak occurred June 2nd with a magnitude of 50 cfs (Figure 4). All three peaks exceeded the forecasted magnitude of 38 cfs.

- Lee Vining Creek: There were no diversions for export during the year. There were two peaks on Lee Vining Creek measured above Intake (Figure 6). The first peak occurred on May 17th with a peak of 201 cfs (average daily) which was slightly higher than which was forecasted (178 cfs). The second peak occurred on May 24th with a magnitude of 192 cfs (Figure 5).

  There was no augmentation made to Rush Creek flows. There were, however, diversions made from Lee Vining Creek for the purpose of increasing the likelihood of a spill at Grant Lake. The diversions commenced on May 11th and were terminated on May 17th when it became apparent that a spill at Grant Lake would not occur due to unseasonable low temperatures and Southern California Edison reducing their power plant outflow. An average flow of approximately 30 cfs was diverted.

- Rush Creek: Grant Lake's elevation on April 1, 2001 was 7,121.3 ft amsl, 8.7 ft below the lip of the spillway, providing another opportunity to spill and pass the peak to lower Rush Creek. To facilitate a spill, releases to Mono Gate Return Ditch were maintained slightly above Rush Creek's minimum flow, exports to the Owens River were also suspended in late March, and water from Lee Vining Creek was diverted to Grant Lake. Unfortunately, due to the low runoff and the need to maintain minimum base flows in lower Rush Creek a spill was not achieved. A peak inflow into Grant Lake (Rush Creek at Damsite) of 222 cfs was forecasted to occur the week of June 5th. Rush Creek at Damsite experienced its peak on May 26th with a magnitude of 231 cfs (average daily) (Figure 6, 7, and 8). Rush Creek below the confluence of the Return Ditch and Grant Lake spill channel experienced a flow of approximately 162 cfs (average daily) on June 14th. The 162 cfs was achieved by ramping up the outflow to the return ditch to its maximum capacity of approximately 160 cfs. Ramping began on June 1st and an outflow of 160 cfs was attained on June 11th. The 160 cfs was maintained for six days and then the flow was ramped back down to slightly above the minimum base flow of 47 cfs.

  Rush Creek below the narrows experienced on June 11th a flow magnitude of approximately 202 cfs (average daily) (Figure 8).

- Mono Basin Runoff: The timing of the Mono Basin peak runoff occurred two to three weeks earlier than predicted for all four creeks. Lee Vining Creek experienced its peak approximately two weeks earlier than predicted. All four creeks experienced flow magnitudes greater than those forecasted. The table below compares April 1st forecasted magnitudes and timing to those actually measured:

	Predicted		Measured	
	Magnitude	Timing	Magnitude	Timing
Rush Creek @ Damsite (Figure 6)	184 cfs	June 5	231 cfs	May 26
Parker Creek (Figure 4)	38 cfs	June 18	56 cfs	May 26
Walker Creek (Figure 3)	24 cfs	June 14	42 cfs	May 16
Lee Vining Creek (Figure 5)	178 cfs	June 3	201 cfs	May 17

- Grant Lake Reservoir: Releases from the reservoir to Rush Creek were maintained slightly above the minimum and exports were suspended on March 31st to help facilitate a spill. Grant Lake did not spill. It achieved a maximum storage on June 10th of 44,467 acre-feet – approximately 3.5 feet below the spillway (Figure 9).

If you have any questions or need additional information regarding operations, please contact me at (760) 873-0225.

Sincerely,

ORIGINAL SIGNED BY
GENE L. COUFAL

GENE L. COUFAL
Manager
Aqueduct Business Group

Enclosures

SBM:lge

bc: Thomas M. Erb
Richard F. Harasick
Gene L. Coufal
Clarence E. Martin
Charlotte L. Rodrigues
James C. Campbell
Wayne Hopper
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Mono Basin Distribution List

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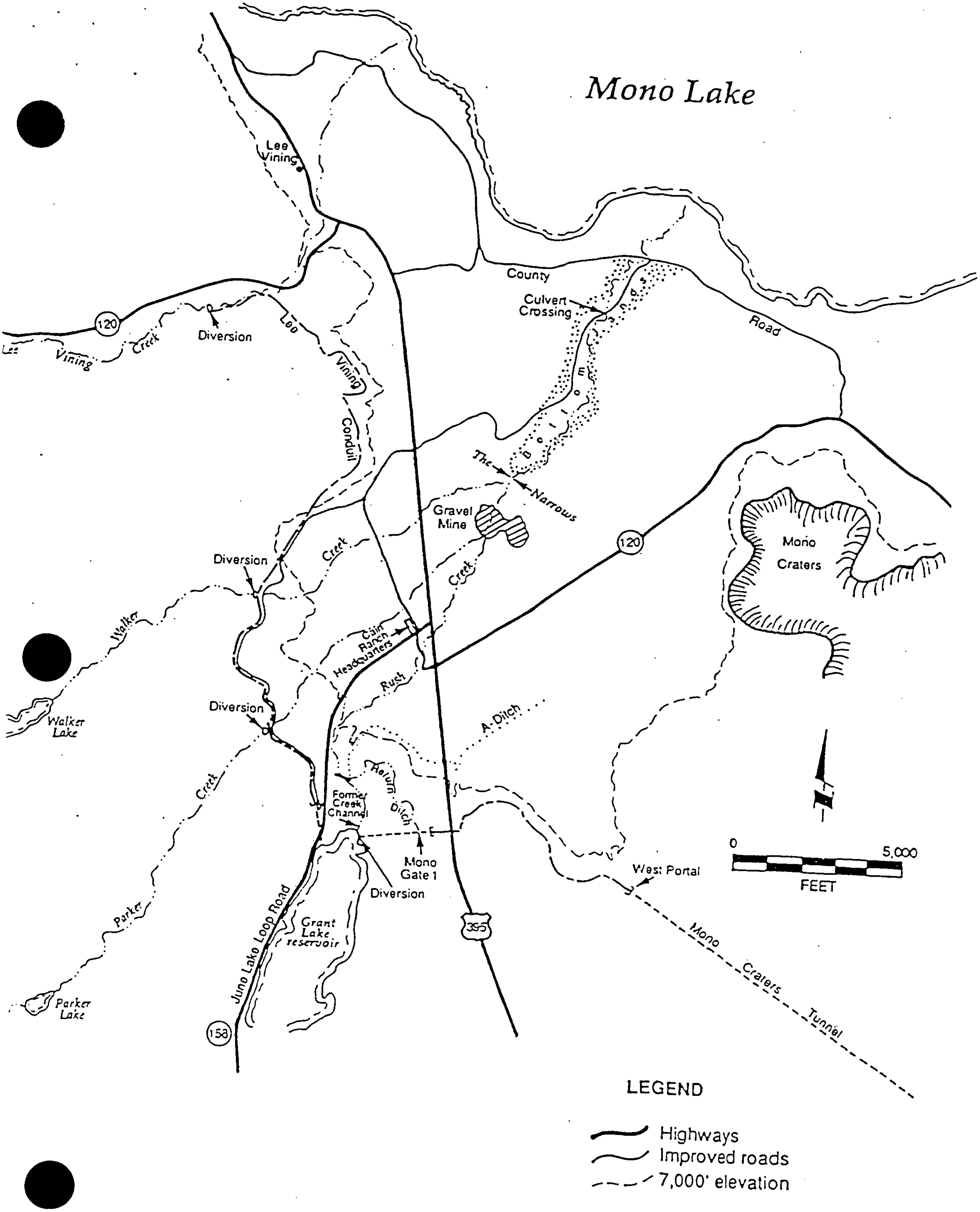


Mono Lake
Lee Vining
120
Lee Vining Creek
Diversion
Lee Vining Conduit
County Road
Culvert Crossing
Sand Flats
The Narrows
Gravel Mine
Creek
Diversion
Walker
Walker Lake
Cain Ranch Headquarters
Rush Creek
Diversion
A-Ditch
Return Ditch
Former Creek Channel
Mono Gate 1
Diversion
Grant Lake reservoir
June Lake Loop Road
158
395
Parker Creek
Parker Lake
Mono Craters
West Portal
Mono Craters Tunnel
0
5,000
FEET
LEGEND
Highways
Improved roads
7,000' elevation

Figure 1

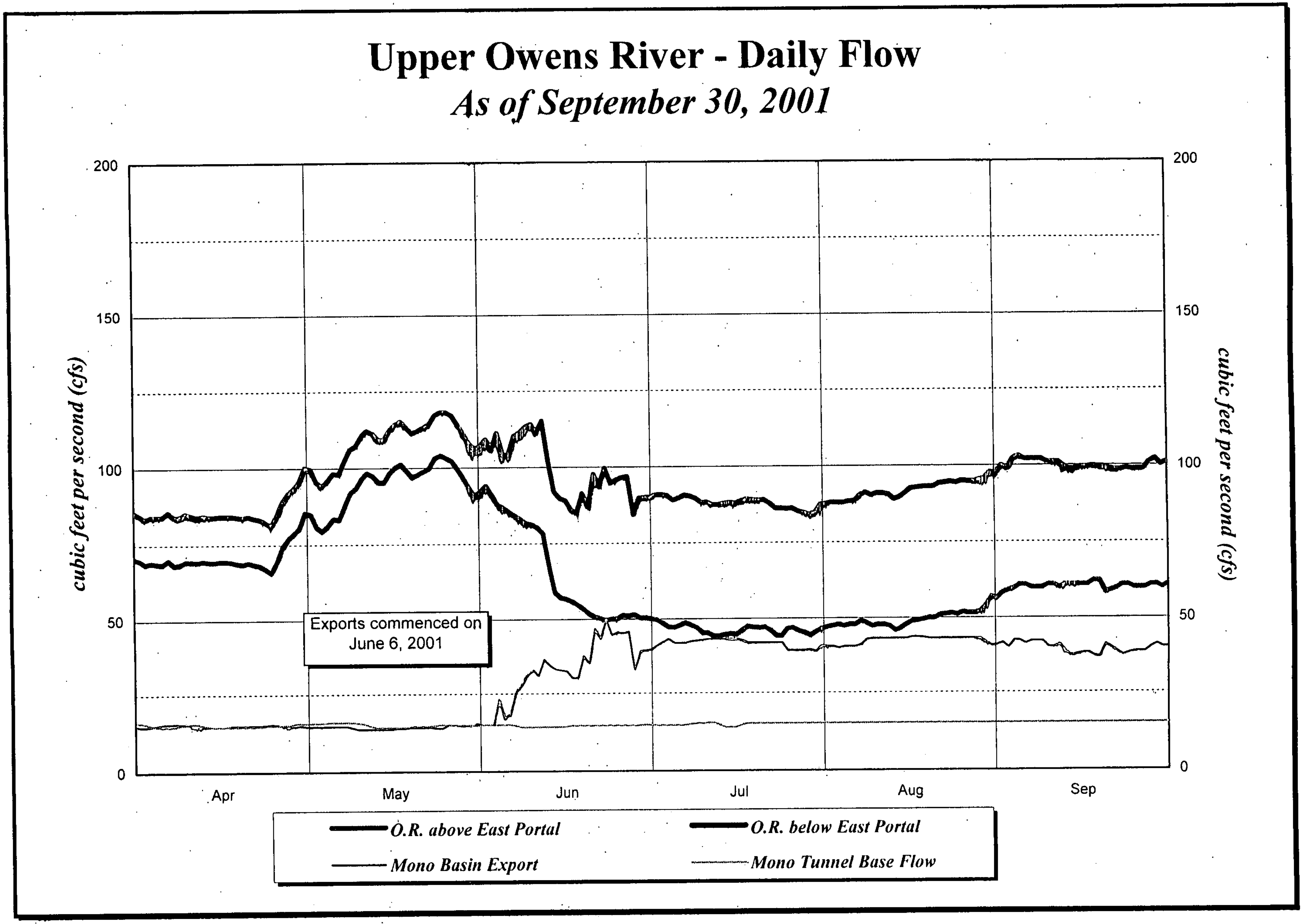
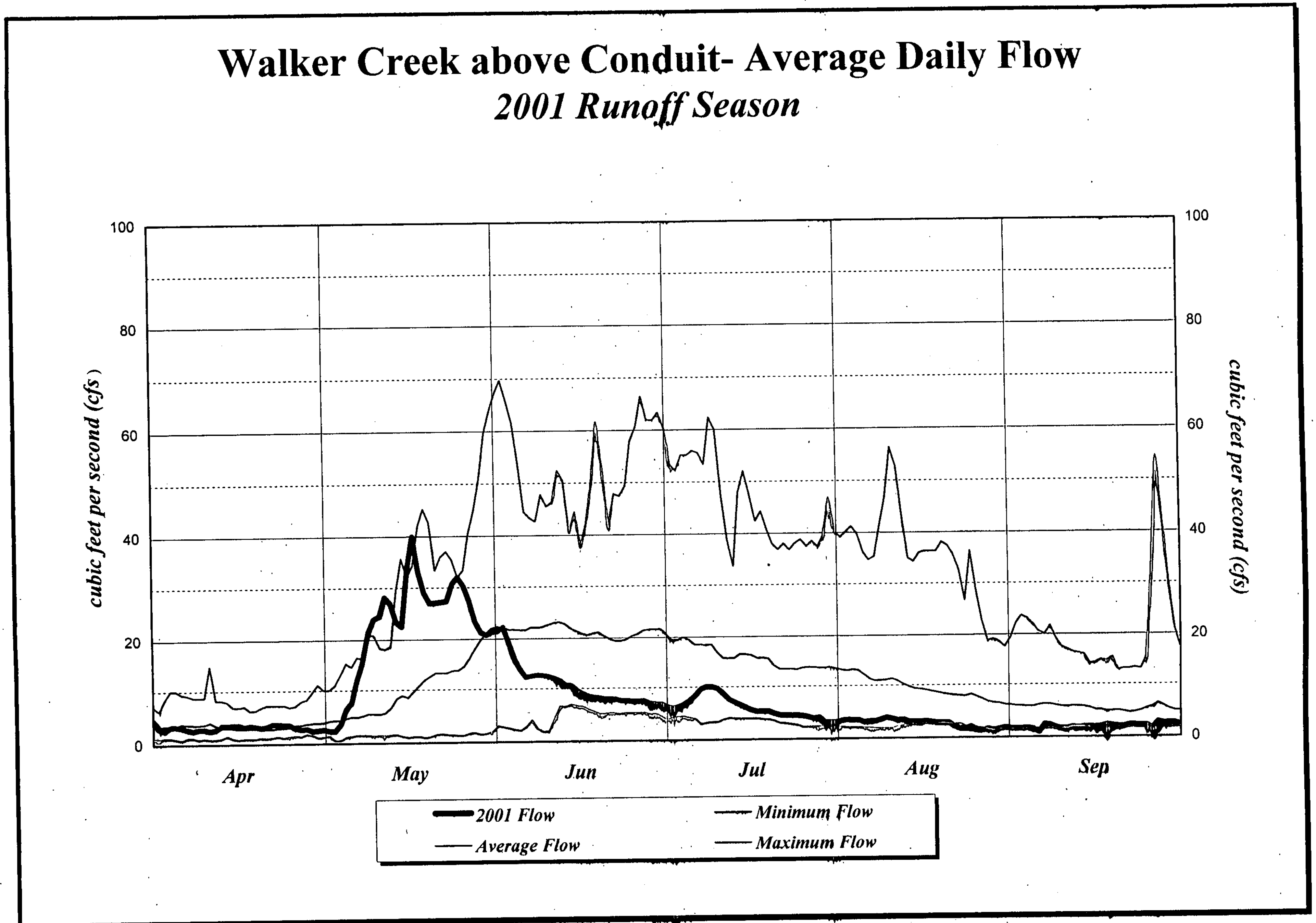
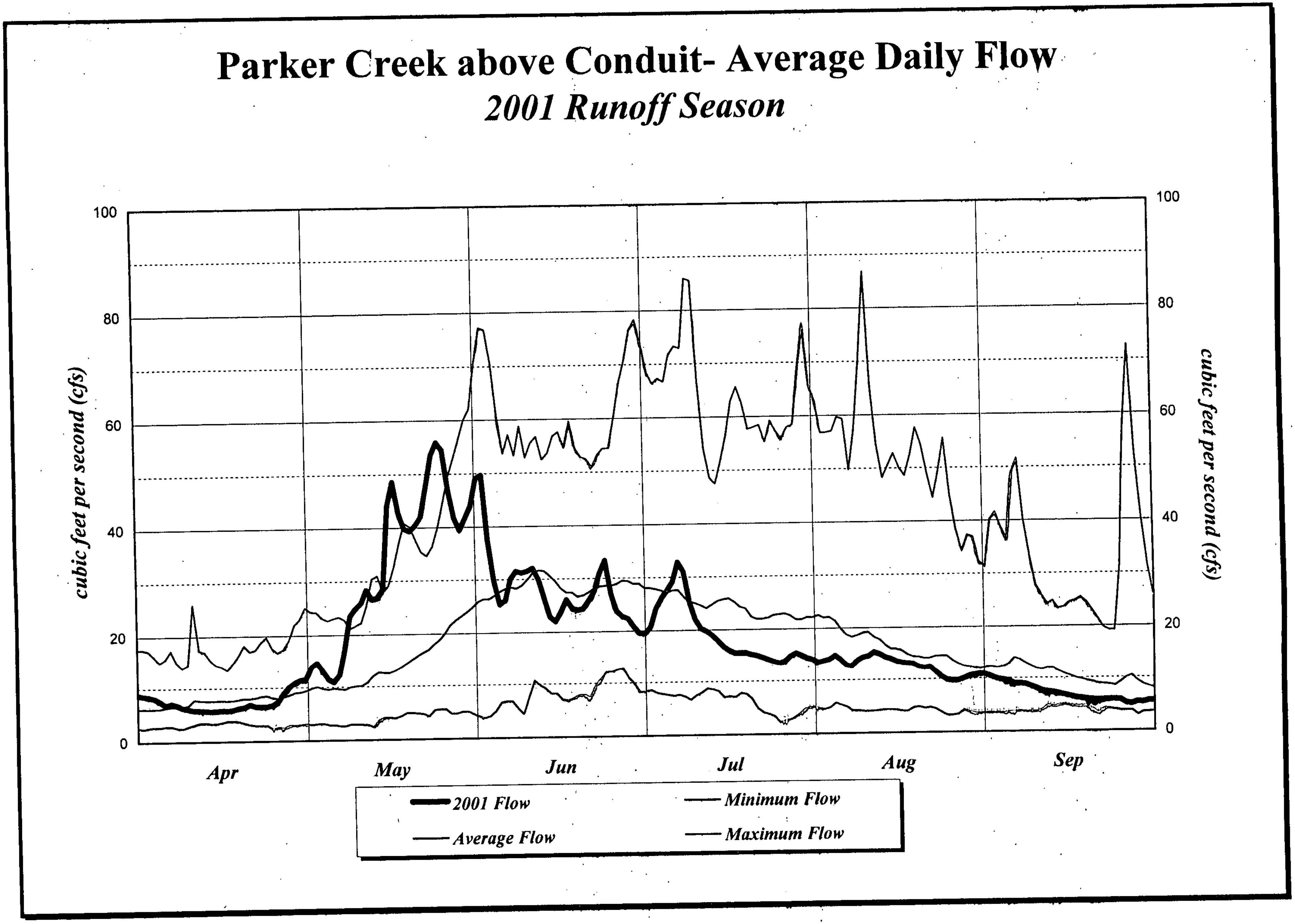

Upper Owens River - Daily Flow
As of September 30, 2001
200
150
100
50
0
cubic feet per second (cfs)
Apr
May
Jun
Jul
Aug
Sep
Exports commenced on
June 6, 2001
O.R. above East Portal
O.R. below East Portal
Mono Basin Export
Mono Tunnel Base Flow

Figure 2



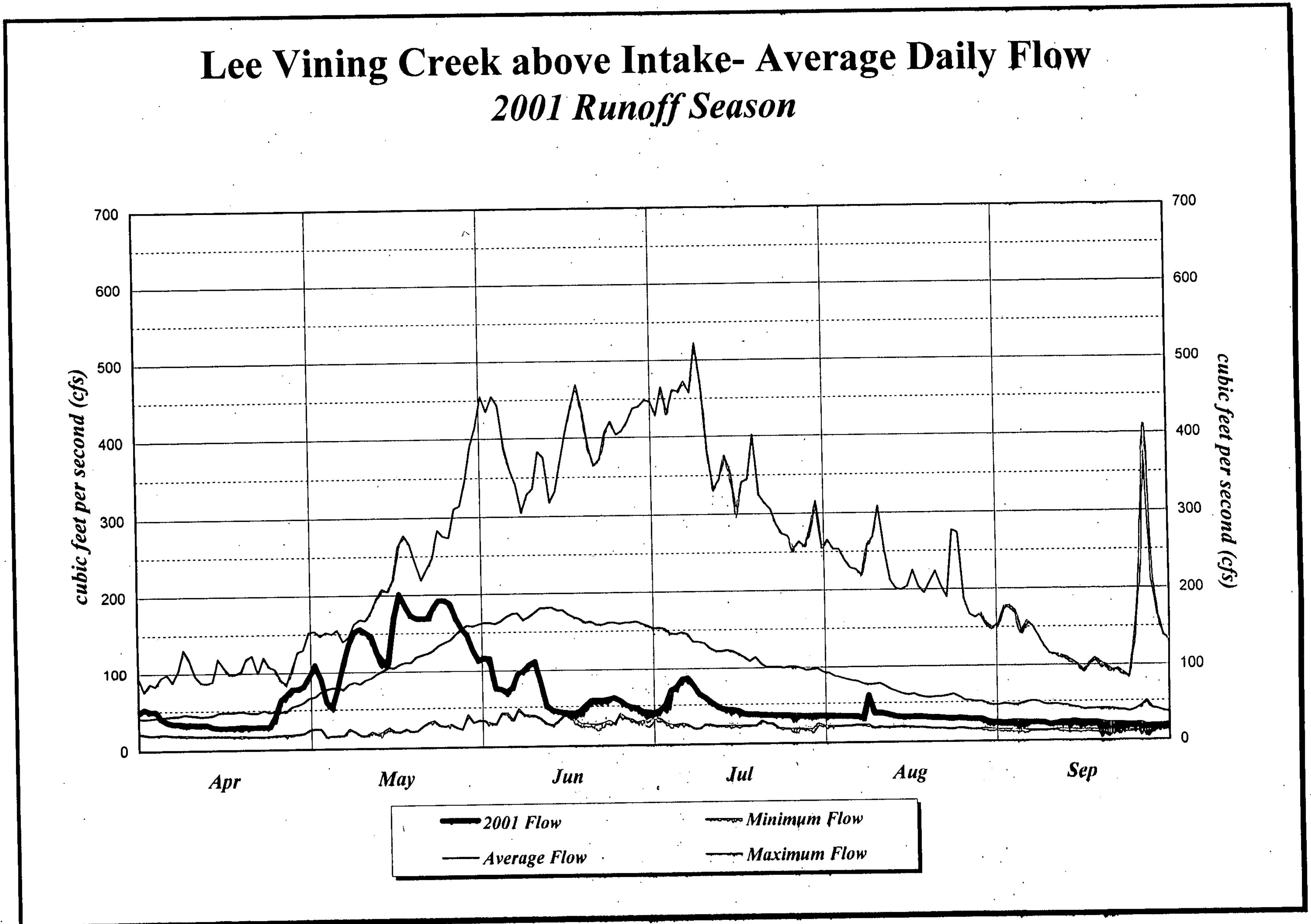
Walker Creek above Conduit- Average Daily Flow
2001 Runoff Season
100
80
60
40
20
0
cubic feet per second (cfs)
Apr
May
Jun
Jul
Aug
Sep
2001 Flow
Average Flow
Minimum Flow
Maximum Flow

Figure 3



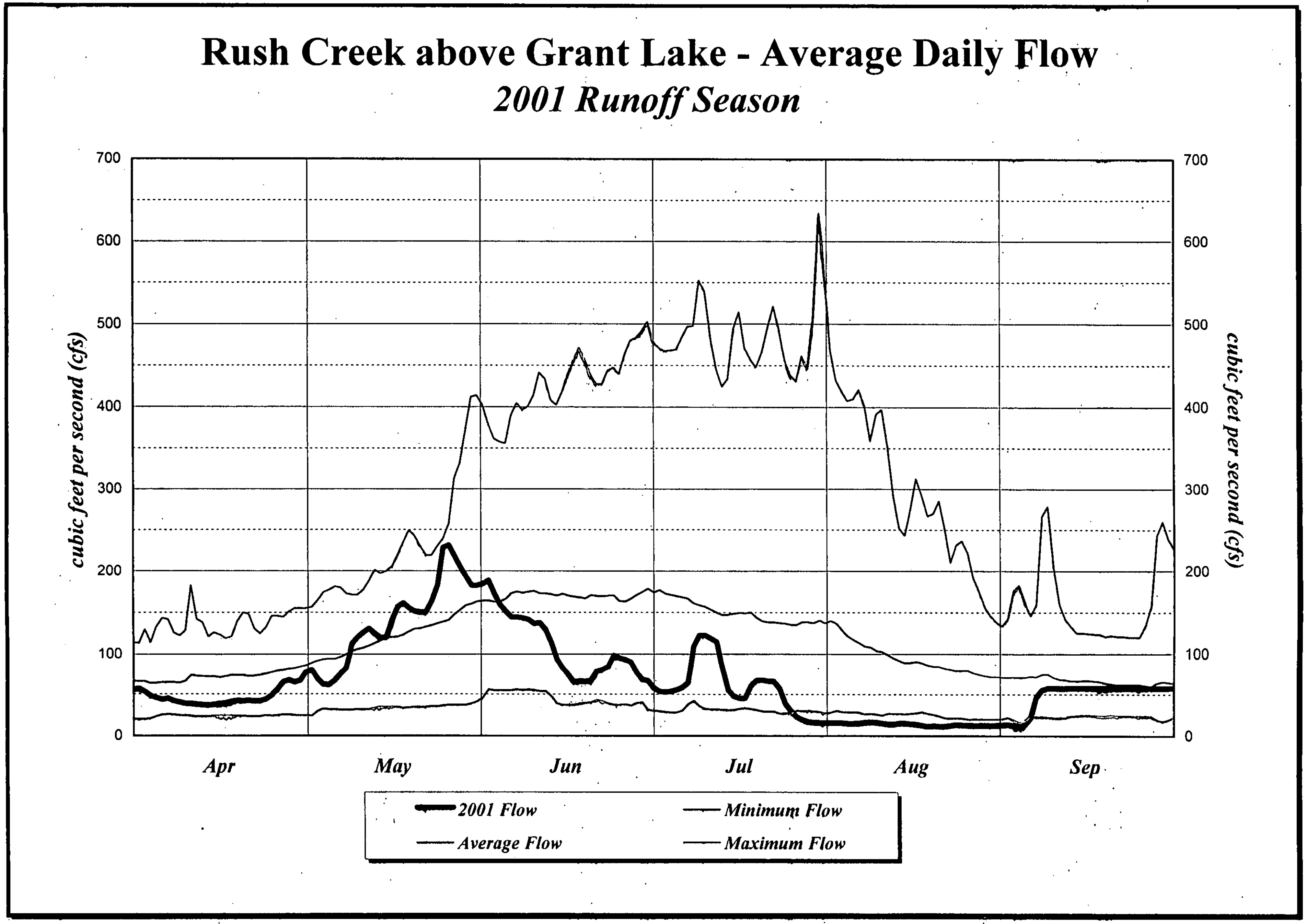
Parker Creek above Conduit- Average Daily Flow
2001 Runoff Season
100
80
60
40
20
0
cubic feet per second (cfs)
Apr
May
Jun
Jul
Aug
Sep
2001 Flow
Minimum Flow
Average Flow
Maximum Flow

Figure 4



Lee Vining Creek above Intake- Average Daily Flow
2001 Runoff Season
700
600
500
400
300
200
100
0
cubic feet per second (cfs)
Apr
May
Jun
Jul
Aug
Sep
2001 Flow
Average Flow
Minimum Flow
Maximum Flow

Figure 5



Rush Creek above Grant Lake - Average Daily Flow
2001 Runoff Season
700
600
500
400
300
200
100
0
cubic feet per second (cfs)
Apr
May
Jun
Jul
Aug
Sep
2001 Flow
Minimum Flow
Average Flow
Maximum Flow

Figure 6

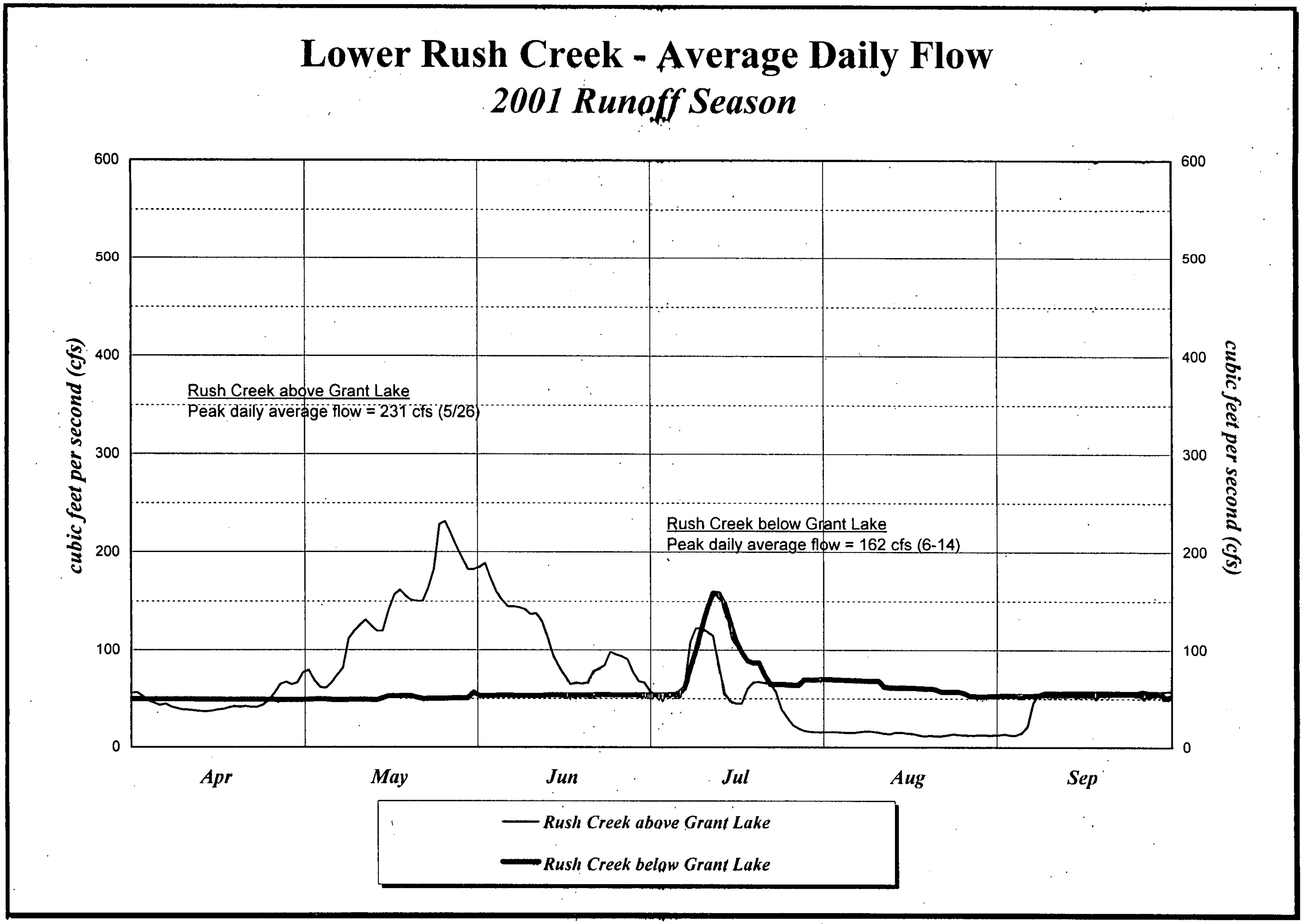
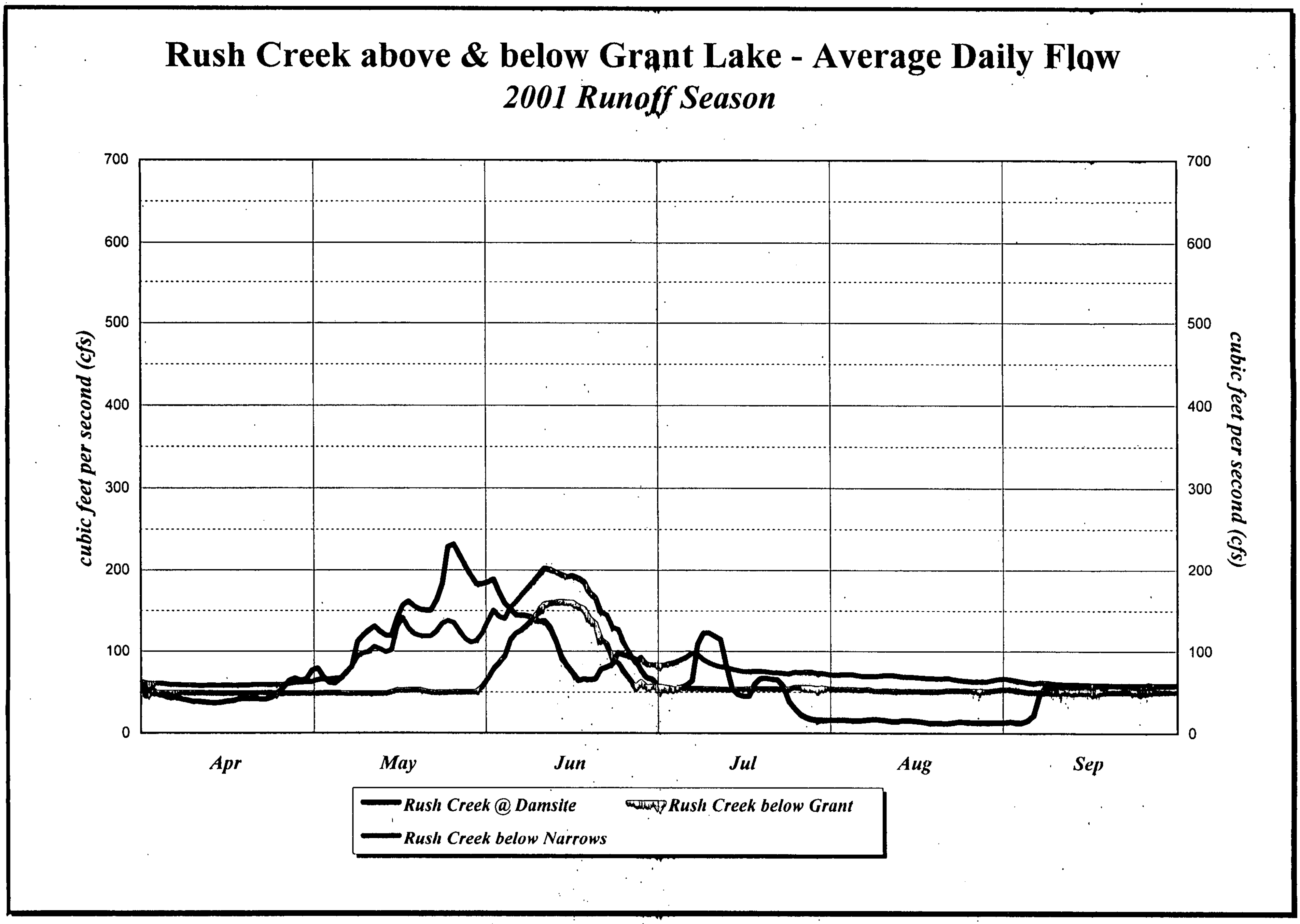

Lower Rush Creek - Average Daily Flow
2001 Runoff Season
600
500
400
300
200
100
0
cubic feet per second (cfs)
Rush Creek above Grant Lake
Peak daily average flow = 231 cfs (5/26)
Rush Creek below Grant Lake
Peak daily average flow = 162 cfs (6-14)
Apr
May
Jun
Jul
Aug
Sep
Rush Creek above Grant Lake
Rush Creek below Grant Lake

Figure 7



Rush Creek above & below Grant Lake - Average Daily Flow
2001 Runoff Season
cubic feet per second (cfs)
700
600
500
400
300
200
100
0
Apr
May
Jun
Jul
Aug
Sep
Rush Creek @ Damsite
Rush Creek below Grant
Rush Creek below Narrows

Figure 8

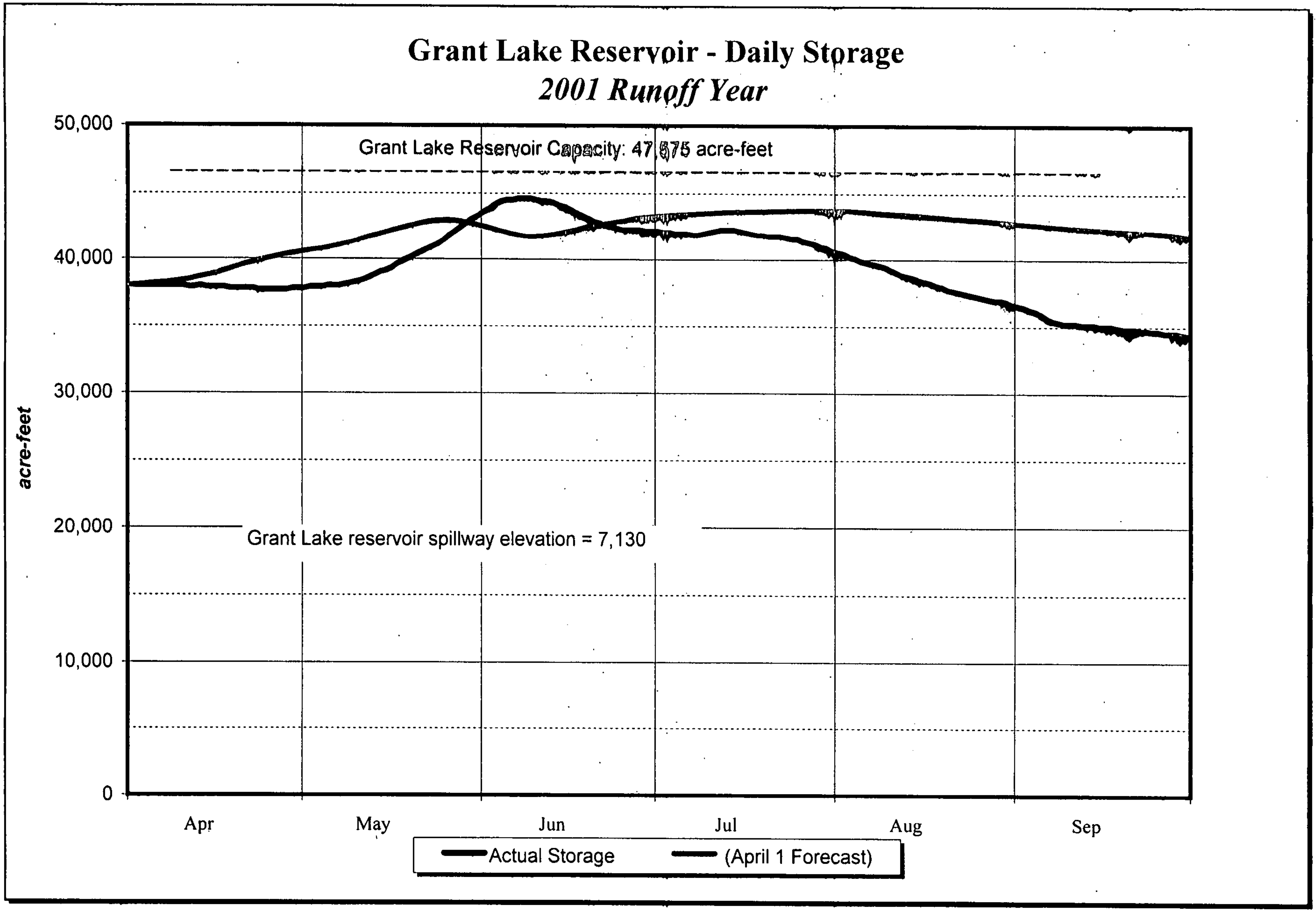

Grant Lake Reservoir - Daily Storage
2001 Runoff Year
Grant Lake Reservoir Capacity: 47,575 acre-feet
Grant Lake reservoir spillway elevation = 7,130
50,000
40,000
30,000
20,000
10,000
0
acre-feet
Apr
May
Jun
Jul
Aug
Sep
Actual Storage
(April 1 Forecast)

Figure 9

2001 ANNUAL REPORT

MIXING AND PLANKTON DYNAMICS IN MONO LAKE, CALIFORNIA

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Santa Barbara, CA 93106

Submitted: 15 April 2002

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EXECUTIVE SUMMARY

Limnological monitoring of the plankton dynamics in Mono Lake continued during 2001. To put the results from 2001 in context, Chapter 1 describes the seasonal plankton dynamics observed from 1979 through 2000, a period which encompassed a wide range of varying hydrologic and annual vertical mixing regimes including two periods of persistent chemical stratification or meromixis (1983–88 and 1995–present). In brief, long-term monitoring has shown that Mono Lake is highly productive compared to other temperate salt lakes, that this productivity is nitrogen-limited, and that year-to-year variation in the plankton dynamics has largely been determined by the complex interplay between varying climate and hydrologic regimes and the resultant seasonal patterns of thermal and chemical stratification which modify internal recycling of nitrogen. The importance of internal nutrient cycling to productivity is highlighted in the years immediately following the onset of persistent chemical stratification (meromixis) when upward fluxes of ammonium are attenuated.

Chapter 2 provides a detailed description of the laboratory and field methods employed.

Chapter 3 describes the results of our limnological monitoring program during 2001. Persistent chemical stratification (meromixis) continued but weakened due to evaporative concentration of the upper mixed layer accompanying a net 0.8 ft decline in surface elevation and slight freshening of water beneath the chemocline. Colder than average mixolimnetic temperatures (1.5–2.2°C) observed in February 2001 enhanced deep mixing. The midsummer difference in density between 2 and 28 m attributable to chemical stratification has declined from 10.5 kg m^{-2} in 2000 to 8.9 kg m^{-3} in 2001. Most likely of greater significance to the overall plankton dynamics is the marked midwinter deepening (ca. 2 m) of the chemocline.

Not only were significant amounts of ammonium-rich monimolimnetic water entrained, but less of the lake is now effectively meromictic. At present only 33% of the lake's area and 12% of the volume beneath the chemocline. Ammonium concentrations in the monimolimnion continued their 6-year increase with concentrations at 28 and 35 m generally 900–1200 μM.

Algal biomass, as characterized by chlorophyll *a* concentration, was similar to that observed during 2000 except that the autumn bloom was somewhat later as adult *Artemia* were more abundant in September and October compared to 2000. The estimated annual primary production in 2001 increased 10% from 2000 to 532 g C m^{-2} yr^{-1}, slightly above the mean annual production (508 g C m^{-2} yr^{-1}) during the recent 5-yr period of monomixis (1990–94).

As in 2000, the 2001 *Artemia* population was characterized by fairly rapid development of the 1st generation, a pulse of ovoviviparous reproduction in June, followed by a decline to very low numbers by November. In 2000, the autumn decline was very rapid and resulted in the lowest seasonal mean abundance of any year studied. In 2001 the autumn decline was less rapid and resulted in a seasonal mean abundance identical to the longterm mean of 20,000 m^{-2}. The 2001 mean annual *Artemia* biomass was 8.8 g m^{-2} or 9 % below the long-term mean of 9.7 g m^{-2} and slightly higher than calculated in 2000 (8.2 g m^{-2}).

In Mono Lake, oviparous (cyst) reproduction is always much higher than ovoviviparous (live-bearing) reproduction. Although adult *Artemia* were more abundant in 2001 compared to 2000, total annual cyst production was lower, 3.02×10^6 m^{-2} compared to 4.03×10^6 m^{-2} in 2000. While this is 37% below the longterm mean of 4.77×10^6 m^{-2}, it is not expected to have a significant impact on 2002 abundance as food availability is a much stronger determinant of the spring generation of *Artemia.*

In summary, weakening chemical stratification, increased primary productivity, and increased *Artemia* abundance all suggest the impacts of ongoing meromixis have now lessened. Thus, while meromixis persisted through 2001, the combined effects of declining lake levels, the reduced proportion of the lake beneath the chemocline, and increased upward fluxes of ammonium due to the large buildup of monimolimnetic ammonium appear to offset the much of the effect of the absence of winter holomixis. Should the current trend of declining lake levels continue, meromixis may break down much sooner than previously predicted (Jellison et al. 1998) and inject a large pulse of nutrients into the euphotic zone.

ACKNOWLEDGEMENTS

Laboratory work was performed at the Sierra Nevada Aquatic Research Lab and University of California, Santa Barbara. Sandra Roll, Kimberly Rose, and Peter Kirchner assisted with field sampling and laboratory analyses. This work was supported by a grant from the Los Angeles Department of Water and Power to R. Jellison and J. M. Melack at the Marine Science Institute, University of California, Santa Barbara.

LIMNOLOGICAL MONITORING COMPLIANCE

This report fulfills the Mono Lake limnological monitoring requirements set forth in compliance with State Water Resources Control Board Order Nos. 98-05 and 98-07. The limnological monitoring program consists of four components: meteorological, physical/chemical, phytoplankton, and brine shimp population data. Meteorological data are collected continuously at a station on Paoha Island, while the other three components are assessed on eleven monthly surveys (every month except January). A summary of previous monitoring is included in Chapter 1, the methodology employed is detailed in Chapter 2, and results and discussion of the monitoring during 2001 presented in Chapter 3. The relevant pages, tables, and figures for the specific elements of each of the four required components are given below.

	Text	Tables	Figures
Meteorological			
Wind Speed	28		2
Wind Direction	28		
Air Temperature	29		3
Incident Radiation	29		4
Humidity	29		5
Precipitation	29		6
Physical/Chemical			
Water Temperature	30	1	8
Transparency	34	5	
Underwater light	34		15
Dissolved Oxygen	36	6	16
Conductivity	31	2	9
Ammonium	37	7	17
Phosphate	38		
Plankton			
Chorophyll *a*	38	8	18
Primary production	45		27
Artemia Abundance	42	9	21
Artemia Instar distribution	40	10	20
Artemia Fecundity/Length	43	12	22
Artemia Reproductive parameters	42	11	22,27
Artemia Biomass	46		26

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CHAPTER 1
INTRODUCTION

Background

Saline lakes are widely recognized as highly productive aquatic habitats, which in addition to harboring unique assemblages of species, often support large populations of migratory birds. Saline lake ecosystems throughout the world are threatened by decreasing size and increasing salinity due to diversions of freshwater inflows for irrigation and other human uses (Williams 1993); notable examples in the Great Basin of North America include Mono Lake (Patten et al. 1987), Walker Lake (Cooper and Koch 1984), and Pyramid Lake (Galat et al. 1981). At Mono Lake, California, diversions of freshwater streams out of the basin beginning in 1941 led to a 14 m decline in surface elevation and an approximate doubling of the lake's salinity.

In 1994, following two decades of scientific research, litigation, and environmental controversy, the State Water Resources Control Board (SWRCB) of California issued a decision to amend Los Angeles' water rights to "establish fishery protection flows in streams tributary to Mono Lake and to protect public trust resources at Mono Lake and in the Mono Lake Basin" (Decision 1631). The decision restricts water diversions until the surface elevation of the lake reaches 1,948 m and requires long-term limnological monitoring of the plankton dynamics.

Long-term monitoring of the plankton and their physical, chemical, and biological environment is essential to understanding the effects of changing lake levels. Measurements of the vertical distribution of temperature, oxygen, conductivity, and nutrients are requisite for interpreting how variations in these variables affect the plankton populations. Consistent methodologies were employed during the 21-yr period, 1979–2000, and have yielded a standardized data set from which to analyze seasonal and year-to-year changes in the plankton. Lakewide monitoring was conducted during eleven surveys in 2000, once each month from February through December.

Seasonal Mixing Regime and Plankton Dynamics

Limnological monitoring at Mono Lake can be divided into several periods corresponding to two different annual circulation patterns, meromixis and monomixis, and the transition between them.

Monomictic and declining lake levels, 1964–82

The limnology of Mono Lake, including seasonal plankton dynamics, was first documented in the mid 1960s (Mason 1967). During this period Mono Lake was characterized by declining lake levels, increasing salinity, and a monomictic thermal regime. No further limnological research was conducted until summer 1976 when a broad survey of the entire Mono Basin ecosystem was conducted (Winkler 1977). Subsequent studies (Lenz 1984; Melack 1983, 1985) beginning in 1979, further described the seasonal dynamics of the plankton. During the period 1979–81, Lenz (1984) documented a progressive increase in the ratio of peak summer to spring abundances of adult brine shrimp. The smaller spring generations resulted in greater food availability and much higher ovoviviparous production by the first generations, leading to larger second generations. Therefore, changes in the size of the spring hatch can result in large changes in the ratio of the size of the two generations.

In 1982, an intensive limnological monitoring program funded by LADWP was established to monitor changes in the physical, chemical, and biological environments in Mono Lake. This monitoring program has continued to the present. Detailed descriptions of the results of the monitoring program are contained in a series of reports to LADWP

(Dana *et al.* 1986, 1992; Jellison *et al.* 1988, 1989, 1990, 1991, 1994, 1995b, 1996a, 1997, 1998b, 1999, 2000) and are summarized below.

Meromixis, 1983–87

In 1983, a large influx of freshwater into Mono Lake resulted in a condition of persistent chemical stratification (meromixis). A decrease in surface salinities resulted in a chemical gradient of ca. 15 g total dissolved solids l^{-1} between the mixolimnion (the mixed layer) and monimolimnion (layer below persistent chemocline). In subsequent years evaporative concentration of the surface water led to a decrease in this gradient and in November 1988 meromixis was terminated.

Following the onset of meromixis, ammonium and phytoplankton were markedly affected. Ammonium concentrations in the mixolimnion were reduced to near zero during spring 1983 and remained below 5 μM until late summer 1988. Accompanying this decrease in mixolimnetic ammonium concentrations was a dramatic decrease in the algal bloom associated with periods when the *Artemia* are less abundant (November through April). At the same time, ammonification of organic material and release from the anoxic sediments resulted in a gradual buildup of ammonium in the monimolimnion over the six years of meromixis to 400 to 500 μM. Under previous monomictic conditions, summer ammonium accumulation beneath the thermocline was 80–100 μM, and was mixed into the upper water column during the autumn overturn.

Artemia dynamics were also affected by the onset of meromixis. The size of the first generation of adult *Artemia* in 1984 (31,000 m^{-2}) was nearly ten times as large as observed in 1981 and 1982, while peak summer abundances of adults were much lower. Following this change, the two generations of *Artemia* were relatively constant during the meromictic period from 1984 to 1987. The size of the spring generation of adult *Artemia* only varied from 23,000 to 31,000 m^{-2} while the second generation of adult *Artemia* varied from 33,000 to 54,000 m^{-2}. The relative sizes of the first and second generation are inversely correlated. This is at least partially mediated by food availability as a large first generation results in decreased algal levels for second generation nauplii and vice versa. During 1984 to 1987, recruitment into the first generation adult class was a nearly constant but small percentage (about 1 to 3%) of the cysts calculated to be available (Dana *et al.* 1990). Also, fecundity showed a significant correlation with ambient algal concentrations (r^2, 0.61).

In addition to annual reports submitted to Los Angeles and referenced herein, a number of published manuscripts document the limnological conditions and algal photosynthetic activity during the onset, persistence, and breakdown of meromixis, 1982–90 (Jellison *et al.* 1992; Jellison and Melack 1993a, 1993b; Jellison *et al.* 1993; Miller *et al.* 1993).

Response to the breakdown of meromixis, 1988–89

Although complete mixing did not occur until November 1988, the successive deepening of the mixed layer during the period 1986–88 led to significant changes in the plankton dynamics. By spring 1988, the mixed layer included the upper 22 m of the lake and included 60% of the area and 83% of the lake's volume. In addition to restoring an annual mixing regime to much of the lake, the deepening of the mixed layer increased the nutrient supply to the mixolimnion by entraining water with very high ammonium concentrations (Jellison *et al.* 1989). Mixolimnetic ammonium concentrations were fairly high during the spring (8–10 μM), and March algal populations were much denser than in 1987 (53 vs. 15 μg chl *a* l^{-1}).

The peak abundance of spring adult *Artemia* in 1988 was twice as high as any previous year from 1979 to 1987. This increase could have been due to enhanced hatching and/or survival of nauplii. The pool of cysts available for hatching was potentially larger in 1988 since cyst production in 1987 was larger than in the four previous years (Dana *et al.* 1990) and significant lowering of the chemocline in the autumn and winter of 1987 allowed oxygenated water to reach cysts in sediments which had been anoxic since 1983. Cysts can remain dormant and viable in anoxic water for an undetermined number of years. Naupliar survival may also have been enhanced since chlorophyll *a* levels in the spring of 1988 were higher than the previous four years. This hypothesis is corroborated by the results of the 1988 development experiments (Jellison *et al.* 1989). Naupliar survival was higher in the ambient food treatment relative to the low food treatment.

Mono Lake returned to its previous condition of annual autumnal mixing from top to bottom with the complete breakdown of meromixis in November 1988. The mixing of previously isolated monimolimnetic water with surface water affected biotic components of the ecosystem. Ammonium, which had accumulated to high levels (600 μM) in the monimolimnion during meromixis, was dispersed throughout the water column raising surface concentrations above previously observed values (>50 μM). Oxygen was diluted by mixing with the anoxic water and consumed by the biological and chemical oxygen demand previously created in the monimolimnion. Dissolved oxygen concentration immediately fell to zero. *Artemia* populations experienced an immediate and total die-off following deoxygenation. Mono Lake remained anoxic for a few months following the breakdown of meromixis in November 1988. By mid-February 1989, dissolved oxygen concentrations had increased (2–3 mg l^{-1}) but were still below those observed in previous years (4–6 mg l^{-1}). The complete recovery of dissolved oxygen concentrations occurred in March when levels reached those seen in other years.

Elevated ammonium concentrations following the breakdown of meromixis led to high chlorophyll *a* levels in spring 1989. Epilimnetic concentrations in March and April were the highest observed (40–90 µg chl *a* l^{-1}). Subsequent decline to low midsummer concentrations (<0.5–2 µg chl *a* l^{-1}) due to brine shrimp grazing did not occur until late June. In previous meromictic years this decline occurred up to six weeks earlier. Two effects of meromixis on the algal populations, decreased winter-spring concentrations and a shift in the timing of summer clearing, are clearly seen over the period 1982–89.

The 1989 *Artemia* population exhibited a small first generation of adults followed by a summer population over one order of magnitude larger. A similar pattern was observed from 1980–83. In contrast, the pattern observed during meromictic years was a larger first generation followed by a summer population of the same order of magnitude. The timing of hatching of *Artemia* cysts was affected by the recovery of oxygen. The initiation of hatching occurred slightly later in the spring and coincided with the return of oxygenated conditions. First generation numbers in 1989 were initially high in March (ca. 30,000 individuals m^{-2}) and within the range seen from 1984–88, but decreased by late spring to 4,200 individuals m^{-2}. High mortality may have been due to low temperatures, since March lake temperatures (2–6°C) were lower than the suspected lethal limit (ca. 5–6°C) for *Artemia* (Jellison *et al.* 1989). Increased mortality may also have been associated with elevated concentrations of toxic compounds (H_2S, NH_4^+, As) resulting from the breakdown of meromixis.

High spring chlorophyll levels in combination with the low first generation abundance resulted in a high level of fecundity that led to a large second generation of shrimp. Spring chlorophyll *a* concentrations were high (30–44 μg chl *a* l^{-1}) due to the elevated ammonium levels (27–44 μM) and are typical of pre-meromictic levels. This abundant food source (as indicated by chlorophyll *a*) led to large *Artemia* brood sizes and high ovigerity during the period of ovoviviparous reproduction and resulted in the large observed summer abundance of *Artemia* (peak summer abundance, 93,000 individuals m^{-2}). Negative feedback effects were apparent when the large summer population of *Artemia* grazed the phytoplankton to very low levels (<0.5–2 μ g chl *a* l^{-1}). The low algal densities led to decreased reproductive output in the shrimp population. Summer brood size, female length, and ovigerity were all the lowest observed in the period 1983–89.

Small peak abundance of first generation adults were observed in 1980–83, and 1989. However, the large (2–3 times the mean) second generations were only observed in 1981, 1982, and 1989. During these years, reduced spring inflows resulted in less than usual density stratification and higher than usual vertical fluxes of nutrients thus providing for algal growth and food for the developing *Artemia* population.

Monomictic conditions with relatively stable lake levels, 1990–94

Mono Lake was monomictic from 1990 to 1994 (Jellison *et al.* 1991, Dana *et al.* 1992, Jellison *et al.* 1994, Jellison *et al.* 1995b) and lake levels (6374.6 to 6375.8 ft asl) were similar to those in the late 1970s. Although the termination of meromixis in November 1988 led to monomictic conditions in 1989, the large pulse of monimolimnetic ammonium into the mixed layer led to elevated ammonium concentrations in the euphotic zone throughout 1989, and the plankton dynamics were markedly different than 1990–94. In 1990–94, ammonium concentrations in the euphotic zone decreased to levels observed prior to meromixis in 1982. Ammonium was low, 0–2 µM, from March through April and then increased to 8–15 µM in July. Ammonium concentrations declined slightly in late summer and then increased following autumn turnover. This pattern of ammonium concentrations in the euphotic zone and the hypolimnetic ammonium concentrations were similar to those observed in 1982. The similarities among the years 1990–94 indicate the residual effects of the large hypolimnetic ammonium pulse accompanying the breakdown of meromixis in 1988 were gone. This supports the conclusion by Jellison *et al.* (1990) that the seasonal pattern of ammonium concentration was returning to that observed before the onset of meromixis.

Spring and summer peak abundances of adult *Artemia* were fairly constant throughout 1990 to 1994. Adult summer population peaks in 1990, 1991, and 1992 were all 35,000 m^{-2} despite the large disparity of second generation naupliar peaks (280,000, 68,000, and 43,000 m^{-2} in 1990, 1991, and 1992, respectively) and a difference in first generation peak adult abundance (18,000, 26,000, and 21,000 m^{-2} in 1990, 1991, and 1992, respectively). Thus, food availability or other environmental factors are more important to determining summer abundance than recruitment of second generation nauplii. In 1993, when freshwater inflows were higher than usual and thus density stratification enhanced, the summer generation was slightly smaller (21,000 m^{-2}). Summer abundance of adults increased slightly (29,000 m^{-2}) in 1994 when runoff was lower and lake levels were declining.

Meromictic conditions with rising lake levels, 1995–present

The winter (1994/95) period of holomixis injected nutrients which had previously accumulated in the hypolimnion into the upper water column prior to the onset of thermal and chemical stratification in 1995 (Jellison *et al.* 1996a). During 1995, above normal runoff in the Mono Basin coupled with the absence of significant water diversions out of the basin led to rapidly rising lake levels. The large freshwater inflows resulted in a 3.4 ft rise in surface elevation and the onset of meromixis, a condition of persistent chemical stratification with less saline water overlying denser more saline water. Due to holomixis during late 1994 and early 1995, the plankton dynamics during the first half of 1995 were similar to those observed during the past four years (1991–94). Therefore 1995 represents a transition from monomictic to meromictic conditions. In general, 1995 March mixed-layer ammonium and chlorophyll *a* concentrations were similar to 1993. The peak abundance of summer adult *Artemia* (24,000 m^{-2}) was intermediate to that observed in 1993 (21,000 m^{-2}) and 1994 (29,000 m^{-2}). The effects of increased water column stability due to chemical stratification only became evident later in the year. As the year continued, a shallower mixed layer, lower mixed-layer ammonium and chlorophyll *a* concentrations, slightly smaller *Artemia,* and smaller brood sizes compared to 1994 were all observed. The full effects of the onset of meromixis in 1995 were not evident until 1996.

Chemical stratification persisted and strengthened throughout 1996 (Jellison *et al.* 1997). Mixolimnetic (upper water column) salinity ranged from 78 to 81 g kg^{-1} while monimolimnetic (lower water column) were 89–90 g kg^{-1}. The maximum vertical density stratification of 14.6 kg m^{-3} observed in 1996 was larger than any year since 1986. During 1996, the annual maximum in Secchi depth, a measure of transparency, was among the highest observed during the past 18 years and the annual minimum was higher than during all previous years except 1984 and 1985 during a previous period of meromixis. While ammonium concentrations were <5 μM in the mixolimnion throughout the year, monimolimnetic concentrations continued to increase. The spring epilimnetic chlorophyll *a* concentrations (~5–23 μg chl *a* l^{-1}) were similar to those observed in previous meromictic years, but were much lower than the concentrations observed in March 1995 before the onset of the current episode of meromixis. During previous monomictic years, 1989–94, the spring maximum epilimnetic chlorophyll *a* concentrations ranged between 87–165 μg chl *a* l^{-1}.

A single mid-July peak in adults characterized *Artemia* population dynamics in 1996 with little evidence of recruitment of second generation *Artemia* into the adult population during late summer. The peak abundance of first generation adults was observed on 17 July (34,600 m^{-2}), approximately a month later than in previous years. The percent ovigery during June 1996 (42%) was lower than that observed in 1995 (62%), and much lower than that observed 1989–94 (83–98%). During the previous meromictic years (1984–88) the female population was also slow to attain high levels of ovigery due to lower algal levels. The maximum of the mean female length on sampling dates through the summer, 10.7 mm, was shorter than those observed during 1993, 1994, and 1995 (11.7, 12.1, and 11.3 mm, respectively). In 1996, brood size ranged from 29 to 39 eggs $brood^{-1}$ during July through November. The summer and autumn brood sizes were smaller than those observed during 1993–95 (40 to 88 eggs $brood^{-1}$), with the exception of September 1995 (34 eggs $brood^{-1}$) when the brood size was of a similar size to September 1996 (33 eggs $brood^{-1}$).

Chemical stratification continued to increase in 1997 as the surface elevation rose an additional 1.6 ft during the year. The midsummer difference in density between 2 and 28 m attributable to chemical stratification increased from 10.4 kg m^{-3} in 1996 to 12.3 kg m^{-3} in 1997. The lack of holomixis during the previous two winters resulted in depleted nutrient levels in the mixolimnion and reduced abundance of phytoplankton. In 1997, the spring (February–April) epilimnetic chlorophyll *a* concentrations at 2 m (~2–3 μg chl *a* l^{-1}) were lower than those observed during 1996 (~5–8 μg chl *a* l^{-1}), and other meromictic years 1984–89 (1.6–57 μg chl *a* l-1), and much lower than those observed during the spring months in the last period of monomixis, 1989–95 (~15–153 μg chl *a* l^{-1}). Concomitant increases in transparency and the depth of the euphotic zone were also observed. As in 1996, a single mid-July peak in adults characterized the Artemia population dynamics in 1997 with little evidence of recruitment of second generation *Artemia* into adults. The peak midsummer adult abundance (27,300 m^{-2}) was slightly lower than 1996 but similar to 1995 (24,400 m^{-2}). The mean length of adult females was 0.2–0.3 mm shorter than the lengths observed in 1996 and the brood sizes lower, 26–33 eggs $brood^{-1}$ in 1997 compared to 29 to 53 eggs $brood^{-1}$ in 1996.

In 1998 the surface elevation of the lake rose 2.2 ft. The continuing dilution of saline mixolimnetic water and absence of winter holomixis led to increased chemical stratification. The peak summer difference in density between 2 and 28 m attributable to chemical stratification increased from 12.3 kg m^{-3} in 1997 to 14.9 kg m^{-3} in August 1998. The 1998 peak density difference due to chemical stratification was higher than that seen in any previous year, including 1983–84. The lack of holomixis during the previous three winters resulted in depleted nutrient levels in the mixolimnion and reduced abundance of phytoplankton. Chlorophyll *a* concentrations at 2 m generally decreased from 14.3 μg chl *a* l^{-1} in February to 0.3 μg chl *a* l^{-1} in June, when the seasonal chlorophyll *a* concentration minimum was reached. After that it increased to 1–2 μg chl *a* l^{-1} during July–October and to ~8 μg chl *a* l^{-1} in early December. In general, the seasonal pattern of mixolimnetic chlorophyll *a* concentration was similar to that observed during the two previous meromictic years, 1996 and 1997, in which the spring and autumn algal blooms are much reduced compared to monomictic years.

As in 1996 and 1997, a single mid-July peak in adults characterized the Artemia population dynamics in 1998 with little evidence of recruitment of second generation *Artemia* into adults. The peak abundance of adults observed on 10 August (34,000 m^{-2}) was slightly higher than that observed in 1997 (27,300 m^{-2}) and, while similar to the timing in 1997, approximately two weeks to a month later than in most previous years. The mean female length ranged from 9.6 to 10.3 mm in 1998 and was slightly shorter than observed in 1996 (10.1–10.7 mm) and 1997 (9.9–10.4 mm). Mean brood sizes in 1998 were 22–50 eggs $brood^{-1}$. The maximum brood size (50 eggs $brood^{-1}$) was within the range of maximums observed in 1995–97 (62, 53, and 33 eggs $brood^{-1}$, respectively), but was significantly smaller than has been observed in any other previous year 1987–94 (81–156 eggs $brood^{-1}$).

Meromixis continued but weakened slightly in 1999 as the net change in surface elevation over the course of the year was -0.1 ft. The midsummer difference in density between 2 and 28 m attributable to chemical stratification declined from 14.9 kg m^{-3} in 1998 to 12.2 kg m^{-3}. The lack of holomixis during the past four winters resulted in depleted inorganic nitrogen concentrations in the mixolimnion and reduced abundance of phytoplankton. In 1999, the spring (February–April) epilimnetic chlorophyll *a* concentrations at 2 m (10–16 μg chl *a* l^{-1}) were similar to those observed in 1998 but slightly higher than the two previous years of meromixis, 1997 (~2–3 μg chl *a* l^{-1}) and 1996 (~5–8 μg chl *a* l^{-1}). However, they are considerably lower than those observed during the spring months of the last period of monomixis, 1989–95 (~15–153 μg chl *a* l^{-1}). As in all of the three immediately preceding years of meromixis, 1996–98, the *Artemia* population dynamics in 1999 were characterized by a single late-summer peak in adults with little evidence of recruitment of second generation *Artemia* into adults. The peak midsummer adult abundance (38,000 m^{-2}) was slightly higher than 1996 (32,200 m^{-2}), 1997 (27,300 m^{-2}), and 1998 (34,000 m`2). The mean length of adult females was slightly longer (10.0–10.7 mm) than 1998 (9.6–10.3 mm) and similar to 1996 (10.1–10.7 mm) and 1997 (9.9–10.4 mm), while the range of mean brood sizes (27–48 eggs $brood^{-1}$) was similar (22–50 eggs $brood^{-1}$; 1996–98).

In 2000, persistent chemical stratification (meromixis) continued but weakened due to evaporative concentration of the upper mixed layer accompanying a net 0.7 ft annual decline in surface elevation and slight freshening of water beneath the chemocline. The midsummer difference in density between 2 and 28 m attributable to chemical stratification declined from 12.2 kg m^{-3} in 1999 to 10.5 kg m^{-2} in 2000. Most likely of greater significance to the overall plankton dynamics is the marked midwinter deepening (ca. 2 m) of the chemocline. Not only were significant amounts of ammonium-rich monimolimnetic water entrained, but less of the lake is now effectively meromictic; only 38% of the lake's area and 16% of the volume were beneath the chemocline.

Algal biomass, as characterized by the concentration of chlorophyll *a*, was higher in 2000 compared to 1999 and varied in the mixolimnion from a midsummer low of 1.4 μg chl *a* l^{-1} to the December high of 54.2 μg chl *a* l^{-1}. The December value is the highest observed during the entire 21 years of study. The estimated annual primary production in 2000 increased 63% over 1999 to 484 g C m^{-2} yr^{-1} only slightly below the mean annual production (508 g C m^{-2} yr^{-1}) during the recent 5-yr period of monomixis (1990–94). Although adult *Artemia* abundance was anomalously low (50% of the long-term mean), *Artemia* biomass and total annual cyst production were only slightly below the long-term mean, 12 and 16%, respectively. Thus, while meromixis persisted in 2000, the combined effects of declining lake levels, the reduced proportion of the lake beneath the chemocline, and increased upward fluxes of ammonium due to the large buildup of monimolimnetic ammonium offset, to some degree, the effect of the absence of winter holomixis.

Long-term integrative measures: annual primary productivity, mean annual *Artemia* biomass and egg production

The availability of dissolved inorganic nitrogen or phosphorus has been shown to limit primary production in a wide array of aquatic ecosystems. Soluble reactive phosphorus concentrations are very high (>400 μM) in Mono Lake and thus will not limit growth. However, inorganic nitrogen varies seasonally, and is often low and potentially limiting to algal growth. A positive response by Mono Lake phytoplankton in ammonium enrichments performed during different periods from 1982 to 1986 indicates inorganic nitrogen limits the standing biomass of algae (Jellison 1992). In Mono Lake, the two major sources of inorganic nitrogen are brine shrimp excretion and vertical mixing of ammonium-rich monimolimnetic water.

Algal photosynthetic activity was measured from 1982 to 1992 (Jellison and Melack, 1988, 1993a; Jellison *et al.* 1994) and clearly showed the importance of variation in vertical mixing of nutrients to annual primary production. Algal biomass during the spring and autumn decreased following the onset of meromixis and annual photosynthetic production was reduced (269–462 g C m^{-2} yr^{-1}; 1984 to 1986) compared to non-meromictic conditions (499–641 g C m^{-2} yr^{-1}; 1989 and 1990) (Jellison and Melack 1993a). Also, a gradual increase in photosynthetic production occurred even before meromixis was terminated because of increased vertical flux of ammonium due to deeper mixing into ammonium-rich monimolimnetic water. Annual production was greatest in 1988 (1,064 g C m^{-2} yr^{-1}) when the weakening of chemical stratification and eventual breakdown of meromixis in November resulted in large fluxes of ammonium into the euphotic zone.

Estimates of annual primary production integrate annual and seasonal changes in photosynthetic rates, algal biomass, temperature, and insolation. Although measurements of photosynthetic rates were discontinued in 1992, most of the variation in photosynthetic rates can be explained by regressions on environmental covariates (i.e. temperature, nutrient, and light regimes) (Jellison and Melack 1993a, Jellison *et al.* 1994). Therefore, estimates of annual primary production using previously derived regressions and current measurements of algal biomass, temperature, and insolation are included as part of the limnological monitoring program (see chapter 3). These estimates of annual primary production indicate a period of declining productivity (1994–1997) associated with the onset of meromixis and increasing chemical stratification, followed by an increasing production during 1998, 1999, and 2000 despite continuing meromixis.

The mean annual biomass of *Artemia* was estimated from instar-specific abundance and length-weight relationships for the period 1983–99. The mean annual biomass has varied from 5.34 to 17.6 g m^{-2} with a 16-yr mean of 9.8 g m^{-2}. The highest estimated mean annual biomass (17.6 g m^{-2}) occurred in 1989 just after the breakdown of meromixis during a period of elevated phytoplankton nutrients (ammonium) and phytoplankton. The lowest annual estimate was in 1997 following two years of meromixis and increasing density stratification. Mean annual biomass was somewhat below the long-term mean during the first 3 years of the 1980s episode of meromixis and then above the mean the next 3 years as meromixis weakened and ended. The lowest annual biomass of *Artemia* (5.3 g m^{-2}) was observed in 1997, the second year of the current episode of meromixis. However, annual biomass increased in 1998, 1999, and 2000 to near the long-term mean.

Scientific publications

In addition to the long-term limnological monitoring, the City of Los Angeles has partially or wholly funded a number of laboratory experiments, analyses, and analytical modeling studies resulting in the following peer-reviewed research publications by University of California, Santa Barbara (UCSB) researchers.

Dana, G. L. and P.H. Lenz. 1986. Effects of increasing salinity on an *Artemia* population from Mono Lake, California. Oecologia 68:428-436.

Dana, G.L., C. Foley, G. Starrett, W. Perry and J.M. Melack. 1988. In situ hatching of Artemia monica cysts in hypersaline Mono Lake, Pages 183-190. In: J.M. Melack, ed., Saline Lakes. Developments in Hydrobiology. Dr. W. Junk Publ., The Hague (also appeared in Hydrobiologia 158: 183-190.)

Dana, G. L., R. Jellison, and J. M. Melack. 1990. *Artemia monica* egg production and recruitment in Mono Lake, California, USA. Hydrobiologia 197:233-243.

Dana, G. L., R. Jellison, J. M. Melack, and G. Starrett. 1993. Relationships between *Artemia monica* life history characteristics and salinity. Hydrobiologia 263:129-143.

Dana, G. L., R. Jellison, and J. M. Melack. 1995. Effects of different natural regimes of temperature and food on survival, growth, and development of Artemia. J. Plankton Res. 17:2115-2128.

Jellison, R. 1987. Study and modeling of plankton dynamics in Mono Lake, California. Report to Community and Organization Research Institute, Santa Barbara.

Jellison, R., G. L. Dana, and J. M. Melack. 1992. Ecosystem responses to changes in freshwater inflow to Mono Lake, California, p. 107–118. In C. A. Hall, Jr., V. Doyle-Jones, and B. Widawski [eds.] The history of water: Eastern Sierra Nevada, Owens Valley, White-Inyo Mountains. White Mountain Research Station Symposium 4. Univ. of Calif., Los Angeles.

Jellison, R., Romero, J., and J. M. Melack. 1998a. The onset of meromixis during restoration of Mono Lake, California: Unintended consequences of reducing water diversions. Limnol. Oceanogr. 43:706-711.

Jellison, R. and J. M. Melack. 1988. Photosynthetic activity of phytoplankton and its relation to environmental factors in hypersaline Mono Lake, California. Hydrobiologia 158:69-88.

Jellison, R., and J. M. Melack. 1993a. Algal photosynthetic activity and its response to meromixis in hypersaline Mono Lake, California. Limnol. Oceanogr. 38:818–837.

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Jellison, R., L. G. Miller, J. M. Melack, and G. L. Dana. 1993. Meromixis in hypersaline Mono Lake, California II. Nitrogen fluxes. Limnol. Oceanogr. 38:1020–1039.

Jellison, R., G. L. Dana, and J. M. Melack. 1995a. Zooplankton cohort analysis using systems identification techniques. J. Plankton Res. 17:2093–2115.

Jellison, R., R. Anderson, J. M. Melack, and D. Heil. 1996b. Organic matter accumulation in Mono Lake sediments during the past 170 years. Limnol. Oceanogr. 41:1539–1544.

Melack, J.M. and R. Jellison. 1998. Limnological conditions in Mono Lake: Contrasting monomixis and meromixis in the 1990s. Hydrobiologia 384:21-39.

Miller, L. G., R. Jellison, R. S. Oremland, and C. W. Culbertson. 1993. Meromixis in hypersaline Mono Lake, California III. Breakdown of stratification and biogeochemical response to overturn. Limnol. Oceanogr. 38:1040–1051.

Romero, J.R. and J.M. Melack. 1996. Sensitivity of vertical mixing to variations in runoff. Limnol. Oceanogr. 41:955–965.

Romero, J. R., R. Jellison, J. M. Melack. 1998. Stratification, vertical mixing, and upward ammonium flux in hypersaline Mono Lake, California. Archiv fuer Hydrobiol. **142:** 283-315.

Romero, J.R., J.C. Patterson, and J. M. Melack. 1996. Simulation of the effect of methane bubble plumes on vertical mixing in Mono Lake. Aquat. Sci. **58:**210–223.

Other related current research

A wide array of research is being conducted at Mono Lake and UCSB researchers are actively collaborating with several other projects. These include a series of NSF-funded research grants on the internal mixing dynamics of Mono Lake (S. MacIntyre, UCSB), an NSF-funded microbial observatory at Mono Lake (J. Hollibaugh and S. Joye, Univ. Georgia; J. Zehr, UCSC) and research into the effects of *Artemia* abundance on feeding and reproductive success of California Gulls (D. Winkler, Cornell; J. Jehl, Hubbs Sea-World Institute).

CHAPTER 2
METHODS

Meteorology

Continuous meteorological data is collected at the Paoha station located on the southern tip of Paoha Island. The station is approximately 30 m from the shoreline of the lake with the base located at 1948 m asl, several meters above the current surface elevation of the lake. Sensor readings are made every second and stored as either ten minute or hourly values. A Campbell Scientific CR10 datalogger records up to 3 weeks of measurements and radio frequency telemetry is used to download the data weekly.

Wind speed and direction (RM Young wind monitor) are measured at a height of 3 m above the surface of the island and are averaged over a 10-minute interval. The maximum wind speed during the ten-minute interval is also recorded. The 10-minute wind vector magnitude, wind vector direction, and the standard deviation of the wind vector direction are computed from the measurements of wind speed and wind direction and stored. Hourly measurements of average photosynthetically available radiation (PAR, 400 to 700 nm, Li-Cor 192-S) and total rainfall (Qualimetrics 601 I-B tipping bucket), and ten minute averages of relative humidity (Vaisalia HMP35C) and air temperature (Vaisalia HNV35C and Omnidata ES-060) are also made and stored.

The Cain Ranch meteorological station is located approximately 7 km southwest of the lake at an elevation of 2088 m. Throughout the 1980s, LADWP measured wind and temperature at this station. Currently UCSB maintains and records hourly averages of incoming shortwave (280 to 2800 nm; Eppley pyranometer), longwave radiation (3000 to 50000 nm; Eppley pyrgeometer) and PAR (400 to 700 nm; Li-Cor 192-S) at this site.

Sampling Regime

Eleven lakewide surveys were conducted in 2001 at approximately monthly intervals. During winter, the plankton dynamics change relatively slowly and thus a survey was not conducted during January. *Artemia*, temperature, conductivity, oxygen, ammonium, chlorophyll *a*, and Secchi depth were sampled on every survey.

Field Procedures

In situ profiles

Water temperature and conductivity were measured at eight buoyed, pelagic stations (2, 3, 4, 5, 6, 7, 8, and12) (Figure 1). Profiles were taken with a high-precision, conductivity-temperature-depth profiler (CTD) (on loan from the University of Georgia) equipped with sensors to additionally measure photosynthetically available radiation (PAR), fluorescence (695 nm), and transmissivity (660 nm). The CTD was deployed by lowering at 0.1-0.2 m s^{-1}. An analysis of salinity spiking from the mismatch in the time response of the conductivity and temperature sensors indicated a 1.7 s displacement of the temperature data provided the best fit. The pumped fluorometer data requires a 3.7 s shift, and other sensors (pressure, PAR, transmissivity) required a distance offset based on their relative placement. As density variations in Mono Lake can be substantial due to chemical stratification, pressure readings were converted to depth by integrating the mass of the water column above each depth.

Conductivity readings at in situ temperatures (C_t) were standardized to 25°C (C_{25}) using

$$C_{25} = \frac{C_t}{1 + 0.02124(t - 25) + 9.16 \times 10^{-5}(t - 25)^2}$$

where t is the in situ temperature. To describe the general seasonal pattern of density stratification, the contributions of thermal and chemical stratification to overall density stratification were calculated based on conductivity and temperature differences between 2 and 28 m at station 6 and the following density equation:

$$\rho(t, C_{25}) = 1.0034 + 1.335 \times 10^{-5} t - 6.20 \times 10^{-6} t^2 + 4.897 \times 10^{-4} C_{25} + 4.23 \times 10^{-6} C_{25}^2 - 1.35 \times 10^{-6} t C_{25}$$

The relationship between total dissolved solids and conductivity for Mono Lake water was given by:

$$TDS(g\,kg^{-1}) = 3.386 + 0.564 \times C_{25} + 0.00427 \times C_{25}^2 .$$

To obtain TDS in grams per liter, the above expression was multiplied by the density at 25°C for a given standardized conductivity given by:

$$\rho_{25}(C) = 0.99986 + 5.2345 \times 10^{-4} C + 4.23 \times 10^{-6} C^2$$

A complete description of the derivation of these relationships is given in Chapter 4 of the 1995 Annual Report.

Dissolved oxygen was measured at one centrally located station (Station 6). Dissolved oxygen concentration was measured with a Yellow Springs Instruments temperature-oxygen meter (YSI, model 58) and probe (YSI, model 5739). The oxygen electrode is calibrated at least once each year against Miller titrations of Mono Lake water (Walker *et al.* 1970).

Water samples

Chlorophyll and nutrient samples were collected from seven to eleven depths at one centrally located station (Station 6). In addition, 9-m integrated samples for chlorophyll *a* determination and nutrient analyses were collected with a 2.5 cm diameter tube at seven stations (Station 1, 2, 5, 6, 7, 8, and 11) (Figure 1). Samples for nutrient analyses were filtered immediately upon collection through Gelman A/E glass-fiber filters, and kept chilled and dark until returned to the lab. Water samples used for the analysis of chlorophyll *a* were filtered through a 120-µm sieve to remove all stages of *Artemia*, and kept chilled and dark until filtered in the laboratory.

Artemia samples

The *Artemia* population was sampled by one net tow from each of twelve, bouyed stations (Figure 1). Samples were taken with a plankton net (1 m x 0.30 m diameter, 120 µm Nitex mesh) towed vertically through the water column. Samples were preserved with 5% formalin in lake water.

Laboratory Procedures

Water samples

Upon return to the laboratory samples were immediately processed for ammonium and chlorophyll determinations. Ammonium concentrations were measured with the indophenol blue method (Strickland & Parsons, 1972) using internal standards for each set of determinations. Chlorophyll samples were filtered onto 47 mm Whatman GF/F filters and kept frozen until the pigments were analyzed. From 1987 through May 2000, Mono Lake chlorophyll *a* samples were filtered onto Gelman A/E filters, which have a pore size of ca. 1.0 µm. The recognition that a small fraction of picoplankton may pass through these filters prompted an additional protocol in which the A/E filtrates from 2, 12, 20, and 28 m depth profiles from station 6 were filtered onto Whatman GF/F filters (ca. 0.7 microns effective pore size) . The chlorophyll *a* means and standard deviations of GF/F-filtered A/E filtrate for 2, 12, 20, and 28 m were 0.419 ± 0.412 (n=55), 0.570 ± 0.403 (n=55), 1.043 ± 0.321 (n=55), and 1.401 ± 0.550 (n=38) µg chl l^{-1}, respectively. During periods of low chlorophyll (<5 µg chl l^{-1}), A/E filtrate onto GF/F filters produced chl *a* values of ca. 20% those from the A/E filters. During periods of higher chlorophyll (>5 µg chl l^{-1}) the relative amount captured by a second filtration onto GF/F filters was

3.9%. Beginning in June 2000, GF/F filters were used exclusively for chlorophyll *a* determinations.

Chlorophyll *a* was extracted and homogenized in 90% acetone at room temperature in the dark. Following clarification by centrifugation, absorption was measured at 750 and 663 ηm on a spectrophotometer (Milton Roy, model Spectronics 301), calibrated once a year by Milton Roy Company. The sample was then acidified in the cuvette, and absorption was again determined at the same wavelengths to correct for phaeopigments. Absorptions were converted to phaeophytin-corrected chlorophyll *a* concentrations with the formulae of Golterman (1969). During periods of low phytoplankton concentrations (<5 μg chl *a* l^{-1}), the fluorescence of extracted pigments was measured on a fluorometer (Sequoia-Turner, model 450) which was calibrated against the spectrophotometer using large-volume lake samples and fresh lettuce. Ammonium concentrations were measured using the indophenol blue method (Strickland and Parsons 1972). In addition to regular standards, internal standards were analyzed because the molar extinction coefficient is less in Mono Lake water than in distilled water. Oxygen gas was bubbled into Mono Lake water and used for standards and sample dilutions. Oxygenating saline water may help reduce matrix effects that can occur in the spectrophotometer (S. Joye, pers. comm.)

Artemia samples

Artemia abundances were counted under a stereo microscope (6x or 12x power). Depending on the density of shrimp, counts were made of the entire sample or of subsamples made with a Folsom plankton splitter. Samples were split so that a count of 150 to 200 animals was obtained. Shrimp were classified into adults (instars > 12), juveniles (instars 8–11), and nauplii (instar 1–7) according to Heath's classification

(Heath 1924). Adults were sexed and the adult females were divided into ovigerous and non-ovigerous. Ovigerous females included egg-bearing females and females with oocytes. Adult ovigerous females were further classified according to their reproductive mode, ovoviviparous or oviparous. A small percentage of ovigerous females were unclassifiable if eggs were in an early developmental stage. Nauplii at seven stations (Stations 1, 2, 5, 6, 7, 8, and 11) were further classified as to instars 1–7.

Live females were collected for brood size and length analysis from seven buoyed stations (Stations 1, 2, 5, 6, 7, 8, and 11) with 20-m vertical net tows and kept cool and in low densities during transport to the laboratory. Immediately on return to the laboratory, females were randomly selected, isolated in individual vials, and preserved. Brood size was determined by counting the number of eggs in the ovisac including those dropped in the vial, and egg type and shape were noted. Female length was measured from the tip of the head to the end of the caudal furca (setae not include).

Long-term integrative measures of productivity

Primary Production

Photosynthetically available radiation (PAR, 400-700 nm) was recorded continuously at Cain Ranch, seven kilometers southwest of the lake, from 1982 to 1994 and on Paoha Island in the center of the lake beginning in 1991 with a cosine-corrected quantum sensor. Attenuation of PAR within the water column was measured at 0.5-m intervals with a submersible quantum sensor. Temperature was measured at 1-m intervals with a thermistor and wheatstone bridge circuit calibrated against a certified thermometer and accurate to 0.05°C prior to 1992 and with a conductivity-temperature-depth profiler (Seabird, SB19) from 1992 to 2000 (see Methods, Chapter 2).

Phytoplankton samples were filtered onto glass fiber filters and extracted in acetone (See Methods, Chapter 2).

Photosynthetic parameters were estimated based on regressions of 1991 and 1992 photosynthetic parameters against temperatures. The chlorophyll-normalized light-saturated uptake rates from carbon uptake measurements performed in 1991 and 1992 were highly correlated with water temperature. The exponential equation:

$$P_m^B = 0.237 \times 1.183^T \quad n=42, r^2=0.86$$

where T is temperature (°C) explained 86% of the overall variation. As found in previous analyses (Jellison and Melack 1993), there was a strong correlation between light-limited and light-saturated rates. A linear regression on light-saturated rates explained 82% of the variation in light-limited rates:

$$\alpha^B = 2.69 + (1.47 \times P_m^B) \qquad n=42, r^2=0.82$$

Both light-limited and light-saturated carbon uptake rates are within the range reported in other studies. During 1995, rising lake levels and greater salinity stratification most likely reduced the vertical flux of nutrients and thus may have affected the photosynthetic rates. However, previous regression analyses (Jellison and Melack 1993), using an extensive data set collected during periods of different nutrient supply regimes, indicates little of the observed variance in photosynthetic rates can be explained by simple estimate of nutrient supply. The above regressions explain most of the variance in photosynthetic rates and thus provide a reasonable alternative to frequent, costly field and laboratory measurements using radioactive tracers. The differences in annual phytoplankton production throughout the period, 1982–1992, resulted primarily from changes in the amount of standing biomass; year to year changes in photosynthetic parameters during the years they were measured (1983–92) were not correlated with annual production. While photosynthetic parameters were not measured in 1993–01, other major factors determining primary production were measured throughout the year.

Estimates of daily integral production were made using a numerical interpolative model (Jellison and Melack 1993). Inputs to the model include the estimated photosynthetic parameters, insolation, the vertical attenuation of photosynthetically available irradiance and vertical water column structure as measured by temperature at 1 m intervals and chlorophyll a from samples collected at 4–6 m intervals. Chlorophyll-specific uptake rates based on temperature were multiplied by ambient chlorophyll a concentrations interpolated to 1-m intervals. The photosynthetically available light field was calculated from hourly-integrated values at the onshore monitoring site, measured water column attenuation, and a calculated albedo. The albedo was calculated based on hourly solar declinations. All parameters, except insolation that was recorded continuously, were linearly interpolated between sampling dates. Daily integral production was calculated by summing hourly rates over the upper 18 m.

Artemia biomass and reproduction

Average daily biomass and annual cyst and naupliar production provide integrative measures of the *Artemia* population allowing simple comparison among years. Prior to 2000, *Artemia* biomass was estimated from stage specific abundance and adult length data, and weight-length relationship determined in the laboratory simulating in situ conditions of food and temperature (see Jellison and Melack 2000 for details). Beginning in 2000, biomass was determined directly by drying and weighing of *Artemia* collected in vertical net tows.

The resulting biomass estimates are approximate because actual instar-specific weights may vary within the range observed in the laboratory experiments. However, classifying the field samples into one of the three categories will be more accurate than using a single instar-specific weight-length relationship. Because length measurements of adult females are routinely made, they were used to further refine the biomass estimates. The adult female weight was estimated from the mean length on a sample date and one of the three weight-length regressions determined in the laboratory development experiments. As the lengths of adult males are not routinely determined, the average ratio of male to female lengths determined from individual measurements on 15 dates from 1996 and 1999 was used to estimate the average male length of other dates.

Naupliar and cyst production was calculated using a temperature-dependent brood interval, ovigery, ovoviviparity versus oviparity, fecundity, and adult female abundance data from seven stations on each sampling date.

CHAPTER 3

RESULTS AND DISCUSSION

Mono Lake remained chemically stratified throughout 2001. The current episode of meromixis was initiated in 1995 when above normal runoff, coupled with reduced volume, resulted in the second largest annual lake level rise this century. The large influx of freshwater above saline lake water initiated a period of persistent chemical stratification or meromixis. Below average runoff during 1999, 2000, and 2001 have resulted in declining lake levels. Evaporative concentration of the surface mixed layer and deep mixing within the lake are weakening the strong chemical stratification initiated in 1995 and should this trend continue, meromixis is expected to break down much sooner than previously predicted (Jellison et al. 1998). A previous episode of meromixis initiated by record runoff in 1982–83 ended 6 years later when the salinity of the mixolimnion (surface mixed layer) eventually became greater than that of the monimolimnion (bottom layer beneath chemocline) due to evaporative concentration and low inputs of freshwater.

Meteorological Data

Wind Speed and Direction

Mean daily wind speed varied from 0.9 – 9.3 m s^{-1} over the year, and averaged 3.2 m s^{-1} (Fig. 2). The daily maximum 10-min averaged wind speeds averaged 1.5 times mean daily wind speeds and the maximum recorded wind speed was 26.2 m s^{-1} on 25 September. The mean monthly wind speed is fairly constant (coefficient of variation, 15%) and only varied from 2.3 m s^{-1} in January to 4.1 m s^{-1} in June. Wind direction through the year was consistently from the southwest. The monthly vector-averaged wind direction was 210 degrees, and ranged from 186 – 222 degrees over the year. These wind speed and direction values are very similar to those observed during 2000.

Air Temperature

Mean daily air temperature ranged from a minimum of –9°C on 16 January to a maximum of 23°C on 19 August (Fig. 3). Air temperatures ranged from 6°C to 32°C during the summer (June through August) and from –12°C to 12°C during the winter (December through February).

Incident Photosynthetically Available Radiation

Photosynthetically available radiation (400-700 nm) exhibits a regular sinusoidal curve varying from about 20 Einsteins m^{-2} day^{-1} in mid-January and mid-December to ~65 Einsteins m^{-2} day^{-1} in mid-June (Fig. 4). Daily values that diverge from the curve indicate overcast or stormy days. During 2001, the annual mean was 37.9 Einsteins m^{-2} day^{-1}, with daily values ranging from 4.2 Einsteins m^{-2} day^{-1} on 15 January to 65.0 Einsteins m^{-2} day^{-1} on 13 June.

Relative Humidity and Precipitation

Mean daily relative humidity followed a general pattern of high values in January and February, decreasing to lows in May through August, and increasing through December, with a brief period of increased humidity (maximum of 79%) from July 3 through 10 (Fig. 5). The yearly mean was 54.4%, with a maximum of 97.4% occurring on 21 January, and a minimum of 23.0% on 17 April (Fig. 5).

During 2001, annual precipitation at the Paoha Island meteorological station was 87.9 mm (Fig. 6). The most rainy days occurred in February (12 days totaling 10.8 mm) and April (9 days totaling 12.4 mm), while the most precipitation fell in November (31 mm), owing to one large precipitation event on November 30 (30 mm). July and August also had substantial rainfall (15.9 mm), while very little precipitation occurred during May through June (0.3 mm). The detection limit for the tipping bucket gage is 1 mm of water. As the tipping bucket is not heated, the instrument is less accurate during periods of freezing due to sublimation or other losses of falling snow.

Surface Elevation

In 2001, the surface elevation of Mono Lake rose 0.6 ft from 6383.4 ft asl (USGS datum) in January to 6384.0 ft by late May (Fig. 7). Then surface elevation declined through the rest of the year reaching 6382.6 ft in December. Thus, a net annual decline of 0.8 ft in surface elevation occurred in 2001, similar to the 0.7 ft decline observed in 2000 and significantly more than the 0.1 ft decline observed in 1999.

Temperature

The annual pattern of thermal stratification in Mono Lake results from seasonal variations in climatic factors (e.g. air temperature, solar radiation, wind speed, humidity) and their interaction with density stratification arising from freshwater inputs. The timing and magnitude of freshwater inputs, primarily precipitation and inflowing streams that mix into the upper portion of the water column, affect vertical mixing and thus the seasonal pattern of thermal stratification. The annual pattern of seasonal thermal stratification observed during 1990–94 is typical of large temperate lakes, with the lake being thermally mixed during holomixis in the late autumn through early winter. This pattern was altered during a previous episode of meromixis (1982-89) and similarly in the current episode of meromixis 1995–01; (Fig. 8, Table 1) due to vertical salinity gradients associated with ongoing meromixis.

Aside from the absence of a winter period of holomixis, the most notable difference in the thermal regime during 1996–01 compared to monomictic years is the presence of significant inverse thermal stratification at mid-depths (20–26 m). In 2001, inverse thermal stratification of ca. 3.5 °C was observed between 24 and 29 m during mid-February. This inverse thermal stratification was significantly greater in 2001 compared to 2000. On the 20 February profile, the upper water column was well-mixed with a temperature of ca. 1.5°C, while below the mixolimnion the temperature increased to ca. 5.0°C (Table 1). Although lessening through the year, modest (0.5°C) inverse stratification was still present in November. The decrease in inverse thermal stratification observed through the year was due both to warming of the metalimnion and cooling of the monimolimnion (region beneath the chemocline). This is the first year since the onset of meromixis in 1995, that significant cooling of the monimolimnion has occurred during the course of the year.

In 2001, the annual variation in mixolimnetic water temperature was somewhat larger than observed in 2000. Mixolimnetic temperatures (1.5–2.2°C) observed in February 2001 were significantly cooler than those observed in February 2000 (3.2–3.6°C). By mid-March 2001, a seasonal thermocline had formed at 8 m and upper water column temperatures began to increase. While initially cooler than observed in 2000, epilimnetic temperatures warmed quickly and exceeded those of 2000 by ~2°C in mid-May. Through the rest of summer and autumn, the epilimnetic water temperature were generally 1–2°C warmer than in 2000. The seasonal thermocline established in March persisted and deepened over the summer to 12 m by mid-August when epilimnetic temperatures were 21–22 °C. After August, the epilimnion began to cool and deepen, and by December the water column was nearly isothermal at 6.3–6.7°C above the chemocline at 24–25 m.

Conductivity and Salinity

Salinity, expressed as total dissolved solids, can be calculated from conductivity measurements corrected to a reference temperature (see Methods). Because total dissolved solids are conservative at the current salinities in Mono Lake, salinity decreases as the volume of the lake increases due to inputs of freshwater in excess of evaporative losses.

In 2001, conductivity of the mixolimnion decreased slightly from 80.2 mS cm^{-1} in February to 79.4–79.8 mS cm^{-1} in May and June due to spring runoff (Fig. 9, Table 2). However, this freshening of the mixolimnion was small due to below average runoff. Evaporative concentration through the second half of the year resulted in mixolimnetic conductivities increasing to 81.2–81.3 mS cm^{-1} by early December. The mixolimnetic salinity (TDS) therefore ranged from 75.1–77.5 g kg^{-1} (80.0–82.6 g l^{-1} at 20°C).

Monimolimnetic conductivities and salinities in 2001 exhibited a significant decrease from 86.7–86.9 mS cm^{-1} (84.4–84.6 g kg^{-1}) in February to 85.7–85.9 mS cm^{-1} (83.1–83.3 g kg^{-1}) in December. While monimolimnetic conductivities and salinities have decreased slightly each year since the beginning of the current period of meromixis (from 90.3 mS cm^{-1} in December 1995), the decrease in 2001 was twice as large as observed during each of the two previous years. This monimolimnetic freshening is indicative of a small amount of mixing through the thermocline and the presence of subsurface freshwater inflows.

During winter 2000/2001, the chemocline was pushed downward ~2 m to 24–25 m where it remained through the rest of the year (Table 2, Fig. 9). At this depth, 33% of the surface area of the lake and 12% of its volume are beneath the chemocline.

Density Stratification: Thermal and Chemical

The large seasonal variation in freshwater inflows associated with a temperate climate and year-to-year climatic variation lead to complex patterns of seasonal density stratification. Much of the year-to-year variation in the plankton dynamics observed during the past two decades years at Mono Lake can be attributed to marked differences in chemical stratification resulting from variation in freshwater inflows.

As in previous meromictic years, density stratification was evident throughout the year in 2001 (Fig. 10, Table 3). Density of water below 28 m ranged from 1.077–1.076 g cm^{-3}, while minimum densities of 1.065 g cm^{-3} were recorded near the surface (< 4 m). This minimum density, occurring in July and August, was slightly higher than observed during 2000 (1.063 g cm^{-3}) and reflects the higher salinity accompanying declining lake levels.

A comparison of the density differences between 2 and 28 m due to thermal versus chemical stratification indicates chemical density stratification continued to predominate throughout 2001 (Fig. 11, Table 4). Annual peaks in chemical stratification increased each year from 1995 to 1998 (from 8.1 kg m^{-3} in August 1995 to 10.4 kg m^{-3} in July 1996, to 12.3 kg m^{-3} in July 1997, to 14.9 kg m^{-3} in August 1998), but have subsequently decreased due to evaporative concentration as the lake level declines. The annual peaks in chemical stratification were 12.2, 10.6 and 8.9 kg m^{-3} in 1999, 2000, and 2001, respectively. The annual peak in chemical stratification occurred earlier in 2001 (May–June versus July–August in most years) reflecting well-below average runoff. Despite the overall lessening of chemical stratification, it still contributed over twice as much as temperature to the overall midsummer density stratification (8.1 versus 3.1 kg m^{-3}).

Summer thermal stratification regularly contributes 3.5 to 4.5 kg m^{-3} of density stratification between 2 and 28 m. During meromictic periods inverse thermal stratification early in the year results in a slight (~0.4 kg m^{-3}) lessening of overall vertical stratification. In 2001, this inverse thermal stratification persisted from February through November and may have significantly enhanced mixing at the deep chemocline.

December conductivity profiles from 1994–2001 (Fig. 12) show that there was an increase in mixolimnetic conductivities due to summer evaporative concentration of surface water while monimolimnetic conductivities decreased, resulting in an overall decrease in chemical stratification during 2001.

The December chemical stratification was lower in 2001 than any other year since the onset of meromixis. The overall maximum density stratification due to temperature and salinity was 12.0 kg m^{-3}, a decrease from the 2000 maximum of 14.1 kg m^{-3}, and similar to the first year of the current episode of meromixis (1995) when it was 12.4 kg m^{-3}.

Transparency and Light Attenuation

In 2001, average lakewide transparencies as determined by Secchi depth were between 1.3–1.6 m during February-April (Fig. 13, Table 5). These values were similar to those observed during 1994 and 1995 following periods of winter holomixis and slightly less (reflecting more phytoplankton) than 1996–99. Secchi depth increased to 5.7 m by mid-May due to grazing by the developing 1st generation of *Artemia* and then to 10–11 m during June through August. The midsummer values are greater than observed during 1994 and 1995 following previous winter holomixis, and similar to 1996, 1998, and 1999.

In Mono Lake, variation in Secchi depth is predominately due to changes in algal biomass. Standing algal biomass reflects the balance between all growth and loss processes. Thus, variation in Secchi depth often reflects the detailed development of the *Artemia* population as much as changes in nutrient availability.

Following the maximum transparency of 10.7 m observed in July, Secchi depth decreased to 1.1 m by early December. The autumn decline was similar to that observed during 2000 and more rapid than observed in either 1998 or 1999. Reduced upward flux of nutrients accompanying meromixis reduces the annual autumn algal bloom during periods of meromixis. However, the autumn algal bloom has increased during each of the past three years presumably due to the observed autumn deepening of the mixed layer and the accompanying entrainment of ammonium-rich monimolimnetic water.

Secchi depth is an integrative measure of light attenuation within the water column. Because absorption is exponential with depth, the long-term variation in Secchi depth is most appropriately viewed on a logarithmic scale. The annual pattern of Secchi depths during 2001 was within the range observed during the past 21 years (Fig. 14).

The attenuation of PAR within the water column varies seasonally, primarily as a function of changes in algal biomass. In 2001, the depth of the euphotic zone, operationally defined as the depth at which only 1% of the surface insolation is present, varied from 6 m during winter (February and December) to 16–17 m during June–August (Fig. 15). This annual pattern is within the previously observed range of monomictic years.

Dissolved Oxygen

Dissolved oxygen concentrations are primarily a function of salinity, temperature, and the balance between photosynthesis and overall community respiration. In the euphotic zone of Mono Lake, dissolved oxygen concentrations are typically highest during the spring algal bloom. As the water temperature and *Artemia* population increase through the spring, dissolved oxygen concentrations decline. Beneath the euphotic zone, bacterial and chemical processes deplete the oxygen once the lake stratifies. During meromictic periods, the monimolimnion (the region beneath the persistent chemocline) remain anoxic throughout the year.

In February–March 2001, dissolved oxygen concentrations in the upper water column ranged from 6.5 to 8.4 mg l^{-1} (Fig. 16, Table 6). The depth of the oxycline associated with persistent chemical stratification was 24–25 m, having slightly deepened from 23–24 m in December 2000. The annual maximum concentrations of mixolimnetic oxygen occurred in April (9–10 mg l^{-1}) and were somewhat higher than those observed in 2000. Mixolimnetic dissolved oxygen declined to midsummer values of 4.0–4.5 mg l^{-1}, increased to 5.0–5.5 mg l^{-1} during the October phytoplankton bloom, and decreased to 1.3–3.9 mg l^{-1} in December. The December dissolved oxygen profile is rather anomalous with a distinct minimum at 10–11 m. The oxycline deepened 6 m between 15 November and 7 December, so it is possible that the December sampling occurred immediately after the entrainment of highly reduced metalimnetic water.

The anoxic zone (depth below which dissolved oxygen concentrations are <0.5 mg l^{-1}) varied between 17–19 m during the period of summer thermal stratification before returning to 24–25 m due to autumn mixing in December 2001. While the absence of any winter period of holomixis continued to maintain anoxic conditions beneath the chemocline, the deepening of the chemocline has resulted in a smaller portion of the lake (33% by area and 12% by volume) remaining anoxic throughout the year.

Nutrients (ammonium)

Nitrogen is the primary limiting macronutrient in Mono Lake as phosphate is in super-abundance (350-450 μM) throughout the year (Jellison *et al.* 1994). External inputs of nitrogen are low relative to recycling within the lake (Jellison *et al.* 1993). Ammonium concentrations in the euphotic zone reflect the dynamic balance between excretion by shrimp, uptake by algae, upward vertical fluxes through thermo- and chemocline(s), release from sediments, ammonia volatilization, and small external inputs. Because a large portion of particulate nitrogen, in the form of algal debris and *Artemia* fecal pellets, sink to the bottom and are remineralized to ammonium in the hypolimnion (or monimolimnion during meromixis), vertical mixing controls much of the internal recycling of nitrogen.

During 2001, ammonium concentrations were low(<0.1–0.6 μM) early in the year (February-April) after which they increased to 2–4 μM from May through August before declining slightly to 0.9–1.4 μM during September through December (Fig. 17, Table 7). During 2001, the May through December values were all higher than observed in 2000.

The seasonal increase observed during May through August results from *Artemia* ammonium excretion and decreased algal uptake accompanying *Artemia* grazing and lower standing algal biomass. While this seasonal feature is observed during both meromictic and monomictic conditions, it is generally larger during monomictic periods. During meromictic conditions it is often reduced in magnitude and often only observed during one monthly sampling. During 2001, elevated ammonium concentrations were observed throughout the summer. While this may arise due to changes in any of the various sources and sinks, nitrogen limitation of photosynthetic activity may be assumed to have lessened during this period.

Ammonium concentrations in the monimolimnion continued to increase during meromixis. Concentrations at 28 and 35 m were generally 900–1200 μM (Table 7). The present accumulation is much higher than that observed during the 1983–88 episode of meromixis when ammonium built up to ~600 μM (Jellison *et al.* 1989). While the current volume of the monimolimnion is only 12% of the total lake volume, the amount of ammonium in the monimolimnion would result in concentrations exceeding 100 μM throughout the water column should meromixis breakdown.

Soluble reactive phosphate concentrations remain several orders of magnitude above those that are saturating for phosphate uptake by phytoplankton. Thus, seasonal variation is not expected to significantly affect the plankton dynamics.

Phytoplankton (chlorophyll *a* and fluorescence)

The phytoplankton community, as characterized by chlorophyll *a* concentration, shows pronounced seasonal variation. Mixolimnetic concentrations varied from 30–40 μg chl *a* l^{-1} in February 2001 to midsummer minimum values of ~1 μg chl *a* l^{-1} to ~50 μg chl *a* l^{-1} during early December (Fig. 18, Table 8). Mixolimnetic chlorophyll *a* concentrations were also higher in March 2001 (20–40 μg chl *a* l^{-1}) compared to March 2000 (8–21μg chl *a* l^{-1}). April through December chlorophyll *a* values in 2001 were generally similar to those observed in 2000, except that the autumn bloom developed almost a month earlier in 2000. Monimolimnetic (28 m) concentrations of chlorophyll *a* were relatively constant, varying from 23 to 40 μg chl *a* l^{-1}, similar to the range observed in previous years.

Prominent mid-depth maxima in chlorophyll were observed throughout much of the period. However, chlorophyll *a* determinations are only made on a limited number of samples collected at discrete depths. *In situ* fluorescence profiles determined at 5–10 cm scales indicate strong vertical variation in biotic conditions.

A Seabird Seacat profiler equipped with a transmissometer, PAR sensor, and fluorometer was acquired and deployed on routine surveys beginning in July 2000. This has enabled a much better characterization of the vertical distribution of fluorescing and light absorbing particles than sampling with a Van Dorn bottle. Regressions of chlorophyll *a* determinations versus in situ fluorescence taken throughout the water column from July through December yielded a strong correlation and indicate the usefulness of fluorescence to characterize chlorophyll *a* distributions. However, there is a fair amount of scatter about the regression on any given day, and thus an accurate estimate of chlorophyll *a* requires depth and date specific comparisons to laboratory chlorophyll *a* extractions. Nevertheless, even without detailed comparisons, variations in fluorescence indicate complex vertical variation in the water column biotic properties.

Fluorescence profiles at station 6 give a detailed image of variation in the vertical structure of the phytoplankton community (Fig. 19). On 17 February 2001, while near surface fluorescence was low in the upper 5 m, it was moderate and fairly uniform below 6 m until the chemocline at 24.5 m. From April through September, prominent mid-depth peaks are noted in the oxycline/nutricline regions. The complex interplay between biogeochemical processing by micro-organisms and in situ light, oxygen, density, and nutrient gradients is a major focus of the NSF-funded Microbial Observatory at Mono

Lake. These mid-depth peaks largely disappear with autumn mixing during October through December.

Artemia Population Dynamics

Population Overview

The *Artemia* population in 2001 was similar to 2000 in that it was characterized by the fairly rapid development of the 1st generation, and a large pulse of ovoviviparous reproduction in June (Fig. 20). The early decline of the adult population that occurred in 2000 was not seen in 2001. The peak in naupliar abundance occurred in May (36,000 m^{-2}) and was substantially smaller than in 1998-2000 (64,400 m^{-2}, 60,600 m^{-2}, and 93,119 m^{-2}, respectively). Juvenile peak abundances (8600 m^{-2}) were higher than in 2000 (5017 m^{-2}) but much lower than the annual peak in 1999 (35,600 m^{-2}) or 1998 (29,135 m^{-2}). Adult abundance reached a maximum in July (38,000 m^{-2}) and August (37,800 m^{-2}). The abundance of adults then decreased steadily to November and December (ca. 25 m^{-2} both months).

Nauplii (Instars 1-7)

Hatching of over-wintering cysts typically becomes significant by late-February, as water temperatures warm after a cold dormancy period (Dana 1981), and continues through May. As in all previously sampled years, with the exception of 1989 when anoxic conditions following the breakdown of meromixis delayed the beginning of the spring hatch until the beginning of March, significant hatching had occurred by the first sampling date of 20 February 2001 (Fig. 20). Naupliar numbers increased through June, when a peak in mean lakewide abundance of 36,000 m^{-2} was observed (Table 9a). This peak naupliar abundance was lower than in 1998 (64,400 m^{-2}), 1999 (60,600 m^{-2}), and 2000 (93,119 m^{-2}), but higher than the range recorded during 1991–1994 (13,000–35,000

m^{-2}). After June 2001, naupliar abundances decreased steadily to 3300 m^{-2} by August, and then continued to decrease through November.

Ovoviviparous second generation nauplii hatched from May through August of 2000 (Table 11a). Peak ovoviviparous hatching occurred in June, when ovoviviparously reproducing females comprised 4.2 percent of fecund females (Table 11c). The percent of ovoviviparous females was somewhat lower in 2000 compared to previous years (8 % in 1999, 12% in 1998). However, adult *Artemia* may rapidly switch reproductive mode and monthly sampling may not accurately capture the peak of ovoviviparous reproduction.

A lack of naupliar recruitment from July to September has been evident in past years, with naupliar instar stages (3-7) absent in *Artemia* samples (1984, 1987, 1989, 1990–91, 1996–98). This pattern was less pronounced in 1999, and was not visible in 2000. Except for instars 6 and 7 in July, all size classes were represented from May through December (Table 10). Naupliar abundances remained similar to higher than those in 1999 through October, but declined in November and December, when instar 1 abundance was ca. 100 m^{-2} (Table 11a).

Juveniles (Instars 8-11)

In 2001 the annual juvenile maximum occurred in May (8618 m^{-2}; Table 9a, Fig. 20) and was higher than in 2000 (5017 m^{-2}), but lower than the range in peaks observed 1993–1999 (9700–32,200 m^{-2}). The timing of maximum abundance was similar to that observed in 2000, 1993-1994 and 1996-1997, but a month earlier than in 1998 and 1999. Juvenile abundance decreased rapidly to 429 m^{-2} in July and remained low through December.

Adults

Adult abundance in 2001 increased to an annual maximum of 38,000 m^{-2} in July. The abundance in August was similar (37,800 m^{-2})(Fig. 20, Table 9a). Abundances from February through August were at the high end of the range observed 1983-1999 (excluding outlier years 1983, 1988, and 1989) (Fig. 21). Abundances decreased more rapidly than on average from August through November. October abundance (6400 m^{-2}) was higher only than 1986 (3200 m^{-2}), 1997 (36 m^{-2}), and 2000 (4900 m^{-2}). Adult abundances were up to 4 times greater on the southwest side of the lake in both 1999 and 2000 (Table 9a).

In 2001, as in 2000, ovigerous females were first observed on the May survey (270 m^{-2}), one month earlier than in 1999 or 1998, but similar to dates of appearance in 1993–94 and 1996–97 (Fig. 22, Table 11a). In May, ovigerous females comprised 58% of all adult females (Table 11c). The number of ovigerous females increased to the year's maximum in August (6600 m^{-2}), though the July abundance was very similar (6500 m^{-2}) then decreased drastically through November (8 m^{-2}), before decreasing to zero in December. The percent ovigerity ranged between 75-90% of the total female population from August through October. The seasonal curve of ovigerity appeared to occur later in the year relative to 2000, as % ovigerity was lower than 2000 from May to August, and higher from September to November. Lower ovigerity early in the year is known to reflect slower maturation rates. During previous meromictic years (1984–88), the female population was slow to attain high levels of ovigerity owing to lower algal biomass.

Ovoviviparity of adult females reached a peak of only 5.1 % on 14 June, higher than 2000 (4.2 %), but lower than the range observed during 1990–99 (8-70 %). The percent of ovoviviparous females decreased to 1.2 % in July and remained near zero for the remainder of the year (Fig. 22, Table 11c).

Mean female length ranged from 9.9 to 12 mm in 2001 (Table 12). The maximum length was higher than the range of maxima from 1996–00 (10.3 to 11.6 mm), and within the range of maxima during the period 1987–95 (11.6 to 13.7 mm). The mean female length decreased from 10.7 mm in June to 9.9 mm in July, indicating juvenile recruitment into the adult stage. Mean female length increased to the annual maximum (12 mm) in October, one month later than in 2000. Shorter lengths of fecund females during the summers of 1996–99 reflect lower ambient algal concentrations. The large females observed in September of 2000 and October 2001 most likely reflect increased chlorophyll *a* concentrations (10/2001: 7.2 $\mu g\ l^{-1}$, 9/2000: 3.4 $\mu g\ l^{-1}$) compared to recent years (1.4 $\mu g\ l^{-1}$ in 1999, 1.2 $\mu g\ l^{-1}$ in 1998) (Table 8).

Mean brood size of ovigerous females in July 2001, when the first generation of *Artemia* matured, was 35 eggs $brood^{-1}$, lower than the brood size at maturation in 2000 (68 eggs $brood^{-1}$ in June). Maximum brood size occurred in October (89 eggs $brood^{-1}$), while the early season maximum (June) was much lower (56 eggs $brood^{-1}$) (Table 12). Smaller brood sizes in June led to a decrease in the peak naupliar abundance, relative to 2000 (Table 9a, Fig. 22). Both maximum and June brood sizes in 2001 were higher than the maximum brood sizes in 1999 (48 eggs $brood^{-1}$) and 1998 (50 eggs $brood^{-1}$), both occurring in June. During the meromictic years 1984–1988 and 1995–2001, as well as 1991-92 and 1994, early summer brood sizes were moderate (20–70 eggs $brood^{-1}$). As in 2001, peak brood size occurred in October or November in 1984–88 and 1991–94. From 1997-1999 the peak occurred in June, and in 1996 it occurred in May. Differences in brood size are largely related to algal abundance and individual size. Larger brood sizes in 2000 and 2001 are therefore expected given the observed larger individuals and more algal biomass.

Artemia Summary Statistics, 1979-2001

Year to year variation in climate, hydrological conditions, vertical stratification, food availability, and possibly salinity have led to large differences in *Artemia* dynamics. During years when the first generation was small due to reduced hatching, high mortality, or delayed development, (1981, 1982, and 1989) the second generation peak of adults was 2–3 times the long term average (Table 13, Fig. 23). Seasonal peak abundances were also significantly higher (1.5–2 times the mean) in 1987 and 1988 as the 1980s episode of meromixis weakened and nutrients that had accumulated beneath the chemocline were transported upward. However, in most years the seasonal peaks of adult abundance were similar (30–40,000 m^{-2}) and the seasonal (1 May to November 30) mean of adult abundance is remarkably constant (14–20,000 m^{-2}). During 2000, Adult *Artemia* abundance was anomalously low. However, the abundance statistics for 2001 are again within the range of data for most years, with a mean and median of 20,000 m^{-2}, and a peak of 38,000 m^{-2}. During most years, the seasonal distribution of adult abundance was roughly normal or lognormal. However, in several years the seasonal abundance was not described well by either of these distributions. Therefore, the abundance-weighted centroid of temporal occurrence was calculated to compare overall seasonal shifts in the timing of adult abundance. The center of the temporal distribution of adults varied from day 205 (24 July) to 230 (18 August) in the 23 years from 1979 to 2001 (Table 13, Fig. 24). During five years when there was a small spring hatch (1980–83, and 1989) the overall temporal distribution of adults was much later (24 August – 9 September) and during 1986 an unusually large 1st generation shifted the seasonal temporal distribution much earlier to 9 July. During 2001, the overall temporal distribution of adults was two weeks earlier (28 July) than the long-term mean (11 August), and 1 day earlier than 2000.

Long-term integrative measures of productivity

Planktonic primary production

Daily estimates of primary production in 2001 ranged from 0.3 to 3.1 g C m^{-2} d^{-1}. This daily range is higher than observed during 1996–98, but within the previously reported range including monomictic periods (Fig. 25) (Jellison and Melack 1988, 1993a; Jellison *et al.* 1994, Jellison *et al.* 1995b, Jellison *et al.* 1996a, Jellison *et al.* 1997). The estimated total annual production of 532 g C m^{-2} yr^{-1} in 2001 represents a 10% increase over the 2000 estimate of 484 g C m^{-2} yr^{-1} and continues the upward trend from the low value estimated in 1997 (149 g C m^{-2} yr^{-1}). The 2001 estimated planktonic primary production is higher than the long-term (1982–99) mean of 467 g C m^{-2} yr^{-1} and slightly higher than the mean annual production (508 g C m^{-2} yr^{-1}) during the last monomictic period from 1990–94. Thus, while meromixis persists in 2001, the combined effects of declining lake levels, the reduced proportion of the lake beneath the chemocline, and increased upward fluxes of ammonium due to the large buildup of monimolimnetic ammonium have offset the effects of the absence of winter holomixis. It is not clear to what extent each of these factors is responsible and continuing meromixis may still reduce the availability of nutrients during periods of rising lake levels.

There are no comparable long-term studies of algal production in other large, deep hypersaline lakes. The annual estimates of planktonic photosynthesis found in this study (149–1063 g C m^{-2} yr^{-1}) are generally higher than other hypersaline lakes in the

Great Basin: Great Salt Lake (southern basin), 145 g C m^{-2} yr^{-1} (Stephens and Gillespie 1976); Soap Lake, 391 g C m^{-2} yr^{-1} (Walker 1975); and Big Soda, 500 g C m^{-2} yr^{-1} (350 g C m^{-2} yr^{-1} phototrophic production) (Cloern *et al.* 1983).

Artemia biomass and egg production

Artemia biomass was estimated from instar-specific population data and previously derived weight-length relationships for the period 1982–99. Variation in weight-length relationships among sampling dates was assessed from 1996–99 and found to lead to errors of up to 20% in the annual estimates. Thus, in 2000 we implemented direct drying and weighing of vertical net tow samples collected explicitly for biomass determinations.

In 2001, *Artemia* biomass increased from ca. 0.01 g dry weight m^{-2} during the February and March surveys to 32.5 g dry weight m^{-2} in mid-August before declining to near zero (0.04 g dry weight m^{-2}) in early December (Fig. 26). The 2001 mean annual biomass of 8.8 g m^{-2} is 9 % below the long-term mean of 9.7 g m^{-2}, slightly higher than calculated in 2000 (8.2 g m^{-2}), and similar to that calculated in 1999 (8.9 g m^{-2}). The highest estimated mean annual *Artemia* biomass (17.6 g m^{-2}) occurred in 1989 just after the breakdown of meromixis during a period of elevated phytoplankton nutrients (ammonium) and phytoplankton. Mean annual biomass was somewhat below the long-term mean during the first 3 years of the 1980s episode of meromixis and then above the mean during the next 3 years as meromixis weakened and ended. Except for lower values in 1997, *Artemia* biomass has remained relatively constant since 1993 and was only slightly higher during 1990–92.

In Mono Lake, oviparous (cyst) reproduction is always much higher than ovoviviparous (live-bearing) reproduction (Fig. 27). In 2001, total annual cyst production (3.02×10^6 m^{-2}) was less than in 2000 (4.03×10^6 m^{-2}), despite increased abundance, and size. The 2001 total annual cyst production was 37% below the long-term (1983–99) mean of 4.77×10^6 m^{-2} but above the lowest value observed in 1997 (2.54×10^6 m^{-2}). In general, cyst production was lower during years following the onset of meromixis and higher during the breakdown of meromixis and during monomictic periods.

Comparison of 1980's and current (1995-present) meromictic events

The onset of meromixis in 1995, coupled with the management policy of restricting water diversions until an elevation of 6392 ft was reached, raised the possibility of a multi-decade period of meromixis (Jellison et al. 1998) and an extended period of reduced overall lake productivity. Although the impacts of meromixis on primary productivity lessened after only two years during the 1980s episode, this weakening of meromixis and its effects on nutrient recycling were due primarily to the evaporative concentration of the upper mixed-layer as freshwater inputs were low due to continued diversions and an extended drought. The current episode of meromixis was expected to last longer as diversions were to be restricted until the lake rose to 6392 ft and continually rising lake levels were expected to maintain meromixis. Indeed primary productivity was reduced during the first five years of the current episode (1995–1999) and impacts were noted on both *Artemia* and avian populations. However, normal or below runoff in 2000 and 2001 and warmer, windier, and drier weather conditions than the preceding four years have led to declining lake levels and a weakening of meromixis. This weakening of meromixis, in combination with a large buildup of ammonium in the monimolimnion, has led to increases in primary productivity similar to those observed during monomictic periods. Here, we directly compare several features of the 1980s and current episodes of meromixis.

Elevation

The lake elevations at the onset of meromixis were 6374.1 ft in 1983 and 6374.5 ft in 1995. In both cases, meromixis was initiated by large influxes of freshwater and a rapid rise (>3 ft yr^{-1}) in lake elevation (Fig. 28). During 1984 and 1985, following the onset of meromixis in 1983, lake level declined due to continued diversions, but rose again in 1986 due to higher snowmelt runoff. The onset of a prolonged drought in 1987 led to declining lake levels and evaporative concentration of the mixed layer until meromixis broke down in late 1988. The elevation at the end of meromixis was approximately 1 ft above the elevation at the onset of this meromictic period.

Unlike the 1980s meromictic event, lake elevation during the current period of meromixis continued to rise until 1999, after which it began a relatively gradual decline. The current lake elevation is 6382.6 ft, is ~8 ft above the elevation at the onset of this period of meromixis.

Area and volume beneath chemocline

Although at any given time Mono Lake may be classified as being either monomictic or meromictic, this dichotomous classification does not capture the complexity of the annual mixing regime. The percent of the lake's surface area or volume which lies below the persistent chemocline under meromictic conditions may vary widely. Following the onset of meromixis in both the 1980s and 1990s episodes, the percent area and volume beneath the chemocline were similar, 55–57 % and 37–39 %, respectively (Fig. 29). The relative proportion of the lake beneath the chemocline decreased over time during both episodes of meromixis and thus the effects of meromixis lessened with time. In the 1990s episode, the continuing rise in lake level during 1996–98 resulted in little change in the relative proportion of the lake beneath the chemocline. However, once surface elevations began to lower in the fifth year of meromixis, winter deepening of the mixed-layer and chemocline occurred, and the trend of decreasing of the relative proportion of the lake beneath the chemocline resumed.

Chemical stratification

The density difference due to salinity between 2 and 28 m at the onset of meromixis was 2.7 kg m^{-3} in 1983 and 4.0 kg m^{-3} in 1995. Initially, chemical stratification increased during both periods of meromixis, though the rise was more rapid in the 1980's event (Fig. 30). The maximum chemical stratification was similar in both episodes (15.5 kg m^{-3} in November 1984, and 15.0 kg m^{-3} in August 1998). Chemical stratification declined rapidly from 1986 to 1988 as the lake level dropped. By summer 1988, evaporative concentration had led to slight inverse chemical stratification (-0.1 kg m^{-3}) with warm, more saline water overlying colder, less saline water before holomixis in November 1988.

A more gradual decline in chemical stratification has been observed during the past three years of the current episode of meromixis. The current density difference due to conductivity is 5.0 kg m^{-3}. If the current trend continues, a simple linear regression of the decrease in salinity stratification over the last three years ($r^2 = 0.91$) would predict meromixis will end in 2004 (Fig. 31). Of course, different meteorological conditions or changes in runoff and management could alter this trend.

The expectation that meromixis will end in the next several years is significantly sooner than that predicted by previous analysis employing the hydrodynamic model, DYRESM (Jellison *et al.* 1998). Several factors may account for all or part of this discrepancy. Subsequent to the DYRESM analysis, measurements of helium isotopes indicate the existence of less saline spring inputs to the monimolimnion. Boundary layer mixing is significant (MacIntyre & Jellison 2001) and may not be adequately described by DYRESM parameterization. Also, the warmer, drier, and windier meteorological conditions of 2000 and 2001 lead to more rapid evaporative concentration of the mixed-layer. All these factors lessen the overall salinity stratification.

Surface ammonium

Under meromictic conditions annual variation in ammonium is attenuated (Jellison and Melack 1993a, Melack and Jellison 1998). During both periods of meromixis in Mono Lake, seasonal variation in ammonium in the surface waters was reduced relative to monomictic years, and mean ammonium concentrations at 2 m were low through the period (1.7 μM during the 1980's event and 1.2 μM during the current event) (Fig. 32).

When meromixis ended in November 1988 and the lake turned over, a large pulse of ammonium was mixed into the upper water column, resulting in high mixed-layer ammonium concentrations (mean concentrations 18.8 μM from 1988 to 1989, compared to 7.8 μM from 1990 to 1994). These elevated concentrations continued through 1989. A similar increase in mixed-layer ammonium concentrations is expected at the breakdown of the current episode of meromixis.

Mixed-layer Chlorophyll a and Artemia

Chlorophyll *a* concentrations during the two meromictic events are quite similar (Fig. 33). The seasonal cycle of algal biomass in the surface waters was attenuated during the initial years of meromixis. Mean chlorophyll *a* concentrations during both periods declined relative to monomictic years (6.0 $\mu g\ l^{-1}$ during 1983 to 1984 and 1995 to

1996 compared to 26.0 μg l^{-1} from 1989 to 1994). In both periods, however, recovery became evident in the third year after the onset of meromixis, though meromixis persisted. While the lake is currently still meromictic, seasonal concentrations are nearly identical to those that occurred immediately after the breakdown of the 1980s episode of meromixis.

As discussed earlier in this (cf. "Long-term Integrative Measures of Productivity section) and previous reports, the effects of meromixis on the *Artemia* population is less than on primary production. Reduced food availability primarily manifests itself in lower annual cyst production and slightly delayed maturation of the spring *Artemia* population. Neither of these impacts was evident this year.

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Table 1. Temperature at Station 6, 2001 (°C)

Depth (m)	2-20	3-13	4-17	5-16	Dates 6-14	7-18	8-16*	9-19	10-19	11-15	12-7
1	2.16	3.48	6.87	15.41	17.93	19.86	21.94	18.74	15.15	10.85	-
2	1.62	3.40	6.77	15.15	18.18	19.88	21.76	18.60	15.12	10.94	6.70
3	1.59	3.25	6.69	15.11	18.14	19.96	21.70	18.74	15.12	10.94	6.65
4	1.58	3.29	6.64	14.66	18.15	19.98	21.67	18.79	15.15	10.93	6.63
5	1.56	3.29	6.64	14.73	18.27	20.01	21.64	18.84	15.15	10.94	6.62
6	1.50	3.28	6.65	14.54	17.91	20.02	21.62	18.84	15.15	10.96	6.62
7	1.48	3.11	6.60	11.82	17.32	20.00	21.61	18.83	15.14	10.98	6.62
8	1.47	2.90	6.40	9.74	16.99	19.93	21.58	18.80	15.13	10.98	6.62
9	1.47	1.89	6.02	8.76	15.15	19.76	21.57	18.78	15.12	10.99	6.64
10	1.46	1.85	5.49	8.14	11.26	18.09	21.54	18.67	15.12	11.00	6.67
11	1.47	1.82	5.42	6.96	8.88	15.77	21.24	18.08	15.01	11.01	6.72
12	1.48	1.69	4.93	6.22	7.67	10.93	17.65	17.55	14.95	11.03	6.67
13	1.50	1.60	4.43	5.29	6.18	7.96	12.98	16.17	14.36	11.04	6.66
14	1.52	1.53	3.66	4.02	5.32	7.06	8.56	15.07	13.56	11.04	6.65
15	1.55	1.50	3.02	3.36	4.35	5.63	7.10	9.53	13.01	11.05	6.60
16	1.55	1.48	2.75	3.02	3.69	4.79	6.01	7.44	10.25	11.06	6.59
17	1.59	1.52	2.59	2.94	3.37	4.31	5.11	5.65	7.43	10.78	6.60
18	1.61	1.52	2.39	2.80	3.22	3.90	4.54	4.48	5.80	8.93	6.53
19	1.63	1.52	2.22	2.66	3.00	3.69	4.12	3.94	5.21	6.38	6.48
20	1.63	1.51	2.14	2.61	2.91	3.53	3.69	3.66	4.58	5.34	6.48
21	1.64	1.54	2.13	2.46	2.76	3.23	3.49	3.48	3.96	4.72	6.46
22	1.68	1.56	2.11	2.42	2.78	3.14	3.34	3.41	3.71	4.07	6.36
23	1.64	1.61	2.07	2.47	2.76	3.06	3.30	3.39	3.59	3.89	6.31
24	1.62	1.91	1.95	2.49	2.81	3.02	3.24	3.41	3.66	3.79	6.12
25	2.92	3.55	2.07	2.79	3.31	3.11	3.32	3.51	3.78	3.84	4.57
26	4.24	4.14	3.41	3.42	3.73	3.64	3.64	3.75	3.96	3.94	4.03
27	4.71	4.61	4.07	3.71	3.94	3.86	3.85	3.93	4.04	4.00	4.04
28	4.82	4.71	4.24	3.93	4.09	3.95	4.01	3.98	4.09	4.08	4.06
29	4.90	4.79	4.37	4.05	4.16	4.01	4.13	4.05	4.12	4.15	4.11
30	5.01	4.91	4.51	4.21	4.23	4.10	4.15	4.11	4.16	4.19	4.14
31	5.01	4.96	4.61	4.33	4.34	4.27	4.21	4.17	4.19	4.21	4.19
32	5.00	4.96	4.66	4.45	4.41	4.22	-	4.20	4.22	4.23	4.22
33	4.99	4.95	4.77	4.54	4.46	4.27	-	4.23	4.27	4.25	4.22
34	4.98	4.94	4.84	4.62	4.50	4.34	-	4.26	4.28	4.26	4.24
35	4.97	4.93	4.87	4.66	4.55	4.37	-	4.27	4.29	4.31	4.27
36	4.96	4.93	4.89	4.73	4.58	4.39	-	4.30	4.34	4.32	4.29
37	4.95	4.93	4.92	4.78	-	4.41	-	4.32	4.35	4.34	4.31
38	4.95	-	-	4.83	-	4.44	-	4.34	-	-	-

*Due to CTD failure, data on this date are from nearby station 7

Table 2. Conductivity (mS/cm at 25°C) at Station 6, 2001

Depth (m)	2-20	3-13	4-17	5-16	Dates 6-14	7-18	8-16*	9-19	10-19	11-15	12-7
1	79.70	79.58	79.64	79.22	79.47	79.80	80.31	80.55	81.00	81.20	-
2	80.08	79.76	79.61	79.38	79.65	79.79	80.36	80.65	81.03	81.23	81.22
3	80.12	79.83	79.63	79.37	79.63	79.69	80.38	80.74	81.04	81.23	81.22
4	80.15	79.85	79.64	79.41	79.68	79.89	80.39	80.79	81.06	81.22	81.23
5	80.17	79.87	79.65	79.53	79.80	79.94	80.38	80.81	81.06	81.25	81.23
6	80.19	79.86	79.65	79.46	79.78	79.97	80.39	80.86	81.06	81.28	81.23
7	80.21	79.85	79.67	79.03	79.68	79.99	80.39	80.90	81.07	81.28	81.23
8	80.22	79.71	79.63	79.33	79.71	80.03	80.39	80.91	81.07	81.30	81.23
9	80.22	80.01	79.66	79.68	79.61	79.71	80.39	80.92	81.07	81.30	81.24
10	80.23	80.05	79.52	79.68	79.07	79.71	80.39	80.88	81.09	81.32	81.26
11	80.24	80.12	79.70	79.58	79.60	79.39	80.29	80.81	81.11	81.32	81.30
12	80.24	80.10	79.60	79.69	79.38	79.11	78.92	80.67	81.10	81.34	81.29
13	80.25	80.13	79.78	79.68	79.60	79.51	78.27	80.59	81.01	81.34	81.32
14	80.25	80.14	79.92	79.76	79.85	79.37	78.89	80.18	80.92	81.35	81.32
15	80.26	80.11	79.97	80.13	79.86	79.81	79.25	79.42	81.01	81.35	81.31
16	80.26	80.17	80.04	80.20	79.99	79.75	79.40	80.00	80.56	81.37	81.34
17	80.28	80.22	80.07	80.26	80.18	79.86	79.66	79.89	80.43	81.07	81.33
18	80.29	80.20	80.05	80.30	80.32	80.07	79.66	79.97	80.56	80.66	81.32
19	80.29	80.21	80.08	80.39	80.40	80.38	80.16	80.31	80.50	80.80	81.33
20	80.29	80.22	80.15	80.46	80.54	80.68	80.51	80.36	80.55	80.64	81.33
21	80.32	80.24	80.21	80.51	80.84	80.90	80.86	80.50	80.52	80.74	81.33
22	80.31	80.31	80.23	80.69	81.16	80.99	80.99	80.58	80.82	81.01	81.30
23	80.31	80.37	80.32	80.96	81.36	81.27	80.99	80.73	81.36	81.30	81.36
24	80.38	83.64	80.36	81.26	81.93	81.48	81.51	80.86	82.56	83.85	81.62
25	86.16	86.62	80.82	83.93	85.91	82.20	82.46	82.63	85.09	85.00	84.14
26	86.33	87.22	86.79	86.62	86.45	85.99	85.56	85.17	85.56	85.32	85.34
27	86.63	87.33	86.98	86.83	86.75	86.48	86.03	85.54	85.63	85.43	85.56
28	86.57	87.27	87.02	86.88	86.77	86.65	86.24	85.68	85.67	85.57	85.63
29	86.64	87.32	87.09	86.93	86.82	86.68	86.39	85.82	85.72	85.64	85.70
30	86.71	87.38	87.14	86.99	86.88	86.39	86.39	85.90	85.73	85.67	85.76
31	86.76	87.38	87.14	87.07	86.93	86.65	86.46	85.97	85.74	85.71	85.80
32	86.79	87.36	87.15	87.13	86.96	86.78	-	86.04	85.78	85.73	85.81
33	86.83	87.35	87.21	87.13	86.97	86.78	-	86.11	85.80	85.74	85.84
34	86.85	87.37	87.23	87.18	86.99	86.82	-	86.13	85.80	85.75	85.85
35	86.87	87.36	87.23	87.20	87.01	86.83	-	86.19	85.82	85.78	85.88
36	86.89	87.35	87.23	87.21	87.02	86.79	-	86.22	85.84	85.78	85.89
37	86.90	87.35	87.20	87.22	-	86.79	-	86.26	85.84	85.79	85.89
38	86.91	-	-	87.21	-	86.82	-	86.28	-	-	-

*Due to CTD failure, data on this date are from nearby station 7

Table 3. Density (g/cm3) at Station 6, 2001

Depth (m)	Dates 2-20	3-13	4-17	5-16	6-14	7-18	8-16*	9-19	10-19	11-15	12-7
1	1.0691	1.0688	1.0683	1.0658	1.0654	1.0651	1.0649	1.0663	1.0679	1.0693	0.9990
2	1.0696	1.0690	1.0683	1.0661	1.0655	1.0651	1.0651	1.0665	1.0680	1.0693	1.0702
3	1.0696	1.0691	1.0683	1.0661	1.0655	1.0649	1.0651	1.0665	1.0680	1.0693	1.0702
4	1.0697	1.0691	1.0683	1.0663	1.0655	1.0652	1.0651	1.0666	1.0680	1.0693	1.0702
5	1.0697	1.0691	1.0683	1.0664	1.0656	1.0652	1.0651	1.0666	1.0680	1.0693	1.0702
6	1.0697	1.0691	1.0683	1.0663	1.0657	1.0652	1.0651	1.0666	1.0680	1.0694	1.0702
7	1.0697	1.0691	1.0684	1.0666	1.0658	1.0653	1.0652	1.0667	1.0680	1.0693	1.0702
8	1.0698	1.0690	1.0684	1.0674	1.0659	1.0653	1.0652	1.0667	1.0680	1.0694	1.0702
9	1.0698	1.0695	1.0685	1.0680	1.0663	1.0650	1.0652	1.0667	1.0680	1.0694	1.0702
10	1.0698	1.0695	1.0684	1.0681	1.0667	1.0656	1.0652	1.0667	1.0681	1.0694	1.0702
11	1.0698	1.0696	1.0686	1.0682	1.0679	1.0659	1.0652	1.0668	1.0681	1.0694	1.0702
12	1.0698	1.0696	1.0686	1.0685	1.0678	1.0668	1.0648	1.0668	1.0681	1.0694	1.0702
13	1.0698	1.0696	1.0689	1.0686	1.0684	1.0679	1.0654	1.0672	1.0682	1.0694	1.0703
14	1.0698	1.0696	1.0691	1.0689	1.0688	1.0679	1.0671	1.0670	1.0683	1.0694	1.0703
15	1.0698	1.0696	1.0693	1.0694	1.0690	1.0687	1.0678	1.0675	1.0685	1.0694	1.0703
16	1.0698	1.0697	1.0694	1.0695	1.0692	1.0688	1.0682	1.0686	1.0687	1.0694	1.0703
17	1.0698	1.0697	1.0694	1.0696	1.0695	1.0690	1.0686	1.0688	1.0691	1.0691	1.0703
18	1.0698	1.0697	1.0694	1.0697	1.0696	1.0693	1.0687	1.0691	1.0695	1.0691	1.0703
19	1.0698	1.0697	1.0695	1.0698	1.0698	1.0697	1.0693	1.0695	1.0696	1.0697	1.0703
20	1.0698	1.0697	1.0696	1.0699	1.0699	1.0700	1.0698	1.0696	1.0697	1.0697	1.0703
21	1.0698	1.0698	1.0697	1.0700	1.0703	1.0703	1.0702	1.0698	1.0698	1.0699	1.0703
22	1.0698	1.0698	1.0697	1.0702	1.0707	1.0704	1.0704	1.0699	1.0702	1.0703	1.0703
23	1.0698	1.0699	1.0698	1.0705	1.0709	1.0708	1.0704	1.0701	1.0708	1.0707	1.0704
24	1.0699	1.0737	1.0699	1.0708	1.0716	1.0710	1.0710	1.0703	1.0722	1.0737	1.0707
25	1.0766	1.0771	1.0704	1.0740	1.0763	1.0719	1.0722	1.0723	1.0752	1.0751	1.0740
26	1.0766	1.0778	1.0773	1.0771	1.0769	1.0763	1.0758	1.0753	1.0758	1.0755	1.0755
27	1.0769	1.0778	1.0775	1.0773	1.0772	1.0769	1.0763	1.0757	1.0758	1.0756	1.0757
28	1.0769	1.0777	1.0775	1.0774	1.0772	1.0771	1.0766	1.0759	1.0759	1.0758	1.0758
29	1.0769	1.0778	1.0776	1.0774	1.0773	1.0771	1.0767	1.0761	1.0759	1.0758	1.0759
30	1.0770	1.0778	1.0776	1.0775	1.0773	1.0767	1.0767	1.0761	1.0759	1.0759	1.0760
31	1.0771	1.0778	1.0776	1.0775	1.0774	1.0770	1.0768	1.0762	1.0759	1.0759	1.0760
32	1.0771	1.0778	1.0776	1.0776	1.0774	1.0772	-	1.0763	1.0760	1.0759	1.0760
33	1.0771	1.0778	1.0776	1.0776	1.0774	1.0772	-	1.0764	1.0760	1.0759	1.0761
34	1.0772	1.0778	1.0776	1.0776	1.0774	1.0772	-	1.0764	1.0760	1.0759	1.0761
35	1.0772	1.0778	1.0776	1.0776	1.0774	1.0772	-	1.0765	1.0760	1.0760	1.0761
36	1.0772	1.0778	1.0776	1.0777	1.0774	1.0772	-	1.0765	1.0760	1.0760	1.0761
37	1.0772	1.0778	1.0776	1.0776	-	1.0772	-	1.0766	1.0760	1.0760	1.0761
38	1.0772	-	-	1.0776	-	1.0772	-	1.0766	-	-	-

*Due to CTD failure, data on this date are from nearby station 7

Table 4. Temperature, conductivity, and density stratification (x 0.0001 g/cm3) at Station 6, 2001

Date	Temperature		Conductivity		Density Difference due to		
	2 m	28 m	2 m	28 m	Temperature	Conductivity	Both
2-20	1.62	4.82	80.08	86.57	-4.5	77.2	72.8
3-13	3.40	4.71	79.76	87.27	-2.0	89.4	87.5
4-17	6.77	4.24	79.61	87.02	4.2	88.0	92.2
5-16	15.15	3.93	79.38	86.88	24.4	88.5	112.9
6-14	18.18	4.09	79.65	86.77	33.4	83.9	117.3
7-18	19.88	3.95	79.79	86.65	39.3	80.8	120.1
8-16*	21.76	4.01	80.36	86.24	46.0	69.2	115.2
9-19	18.60	3.98	80.65	85.68	34.9	59.3	94.2
10-19	15.12	4.09	81.03	85.67	24.1	54.8	78.9
11-15	10.94	4.08	81.23	85.57	13.2	51.4	64.6
12-7	6.70	4.06	81.22	85.63	4.4	52.4	56.8

*Due to CTD failure, data on this date are from nearby station 7

Table 5. Secchi Depths (m), 2001

Station	2-20	3-13	4-17	5-16	6-14	7-18	8-16	9-19	10-19	11-15	12-7
					Dates						
Western sector:											
1	-	1.50	1.25	3.80	10.00	9.50	12.25	6.90	2.50	1.30	1.10
2	-	1.10	1.20	5.00	10.75	10.75	12.40	8.00	2.10	1.30	1.10
3	-	1.25	1.25	5.40	10.30	11.60	11.00	6.50	2.30	1.40	1.20
4	-	1.20	1.30	5.50	10.00	9.55	10.90	7.50	2.50	1.50	1.05
5	1.30	1.20	1.40	4.60	9.40	11.20	11.00	7.60	2.80	1.30	1.15
6	1.30	1.14	1.35	5.50	-	10.50	11.00	7.10	3.00	1.40	1.10
Avg.	1.30	1.23	1.29	4.97	10.09	10.52	11.43	7.27	2.53	1.37	1.12
S.E.	0.00	0.06	0.03	0.27	0.22	0.35	0.29	0.22	0.13	0.03	0.02
n	2.00	6.00	6.00	6.00	5.00	6.00	6.00	6.00	6.00	6.00	6.00
Eastern sector:											
7	-	1.10	1.60	6.40	9.60	10.20	10.50	4.50	2.80	1.40	1.10
8	-	1.10	1.40	6.75	11.00	11.20	9.00	4.90	3.20	1.30	1.15
9	-	1.20	1.35	6.40	9.20	10.80	8.00	7.00	3.10	1.50	1.10
10	-	1.10	1.30	6.00	9.70	11.80	8.60	7.50	3.00	1.40	1.10
11	-	1.10	1.40	6.00	9.00	-	-	4.00	2.20	1.10	1.20
12	-	1.10	1.50	7.20	9.40	10.90	8.00	6.20	3.00	1.40	1.10
Avg.	-	1.12	1.43	6.46	9.65	10.98	8.82	5.68	2.88	1.35	1.13
S.E.	-	0.02	0.04	0.19	0.29	0.26	0.46	0.58	0.15	0.06	0.02
n	0.00	6.00	6.00	6.00	6.00	5.00	5.00	6.00	6.00	6.00	6.00
Total Lakewide											
Avg.	1.30	1.17	1.36	5.71	9.85	10.73	10.24	6.48	2.71	1.36	1.12
S.E.	0.00	0.03	0.03	0.28	0.19	0.23	0.48	0.38	0.11	0.03	0.01
n	2.00	12.00	12.00	12.00	11.00	11.00	11.00	12.00	12.00	12.00	12.00

Table 6. Dissolved oxygen (mg/l) at Station 6, 2001

Depth (m)	Dates 2-20	3-13	4-17	5-16	6-14	7-18	8-16	9-19	10-19	11-15	12-7
0	6.9	7.2	10.2	4.3	5.6	4.3	4.1	4.6	5.1	4.9	3.9
1	6.9	8.0	9.7	4.3	5.6	4.3	4.2	4.6	5.2	5.0	3.9
2	7.0	8.3	9.3	4.4	5.6	4.3	4.1	4.6	5.2	4.9	3.2
3	7.0	8.3	9.4	4.5	5.6	4.3	4.2	4.6	5.2	4.4	2.8
4	6.9	8.4	9.8	4.6	5.6	4.4	4.1	4.6	5.2	4.1	2.7
5	6.4	8.4	9.8	4.6	5.4	4.4	4.2	4.7	5.2	4.0	2.5
6	6.0	8.3	9.7	4.6	5.3	4.4	4.2	4.7	5.1	4.2	2.4
7	5.8	8.1	8.9	5.9	5.4	4.5	4.6	4.7	5.1	4.2	2.3
8	5.7	7.9	9.1	6.5	5.8	4.6	4.5	4.7	5.1	4.1	2.3
9	5.6	7.0	9.2	6.4	6.5	4.5	4.3	4.7	5.1	4.1	2.2
10	5.6	6.3	8.0	6.1	7.9	4.3	4.1	4.5	5.1	4.4	1.6
11	5.5	5.6	7.4	5.6	7.2	4.6	3.9	4.0	5.0	4.5	1.3
12	5.5	5.8	6.9	4.2	7.1	4.1	4.0	3.8	4.6	4.7	2.6
13	5.4	5.2	5.8	2.2	4.0	3.1	4.6	3.5	3.6	4.4	3.2
14	5.4	5.1	4.7	1.5	1.2	1.2	3.5	3.0	2.7	4.4	3.4
15	5.4	5.1	4.0	<0.5	1.1	0.9	3.0	2.2	1.8	4.5	3.5
16	5.3	4.9	3.7	<0.5	1.9	0.9	2.3	1.9	1.1	4.5	3.5
17	5.3	4.9	3.0	<0.5	<0.5	1.9	2.5	1.5	<0.5	4.5	3.3
18	5.2	4.9	2.9	<0.5	<0.5	0.8	1.5	<0.5	<0.5	2.3	3.4
19	5.2	4.9	3.0	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	3.4
20	5.2	4.6	2.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	3.5
21	5.1	4.5	1.8	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	3.4
22	4.9	4.3	1.7	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	3.4
23	5.2	4.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	3.6
24	4.7	3.8	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	1.8
25	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
26	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
27	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

Table 7. Ammonium at Station 6, 2001 (µM)

Depth (m)	Dates 2-20	3-13	4-17	5-16	6-14	7-18	8-16	9-19	10-19	11-15	12-7
1	-	-	-	-	-	-	-	-	-	-	-
2	0.0	0.7	0.6	2.5	3.5	3.8	2.5	0.9	1.2	1.2	1.4
3	-	-	-	-	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-	-	-	-	-
5	0.1	-	-	-	-	-	-	-	-	-	-
6	-	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-
8	-	0.8	0.2	1.4	3.7	2.9	0.9	0.9	1.2	1.0	2.8
9	-	-	-	-	-	-	-	-	-	-	-
10	0.0	-	0.6	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-
12	-	1.0	0.5	1.4	0.9	2.9	3.1	2.9	1.0	1.1	3.1
13	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	1.6	-	-	-	-	2.7	-	-
15	0.0	-	-	-	-	-	-	0.7	-	-	-
16	-	2.0	-	6.8	0.9	1.3	0.6	2.6	5.5	1.0	1.4
16.5	-	-	-	-	-	1.0	-	-	-	-	-
17	-	-	-	5.0	1.1	0.9	-	2.4	-	-	-
17.5	-	-	-	-	3.3	1.1	-	-	-	-	-
18	-	-	1.2	-	7.0	-	-	-	-	-	-
19	-	-	0.3	-	-	-	-	-	-	-	-
20	0.2	34.1	1.0	76.8	172.7	167.4	132.4	78.5	54.3	59.4	43.0
21	-	-	0.7	-	-	-	-	-	-	-	-
22	-	60.5	-	-	-	-	-	-	74.6	-	-
23	-	-	2.5	-	-	-	-	-	-	-	-
24	0.4	64.7	74.4	115.1	214.5	234.9	207.5	174.4	132.0	99.9	52.0
24.5	3.6	-	-	-	-	-	-	-	-	-	-
25	346.8	-	505.6	-	-	-	-	-	-	-	-
25.5	447.7	-	-	-	-	-	-	-	-	-	-
26	483.1	-	532.6	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-
28	-	883.1	-	876.3	1093.6	1106.6	1085.2	973.2	928.7	-	964.8
29	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-
31	-	-	-	-	-	-	-	-	-	-	-
32	-	-	-	-	-	-	-	-	-	-	-
33	-	-	-	-	-	-	-	-	-	-	-
34	-	-	-	-	-	-	-	-	-	-	-
35	-	919.9	-	1054.7	1139.9	1193.0	1105.4	1002.1	1002.9	-	1058.3

Table 8. Chlorophyll a (µg/l) at Station 6, 2001.

Depth (m)	2-20	3-13	4-17	5-16	Dates 6-14	7-18	8-16	9-19	10-19	11-15	12-7
1	28.1	-	-	-	-	-	-	-	-	-	-
2	34.9	21.1	12.8	2.0	3.8	0.9	2.0	2.7	4.2	29.5	52.7
3	35.2	-	-	-	-	-	-	-	-	-	-
4	33.4	-	-	-	-	-	-	-	-	-	-
5	37.5	-	-	-	-	1.5	-	-	-	-	-
6	42.7	-	-	-	-	-	-	-	-	-	-
7	-	-	-	-	-	-	-	-	-	-	-
8	40.5	47.3	14.2	6.8	6.1	1.5	2.8	4.5	4.6	27.4	48.2
9	-	-	-	-	-	-	-	-	-	-	-
10	-	-	17.1	-	-	-	-	-	-	-	-
11	-	-	-	-	-	-	-	-	-	-	-
12	43.1	39.0	27.0	46.9	2.2	1.2	1.9	2.9	6.7	24.4	49.3
13	-	-	-	-	-	-	-	-	-	-	-
14	-	-	37.7	52.3	-	-	-	-	11.3	-	-
15	-	-	-	-	-	-	-	4.0	-	-	-
16	40.5	34.6	40.6	47.9	12.3	9.0	1.4	12.4	12.3	29.5	52.0
16.5	-	-	-	-	-	12.2	-	-	-	-	-
17	-	-	-	38.0	85.7	10.5	-	13.2	-	-	-
17.5	-	-	-	-	62.0	11.1	-	-	-	-	-
18	-	-	39.0	-	39.3	-	-	-	-	-	-
19	-	-	-	-	-	-	-	-	-	-	-
20	39.2	38.2	-	23.7	21.6	25.1	19.0	25.6	17.1	21.6	52.0
21	-	-	38.4	-	-	-	-	-	-	-	-
22	-	32.0	-	-	-	-	-	-	26.1	-	-
23	-	-	-	-	-	-	-	-	-	-	-
24	38.6	38.0	32.0	21.8	20.3	15.1	12.7	17.9	16.5	22.4	48.9
25	-	-	-	-	-	-	-	-	-	-	-
26	-	-	30.7	-	-	-	-	-	-	-	-
27	-	-	-	-	-	-	-	-	-	-	-
28	40.0	33.1	31.6	29.3	27.4	25.2	23.2	28.5	33.9	26.1	29.3

Table 9a. Artemia lake and sector means, 2001.

	Instars 1-7	Instars 8-11	adult male	adult fem ?	adult fem e	adult fem c	adult fem n	adult fem tot	adult total	total
Lakewide Mean:										
2/20	3,400	0	0	0	0	0	0	0	0	3,400
3/13	3,245	0	0	0	0	0	0	0	0	3,245
4/17	30,129	0	0	0	0	0	0	0	0	30,129
5/16	36,009	8,618	5,365	148	6,311	121	0	6,579	11,945	56,573
6/14	23,085	2,039	14,366	148	5,755	3,488	215	9,604	23,971	49,095
7/18	7,760	429	27,398	0	4,165	6,204	268	10,637	38,035	46,224
8/16	3,293	134	29,450	104	1,814	6,372	60	8,350	37,800	41,227
9/19	2,458	0	16,247	141	382	3,447	81	4,051	20,299	22,757
10/19	2,795	421	5,813	22	121	475	13	630	6,444	9,660
11/5	288	80	15	2	7	0	0	8	23	392
12/7	404	40	13	0	17	0	0	17	30	475
Western Sector Mean:										
2/20	3,400	0	0	0	0	0	0	0	0	3,400
3/13	3,010	0	0	0	0	0	0	0	0	3,010
4/17	4,685	0	0	0	0	0	0	0	0	4,685
5/16	28,826	4,306	1,985	27	3,072	81	0	3,179	5,164	38,296
6/14	22,777	1,958	15,828	134	4,346	3,166	242	7,888	23,716	48,451
7/18	9,470	698	42,871	0	5,392	5,822	215	11,429	54,299	64,467
8/16	2,737	215	47,378	107	3,059	7,673	0	10,839	58,216	61,167
9/19	2,415	0	20,657	188	590	3,595	134	4,507	25,165	27,579
10/19	3,065	308	6,385	3	74	362	27	466	6,851	10,225
11/5	94	43	17	0	3	0	0	3	20	158
12/7	74	10	0	0	3	0	0	3	3	87
Eastern Sector Mean:										
2/20	na	na	na	na	na	na	na	na	na	na
3/13	3,441	0	0	0	0	0	0	0	0	3,441
4/17	55,574	0	0	0	0	0	0	0	0	55,574
5/16	43,192	12,931	8,746	268	9,551	161	0	9,980	18,726	74,849
6/14	23,394	2,120	12,904	161	7,163	3,810	188	11,321	24,225	49,739
7/18	6,050	161	11,925	0	2,937	6,586	322	9,846	21,771	27,981
8/16	3,850	54	11,522	101	570	5,071	121	5,862	17,384	21,288
9/19	2,502	0	11,838	94	174	3,300	27	3,595	15,433	17,935
10/19	2,525	533	5,241	40	168	587	0	795	6,036	9,095
11/5	483	117	13	3	10	0	0	13	27	627
12/7	735	70	27	0	30	0	0	30	57	862

(?): undifferentiated egg mass (e): empty ovisac
(c): cysts (n): nauplii (na): missing data

Table 9b. Standard errors of Artemia sector means (Table 9a), 2001.

	Instars 1-7	Instars 8-11	adult male	adult fem ?	adult fem e	adult fem c	adult fem n	adult fem tot	adult total	total
SE of Lakewide Mean:										
2/20	2,541	0	0	0	0	0	0	0	0	2,541
3/13	498	0	0	0	0	0	0	0	0	498
4/17	12,173	0	0	0	0	0	0	0	0	12,173
5/16	3,868	1,741	1,344	108	1,238	60	0	1,342	2,564	7,039
6/14	2,380	282	2,441	46	635	633	70	1,077	3,239	5,069
7/18	1,080	188	8,575	0	588	552	75	686	8,811	9,641
8/16	628	74	6,198	40	589	1,188	30	1,694	6,763	6,696
9/19	408	0	2,126	44	104	468	54	560	2,552	2,707
10/19	925	91	1,707	14	36	190	13	235	1,906	2,697
11/5	87	25	4	2	4	0	0	4	5	112
12/7	138	21	7	0	7	0	0	7	13	155
SE of Western Sector Mean:										
2/20	2,541	0	0	0	0	0	0	0	0	2,541
3/13	880	0	0	0	0	0	0	0	0	880
4/17	806	0	0	0	0	0	0	0	0	806
5/16	5,111	711	580	27	486	55	0	534	1,090	4,484
6/14	4,494	569	4,670	49	513	1,116	100	1,578	6,178	9,809
7/18	1,397	347	14,977	0	858	840	107	864	15,165	16,338
8/16	883	136	5,997	68	950	2,197	0	3,077	5,301	5,293
9/19	432	0	2,776	77	170	479	105	719	3,286	3,287
10/19	1,855	90	2,399	3	22	198	27	231	2,566	4,300
11/5	36	12	6	0	3	0	0	3	7	49
12/7	26	7	0	0	3	0	0	3	3	24
SE of Eastern Sector Mean:										
2/20	na	na	na	na	na	na	na	na	na	na
3/13	612	0	0	0	0	0	0	0	0	612
4/17	19,808	0	0	0	0	0	0	0	0	19,808
5/16	4,367	2,322	1,744	211	1,518	110	0	1,736	3,058	8,019
6/14	2,165	152	1,884	83	847	691	105	1,196	2,824	4,082
7/18	1,419	83	1,860	0	430	758	110	1,037	2,409	2,990
8/16	913	54	2,122	48	71	838	50	823	2,534	3,197
9/19	738	0	2,097	44	32	852	27	882	2,898	3,485
10/19	545	153	2,633	26	66	337	0	422	3,054	3,659
11/5	129	45	7	3	7	0	0	7	8	174
12/7	198	39	11	0	11	0	0	11	21	211

(?): undifferentiated egg mass (e): empty ovisac
(c): cysts (n): nauplii (na): missing data

Table 9c. Percentage in different classes for Artemia sector means (Table 9a), 2001.

	Instars 1-7	Instars 8-11	adult male	adult fem ?	adult fem e	adult fem c	adult fem n	adult fem tot	adult total	total
Lakewide (%):										
2/20	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
3/13	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
4/17	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
5/16	63.7	15.2	9.5	2.2	95.9	1.8	0.0	11.6	21.1	100.0
6/14	47.0	4.2	29.3	1.5	59.9	36.3	2.2	19.6	48.8	100.0
7/18	16.8	0.9	59.3	0.0	39.2	58.3	2.5	23.0	82.3	100.0
8/16	8.0	0.3	71.4	1.2	21.7	76.3	0.7	20.3	91.7	100.0
9/19	10.8	0.0	71.4	3.5	9.4	85.1	2.0	17.8	89.2	100.0
10/19	28.9	4.4	60.2	3.5	19.2	75.4	2.1	6.5	66.7	100.0
11/5	73.5	20.4	3.8	25.0	87.5	0.0	0.0	2.0	5.9	100.0
12/7	85.1	8.4	2.7	0.0	100.0	0.0	0.0	3.6	6.3	100.0
Western Sector (%):										
2/20	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
3/13	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
4/17	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
5/16	75.3	11.2	5.2	0.8	96.6	2.5	0.0	8.3	13.5	100.0
6/14	47.0	4.0	32.7	1.7	55.1	40.1	3.1	16.3	48.9	100.0
7/18	14.7	1.1	66.5	0.0	47.2	50.9	1.9	17.7	84.2	100.0
8/16	4.5	0.4	77.5	1.0	28.2	70.8	0.0	17.7	95.2	100.0
9/19	8.8	0.0	74.9	4.2	13.1	79.8	3.0	16.3	91.2	100.0
10/19	30.0	3.0	62.4	0.6	15.9	77.7	5.8	4.6	67.0	100.0
11/5	59.5	27.2	10.8	0.0	100.0	0.0	0.0	1.9	12.7	100.0
12/7	85.1	11.5	0.0	0.0	100.0	0.0	0.0	3.4	3.4	100.0
Eastern Sector (%):										
2/20	na	na	na	na	na	na	na	na	na	na
3/13	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
4/17	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
5/16	57.7	17.3	11.7	2.7	95.7	1.6	0.0	13.3	25.0	100.0
6/14	47.0	4.3	25.9	1.4	63.3	33.7	1.7	22.8	48.7	100.0
7/18	21.6	0.6	42.6	0.0	29.8	66.9	3.3	35.2	77.8	100.0
8/16	18.1	0.3	54.1	1.7	9.7	86.5	2.1	27.5	81.7	100.0
9/19	14.0	0.0	66.0	2.6	4.8	91.8	0.8	20.0	86.0	100.0
10/19	27.8	5.9	57.6	5.0	21.1	73.8	0.0	8.7	66.4	100.0
11/5	77.0	18.7	2.1	23.1	76.9	0.0	0.0	2.1	4.3	100.0
12/7	85.3	8.1	3.1	0.0	100.0	0.0	0.0	3.5	6.6	100.0

(?): undifferentiated egg mass (e): empty ovisac
(c): cysts (n): nauplii (na): missing data
The fem-?,e,c,n percentages are of the total females.

Table 10. Lakewide Artemia instar analysis, 2001.

	Instars									
	1	2	3	4	5	6	7	8-11	adults	total
Mean:										
2/20	3,315	65	10	10	0	0	0	0	0	3,400
3/13	2,690	10	0	0	0	0	0	0	0	2,700
4/17	9,370	4,576	4,878	2,912	256	0	0	0	0	21,992
5/16	7,634	5,105	3,840	3,449	3,633	4,530	5,450	6,393	11,291	51,325
6/14	16,763	7,427	506	368	621	368	598	1,679	27,548	55,878
7/18	3,909	3,783	713	115	92	34	103	161	47,197	56,108
8/16	57	33	4	1	5	0	0	184	41,150	44,346
9/19	23	33	22	10	9	3	0	0	20,920	23,432
10/19	20	10	12	15	14	18	10	402	8,606	12,544
11/5	46	49	63	34	29	46	46	98	20	431
12/7	92	63	29	14	3	6	9	6	20	241
Standard error of mean:										
2/20	2,462	59	10	10	0	0	0	0	0	2,541
3/13	788	10	0	0	0	0	0	0	0	794
4/17	4,040	2,882	2,841	1,536	126	0	0	0	0	11,301
5/16	1,470	1,361	1,220	788	842	1,043	1,508	2,003	2,906	8,348
6/14	3,187	1,234	181	91	244	110	240	394	5,114	7,327
7/18	949	855	258	58	59	24	46	93	14,441	15,842
8/16	11	11	2	1	5	0	0	119	9,626	9,844
9/19	10	4	7	3	3	2	0	0	4,089	4,289
10/19	3	2	2	3	3	1	1	144	2,914	4,292
11/5	19	25	42	13	11	23	22	42	8	192
12/7	42	32	19	9	3	4	4	6	8	111
Percentage in different age classes:										
2/20	97.5	1.9	0.3	0.3	0.0	0.0	0.0	0.0	0.0	100.0
3/13	99.6	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
4/17	42.6	20.8	22.2	13.2	1.2	0.0	0.0	0.0	0.0	100.0
5/16	14.9	9.9	7.5	6.7	7.1	8.8	10.6	12.5	22.0	100.0
6/14	30.0	13.3	0.9	0.7	1.1	0.7	1.1	3.0	49.3	100.0
7/18	7.0	6.7	1.3	0.2	0.2	0.1	0.2	0.3	84.1	100.0
8/16	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.4	92.8	100.0
9/19	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	89.3	100.0
10/19	0.2	0.1	0.1	0.1	0.1	0.1	0.1	3.2	68.6	100.0
11/5	10.7	11.4	14.6	7.9	6.7	10.7	10.7	22.7	4.6	100.0
12/7	38.2	26.1	12.0	5.8	1.2	2.5	3.7	2.5	8.3	100.0

Table 11a. Artemia reproductive summary, lake and sector means, 2001.

	Adult Females					
	Total	Ovig	e	?	c	n
Lakewide Mean:						
2/20	0	0	0	0	0	0
3/13	0	0	0	0	0	0
4/17	0	0	0	0	0	0
5/16	6,579	268	6,311	148	121	0
6/14	9,604	3,850	5,755	148	3,488	215
7/18	10,637	6,472	4,165	0	6,204	268
8/16	8,350	6,536	1,814	104	6,372	60
9/19	4,051	3,669	382	141	3,447	81
10/19	630	510	121	22	475	13
11/5	8	2	7	2	0	0
12/7	17	0	17	0	0	0
Western Sector Mean:						
2/20	0	0	0	0	0	0
3/13	0	0	0	0	0	0
4/17	0	0	0	0	0	0
5/16	3,179	107	3,072	27	81	0
6/14	7,888	3,541	4,346	134	3,166	242
7/18	11,429	6,036	5,392	0	5,822	215
8/16	10,839	7,780	3,059	107	7,673	0
9/19	4,507	3,917	590	188	3,595	134
10/19	466	392	74	3	362	27
11/5	3	0	3	0	0	0
12/7	3	0	3	0	0	0
Eastern Sector Mean:						
2/20	na	na	na	na	na	na
3/13	0	0	0	0	0	0
4/17	0	0	0	0	0	0
5/16	9,980	429	9,551	268	161	0
6/14	11,321	4,158	7,163	161	3,810	188
7/18	9,846	6,908	2,937	0	6,586	322
8/16	5,862	5,292	570	101	5,071	121
9/19	3,595	3,421	174	94	3,300	27
10/19	795	627	168	40	587	0
11/5	13	3	10	3	0	0
12/7	30	0	30	0	0	0

(?): undifferentiated egg mass (e): empty ovisac
(c): cysts (n): nauplii (na): missing data

Table 11b. Standard errors of Artemia reproductive summary (Table 11a), 2001.

	Total	Ovigery	Adult Females e	?	c	n
Standard Error of Lakewide Mean:						
2/20	0	0	0	0	0	0
3/13	0	0	0	0	0	0
4/17	0	0	0	0	0	0
5/16	1,342	156	1,238	108	60	0
6/14	1,077	682	635	46	633	70
7/18	686	582	588	0	552	75
8/16	1,694	1,197	589	40	1,188	30
9/19	560	510	104	44	468	54
10/19	235	203	36	14	190	13
11/5	4	2	4	2	0	0
12/7	7	0	7	0	0	0
Standard Error of Western Sector Mean:						
2/20	0	0	0	0	0	0
3/13	0	0	0	0	0	0
4/17	0	0	0	0	0	0
5/16	534	54	486	27	55	0
6/14	1,578	1,184	513	49	1,116	100
7/18	864	903	858	0	840	107
8/16	3,077	2,242	950	68	2,197	0
9/19	719	609	170	77	479	105
10/19	231	214	22	3	198	27
11/5	3	0	3	0	0	0
12/7	3	0	3	0	0	0
Standard Error of Eastern Sector Mean:						
2/20	na	na	na	na	na	na
3/13	0	0	0	0	0	0
4/17	0	0	0	0	0	0
5/16	1,736	307	1,518	211	110	0
6/14	1,196	778	847	83	691	105
7/18	1,037	775	430	0	758	110
8/16	823	812	71	48	838	50
9/19	882	864	32	44	852	27
10/19	422	359	66	26	337	0
11/5	7	3	7	3	0	0
12/7	11	0	11	0	0	0

(?): undifferentiated egg mass (e): empty ovisac
(c): cysts (n): nauplii (na): missing data

Table 11c. Artemia percentages in different reproductive categories (Table 11a), 2001.

	Total	Ovigery	Adult e	Females ?	c	n
Lakewide Mean (%):						
2/20	0.0	0.0	0.0	0.0	0.0	0.0
3/13	0.0	0.0	0.0	0.0	0.0	0.0
4/17	0.0	0.0	0.0	0.0	0.0	0.0
5/16	100.0	4.1	95.9	55.2	100.0	0.0
6/14	100.0	40.1	59.9	3.8	94.2	5.8
7/18	100.0	60.8	39.2	0.0	95.9	4.1
8/16	100.0	78.3	21.7	1.6	99.1	0.9
9/19	100.0	90.6	9.4	3.8	97.7	2.3
10/19	100.0	81.0	19.2	4.3	97.3	2.7
11/5	100.0	25.0	87.5	100.0	0.0	0.0
12/7	100.0	0.0	100.0	0.0	0.0	0.0
Western Sector Mean (%):						
2/20	0.0	0.0	0.0	0.0	0.0	0.0
3/13	0.0	0.0	0.0	0.0	0.0	0.0
4/17	0.0	0.0	0.0	0.0	0.0	0.0
5/16	100.0	3.4	96.6	25.2	100.0	0.0
6/14	100.0	44.9	55.1	3.8	92.9	7.1
7/18	100.0	52.8	47.2	0.0	96.4	3.6
8/16	100.0	71.8	28.2	1.4	100.0	0.0
9/19	100.0	86.9	13.1	4.8	96.4	3.6
10/19	100.0	84.1	15.9	0.8	93.1	6.9
11/5	100.0	0.0	100.0	0.0	0.0	0.0
12/7	100.0	0.0	100.0	0.0	0.0	0.0
Eastern Sector Mean (%):						
2/20	na	na	na	na	na	na
3/13	0.0	0.0	0.0	0.0	0.0	0.0
4/17	0.0	0.0	0.0	0.0	0.0	0.0
5/16	100.0	4.3	95.7	62.5	100.0	0.0
6/14	100.0	36.7	63.3	3.9	95.3	4.7
7/18	100.0	70.2	29.8	0.0	95.3	4.7
8/16	100.0	90.3	9.7	1.9	97.7	2.3
9/19	100.0	95.2	4.8	2.7	99.2	0.8
10/19	100.0	78.9	21.1	6.4	100.0	0.0
11/5	100.0	23.1	76.9	100.0	0.0	0.0
12/7	100.0	0.0	100.0	0.0	0.0	0.0

(?): undifferentiated egg mass (e): empty ovisac
(c): cysts (n): nauplii (na): missing data
Total, ovigery, and e given as percentages of total number of females.
? given as percentage is of ovigerous females.
Cyst and naup given as percentages of individuals with differentiated egg masses.

Table 12. Artemia fecundity summary, 2001.

	#eggs/brood				female length		
	mean	SE	%cyst	%indented	mean	SE	n
Lakewide Mean:							
6/14	56.2	3.1	99.0	57.0	10.7	0.1	7
7/18	35.3	2.3	99.0	58.0	9.9	0.3	7
8/16	35.5	4.1	99.0	71.0	10.4	0.1	7
9/19	45.9	2.1	91.0	61.0	10.8	0.2	7
10/19	89.5	5.6	100.0	79.0	12.3	0.0	2
Western Sector Mean:							
6/14	60.2	3.8	98.0	54.0	10.7	0.1	4
7/18	33.3	3.7	100.0	70.0	9.7	0.4	4
8/16	29.5	4.8	98.0	68.0	10.3	0.2	4
9/19	43.3	1.4	95.0	58.0	10.5	0.1	4
10/19	na	na	na	na	na	na	»1
Eastern Sector Mean:							
6/14	50.7	3.4	100.0	60.0	10.6	0.1	3
7/18	38.0	2.1	97.0	43.0	10.3	0.1	3
8/16	43.5	3.9	100.0	77.0	10.6	0.0	3
9/19	49.4	3.9	87.0	67.0	11.3	0.2	3
10/19	89.5	5.6	100.0	79.0	12.3	0.0	2

n in the last column refers to number of stations averaged together.
Ten females were collected and measured from each station.

Table 13. Summary Statistics of Adult *Artemia* Abundance from 1 May through 30 November, 1979–2001.

Year	Mean	Median	Peak	Centroid*
1979	14118	12286	31700	216
1980	14643	10202	40420	236
1981	32010	21103	101670	238
1982	36643	31457	105245	252
1983	17812	16314	39917	247
1984	17001	19261	40204	212
1985	18514	20231	33089	218
1986	14667	17305	32977	190
1987	23952	22621	54278	226
1988	27639	25505	71630	207
1989	36359	28962	92491	249
1990	20005	16775	34930	230
1991	18129	19319	34565	226
1992	19019	19595	34648	215
1993	15025	16684	26906	217
1994	16602	18816	29408	212
1995	15584	17215	24402	210
1996	17734	17842	34616	216
1997	14389	16372	27312	204
1998	19429	21235	33968	226
1999	20221	21547	38439	225
2000	10550	9080	22384	210
2001	20031	20037	38035	209

*Centroid calculated as the abundance-weighted mean day of occurrence.

Table 14. Long-term Integrative Measures of Productivity: Annual Primary Production, *Artemia* biomass and egg production (see Chapter 2 for methods).

Year	Planktonic Primary Production ($g\ C\ m^{-2}\ y^{-1}$)	*Artemia* Biomass (g dry weight m^{-2})	*Artemia* Naupliar Production ($10^6\ m^{-2}$)	*Artemia* Cyst Production ($10^6\ m^{-2}$)
1982	1107	9.3	0.2	4.8
1983	523	7.8	0.1	3.7
1984	269	7.8	0.2	4.6
1985	399	7.7	0.4	3.0
1986	462	12.5	0.2	6.4
1987	371	15.2	0.2	4.7
1988	1064	17.6	0.1	6.7
1989	499	11.0	1.0	6.1
1990	641	9.7	0.7	5.5
1991	418	10.2	0.3	5.8
1992	435	8.9	0.3	6.3
1993	602	8.7	0.2	5.6
1994	446	8.4	0.4	4.9
1995	277	8.2	0.0	3.6
1996	221	5.3	0.0	2.5
1997	149	8.0	0.0	2.8
1998	228	8.9	0.0	4.2
1999	297	0.0	0.1	4.0
2000	484	0.0	0.1	3.0
2001	532	9.3	0.2	4.8

FIGURE CAPTIONS

Fig. 1. UCSB sampling stations at Mono Lake. Solid circles represent permanently moored buoys. Open circles represent old intermediate stations.

Fig. 2. Wind speed; daily mean and 10-min. maximum, 2001.

Fig. 3. Daily air temperature; mean, maximum, and minimum, 2001.

Fig. 4. Daily photosynthetically available radiation, 2001.

Fig. 5. Mean daily relative humidity, 2001.

Fig. 6. Daily precipitation, 2001.

Fig. 7. Mono Lake surface elevation (ft asl), 1979–01, USGS datum.

Fig. 8. Temperature (°C) at station 6, 2001.

Fig. 9. Conductivity (mS cm^{-1} corrected to 25°C) at station 6, 2001.

Fig. 10. Density (kg m^{-3}) at station 6, 2001.

Fig. 11. Density difference (10^{-4} g cm^{-3}) between 2 and 28 m at station 6 due to temperature and chemical stratification from 1983 through 2001.

Fig. 12. Winter salinity stratification, 1994–01.

Fig. 13. Mean lakewide Secchi depth (m), 1994–01. Error bars show standard errors of the lakewide estimate based on 12-20 stations.

Fig. 14. Mean lakewide Secchi depth ($\log_{10}$ m) 1979–01.

Fig. 15. Light attenuation (% of surface) at station 6, 2001. Dots denote the dates and depths of samples.

Fig. 16. Dissolved oxygen concentration (mg O_2 l^{-1}) at station 6, 2001.

Fig. 17. Ammonium concentration (µM) at station 6, 2001. Dots denote the dates and depths of samples.

Fig. 18. Concentration of chlorophyll *a* (µg chl *a* l^{-1}) at station 6, 2001. Dots denote the dates and depths of samples.

Fig. 19. Seasonal fluorescence profiles at station 6, 2001.

Fig. 20. Lakewide *Artemia* abundance during 2001: nauplii (instars 1-7), juveniles (instars 8-11), and adults (instars 12+).

Fig. 21. Reproductive characteristics of *Artemia* during 2001: lakewide mean abundance of total females and ovigerous females (top), percent of females ovoviviparous and ovigerous (middle), and brood size (bottom). Vertical lines are the standard error of the estimate.

Fig. 22. Lakewide estimates of adult *Artemia* based on 3-20 stations, 1982–01 (see Methods). The mean relative error of the lakewide estimates is 20-25%.

Fig. 23. Summary statistics of the seasonal (1 May through 30 November) lakewide abundance of adult *Artemia*, 1979–01. Values are based on interpolated daily abundances.

Fig. 24. Temporal center of abundance-weighted centroid of the seasonal (1 May through 30 November) distribution of adult *Artemia*, 1979–01. Centroid is based on interpolated daily abundances of adult *Artemia*.

Fig. 25. Annual phytoplankton production estimates (g C m^{-2}), 1982–01.

Fig. 26. Mean annual *Artemia* biomass, 1983–01. Data for the period 1982–99 estimated from instar-specific population data and previously derived weight-length relationships. In 2000–01, *Artemia* biomass was measured directly by determining dry weights of plankton tows.

Fig. 27. Annual *Artemia* reproduction, ovoviviparous (live-bearing) and oviparous (cyst-bearing), 1983–01.

Fig. 28. Changes in lake surface elevation from the height at the onset of meromixis during 1983–1989 and 1995–2001. Years of each meromictic event are overlayed. Surface elevations at the onset of meromixis were 6374.1 ft (1983) and 6374.5 ft (1995).

Fig. 29. Changes in percent area and volume of lake water beneath the chemocline during 1984–1988 and 1995–2002. Years of meromictic events are overlayed.

Fig. 30. Changes in the density difference due to salinity between 2 and 28 m during 1983–1989 and 1995–2001. Years of meromictic events are overlayed.

Fig. 31. Linear regression of the temporal trend of salinity stratification from 1998–2001, extending the regression line to zero salinity stratification (the density difference at which the lake should mix). Years of meromictic events are overlayed.

Fig. 32. Changes in ammonium (µM) at 2 m during 1983–1989 and 1995–2001. Years of meromictic events are overlayed.

Fig. 33. Changes in algal biomass (µg l^{-1}) at 2 m during 1983–1989 and 1995–2001. Years of meromictic events are overlayed.

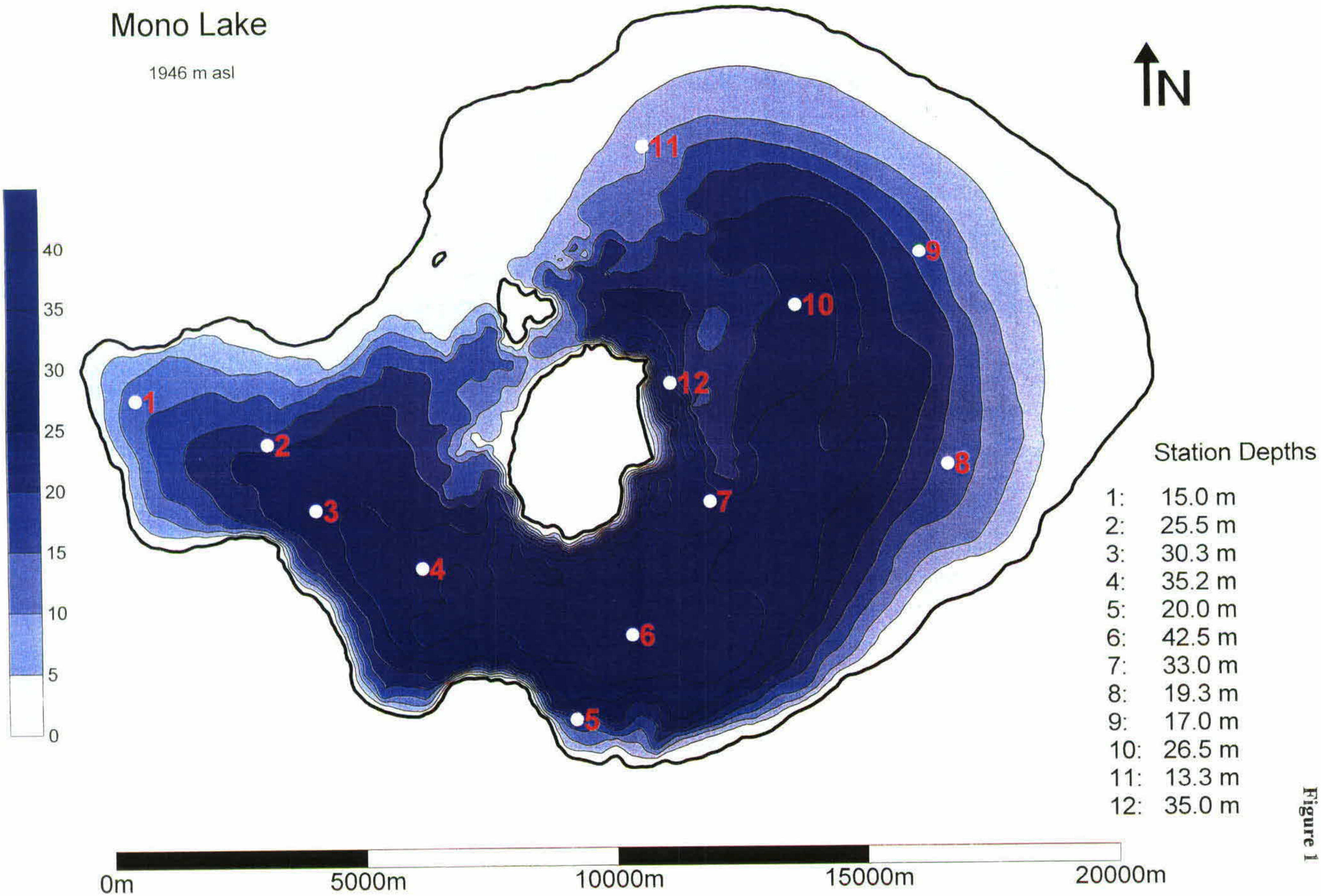
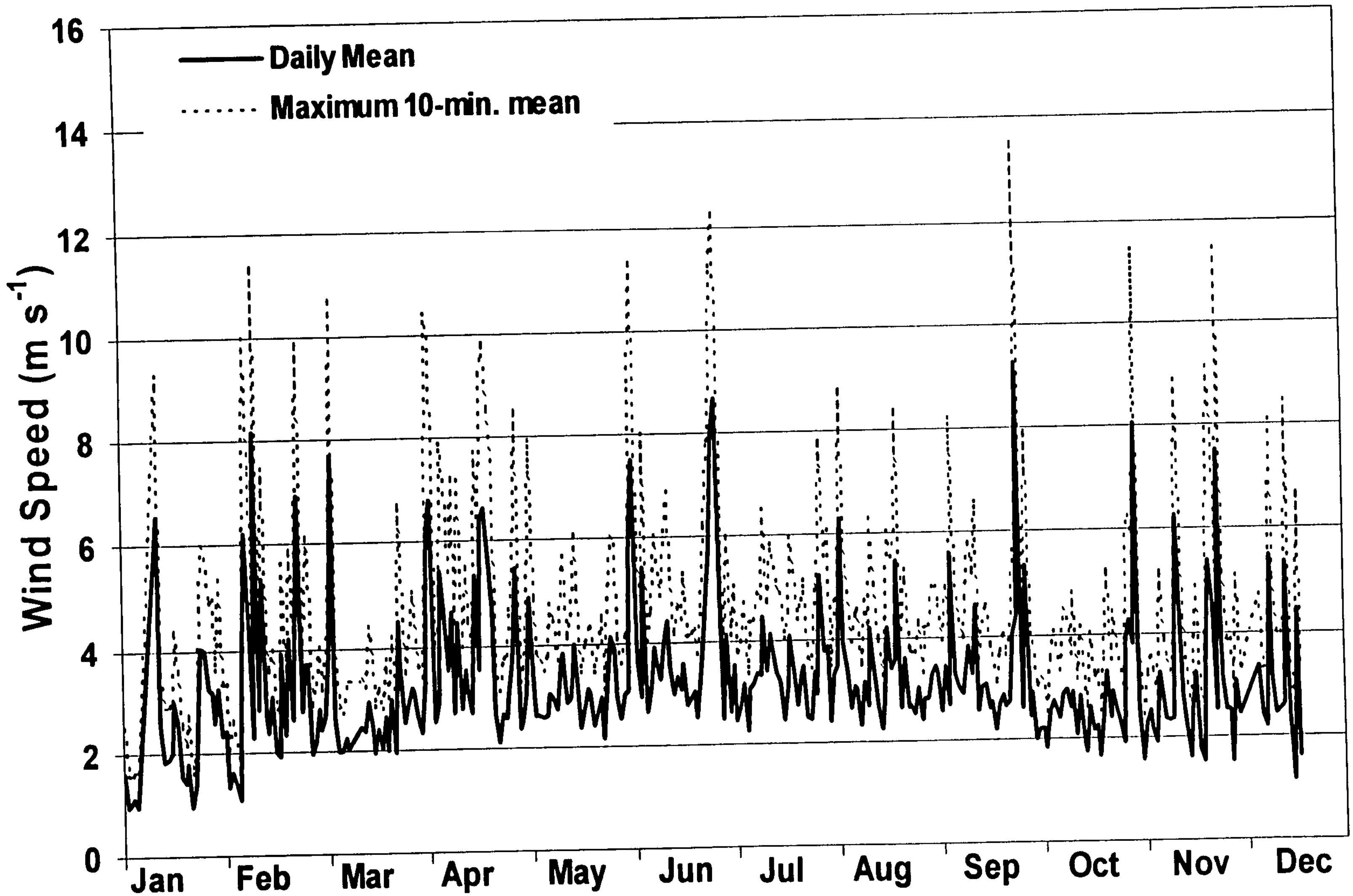

Mono Lake
1946 m asl
N
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
Station Depths
1: 15.0 m
2: 25.5 m
3: 30.3 m
4: 35.2 m
5: 20.0 m
6: 42.5 m
7: 33.0 m
8: 19.3 m
9: 17.0 m
10: 26.5 m
11: 13.3 m
12: 35.0 m
0m
5000m
10000m
15000m
20000m

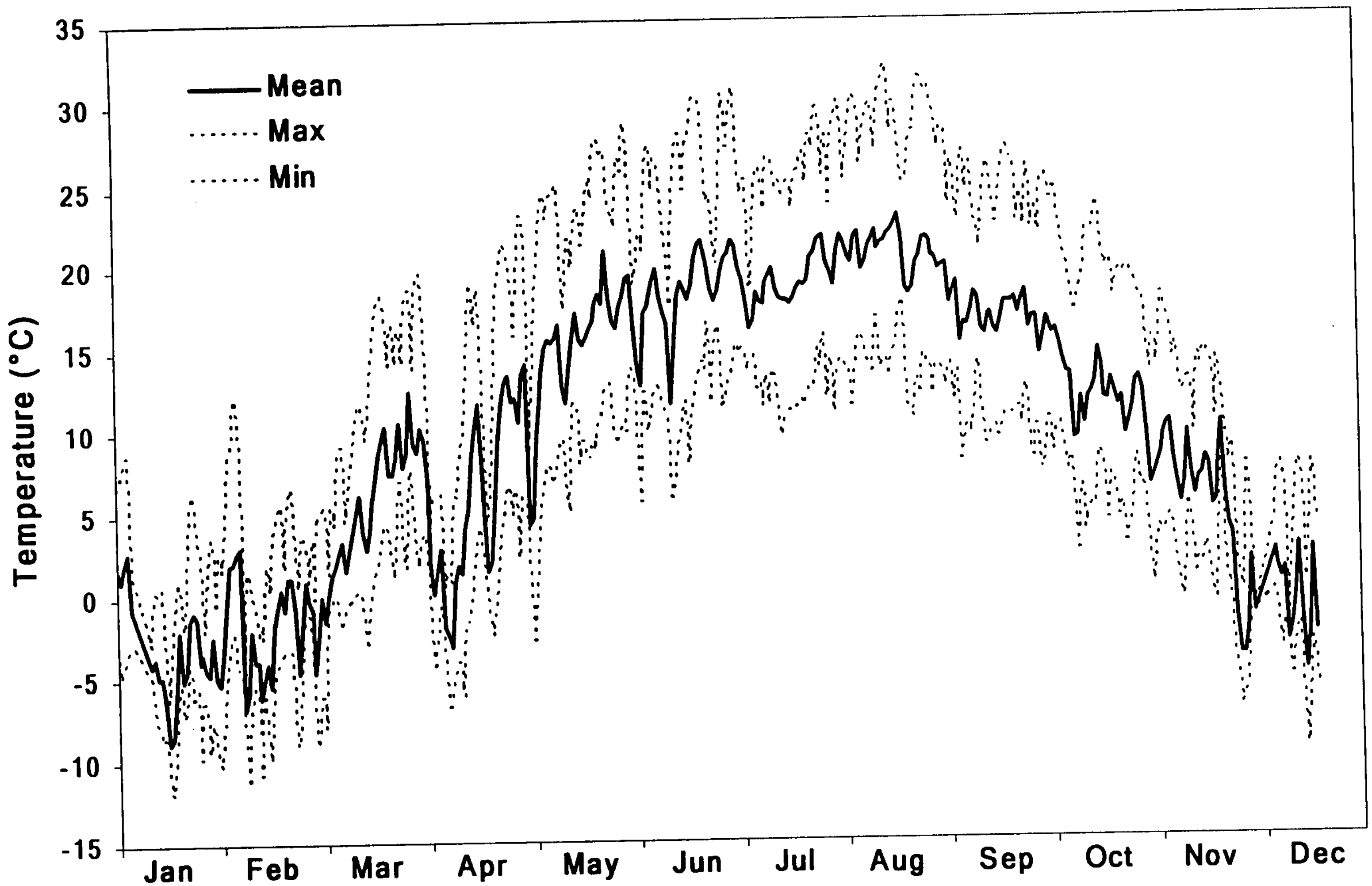
Figure 1



2001 Wind Speed

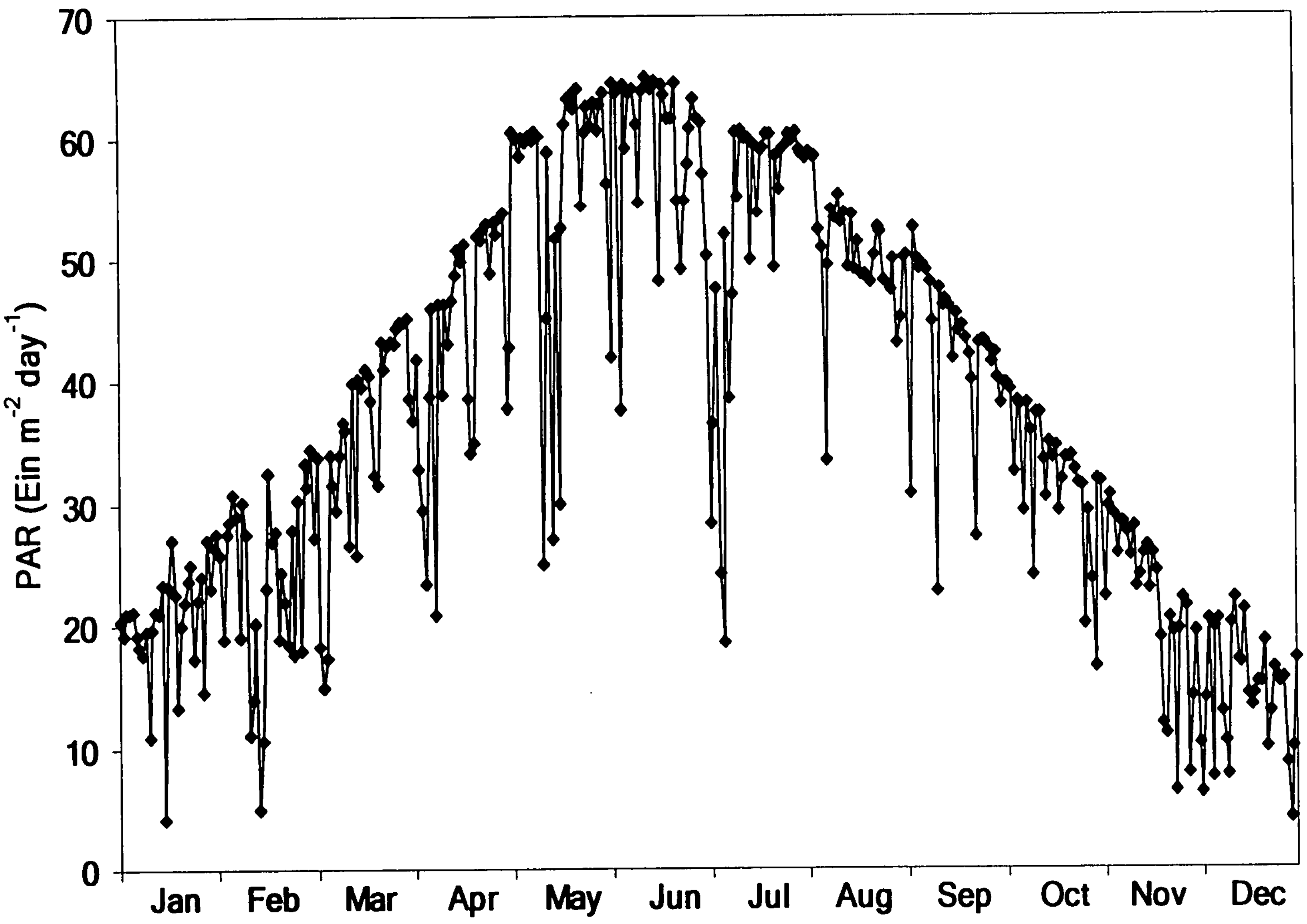
77

Figure 2



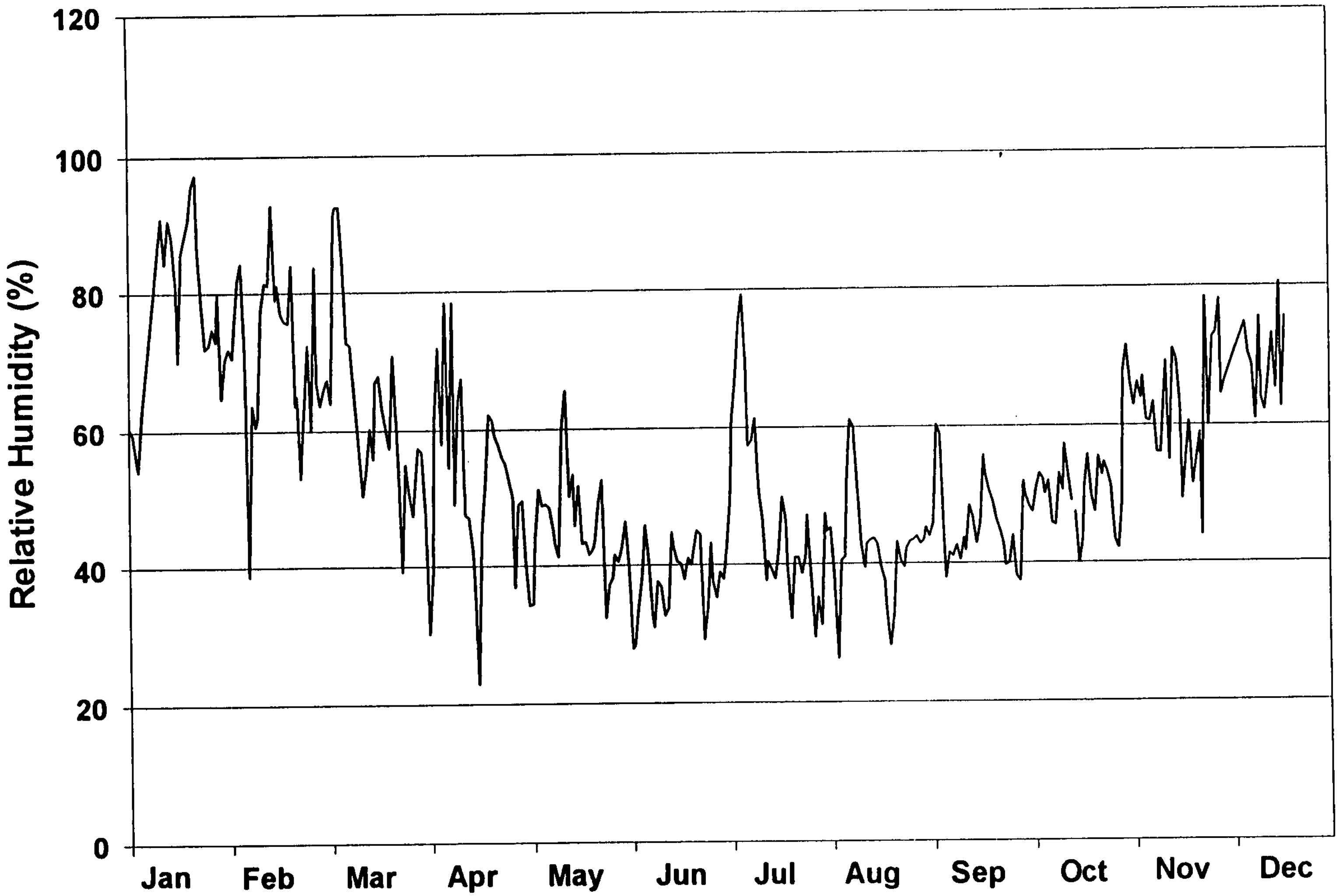
2001 Daily Air Temperature

Figure 3



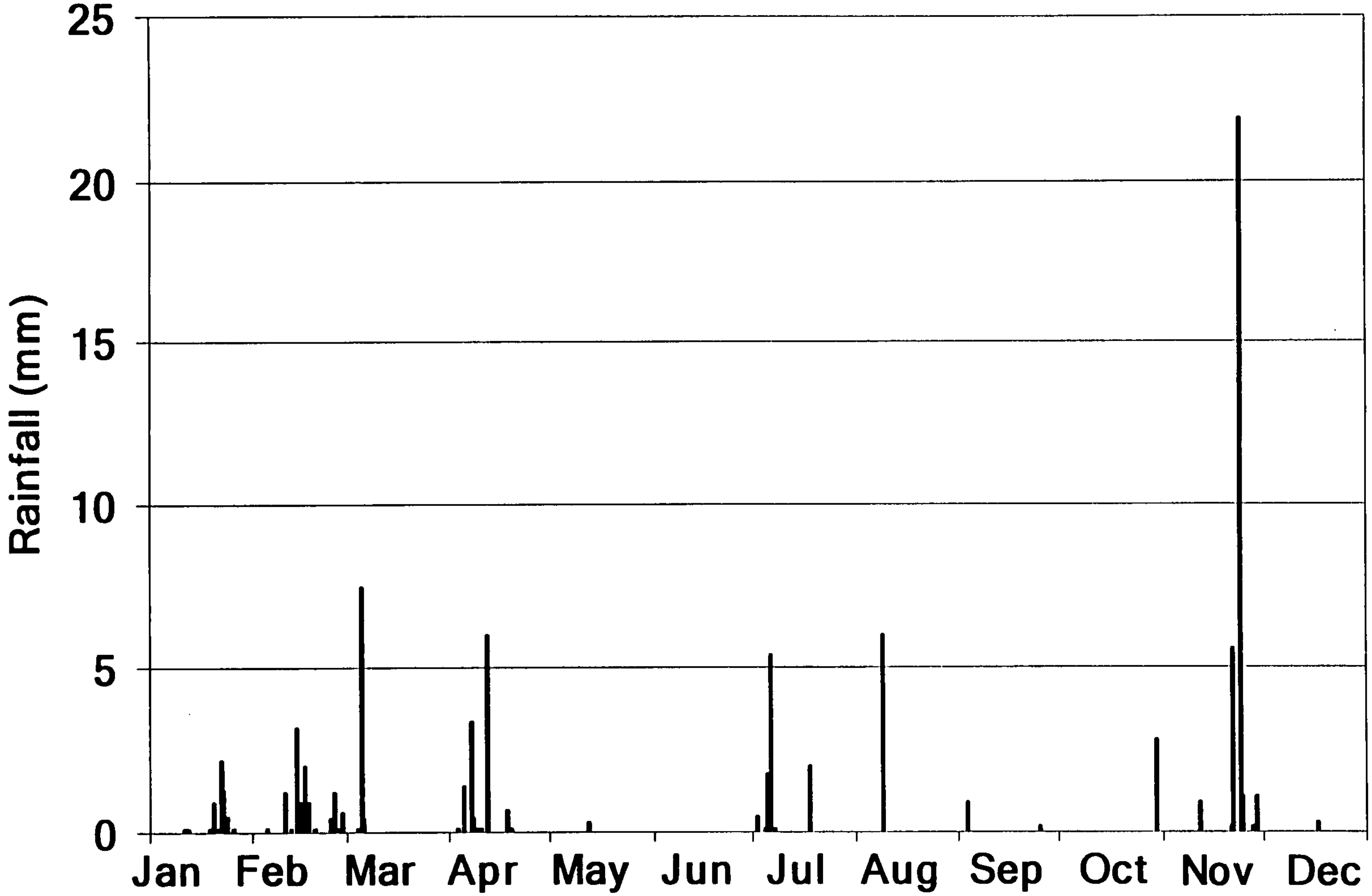
2001 Photosynthetically Available Radiation

Figure 4



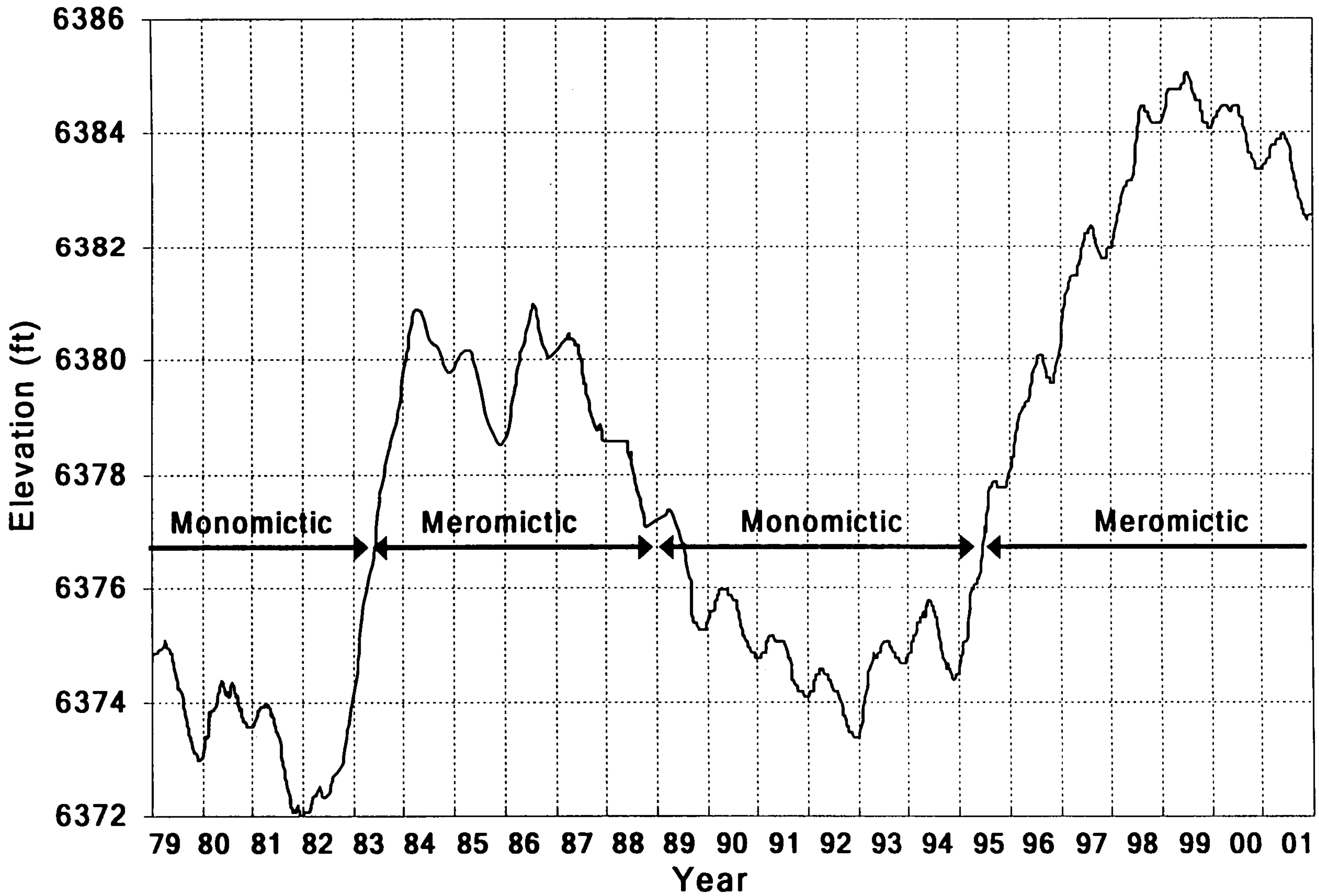
2001 Mean Daily Relative Humidity

Figure 5



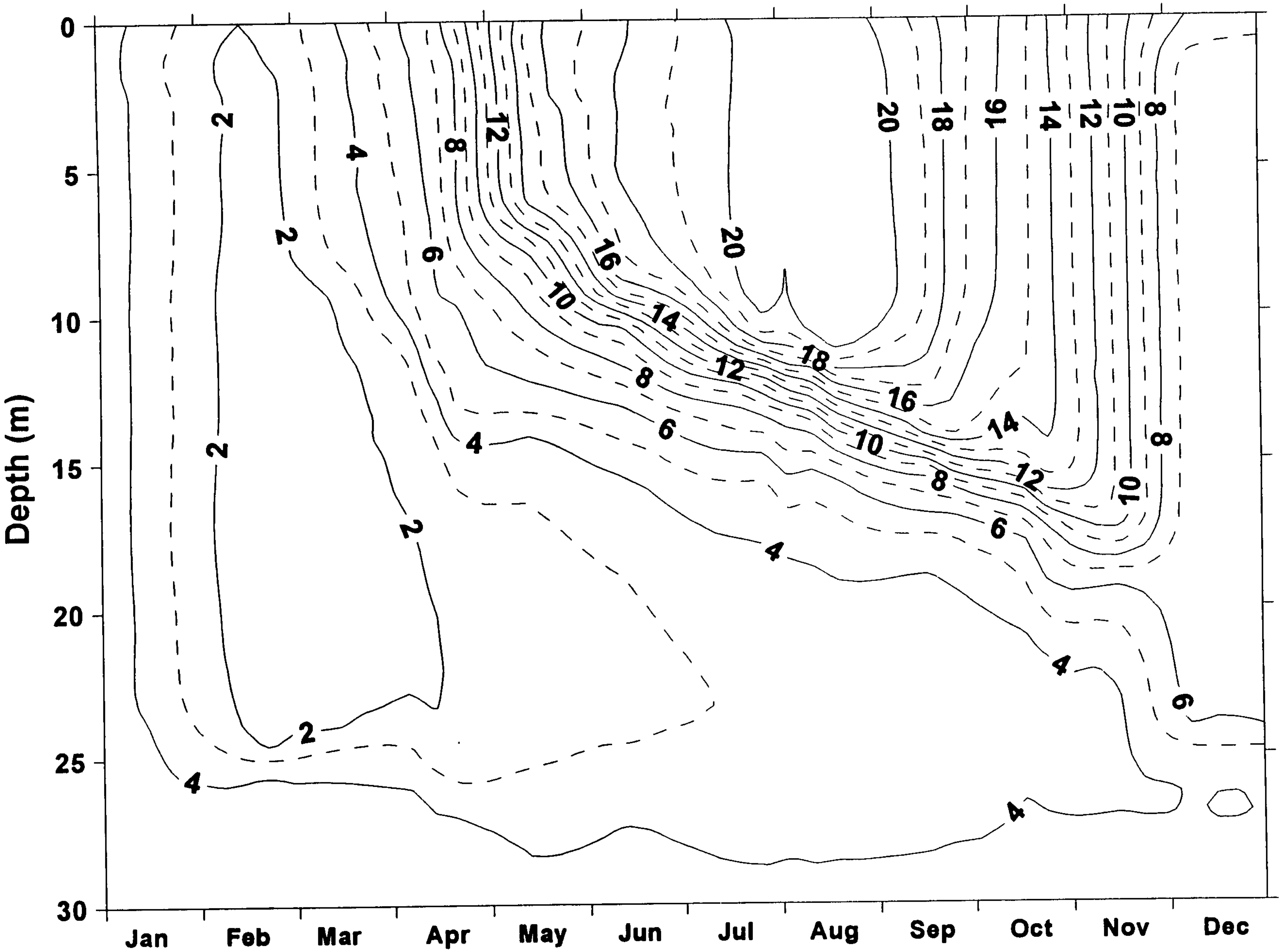
2001 Daily Precipitation

Figure 6



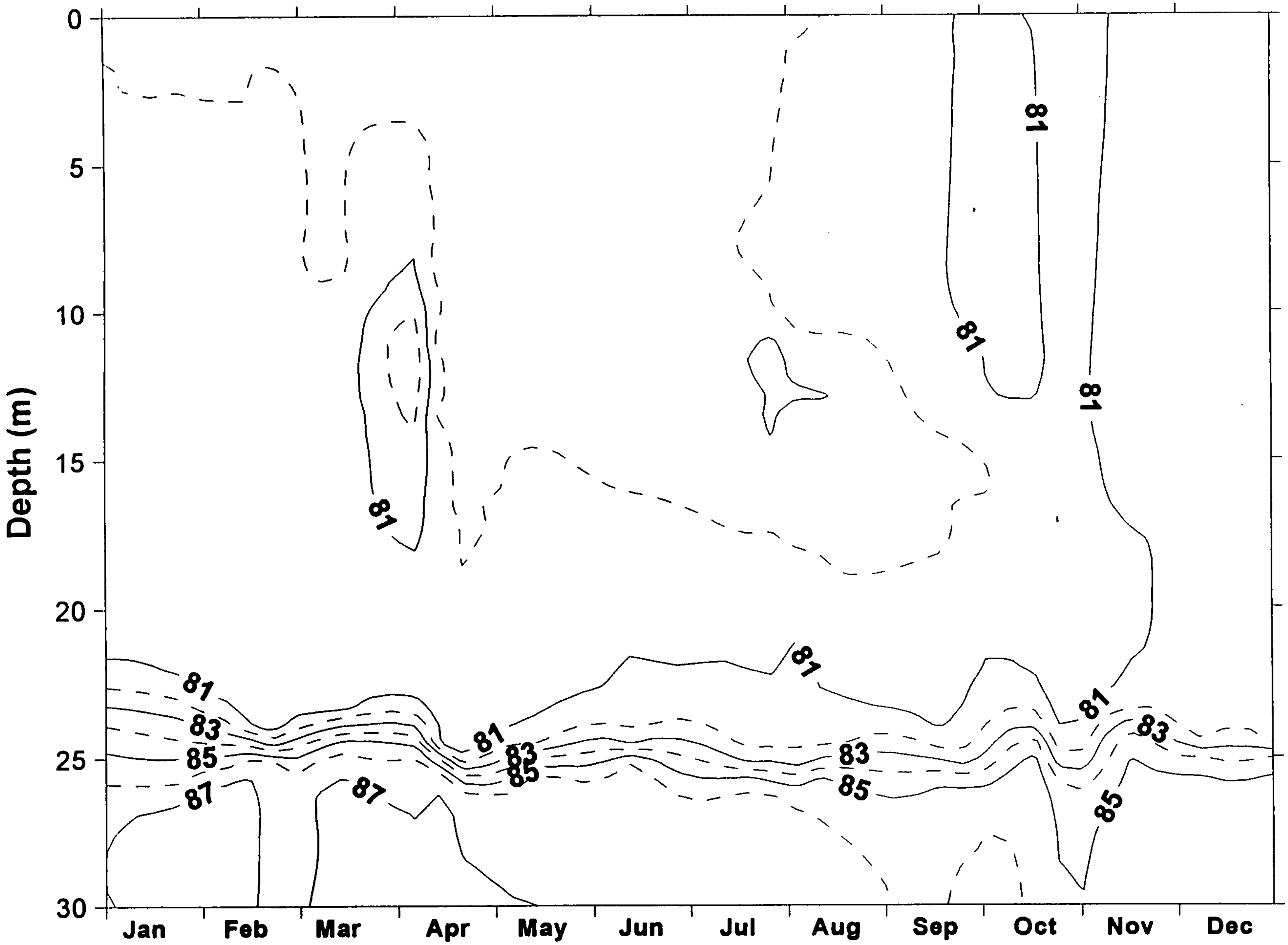
Mono Lake Surface Elevation

Figure 7



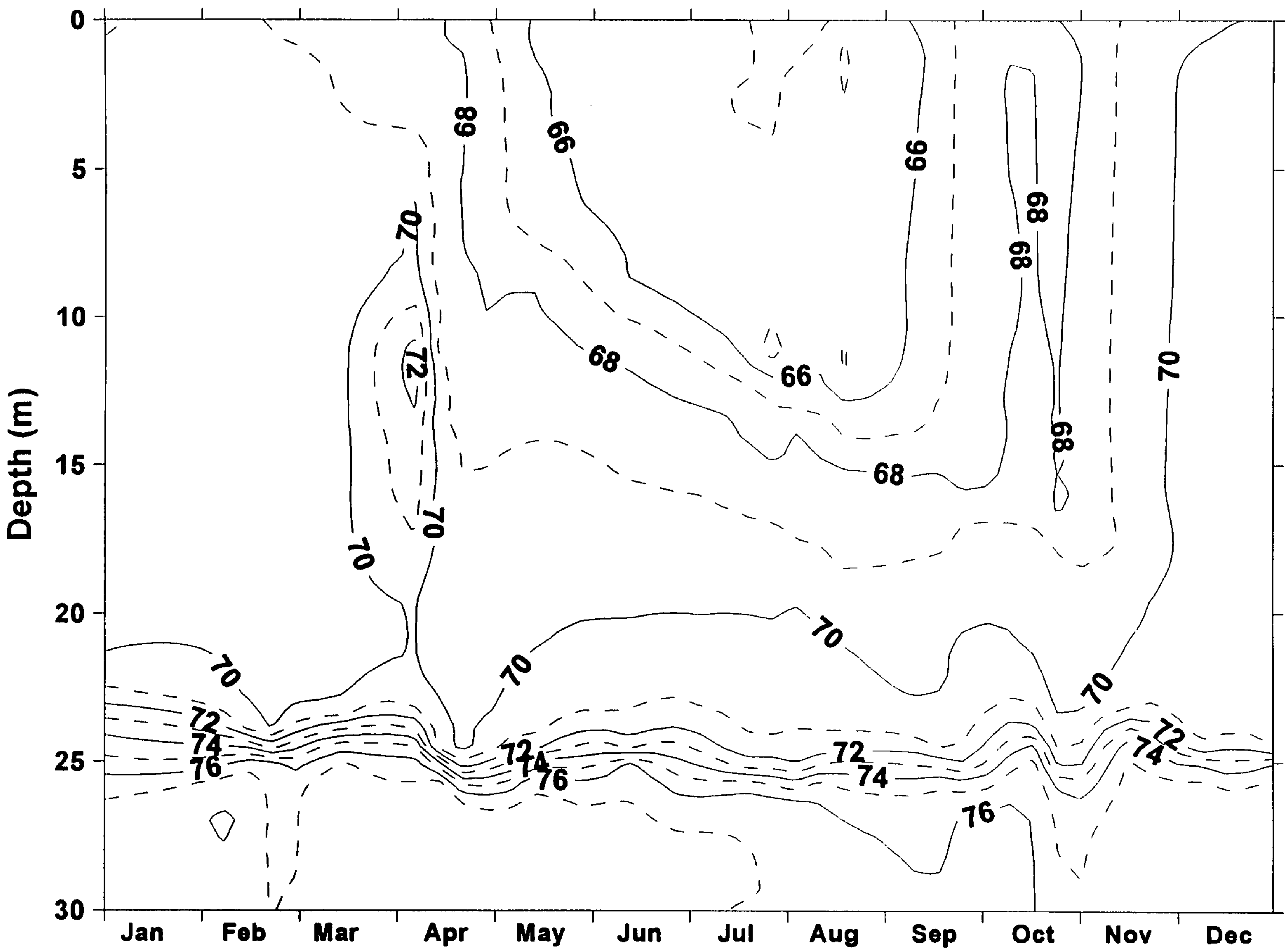
Temperature (°C) at Station 6, 2001

Figure 8



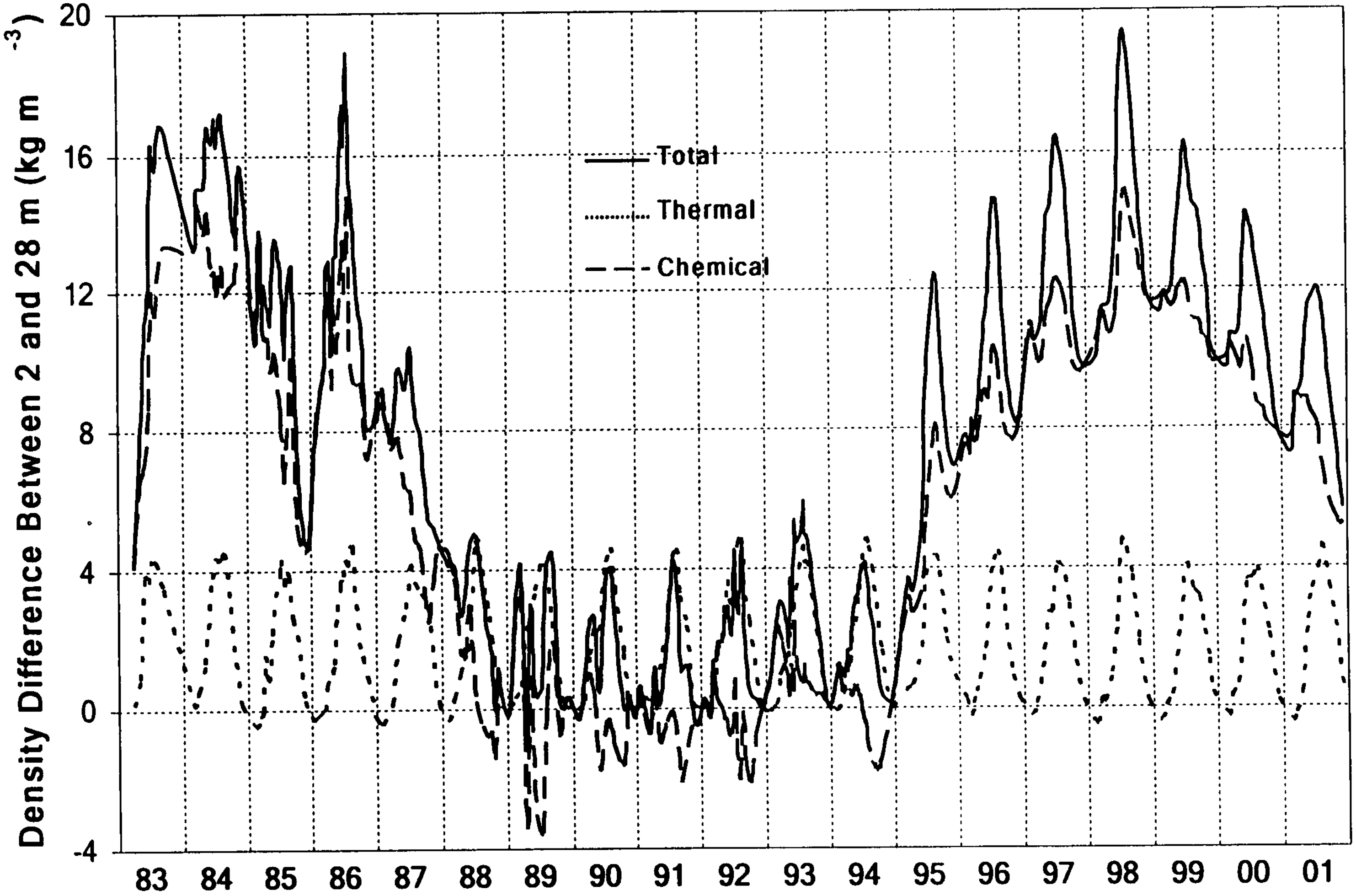
Conductivity (mS/cm) at Station 6, 2001

Figure 9



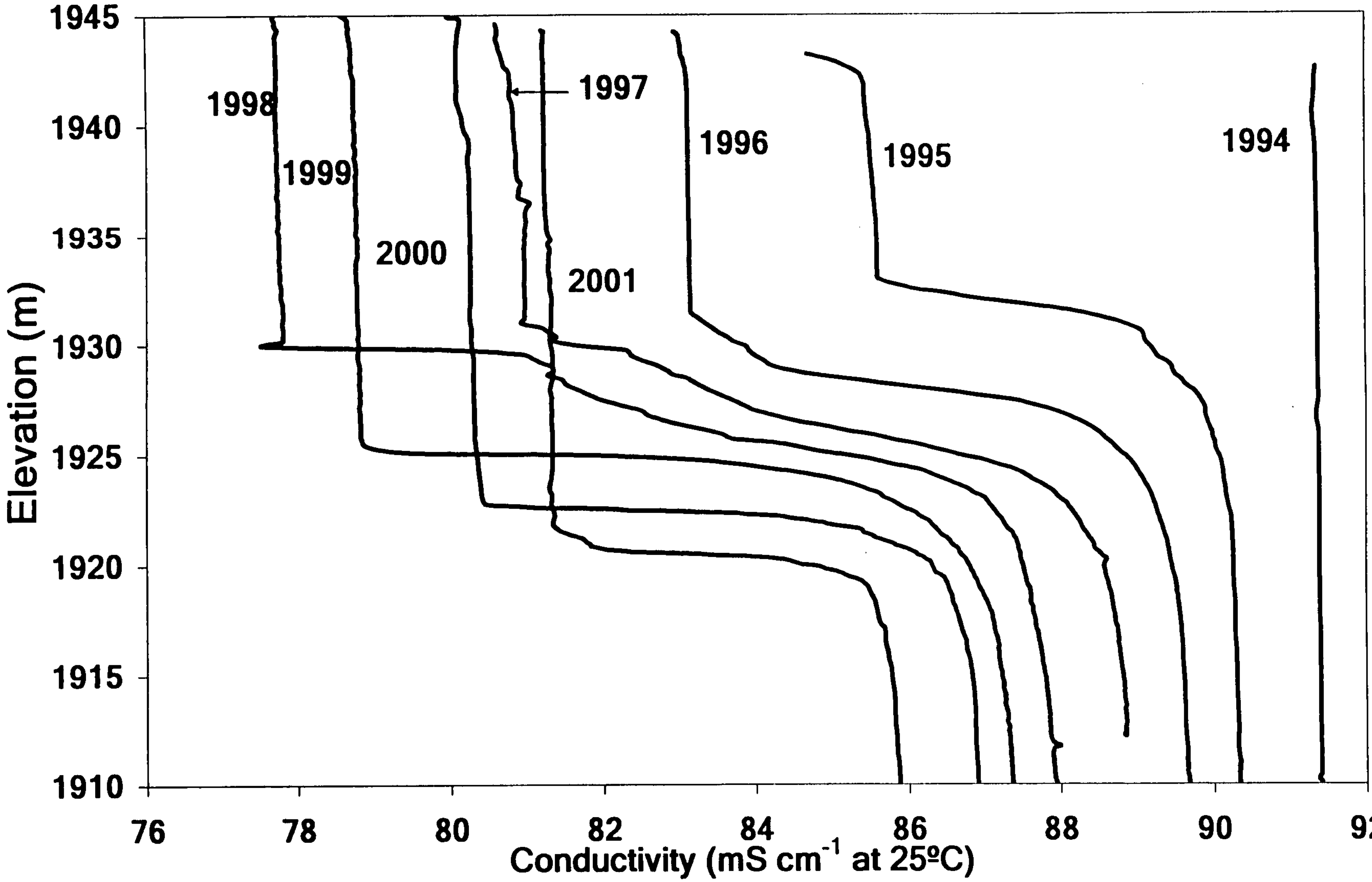
Excess Density (kg/m3) at Station 6, 2001

Figure 10



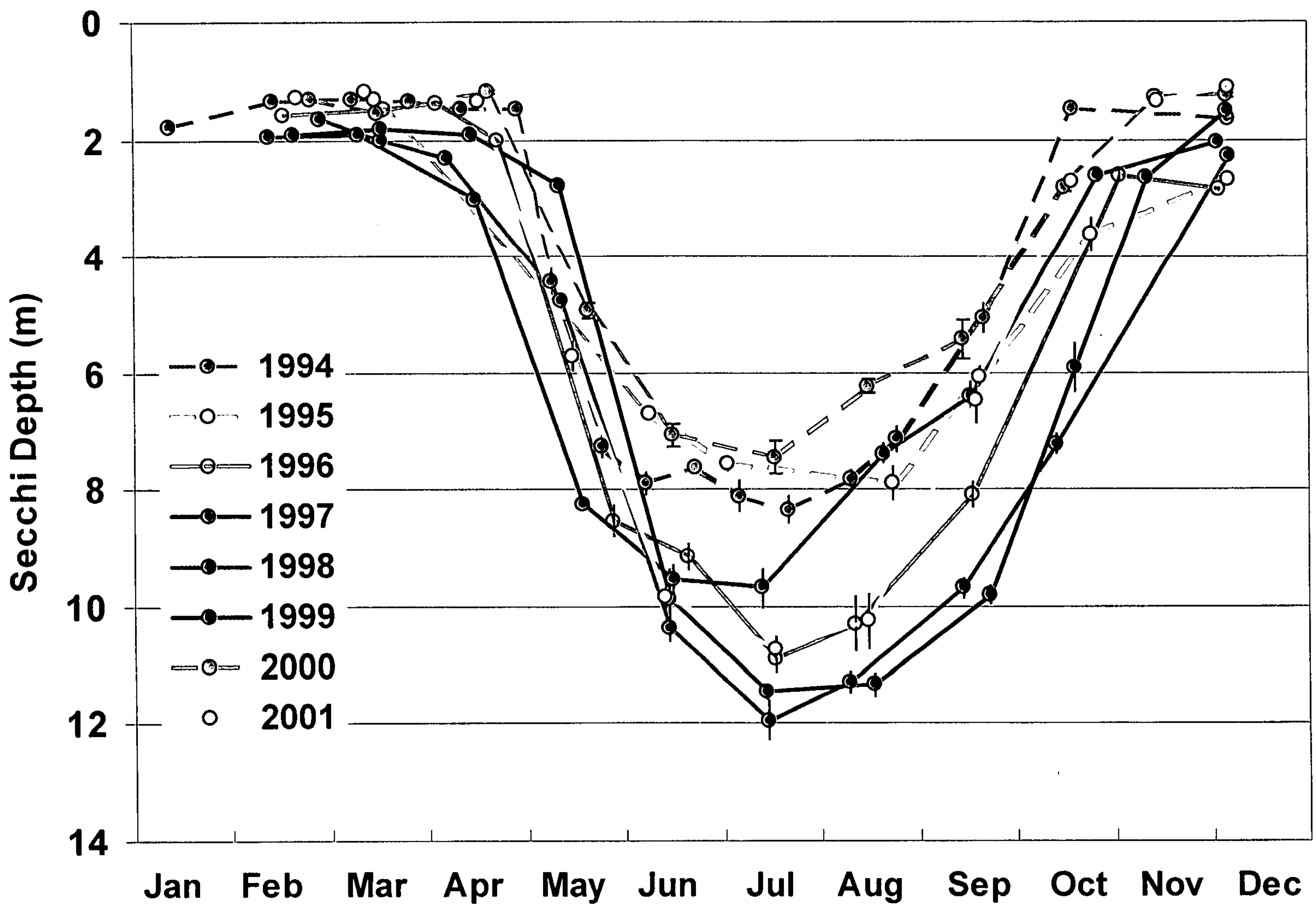
Density Stratification

Figure 11



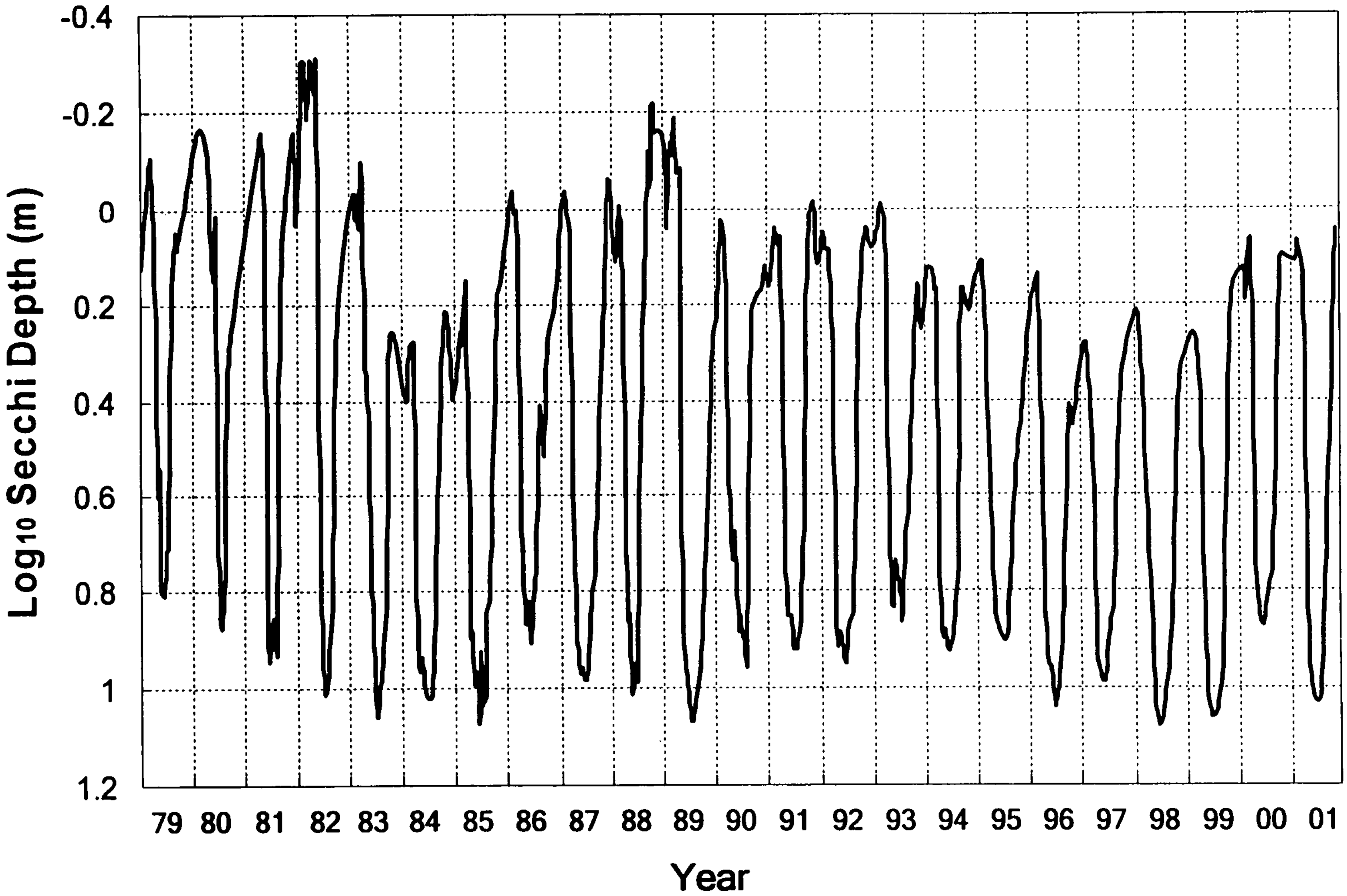
December Salinity Stratification in Mono Lake

Figure 12



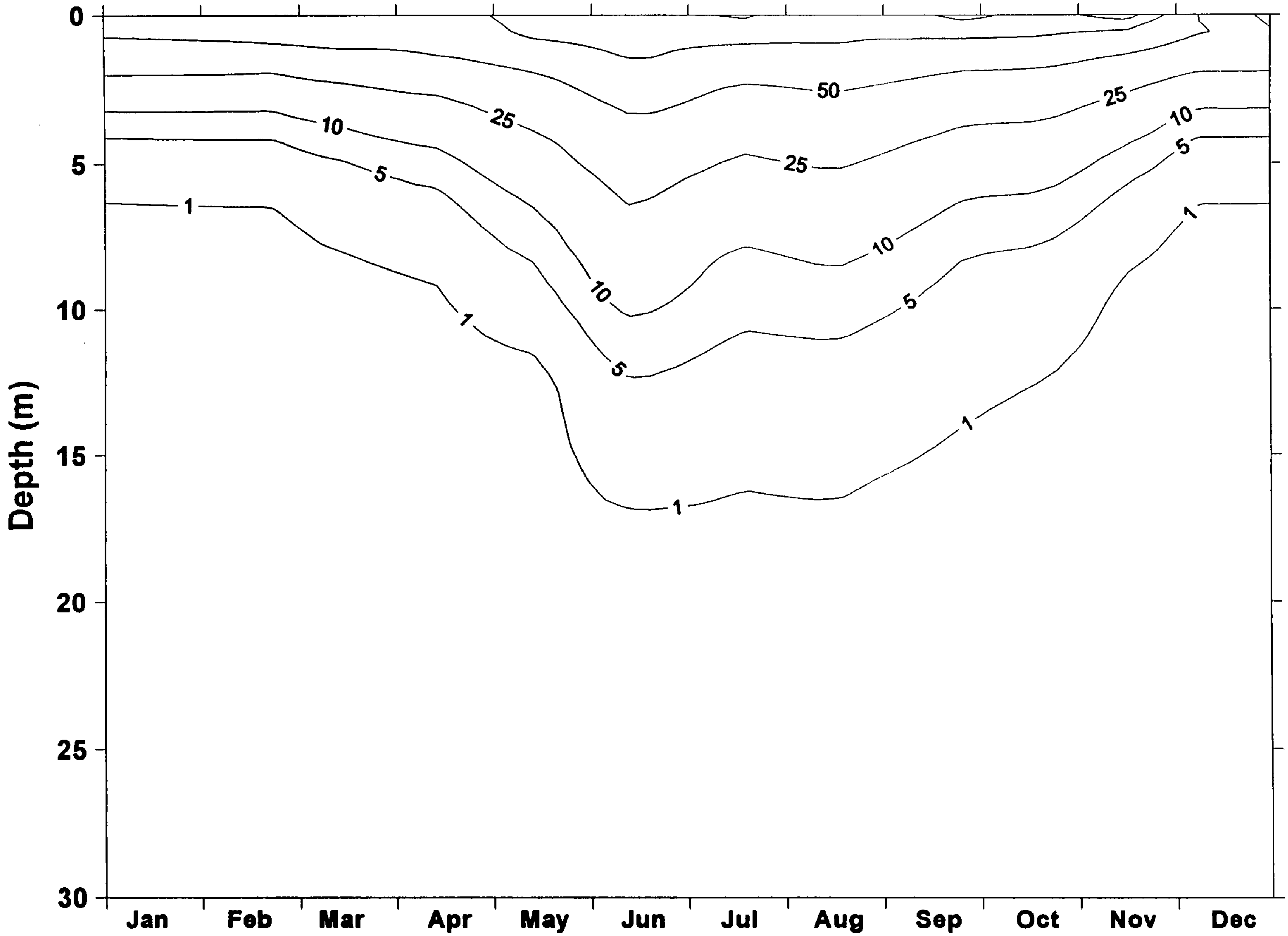
Mono Lake Transparency

Figure 13



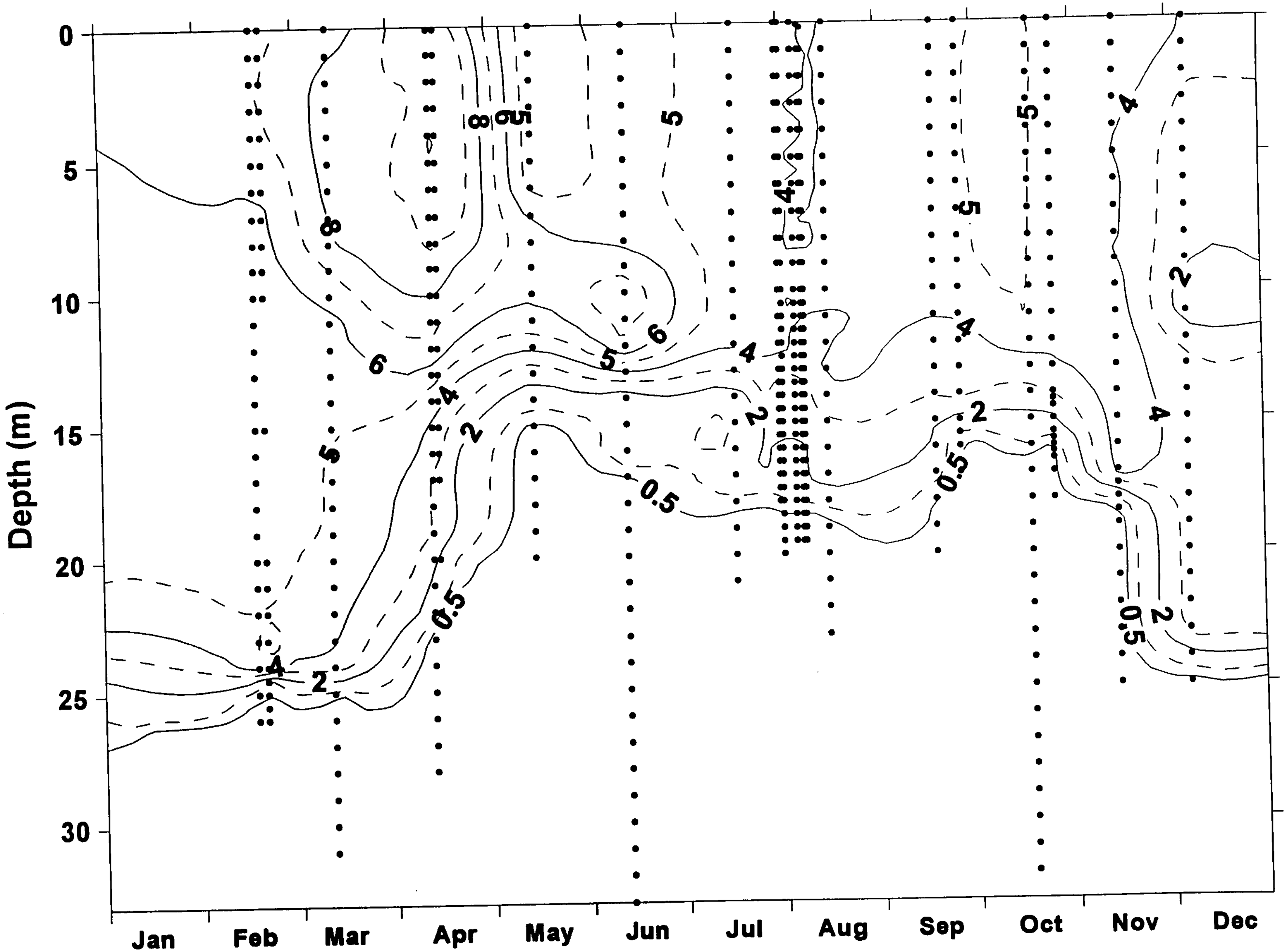
Transparency in Mono Lake

Figure 14



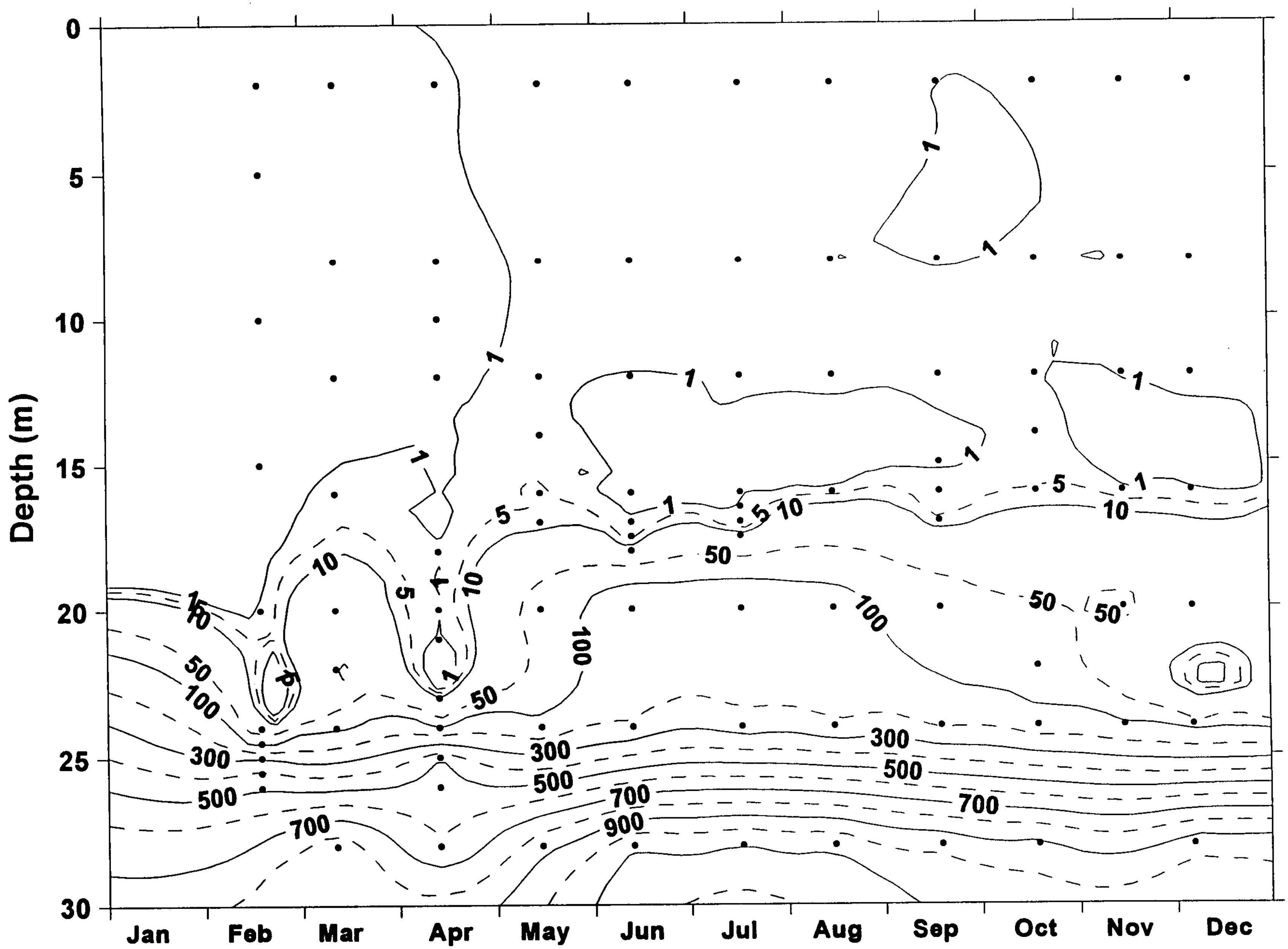
2001 Light Attenuation (percent of surface)

Figure 15



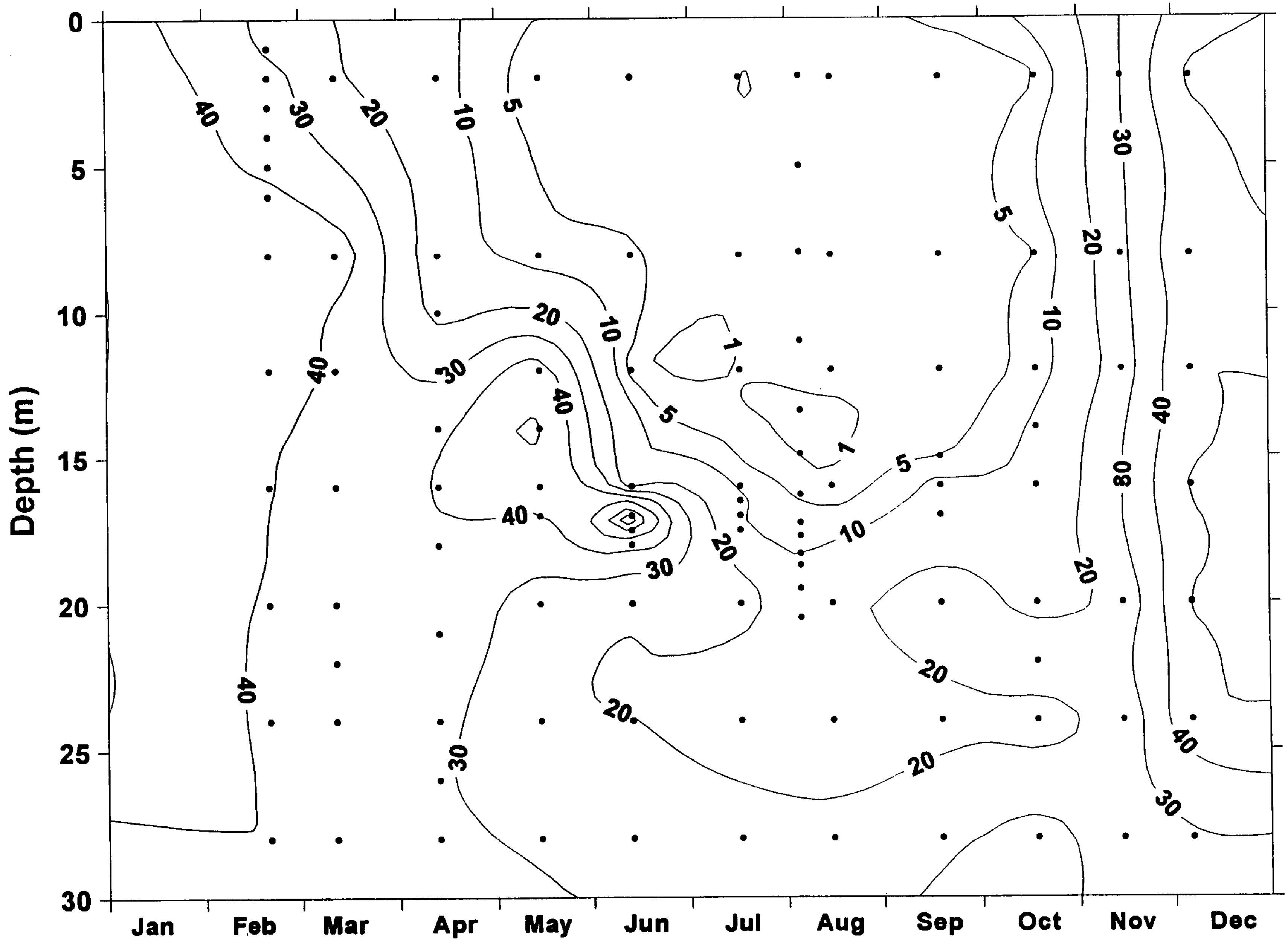
Dissolved Oxygen (mg/l) at Station 6, 2001

Figure 16



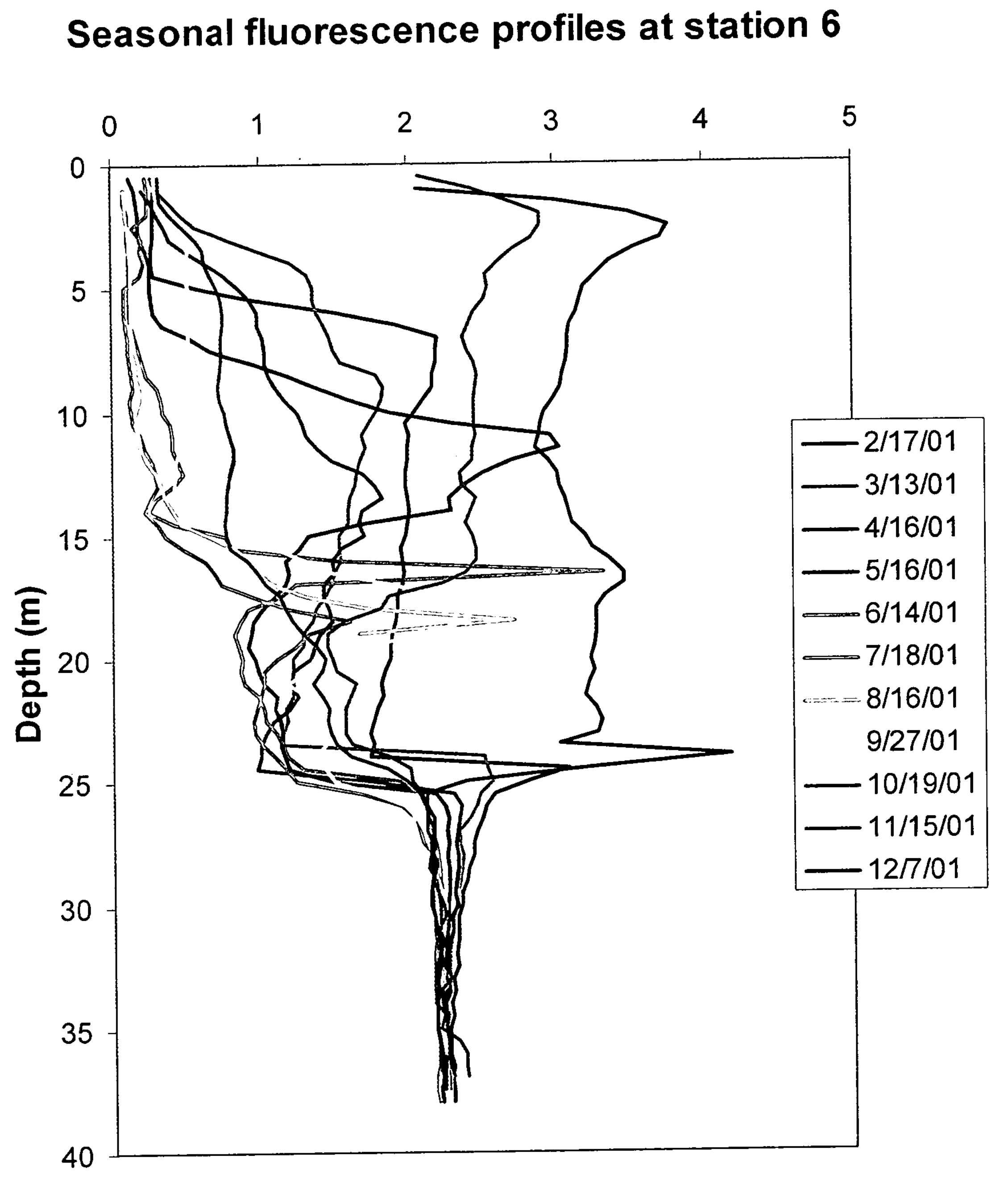
Ammonium (uM) at Station 6, 2001

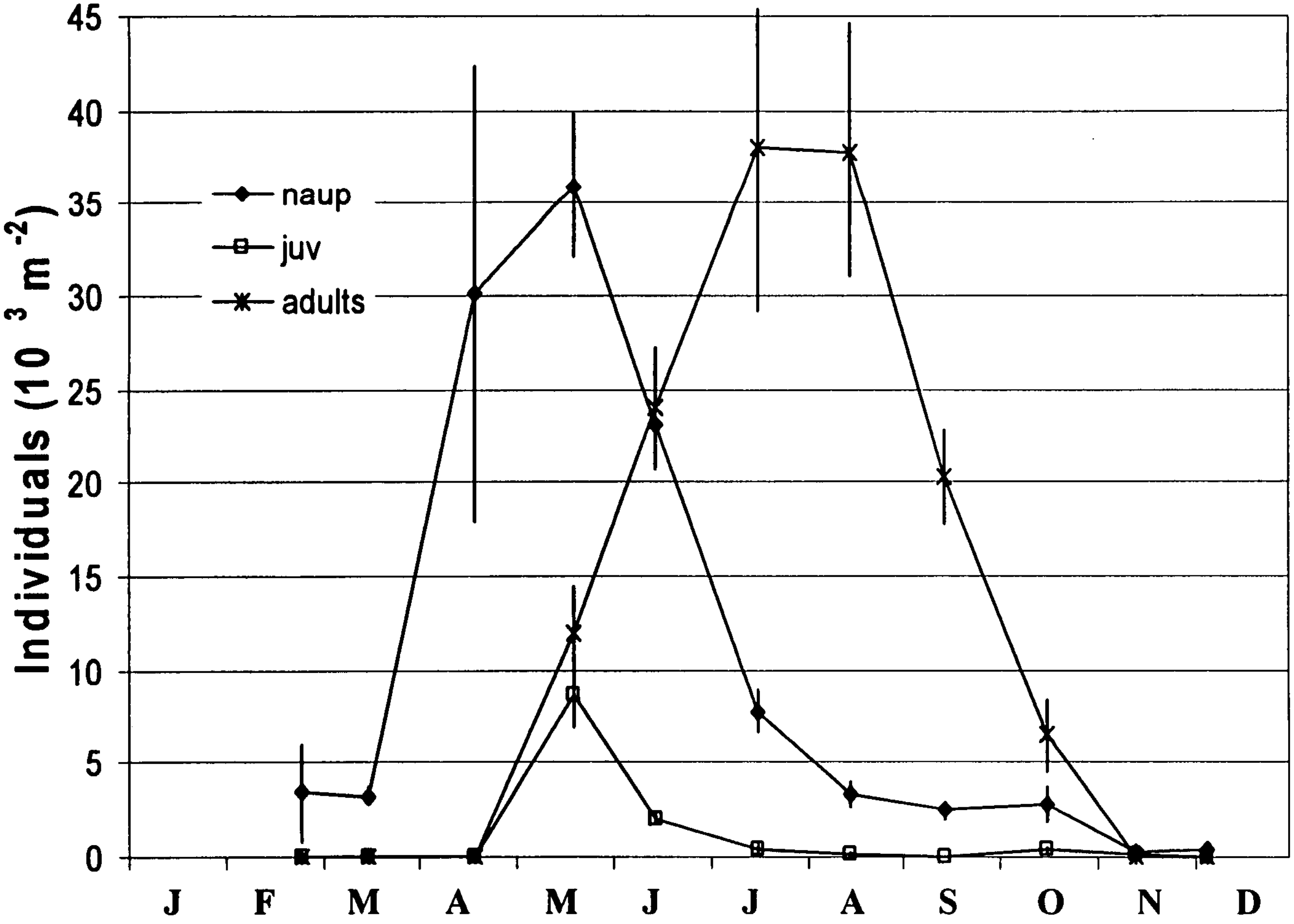
Figure 17



Chlorophyll a (ug/l) at Station 6, 2001

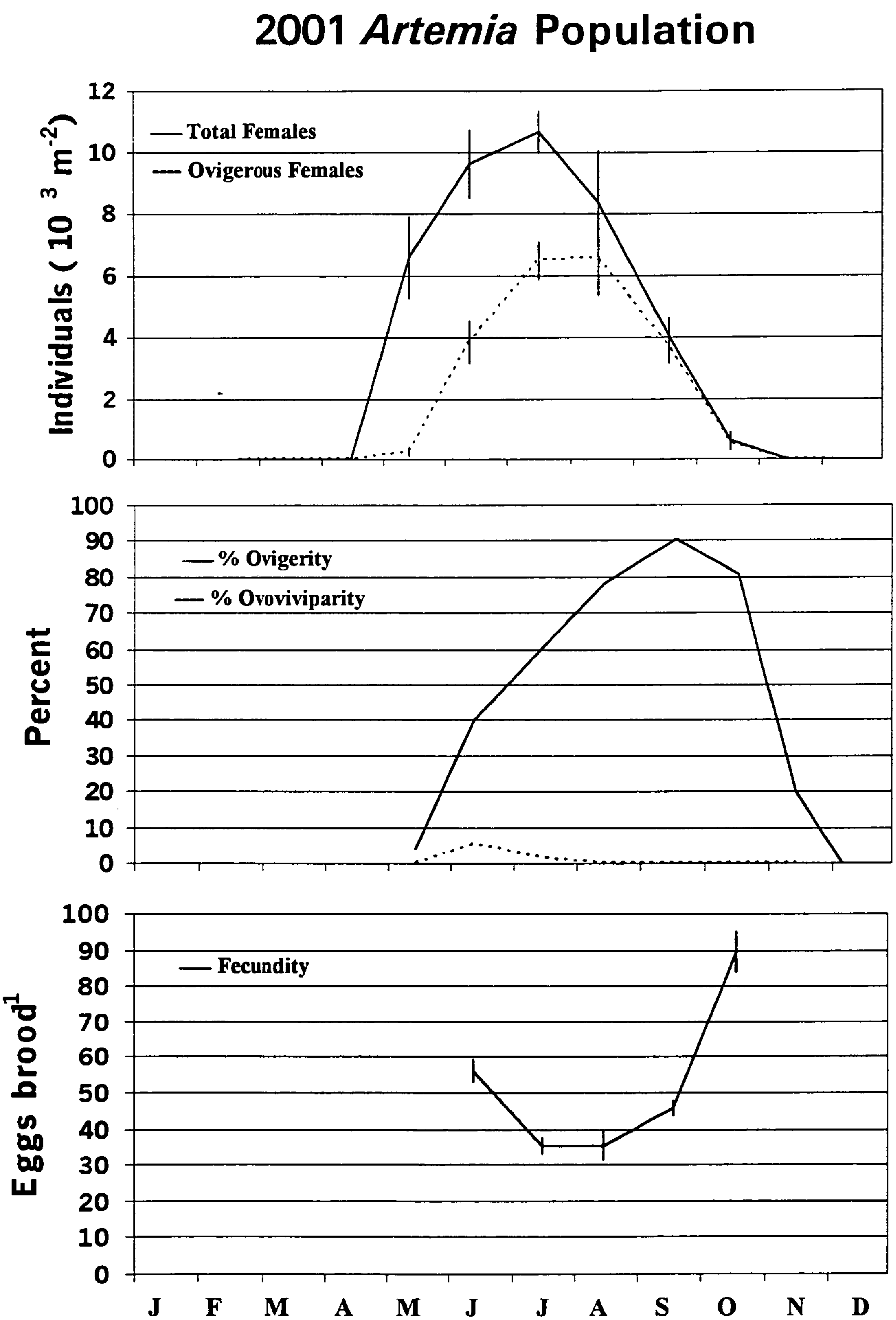
Figure 18


Seasonal fluorescence profiles at station 6
0
1
2
3
4
5
0
5
10
15
20
25
30
35
40
Depth (m)
2/17/01
3/13/01
4/16/01
5/16/01
6/14/01
7/18/01
8/16/01
9/27/01
10/19/01
11/15/01
12/7/01

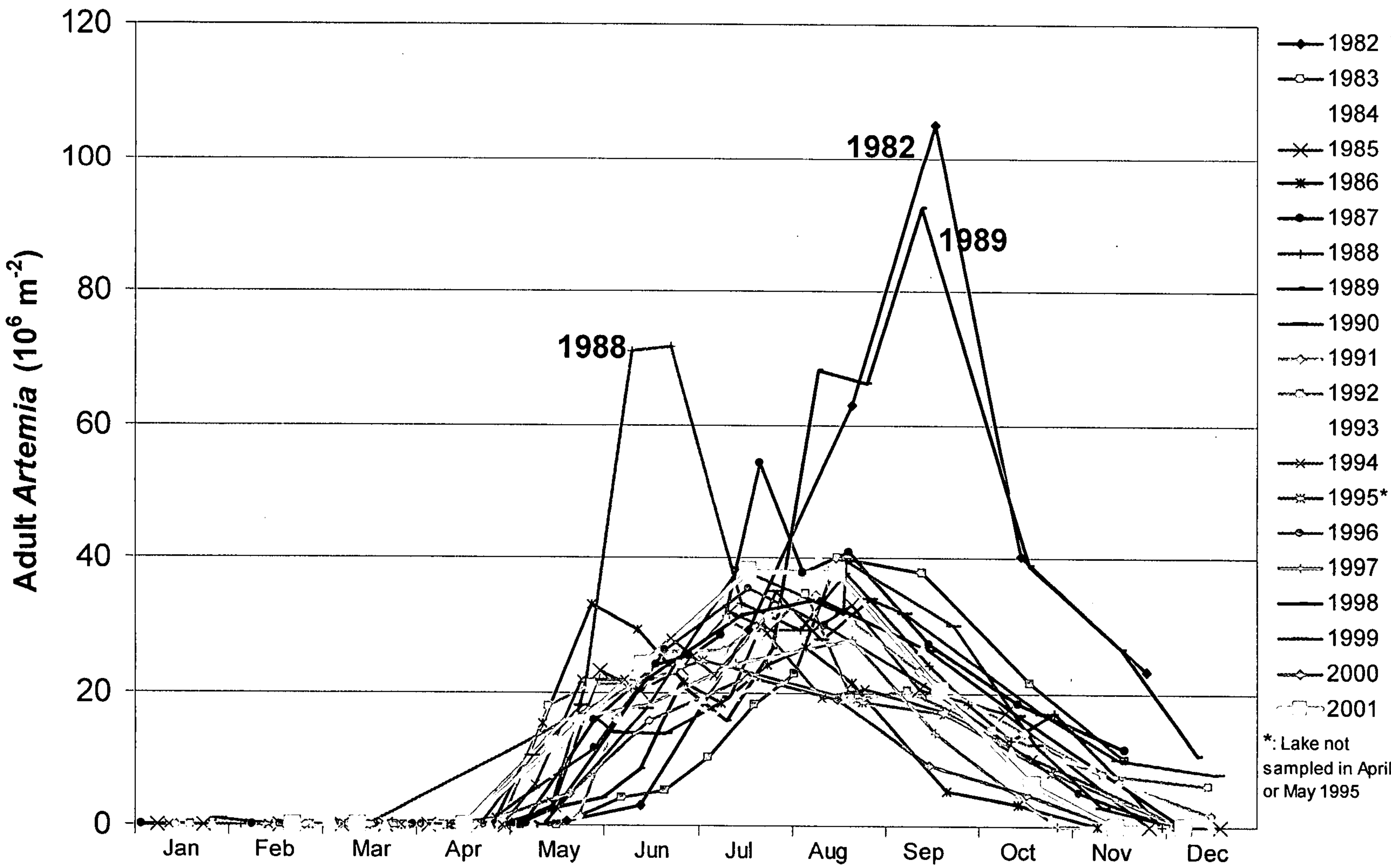


2001 *Artemia* Population

Figure 20

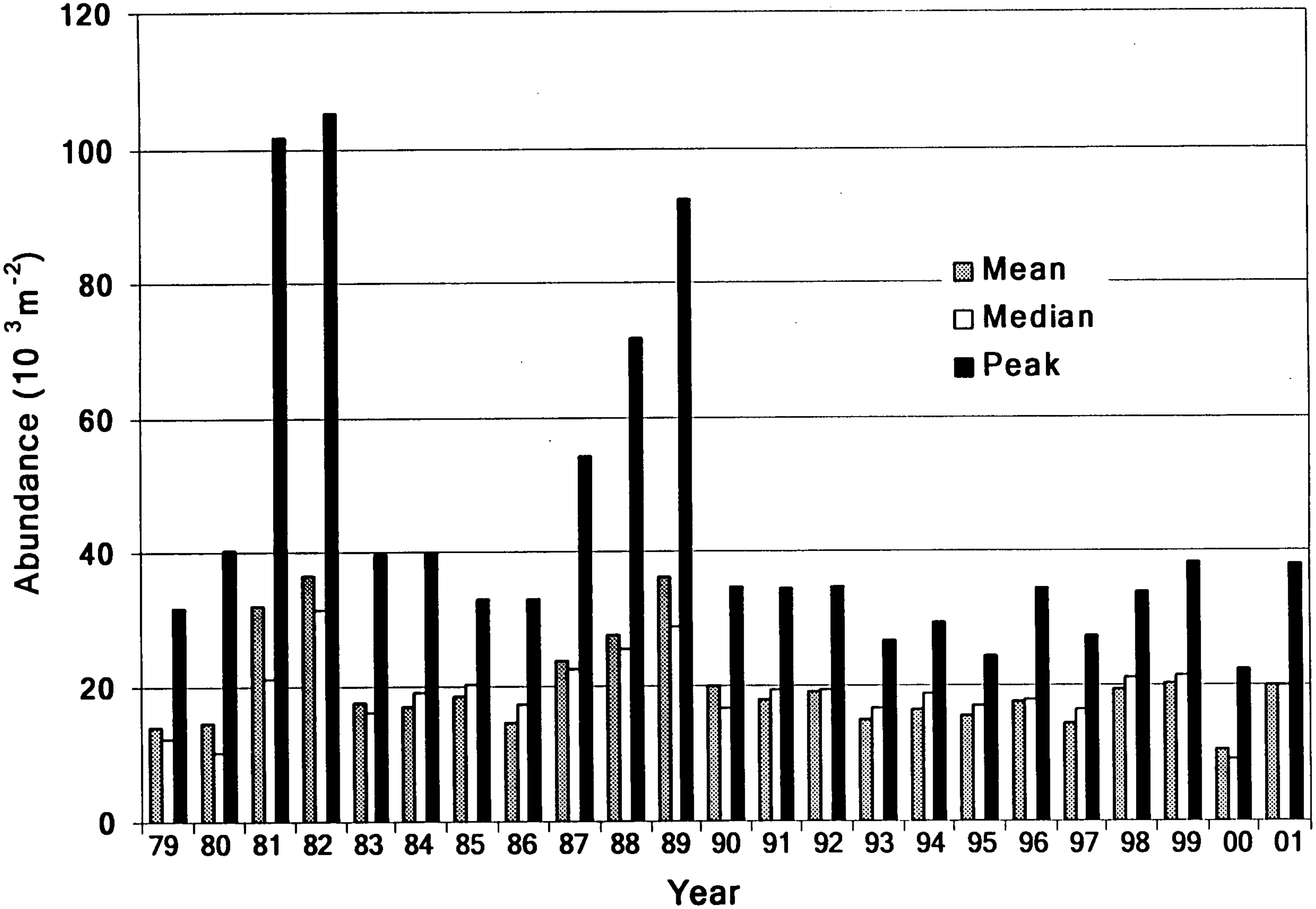

2001 Artemia Population
Individuals (10 3 m-2)
12
10
8
6
4
2
0
Total Females
Ovigerous Females
Percent
100
90
80
70
60
50
40
30
20
10
0
% Ovigerity
% Ovoviviparity
Eggs brood-1
100
90
80
70
60
50
40
30
20
10
0
Fecundity
J F M A M J J A S O N D

Adult *Artemia* Abundance



Adult *Artemia* Abundance

Figure 22



Adult *Artemia* Summary Statistics

Figure 23

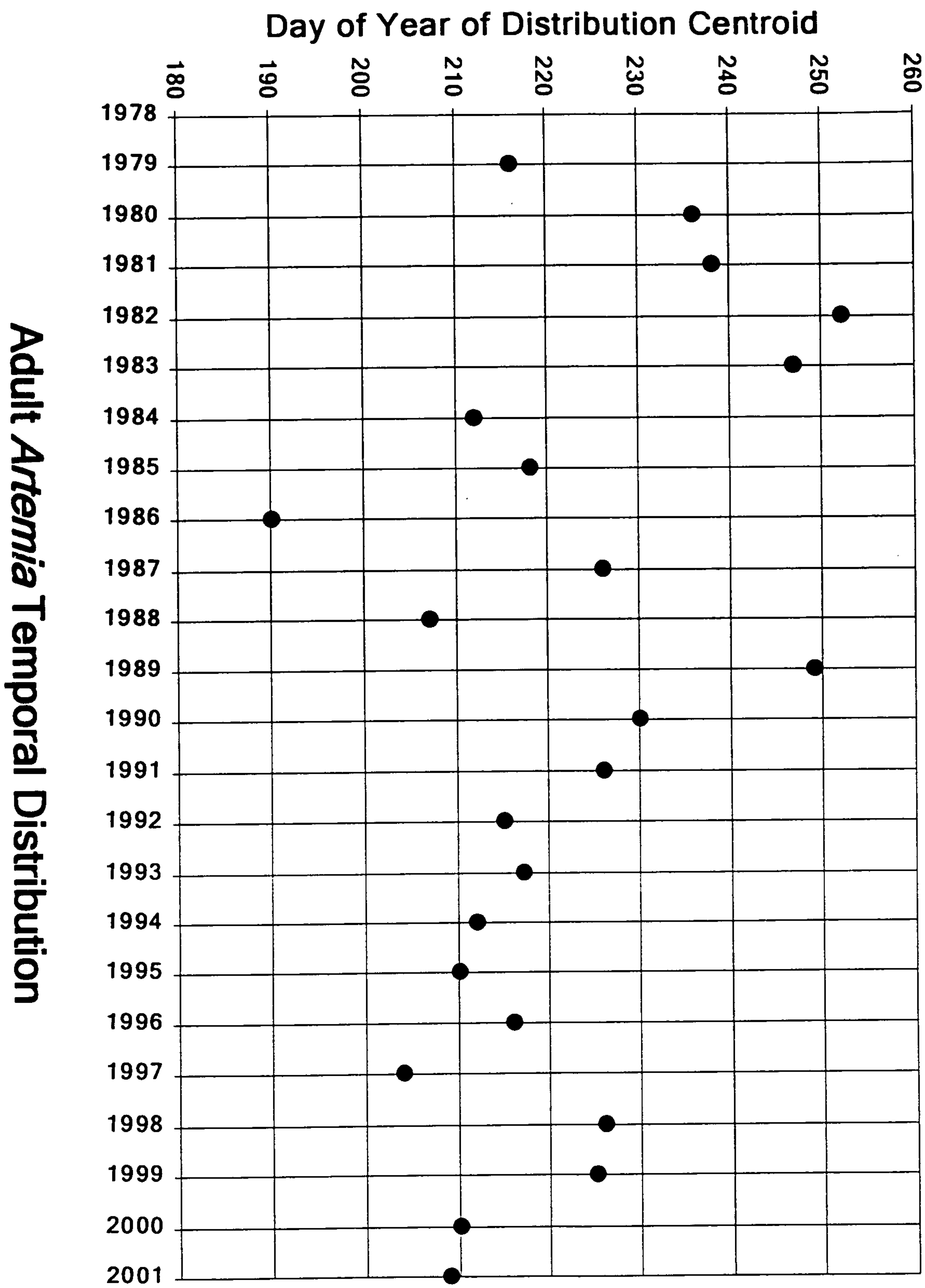

Adult *Artemia* Temporal Distribution
Day of Year of Distribution Centroid
180
190
200
210
220
230
240
250
260
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001

Figure 24

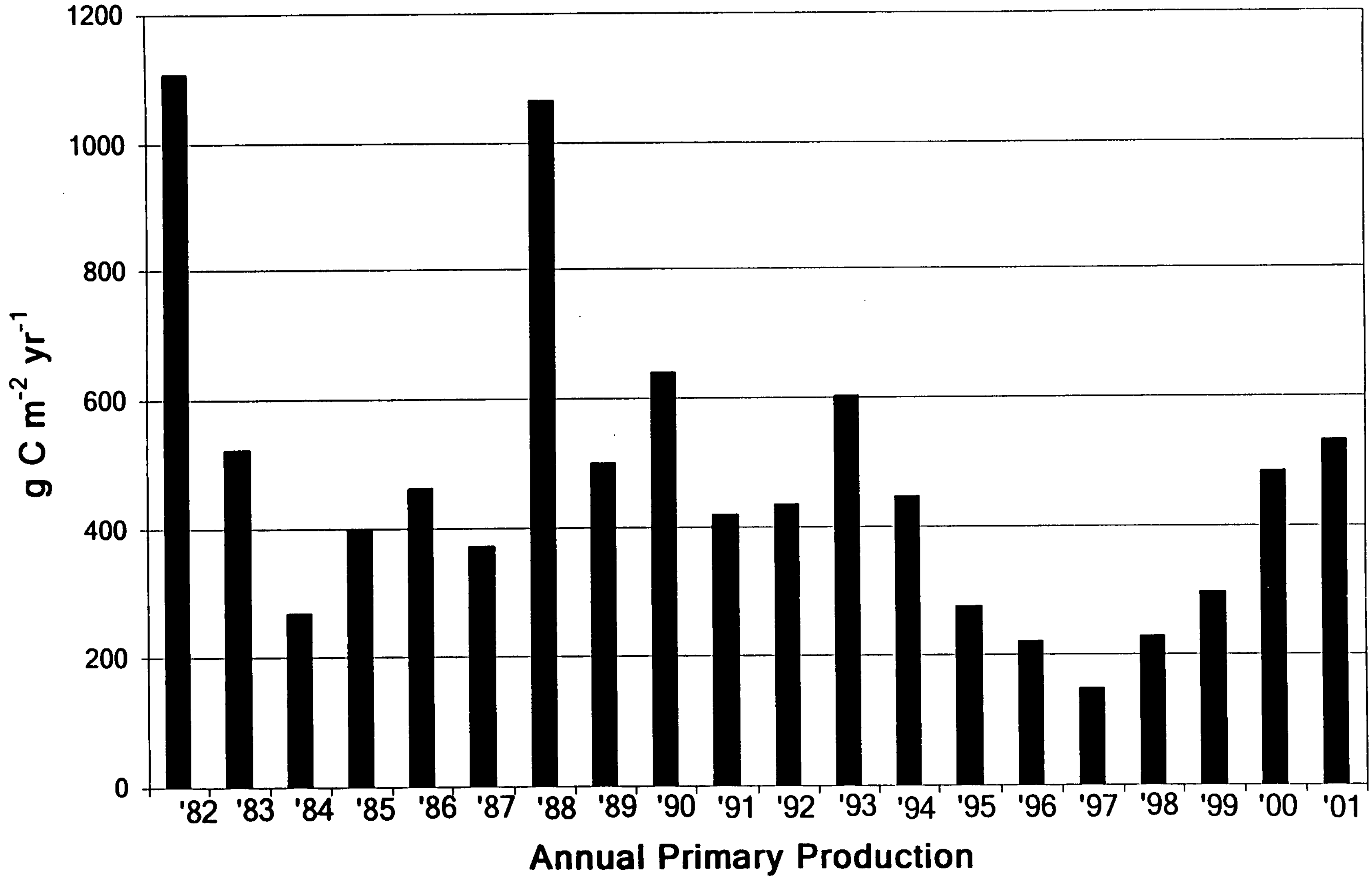
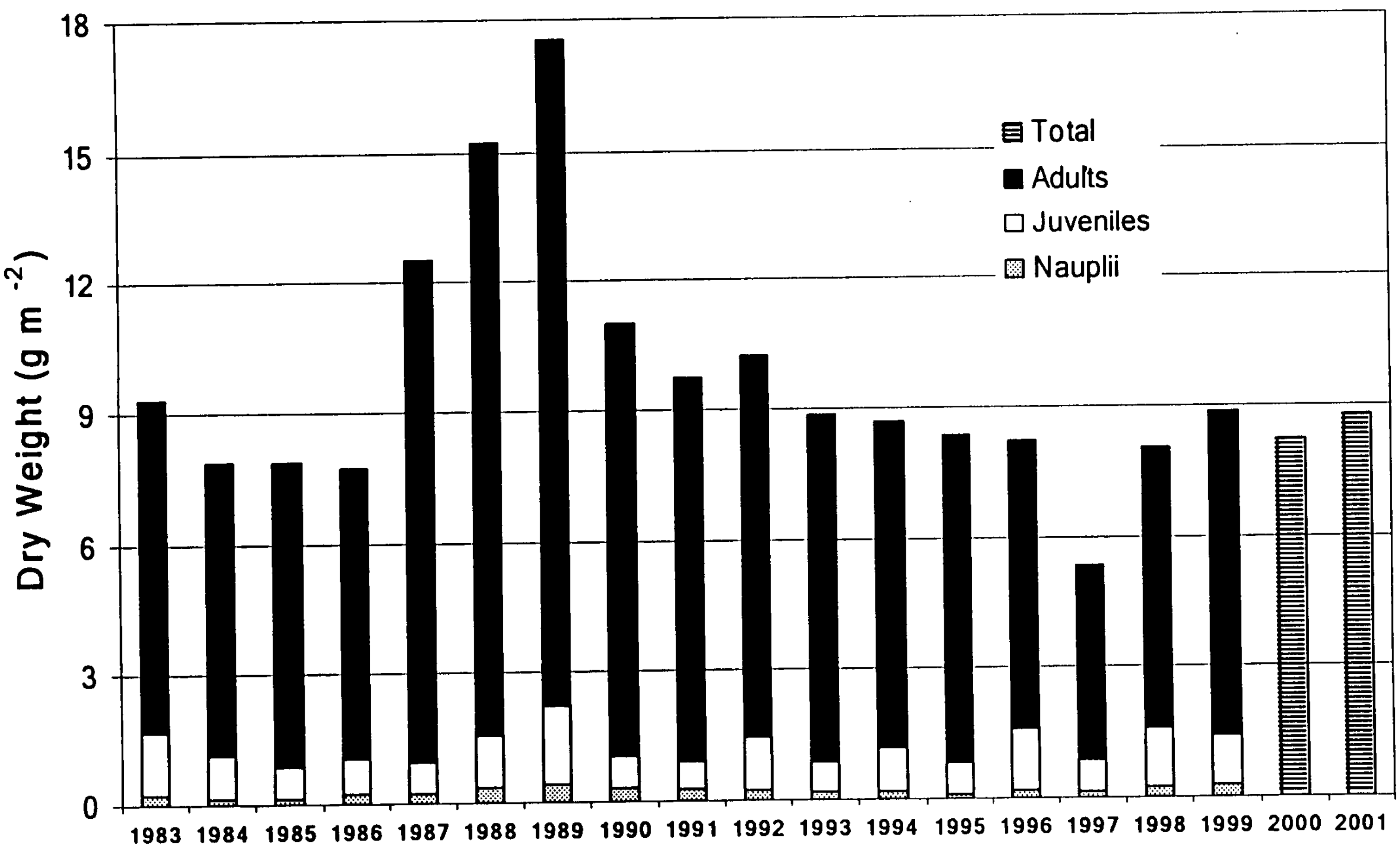
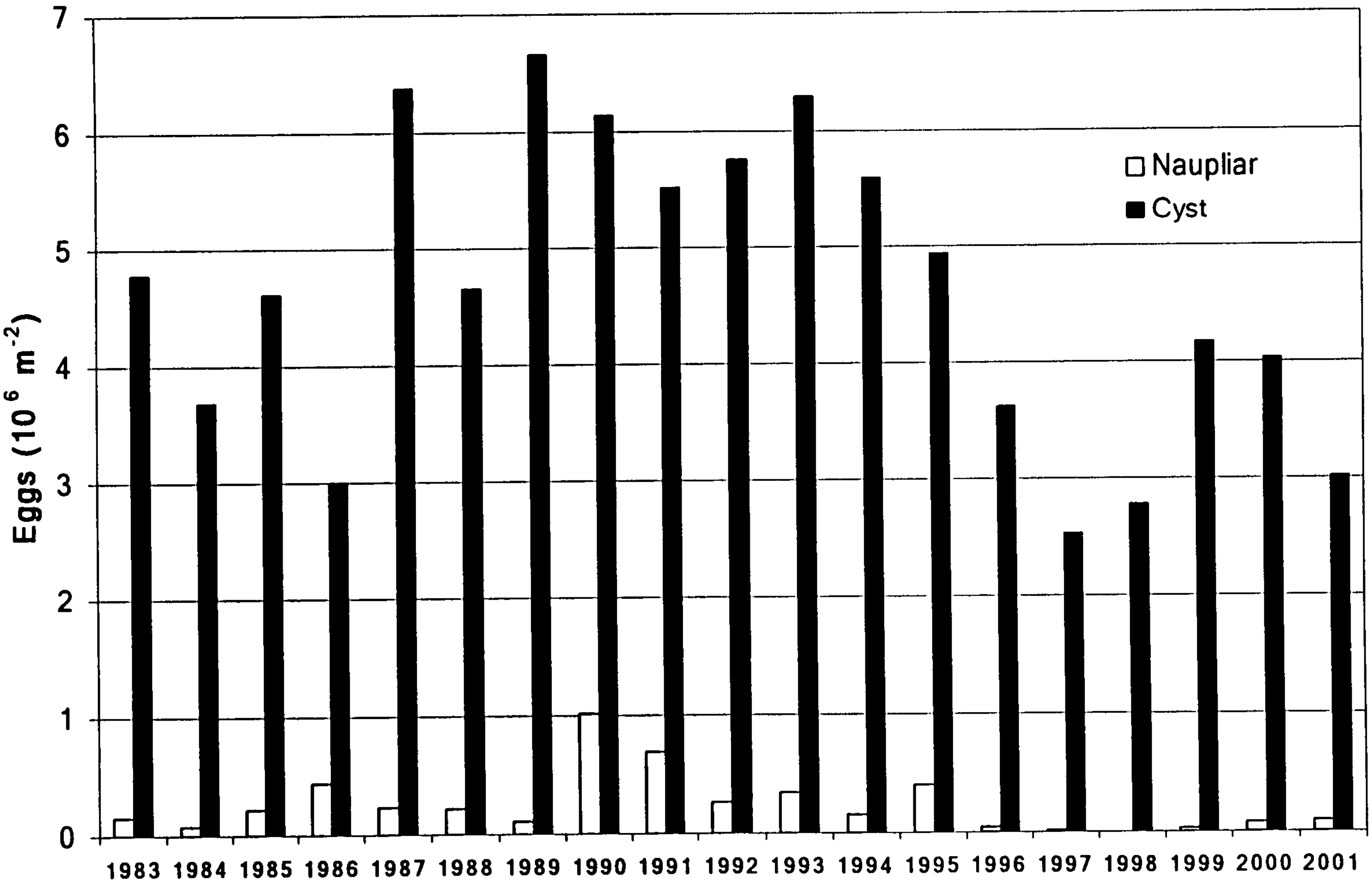

1200
1000
800
600
400
200
0
g C m-2 yr-1
'82
'83
'84
'85
'86
'87
'88
'89
'90
'91
'92
'93
'94
'95
'96
'97
'98
'99
'00
'01
Annual Primary Production

Figure 25



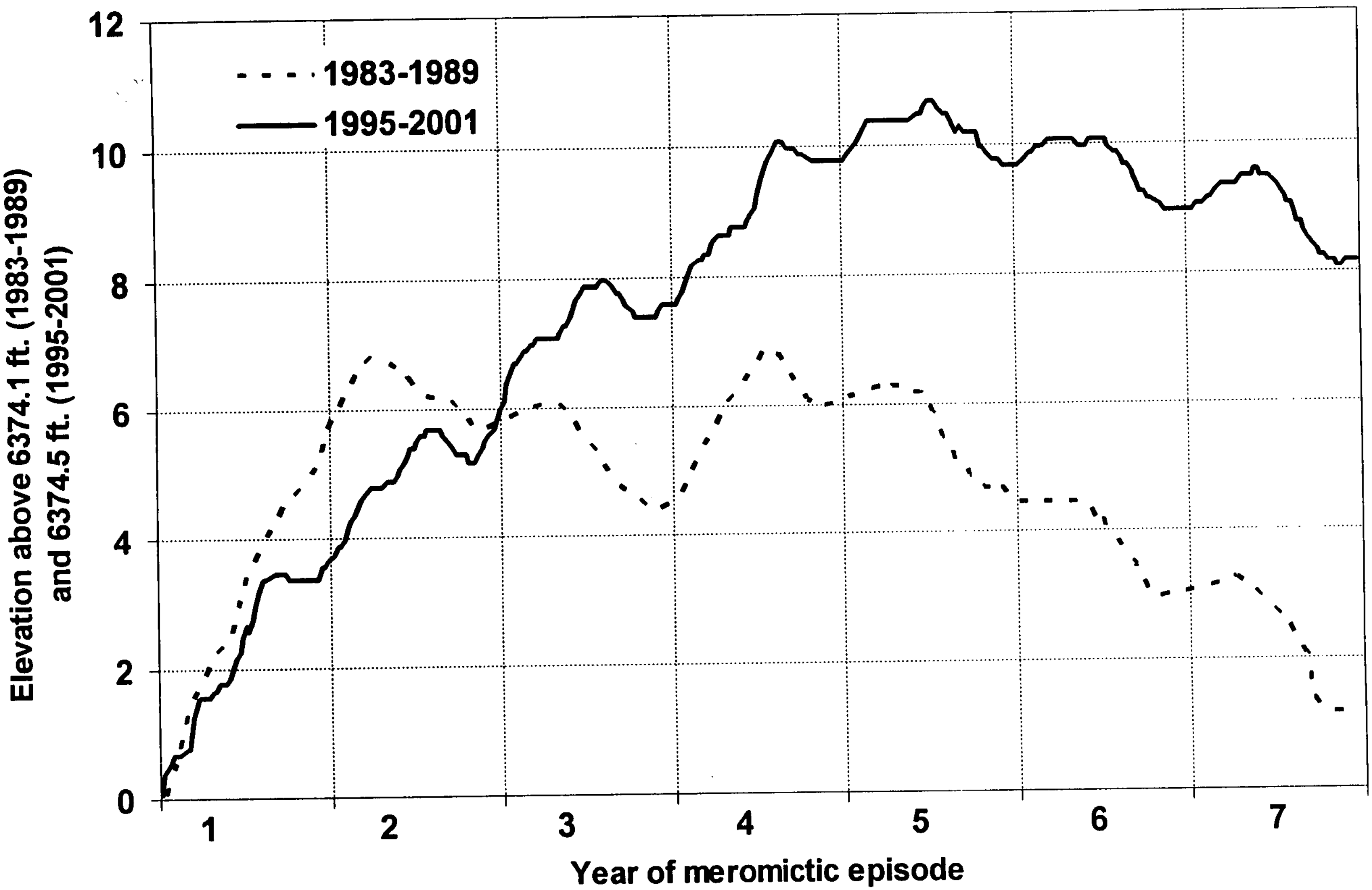
Mean Annual *Artemia* Biomass

Figure 26



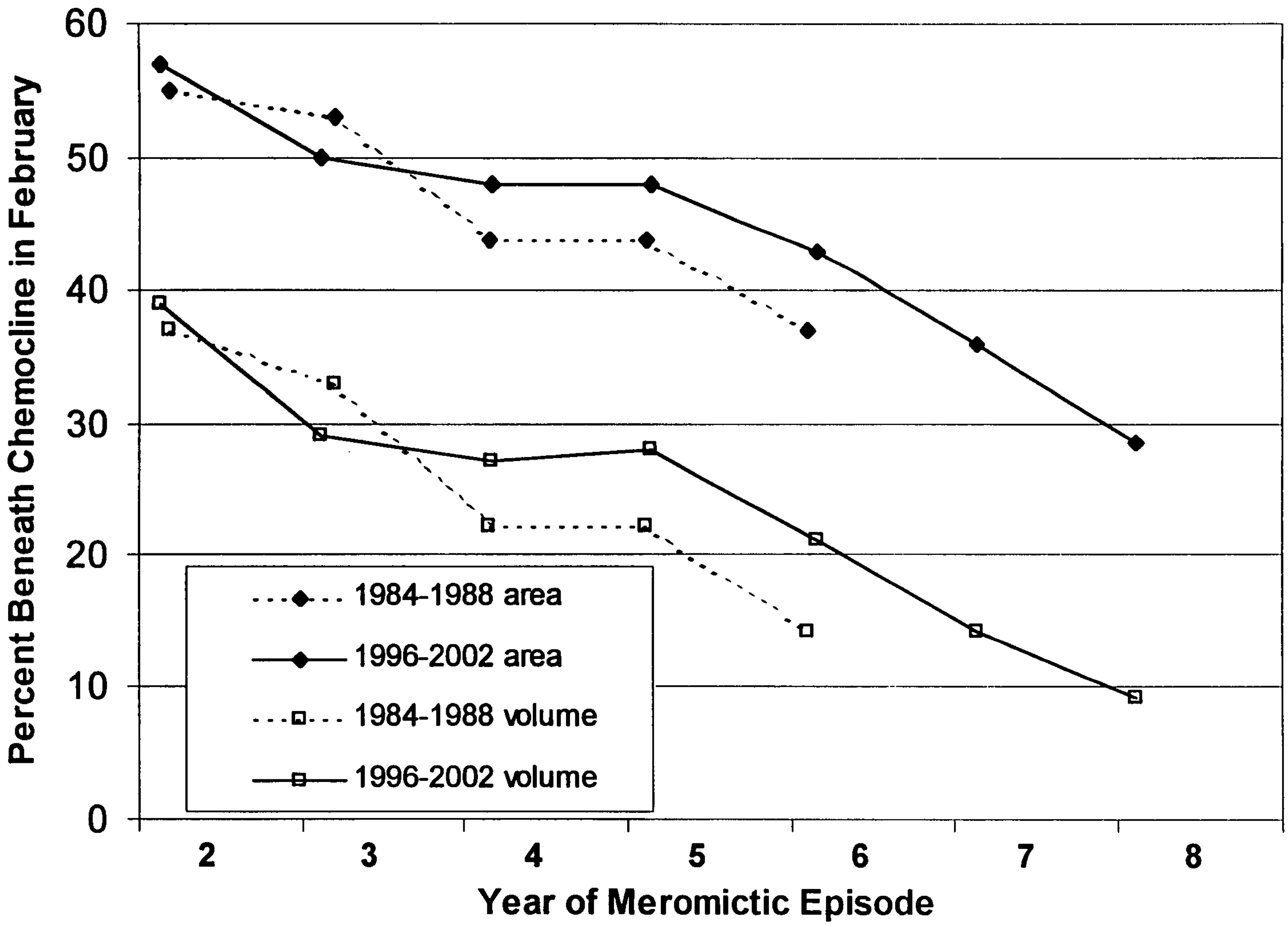
Artemia Reproduction

Figure 27



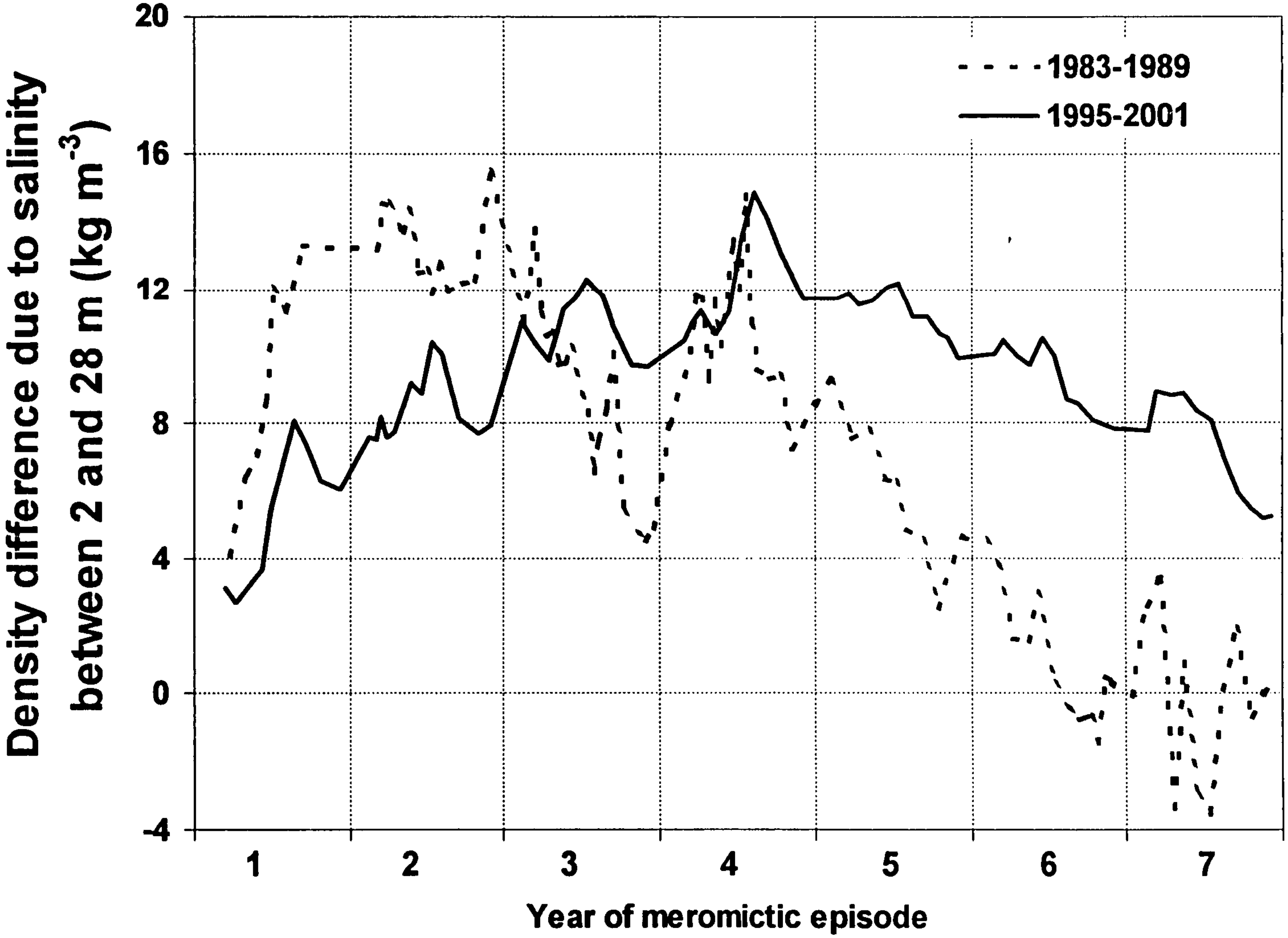
Changes in Surface Elevation

Figure 28



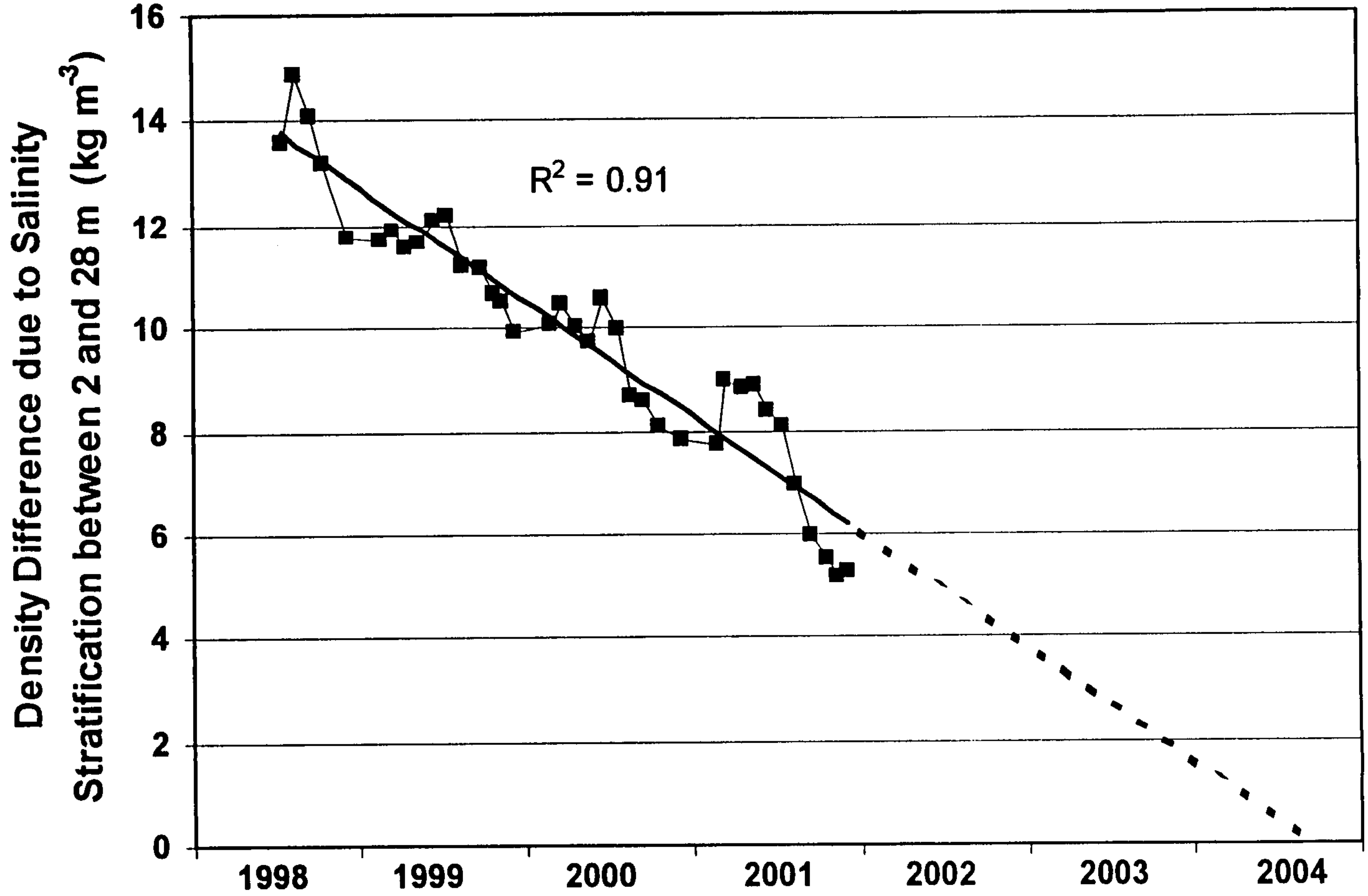
Changes in Area and Volume beneath Chemocline

Figure 29



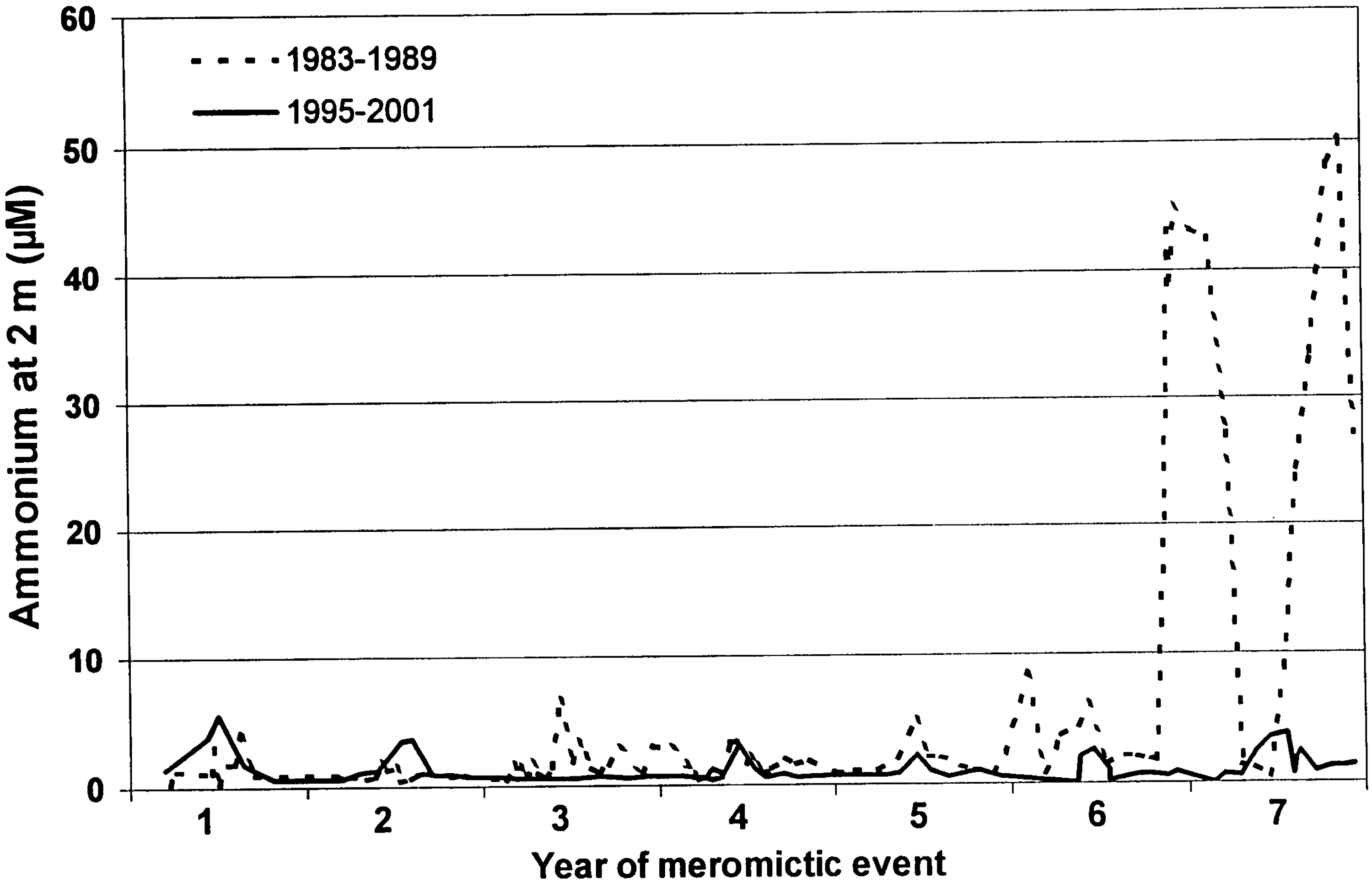
Changes in Salinity Stratification

Figure 30



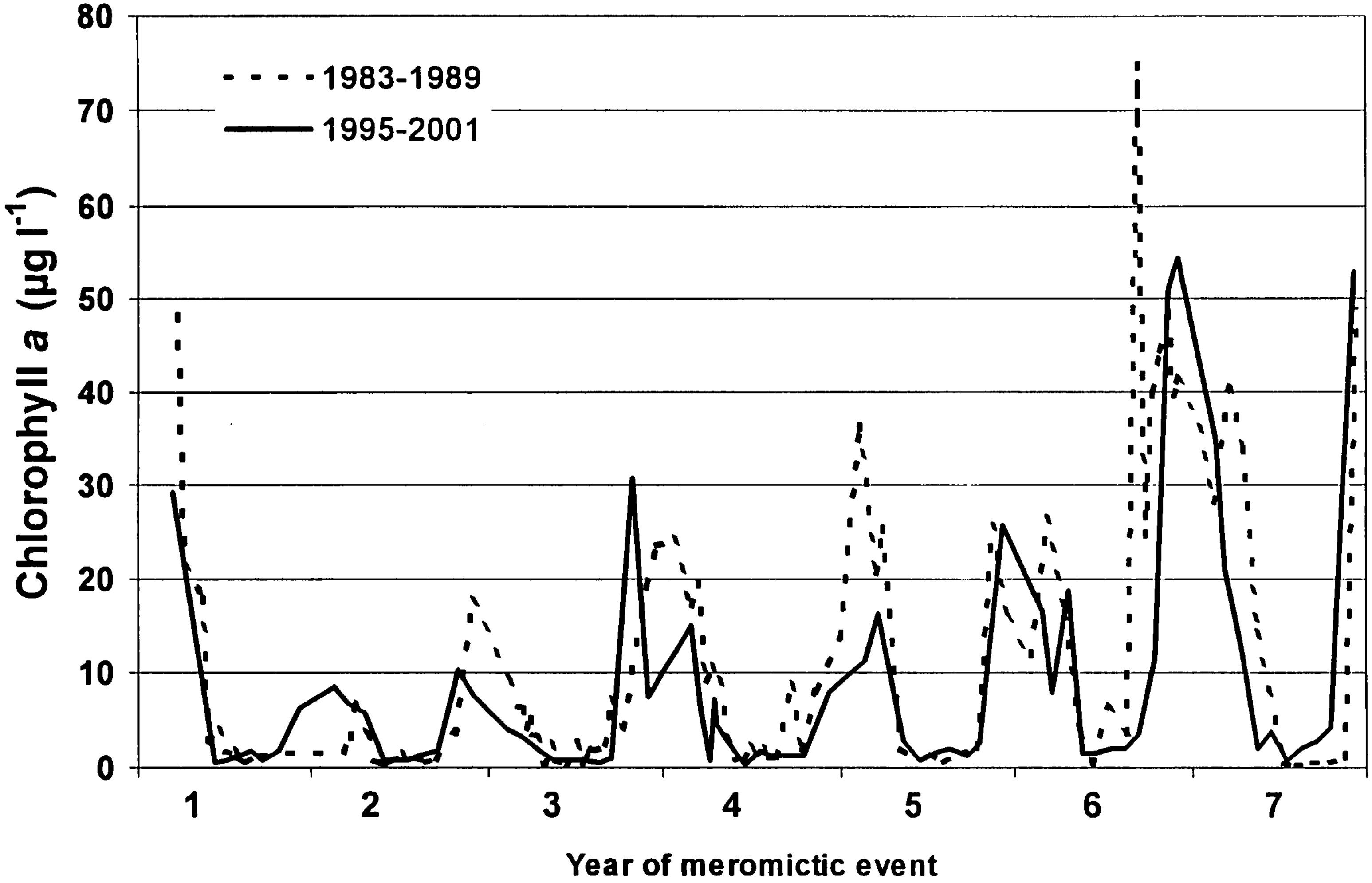
Temporal Trend of Salinity Stratification

Figure 31



Changes in Ammonium

Figure 32



Changes in Algal Biomass

Figure 33

WATERFOWL POPULATIONS AT MONO LAKE, CALIFORNIA, 2001

Joseph R. Jehl, Jr.

Hubbs SeaWorld Research Institute

Technical Report 2002-330

February 2002

NOTICE

TABLE OF CONTENTS

Cover: Canada Geese at mouth of Rush Creek, 21 November 2001.

WATERFOWL POPULATIONS AT MONO LAKE, CALIFORNIA, 2001

Joseph R. Jehl, Jr.

Abstract.--This report summarizes waterfowl populations and biology at Mono Lake, California, and adjacent wetlands in 2001. The data were gathered to comply with the requirements of State Water Resources Control Board Orders 98-05 and 98-07.

The surface elevation of Mono Lake was nearly one foot lower in autumn 2001 than in 2000. The numbers of migrating waterfowl were higher than in previous years due mainly to large numbers of Northern Shovelers in September. The number of breeding Gadwall also rose. On seven shoreline censuses conducted between late July and late November over 20,000 waterfowl of 15 species were identified. Peak numbers occurred in late September. The Wilson Creek Delta was the major concentration point; the Sammann's Springs area was little used. The south shore between Navy Beach and Sammann's Springs attracted few birds because the fringing ponds had mostly dried out by early autumn.

On seven surveys of freshwater ponds along the north shore in the same interval I encountered 298 waterfowl of 14 species, with Gadwalls (mostly local breeding birds) and Mallards predominating. These ponds provided foraging and breeding habitat for a few waterfowl (including three species not observed on the main lake), but contributed little to overall abundance.

The Ruddy Duck is the dominant species on the lake in fall. It was present in usual numbers and peaked at about 7700 in October.

There was no evidence that waterfowl used areas that had been burned to create waterfowl habitat.

Numbers of waterfowl at Mono Lake, Bridgeport Reservoir and Crowley Lake in mid October were determined by aerial censuses. The total number of ducks (other than Ruddies) was the lowest at Mono Lake, whereas the number of Ruddies was 4-10 times greater.

INTRODUCTION

Hubbs-Sea World Research Institute initiated research on the biology and ecology of dominant species of waterbirds at Mono Lake, California in 1980: California Gull, Eared Grebe, Wilson's Phalarope, and Red-necked Phalarope. In 1995, the State Water Quality Control Board requested information on waterfowl, to include species composition, timing and peak of migration periods, population size, distribution, behavior, time budgets, food habits, and abundance at nearby lakes.

This report summarizes data on population monitoring in the 2001 field season. Reports on other aspects of waterfowl biology are in preparation. Such information is essential because the feasibility of the restoration program cannot be judged without detailed information about the habits and requirements of individual species. This report is intended to comply with the monitoring requirements outlined in State Water Resources Control Board Orders 98-05 and 98-07.

METHODS AND RATIONALE

Definitions. Waterfowl refers to members of the Anatidae (ducks and geese). For clarity, the Ruddy Duck is treated separately because its biology at Mono Lake differs from that of other ducks and geese.

Lake level. During the 2001 waterfowl season the level of Mono Lake was lower than in 2000 (6382.3' vs 6383.2'; W. Hooper, LADWP)

Census Methods: Mono Lake

Boat

To determine waterfowl numbers, I made full shoreline censuses of Mono Lake and of all fringing habitats that can support waterfowl. I made three surveys in May-July specifically to detect the location and success of breeding ducks. Other data on breeding success and population health were obtained later in the year when I captured and banded as many waterfowl as possible.

In the main migration period, late July through November, I censused migrants at 2-3 week intervals using a 14-foot Boston Whaler boat equipped with a 35 HP outboard motor. I cruise 100-200 m from shore around the entire periphery along a standard route, starting at the LADWP boat launch and continuing counterclockwise around the lake. The census starts at about 0800. If it cannot be completed in one day, uncensused areas are surveyed as soon thereafter as feasible, usually the following day.

I count all waterfowl and record their numbers on a standard form (see Appendix I; scientific names are given in Appendix II). Data are recorded by general areas suggested by the State Water Quality Control Board (Fig. 1). GPS boundaries of these area were determined with a Garmin 45 CPR unit (Appendix III) . Insofar as possible, data from Wilson Creek (area 11) and Mill Creek (area 12) are treated separately. However, because disturbed birds often move back and forth in this small region (indicated by arrows on the forms), data from some censuses are pooled. If birds flush at a distance, I estimate the size of the flock and the percentage of each species. I also note the presence of other waterbirds, except for Eared Grebes, which are too numerous to count without using aerial photography (see Boyd and Jehl, Colonial Waterbirds 21:236-241, 1998).

To gather information on usage of nearshore ponds and lagoons, I go ashore in areas where coverage from the boat may be incomplete. These vary from census to census. Shore-based work may also entail collecting food samples from areas where ducks forage. Data on food habits will be presented elsewhere. In addition, I make regular foot surveys of ponds along the south shore to detect any waterfowl that may not be detected from the boat.

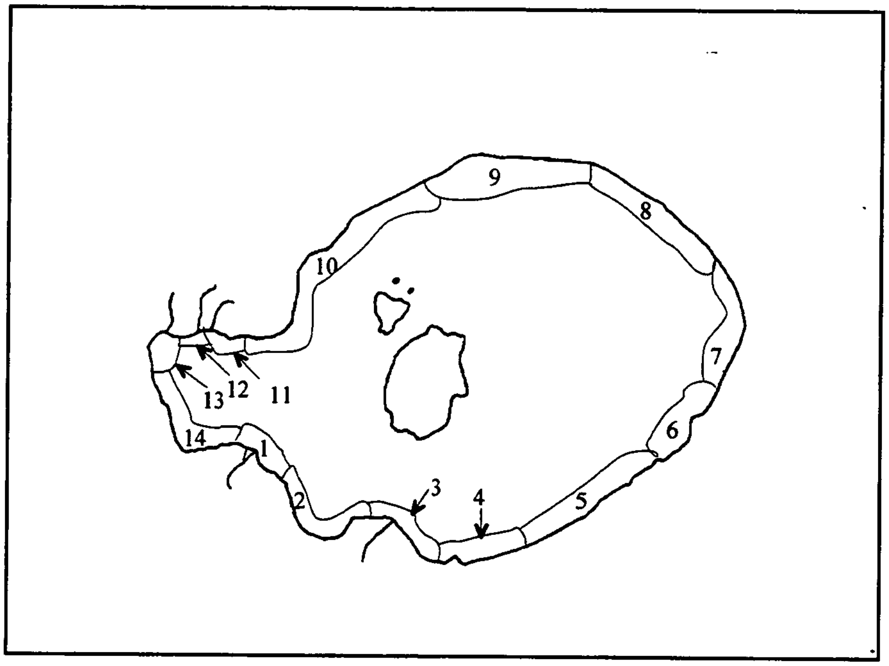


FIGURE 1. Observation areas used in lakewide waterfowl censuses: 1) Lee Vining Creek, 2) Ranch Cove, 3) Rush Creek, 4) South Tufa, 5) South Shore, 6) Sammann's Springs, 7) Warm Springs, 8) NE Shore, 9) Black Point E, 10) Black Point, 11) Wilson Creek, 12) Mill Creek, 13) County Park, 14) West Shore.

All but one (Ruddy Duck) of the species that use Mono Lake are closely tied to the vicinity of freshwater situations (marshes, creek mouths, seeps), and except when disturbed occur within <50 m of shore. Boat surveys are the most effective way to study waterfowl because:

- They allow closer approach than air or foot censuses, cause minimal disturbance, and provide better data on numbers and species composition. I judge that counts are accurate to within ± 15%.
- They provide access to all shoreline areas and creek mouth areas, except for a few freshwater seeps east of Black Point, which at some lake levels are inaccessible because of submerged rocks.

Foot

Foot surveys are impractical for surveys on the main lake because of the great area that must be covered, and because a walking human causes ducks to move around. This leads to the chance of over- or undercounting. Foot surveys, however, are the best way to study waterfowl on ponds adjacent to the lake.

Concomitant with the boat surveys, I census all fresh water ponds [Dechambeau Ponds (5) and County Ponds (2)] on the north shore near Black Point. Counts are usually made in the late afternoon (1600-1900), when some ducks move from the main lake to these freshwater feeding locations. The number of birds is so small that counting errors do not exceed 5%. This area is heavily visited by hunters, tourists, and birders, which affect the number of birds that may be encountered.

Air

Aerial surveys at Mono Lake follow the same route as the boat surveys. They are made from an elevation of about 200 feet above lake level and at a speed of about 80 mph. Usually there is one observer on the shore side of the plane. The pilot acts as an additional observer, alerting the recorder to any duck activity on the lake side.

Aerial surveys provide a good indication of overall abundance and distribution, because waterfowl (excepting Ruddy Ducks) are clumped along the shore. They also allow observations at sites on the north shore that are sometimes inaccessible by boat. However, they are less precise than boat surveys, because they are usually more disturbing, causing ducks to flush at greater distances, thereby making estimates of flock size and species difficult.

Ruddy Duck

This is a difficult species to monitor, because its distribution, unlike that of other ducks and geese is not constrained by proximity to fresh water. Although it prefers shallow water habitats, at times the bulk of the population may be offshore, where Ruddies become undetectable among the hundreds of thousands of Eared Grebes. Accordingly, numbers cannot be fully determined by near-shore boat routes. Cross-lake transects provide a clue to numbers offshore, but are impractical because of the size of the lake and the problem of detection. Aerial surveys will underestimate numbers because Ruddies, unlike most other waterfowl, (1) do not fly in response to a plane, and (2) from the air cannot be consistently distinguished from grebes.

Ruddies occur in peak numbers in October when hordes of grebes are present. At that time, their population size is best estimated from a combination of foot and boat observations. Later in the season, after grebes have migrated, any remaining Ruddies can be censused by air.

Comparative surveys

To determine the importance of Mono Lake relative to other nearby waterfowl habitats, I surveyed the two large freshwater lakes in the vicinity: Bridgeport Reservoir and Crowley Lake. These surveys are done by air, if possible, using procedures similar to those at Mono Lake, except that in addition to shoreline surveys, cross-lake transects are used, as necessary, to cover the open lake. Each lake is flown twice and the mean count is used to indicate total numbers. Ruddy Ducks can be counted because Eared Grebes are scarce. If weather conditions are not suitable, or if a plane is not available, surveys are done from land.

Land censuses at Bridgeport Reservoir are made from the road along the entire south side of the lake, using a 20-60 × spotting scope. This provides good information on total numbers, but only limited information on species composition because many dabbling ducks congregate on the distant northwest shore.

Land censuses at Crowley Lake are made from vantage points on the northeast corner and along the entire west shore, from the mouth of Hot Creek to the dam. Because very few dabbling ducks occur along the eastern shore (there is little suitable habitat), this procedure is satisfactory for determining abundance and species composition lakewide.

In 2001 only one comparative survey was done, in October. The survey schedules for late September were not possible owing to extremely high winds (> 100 km hr) and hazardous flight conditions in the Mono Basin.

RESULTS

Mono Lake

Between 25 May and 23 November I conducted eight boat and three plane censuses of the main lake and made nine censuses of waterfowl on the north shore ponds.

Breeding waterfowl

The May-July surveys emphasized breeding waterfowl. The Gadwall is the only duck that breeds regularly and rears young on the fringes of Mono Lake. In late July, there were a maximum of 50-53 pairs in the area, including 40-42 along Mono Lake itself, with the rest on the north shore [Dechambeau Ponds 3, and County Ponds 7; Fig. 2]. This estimate is probably 10-15% inflated because families move around in the brood-rearing period and often cannot be relocated in the same area on subsequent surveys.

For the majority of Gadwall hens, the nesting areas were probably close to the brood rearing areas, as shown by the presence of very small(< 3 day) ducklings. There were two main rearing areas. One was on the western arm between Wilson Creek and Ranch Cove. The other was along the South Shore (Area 5), where as many as 12 broods including 120 young were present on Pond 1 on 29 July. These had evidently been attracted from much of the south shore and Paoha Island, as all other ponds had dried and there was no other fresh water habitat suitable for ducklings. As in 2000, only one (perhaps 2) brood was seen at Sammann's Springs, which for many years had been an important rearing area. For the first time in several years, the species also nested on Paoha Island.

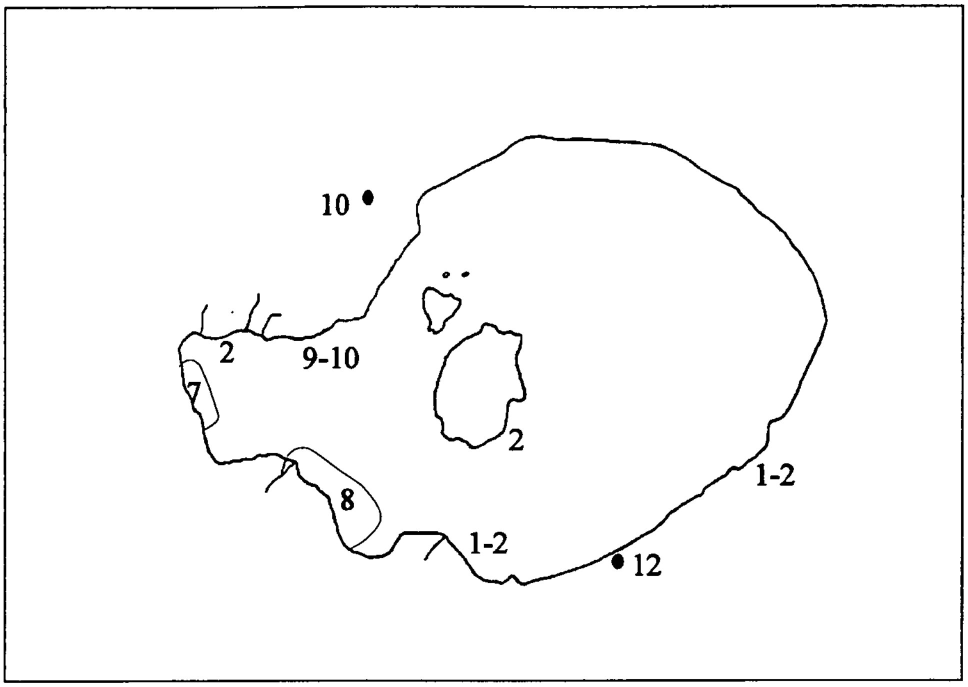


FIGURE 2. Number and location of Gadwall females with broods in mid-July-early August 2001.

Judged by duckling size, hatching began about 24 June (several broods with 10-day young on 4-5 July) and continued until about 25 July. The peak was in the last week of June. Through late August I could account for about 200 young on the main lake and about 75 more on the North Shore Ponds.

In most years, a few adult male Gadwalls molt locally. On 25-26 May, nearly 200 males were scattered in lagoons on the eastern shore, between South Shore and Warm Springs. Similar numbers were at Wilson Creek a month later. Only about 20 remained through the summer. At least four nonflying males with crippled wings that had missed molt were still present on 13 October and two on 23 November (Fig. 3). I captured three and took them to San Diego for rehabilitation.

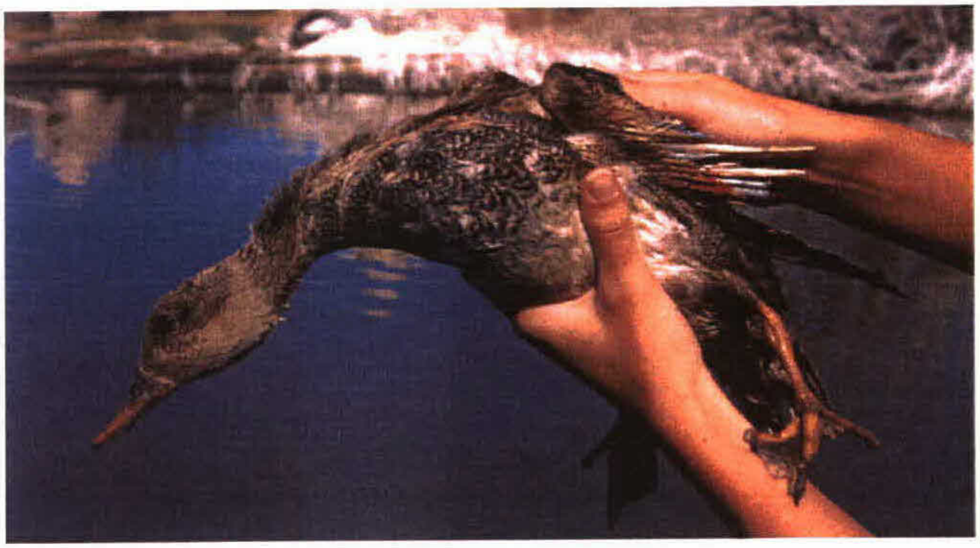


FIGURE 3. Gadwall male with twisted wing that had missed wing molt and was unable to fly, Mono Lake, 23 November 2001.

Other waterbirds breeding on the North Shore ponds included Canada Goose (pair with three young on 26 May), Northern Pintail (brood of three on 28 July), and American Coot (3-4 broods on Dechambeau Ponds, including at least 20 young). A Pintail with seven week-old young was on South Shore Pond 1 on 29 July.

Migrating waterfowl (exclusive of Ruddy Duck)

Most of the 338 waterfowl (5 species of ducks, 1 goose) seen on 25-26 May were Gadwalls and Mallards (Table 1). Most of the former were adult males, evidently on a molt migration; they were largely distributed in lagoons on the east and south shores.

On 4-5 July I recorded 423 waterfowl (8 ducks, 1 goose), with Mallards and Gadwalls making up about 75% of the sightings. As in late May, the majority of the Gadwalls were adult males, although a few hens and their broods were seen.

TABLE 1. Waterfowl detected on all-lake censuses on Mono Lake, CA, 2001.

Species	25-26 May	4-5 Jul	28-29 Jul	24-25 Aug	5 Sep	21-22 Sep	12-13 Oct	31 Oct	21-23 Nov[d]	TOTAL	Percent
Waterfowl											
White-fronted Goose						2			3	5	0.02
Ross's Goose									1	1	0.00
Canada Goose	2	17	22				1		14	56	0.27
Brant								1		1	0.00
Gadwall	237[b]	≈250	87	75	812	56	12	1	8	1538	7.41
American Wigeon		11				40			4	55	0.26
Mallard	65	103	30	153	900	726	571+	308	100	2956	14.23
Cinnamon Teal	5	22	1	118	140	70				356	1.71
Northern Shoveler			24	385	1180	8800[c]	750+	505	4	11648+	56.09
Northern Pintail	12	4	7	23	102	3		8	10	169	0.81
Green-winged Teal		4	9	115	60	400	160+	364	271	1383+	6.66
Redhead	2	6								8	0.04
Lesser Scaup								2	1	3	0.01
Bufflehead									10	10	0.05
Common Merganser		1								1	0.00
Unidentified ducks	15	5	2	59	1500	240	650	57	49	2577	12.41
TOTAL Waterfowl[a]	338	423	182	928	4694	10337	2164	1246	475	20767	
Ruddy Duck	11			142	5	5450	7692+	2580	880	16760+	

[a] Excludes Ruddy Duck

[b] Maximum count

[c] Wilson/Mill Creek, 22 September. Estimated 6500 ducks, 90% Shovelers. Not clear if these had been flushed from Sammonn's Spring earlier in day. Lakewide total ≈ 6500-10,000 Shovelers. 8800 used in calculations.

[d] Combined aerial and boat censuses: maximum counts.

The first obvious fall migrants (mainly Northern Shovelers) were present on the 28-29 July census. Numbers then increased rapidly, and by late September there were about 10,000 ducks on the lake, most of which were Shovelers. The number is uncertain because several thousand Shovelers (minimum 6500) moved between Sammann's Springs and Wilson Creek. Numbers of waterfowl then decreased sharply, so that by mid-October (and *prior* to the opening of duck season) the population was only 2164. Later censuses recorded only a few hundred birds, with Mallards and Green-winged Teal predominating (Fig. 4). Fair numbers of Shovelers persisted into late October. Pintail, however, were scarce.

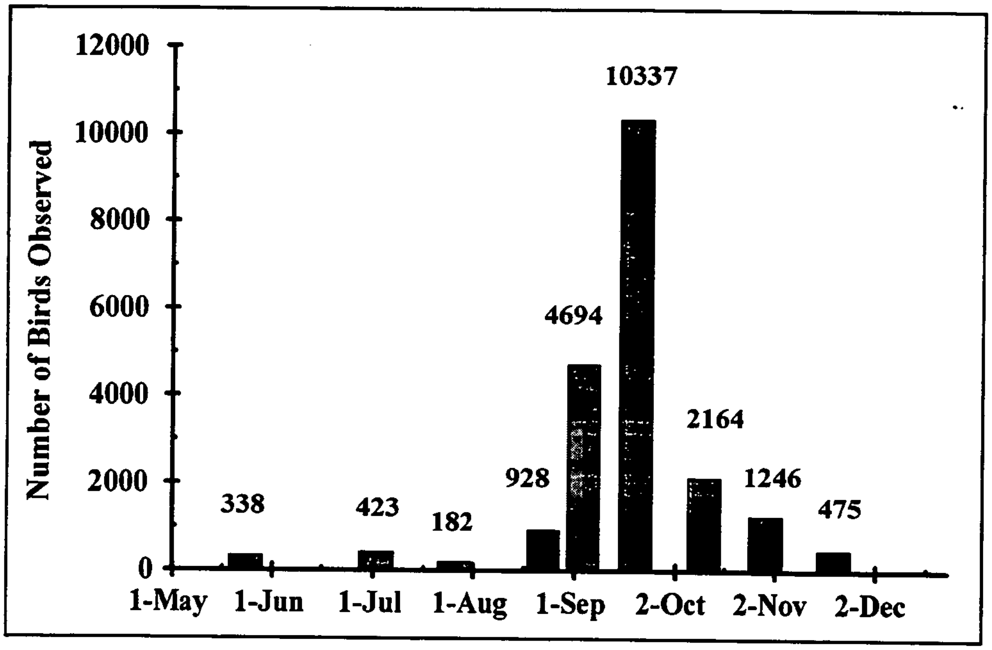


FIGURE 4. Waterfowl (excluding Ruddy Duck) observed on shoreline censuses of Mono Lake, 2001. This graph excludes flightless Gadwall juveniles (July-August). After fledging young Gadwalls become indistinguishable from adults, and counts in September include local young in addition to migrants.

Through the entire fall the Wilson Creek mouth was the area most attractive to waterfowl, as it provided the best habitat for most of the species visiting and breeding at Mono Lake (see photos in Appendix IV).

Exclusive of Ruddies, 20,767 waterfowl of 15 species were recorded on the lake.

Northern Shovelers comprised 56% of all sightings and 64% of ducks identified to species.

Migration timing of the commonest species is shown in Figure 5.

Ruddy Duck

The Ruddy Duck is the commonest duck through most of the fall. Small numbers of postbreeding adults arrived in late August. The main influx started in mid-September and some birds remained into early winter. Peak numbers occurred in October. The high estimate was ≈7700 on 12-13 October.

North Shore Ponds

Waterbirds breeding in the vicinity of the Dechambeau and County ponds are discussed above.

The timing of fall migration at these ponds parallels that on the main lake. On seven surveys between 28 July and 23 November (Table 2) I recorded 335 waterfowl; 101 were Gadwalls, most of which were hatched locally. Among unquestioned migrants, Mallards predominated. American Coots were the most common and consistent migrants, with a peak of 141 on 30 October, and a total of 535.

The attractiveness of the ponds varies. In 2001, the County Ponds held water through the season and together attracted about 80% of all migratory waterfowl (Gadwall not included); there was a clear preference for Pond 2. As noted in 2000, the County Ponds have replaced Dechambeau 4 as the preferred bathing/drinking site for California Gulls. Marsh vegetation continued to proliferate in the Dechambeau Ponds, to the extent that the surface of Pond 3 was often clogged with weeds. Dechambeau Pond 5, constructed late in 2000, held water in 2001, but I never saw any waterbirds there. It is too small and enclosed to be attractive to ducks.

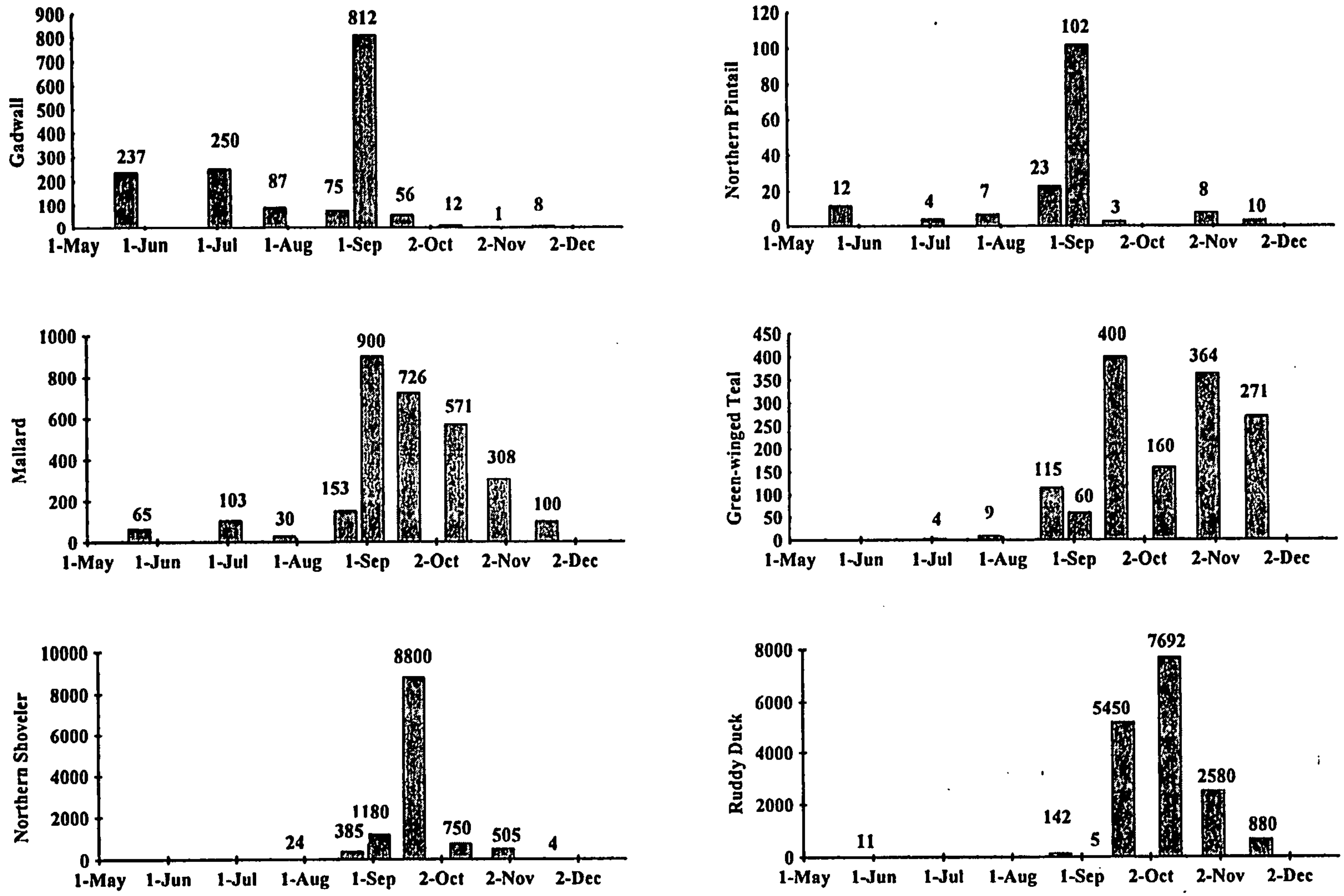


FIGURE 5. Timing and abundance of the commonest species of waterfowl at Mono Lake, 2001.

TABLE 2. Waterfowl detected on freshwater ponds on the north shore of Mono Lake, CA, 2001.

Species	26 May	3 Jul	28 Jul	23 Aug	6 Sep	23 Sep	12 Oct	30 Oct	23 Nov	Total
Waterfowl										
White-fronted Goose					1					1
Ross' s Goose									2	2
Canada Goose	2									2
Wood Duck							1			1
Gadwall	6	4	13	14	53	7	2	2		101
American Wigeon							2			2
Mallard				41	11	45	3			100
Blue-winged Teal		6			2					8
Cinnamon Teal	4	15	6		6					31
Northern Shoveler			3	40		2				45
Northern Pintail			1	5	9	5	1			21
Green-winged Teal				8		2	4			14
Ring-necked Duck							1	1	1	3
Bufflehead								3		3
Unidentified ducks						1				1
TOTAL Waterfowl*	12	25	23	108	82	62	14	6	3	335
Ruddy Duck			1	1				7	1	10
American Coot	16	5+B	8+B	44	47	52	137	141	85	535

*Excluding Ruddy Duck

Comparison with other lakes

I made comparative surveys of Mono Lake, Crowley Lake, and Bridgeport Reservoir on 11 October (Table 3). Water level at Crowley was similar to previous years. Bridgeport was much lower than usual, and the mudflats were extensive, providing good habitat. Excluding Ruddies, waterfowl were only half as common at Mono Lake as elsewhere. As in previous surveys, Mono Lake attracted the majority (76%) of the Ruddy Ducks in the region (Table 4).

TABLE 3. Aerial surveys of waterfowl populations at Bridgeport Reservoir, Mono Lake, and Crowley Lake, 11 October 2001.

	Bridgeport Reservoir	Mono Lake	Crowley Lake
Waterfowl			
Canada Goose			6
Mallard	+	+	250
Northern Shoveler	+	+	
Northern Pintail			
Green-winged Teal	+	+[50]	
Common Merganser	2		
Bufflehead	+		
Unidentified ducks	1500	735	1900
Total	1502	[785]	2156
Ruddy Duck	1500	[6910]	700
Other Species			
Western Grebe			80
Eared Grebe		1 million +	10
American White Pelican			40
Double-crested Cormorant	15		300
Great Blue Heron	1	1	
American Coot	6000	50	1800-2000

+ = present and identified from the air
[ ] = minimum count

TABLE 4 Comparative counts of waterfowl at Bridgeport Reservoir, Mono Lake, and Crowley Lake. Totals include all species . Numbers of Ruddy Ducks in parentheses. For details of techniques and type of survey see earlier reports.

Year	Date	Bridgeport Reservoir	Mono Lake	Crowley Lake
1996	5-9 Sep	2871 (0)	1225 (40)	-
1997	17 Sep	27,050 (0)	2338 (6)	12,035 (600)
1999	17 Sep	8350 (106)	3576 (627)	10,716 (750)
2000	6-8 Sep	16-24K (0)	1243 (500)	680 (0)
1996	16 Oct	6860 (0)	2153 (360)	8516 (3840)
1997	14-15 Oct	3908 (2845)	1662 (500)	2000 (500)
1998	17 Oct	-	6230 (4250)	-
1999	14 Oct	4948 (400)	10,657 (3998)	4562 (1300)
2000	7-8 Oct	4850 (<100)	3162 (855)	7791 (1050)
2001	11 Oct	1502 (1500)	785 (6910+)	2156 (700)

Although this census was made under excellent flying conditions, the results were disappointing because only a few ducks flushed and could be identified to species. Further, many birds were not detected. Land-based observations near Black Point that afternoon encountered at least 500 Shovelers and 200 Green-winged Teal that were not seen from the air.

Comparison of aerial and boat censuses

To further assess the efficacy of plane vs. boat censuses I compared observations made in eight areas on 21 (air) and 23 November (boat; Table 5). These were the only areas where coverage was complete. Both techniques detected similar numbers of waterfowl (excluding Ruddies; air, 285, boat 236). Boat observations were much better for determining species (8 vs 2) and for censussing Ruddy Ducks (870 vs 205). (See also Comparison with other lakes, above).

TABLE 5. A comparison of waterfowl observed in the same areas of Mono Lake on an aerial survey on 21 November (**bold**) vs. a boat/ground survey (Roman) on 22-23 November.

Species	LV Ck.	Ranch Cove	Rush Ck	So Tufa	Blk Pt	Wilson Ck	Co Park	W Shore	**Total**
Waterfowl									
Canada Goose			14						**0/14**
Ross' Goose				1					**0/1**
Gadwall	2						2	4	**0/8**
American Wigeon									
Mallard	**50/4**	4							**50/8**
Cinnamon Teal									
Northern Shoveler	4								4
Northern Pintail	2								2
Green-winged Teal	5					175	**200**	**30/8**	**230/188**
Redhead									
Lesser Scaup				1					1
Bufflehead									
Unidentified ducks		5			5	**5**			**5/10**
Waterfowl*	**50/17**	**0/9**	**0/14**	**0/2**	**0/5**	**5/175**	**200/2**	**30/12**	**285/236**
Ruddy Duck	**100/30**	**5/20**	**100/10**	**0/300**	**0/280**	**0/30**	**0/20**	**0/180**	**205/870**
Total	150/47	5/29	100/24	0/302	0/285	5/175	200/22	30/192	490/1106

Banding and migration studies

In 2001 we banded 3 Canada Geese (molting adults), 18 Ruddy Ducks, 1 Shoveler, and 48 Gadwall (19 adults, 28 juveniles, 1 unknown) to learn more about the movements of waterfowl breeding or molting at Mono Lake. As of 3 December 2001, there have been four recoveries from hunter kills (Fig. 6).

A Gadwall banded as a local juvenile in 2000 returned in 2001. This was the first evidence that at least some local birds return to their natal area.

FIGURE 6. Band recoveries of birds banded at Mono Lake in 2001. Solid lines are Gadwalls, dashed lines are Canada Geese.

Disease, mortality

Gadwalls at Mono Lake suffer from severe necrosis of the feet. The condition can range in severity from minor holes or loss of tissue on the margins of the webs to the loss of entire toes. It develops in ducklings as young as three weeks old and is present in virtually all locally-produced birds. (Jehl 2001; Appendix V). It also occurs in adults, which may be reinfected when they return to the lake (Fig. 7). We are studying its etiology in conjunction with wildlife veterinarians.

Species of waterbirds that are not adapted to highly saline lakes suffer disproportionate mortality if they land at Mono Lake (Jehl, Auk 105:97-101, 1988). On 31 October, I captured three Western Grebes that were unable to dive proficiently. These were near starvation because they could not cope with the lack of food and physiological stress in salt lakes. I released them on Grant Lake (fresh water, fish populations).

Controlled burning

The Recovery Plan called for burning marsh vegetation on the south and east sides of the lake. Two areas were burned, one in 1995 and one in 1998. During no aerial or boat survey, did I encounter any waterfowl in or near either area in 2001. This requirement needs to be reconsidered (see Kruse and Bowen, J. Wildl. Manage. 60:233-246, 1996), as the areas to be burned are so flat that removal of vegetation will not create ponds that might attract ducks. Furthermore, regrowth is rapid, making any vegetational changes transitory. And even if some benefits were realized, they would be lost as the lake rises.

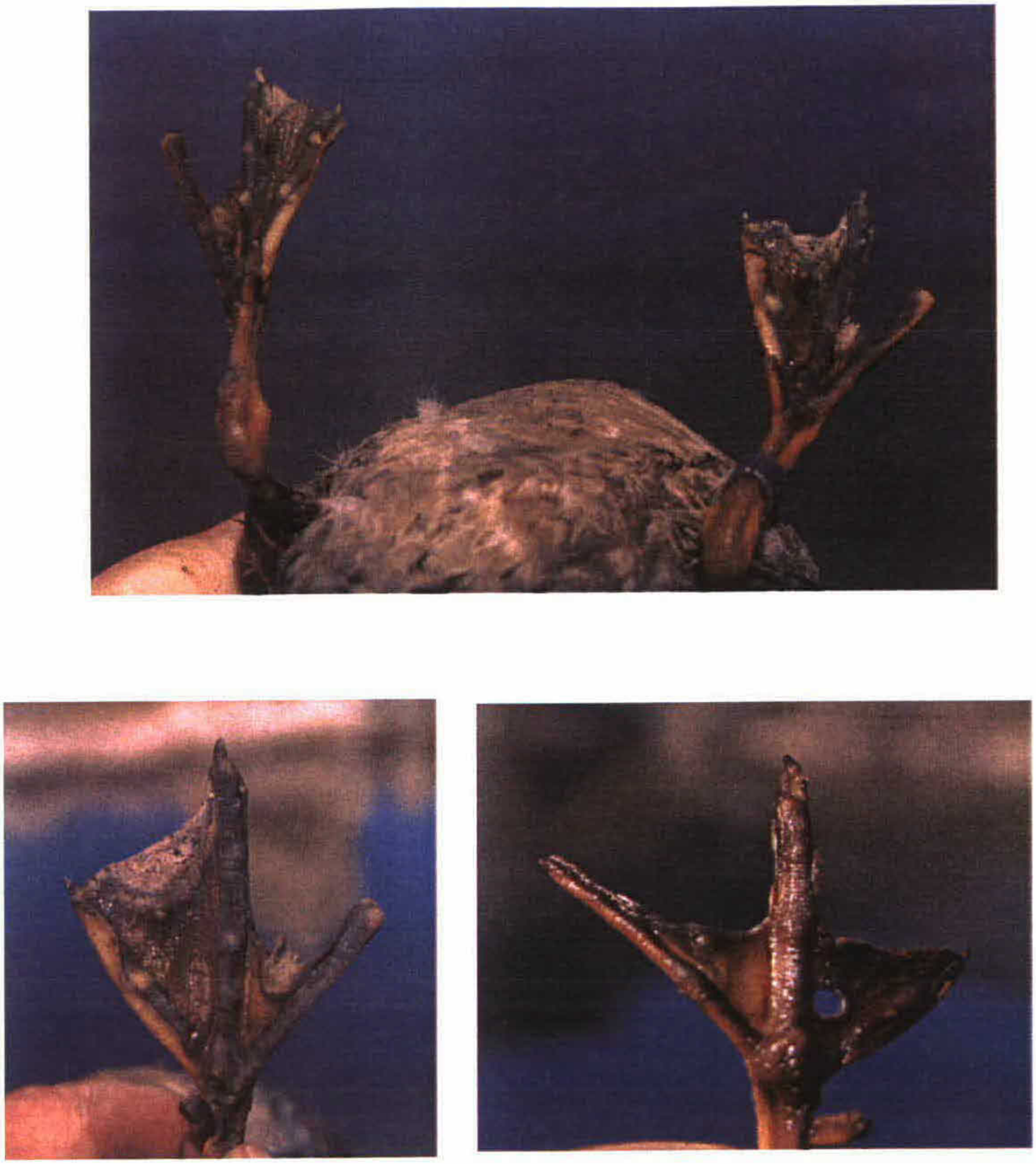


FIGURE 7. Necrotic feet of adult male Gadwalls at Mono Lake, CA, October 2001.

Time budgets

Because waterfowl are highly mobile, easily frightened, and frequently disturbed at Mono Lake, classical time budget studies can rarely be carried out long enough to be meaningful (see Jehl, HSWRI Tech. Rept. 2001-311, 2001). However, useful data can be gathered on Ruddy Ducks, because they rarely fly and can be studied for long periods. In 2001 we extended previous studies of Ruddy Duck behavior by using radio-tagged birds to study movements, length of stay, and foraging behavior. A report will be submitted separately.

DISCUSSION

Census results from 1995-2001 are presented in Figure 8 to show total waterfowl, waterfowl exclusive of Ruddy Ducks, and Ruddy Ducks. Migrants were more numerous in 2001 than in previous years, due to large number of Shovelers in late September. Some other species, notably Pintail, were much less common than previously. The size and pattern of the Ruddy Duck migration, was similar to other years. The number of breeding Gadwalls, though not precisely known, was higher than in earlier years and large numbers of young were fledged.

Annual differences in the size and composition of fall flights are expected in response to production on the breeding grounds, and timing varies in response to weather conditions farther north. Data obtained locally are not adequate to clarify reasons for the annual differences observed in the Mono Basin.

How closely the number of waterfowl observed at Mono Lake corresponds to the actual number using the lake requires information on length of stay (turnover times). Some information is derived from banding studies.

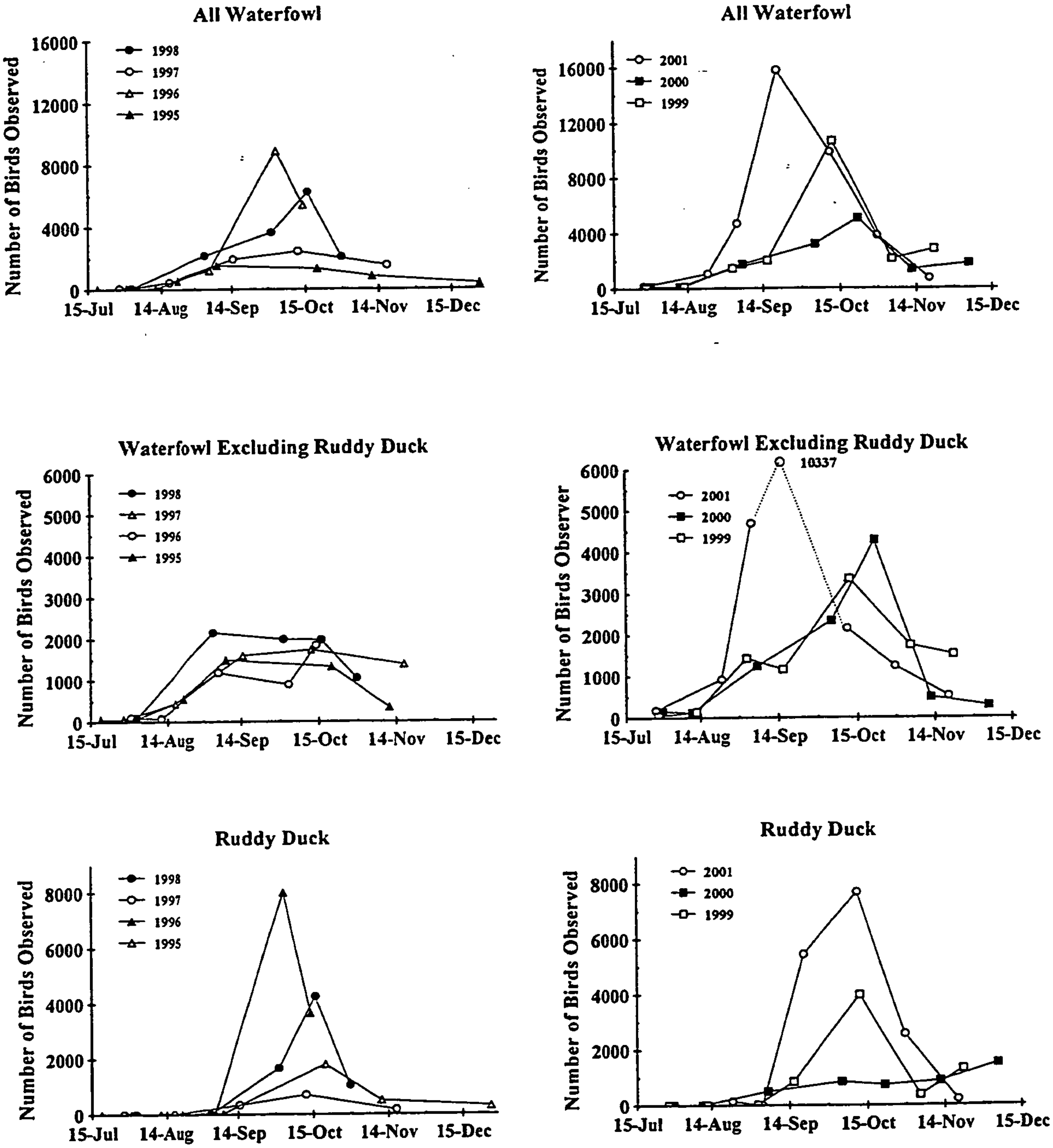


FIGURE 8. Waterfowl censuses at Mono Lake from 1995 through 2001.

Except for one date (22 September), for which the data are uncertain because of extensive movements, the Sammann's Springs area attracted few migrating ducks in 2001. This continued a trend noted in 2000. It was also essentially ignored by nesting ducks, migrating Wilson's and Red-necked phalaropes, and staging Eared Grebes, which can usually be found there by the thousands in late summer and fall. The South Shore also attracted few ducks, because the several freshwater ponds had dried by early summer, leaving no suitable habitat, except for a small area on Pond 1.

Since 1995, the surface elevation of Mono Lake has ranged over a difference of about 8 feet, from about 6377.0' in 1995 to 6384.7' in 1999-2000. It is not evident that this change in level and in associated lakeshore habitats has been reflected in any consistent change in the numbers of waterfowl observed.

Acknowledgments

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Appendix I.

Table 1. Results of shoreline censuses of waterfowl and other aquatic birds at Mono Lake, CA, 2001.

Table 2. Results of waterfowl censuses at freshwater ponds on the north shore of Mono Lake, CA, 2001.

APPENDIX I

TABLE 1. Results of shoreline censuses of waterfowl and other aquatic birds at Mono Lake, CA, 2001.

Waterfowl at Mono Lake, CA   Date: 25-26 May 2001   Survey: Boat   Observers: J. Jehl, B. White

Species	LV Ck.	Ranch Cove	Rush Ck	So Tufa	So Shore	Sammann's	Warm Sp	NE Shore	Blk PT E	Blk Pt	Wilson Ck	Mill Ck	Co Park	W Shore	Other	Total	Comments
date	25	25	26	26	26	26	26	26	26	26	26	26	26	26	26		
Waterfowl																	
Canada Goose											2					2	
Gadwall	8	5	6		49	77	70			2	5	5		8	2	237[c]	
American Wigeon																	
Mallard	30	1 ♂	4 ♂		14	2	8							6		65	
Cinnamon Teal			1								4					5	
Northern Shoveler																	
Northern Pintail							10				2					12	
Green-winged Teal																	
Redhead		2 ♂														2	
Lesser Scaup																	
Bufflehead																	
Unidentified ducks							2			0	3	10		0		15	
TOTAL Waterfowl*	38[a]	8	11[a]	ND	63	79[b] ⟷	90[b]	0	0	2	16	15	ND	14	2	338	
Ruddy Duck	2										5			2	2	11	Over half of Ruddies cannot fly
Other Species																	
White-faced Ibis							4									4	
American Coot			1		3	1										5	
Wilson's Phalarope			2													2	

* Excluding Ruddy Duck

[a] All in creek

[b] Considerable movement of birds from Sammann's to Warm Springs. Some duplication is inevitable.

[c] Maximum count. See footnote b.

APPENDIX I, Table 1.

Waterfowl at Mono Lake, CA   Date: 4-5 July 2001   Survey: Boat   Observers J. Jehl, B. White

Species	LV Ck.	Ranch Cove	Rush Ck	So Tufa	So Shore	Sammann's	Warm Sp	NE Shore	Blk PT E	Blk Pt	Wilson / Mill Ck	Co Park	W Shore	Other	Total	Comments
date	4	4	4	5	5	5	5	5	4	4	4	4	4			
Waterfowl																
Canada Goose		6 (3banded)			5								6		17	Moving, max. count ±12
Gadwall	4(1br[a])	2	20		3(3br[b])						220(2br[c])	1(br[d])			≈250	250-300
American Wigeon			1♂								10				11	
Mallard	1	1♀	25		1						75				103	
Cinnamon Teal			2		20										22	
Northern Shoveler															0	
Northern Pintail	1				3										4	
Green-winged Teal											4				4	
Redhead	1♂										5				6	
Lesser Scaup															0	
Bufflehead															0	
Common Merganser			1												1	
Unidentified ducks		1								2	2				5	
TOTAL Waterfowl*	7	10	49	0	32	0	0	0	0	2	316	1	6	0	423	
Ruddy Duck															0	

* Excluding Ruddy Duck

[a] Brood of 6-7 at day 3.

[b] Brood of 32 at day 10.

[c] One brood of 12 at day 4, one brood of 10 at day 10.

[d] Brood of 10 at day 10.

APPENDIX I, Table 1.

Waterfowl at Mono Lake, CA Date: 28-30 July 2001 Survey: Boat Observers: J. Jehl, J. Hite

Species	LV Ck.	Ranch Cove	Rush Ck	So Tufa	So Shore	Sammann's	Warm Sp	NE Shore	Blk Pt E	Blk Pt	Wilson Ck	Mill Ck	Co Park	W Shore	Other	Total	Comments
date	28	28	28	29	29	29	29	30	30	30	30	30	30	30			
Waterfowl																	
Canada Goose											22					22	
Gadwall		5 +B	8 +B		30 +12B	4 +B					40 +B			7B		87	
American Wigeon																	
Mallard					20	6					4					30	
Cinnamon Teal					1											1	
Northern Shoveler					4	20										24	
Northern Pintail					1 +B							6				7	
Green-winged Teal		2			3	2					2					9	
Redhead																	
Lesser Scaup																	
Bufflehead																	
Unidentified ducks		2														2	
TOTAL Waterfowl*	0	9	8	0	59	32	0	0	0	0	68	6	0	0	0	182	
Ruddy Duck																0	
Other Species																	
American Coot												1				1	

* Excluding Ruddy Duck

W Shore: All 7 broods near point off Tioga Lodge.

Ranch Cove: 8 broods; 4 totaling 40 young (creche), weighing up to 600 g; one brood of 2 @ 5oo g; 3 broods totaling 30 young. Total @ 72 young.

Sammann's: one brood of 7, banded @ 525 g.

South Shore: Brood of about 7 young at Slimy Spr. At Pond 1 @ 140 Gadwall, including about 120 young, from 60 to 600 +g.
Estimate 12 broods. Also 1 brood of Pintail with seven one week old young.

NB. On 30 July at 15:00 Pond 1 held: Gadwall 62 (ad + yg), Cinnamon Teal 4, Shoveler 2, Mallard 2, Long-billed Dowitcher 1, Black-bellied Plover 1, Coot 1.
Broods could not be broken down

APPENDIX I, Table 1.

Waterfowl at Mono Lake, CA — Date: 24 -25 August 2001 — Survey: Boat (NE Shore to Mill Ck on the 25th) — Observers: J. Jehl, D. House

Species	LV Ck	Ranch Cove	Rush Ck	So Tufa	So Shore	Sammann's	Warm Sp	NE Shore	Blk Pt E	Blk Pt	Wilson Ck	Mill Ck	Co Park	W Shore	Other	Total
date	24	24	24	24	24	24	24	25	25	25	25	25	24	24		
Waterfowl																
Canada Goose																
Gadwall	2 + B	2 + B			5						30 + B		6	30 + B		75
American Wigeon																
Mallard	15	49			60	6					10		5	8		153
Cinnamon Teal	3				20						75		15	5		118
Northern Shoveler	2			8	15	160					190		10			385
Northern Pintail					4	2			6		10		1			23
Green-winged Teal	20				40						30		15	10		115
Redhead																
Lesser Scaup																
Bufflehead																
Unidentified ducks	10	1			8	20				0				20		59
TOTAL Waterfowl*	52	52	0	8	152	188	0	0	6	0	345		52	73	0	928
Ruddy Duck									120						22	142

* Excluding Ruddy Duck

LVC: brood of seven @ 550-650 g

Ranch Cove: two broods of five, one of five, one of nine (440-660 g)

Rush Ck: empty, people camping

APPENDIX I, [illegible]1.

Waterfowl at Mono Lake, CA   Date: 5 September 2001   Survey: Aerial   Observers: J. Hite, P. DeWitt

Species	LV Ck.	Ranch Cove	Rush Ck	So Tufa	So Shore	Sammann's	Warm Sp	NE Shore	Blk Pt E	Blk Pt	Wilson Ck	Mill Ck	Co Park	W Shore	Other	Total
Waterfowl																
Canada Goose																
Gadwall	7				200		5		20		500			80		812
American Wigeon																
Mallard					300						500			100		900
Cinnamon Teal											100	30	10			140
Northern Shoveler					200	100			80		800					1180
Northern Pintail											100	2				102
Green-winged Teal						50							10			60
Redhead																
Lesser Scaup																
Bufflehead																
Unidentified ducks					400	100					1000					1500
TOTAL Waterfowl*	7	0	0	0	1100	250	5	0	100	0	3000	32	20	180	0	4694
Ruddy Duck									5							5
Other Species																
American Avocet				10	80	30	2		500	900			30	120		1672
White-faced Ibis							1									1
Long-billed Curlew										5						5

* Excluding Ruddy Duck

APPENDIX I, [illegible] 1.

Waterfowl at Mono Lake, CA   Date: 21-22 September 2001   Survey: Boat   Observers: J. Jehl, B. Johnson

Species	LV Ck.	Ranch Cove	Rush Ck	So Tufa	So Shore	Sammann's	Warm Sp	NE Shore	Blk Pt E	Blk Pt	Wilson/ Mill Ck	Co Park	W Shore	Other	Total
date	21[a]	22	22	22	22	22	22	21	21	21	21	21	21	21	
Waterfowl															
White-fronted Goose														2	2
Canada Goose															
Gadwall	10	6											40		56
American Wigeon												40			40
Mallard	20	6	100								400		200		726
Cinnamon Teal	20											50			70
Northern Shoveler	2		200			5000				3	4500	250			6500-10,000[b] (8800)
Northern Pintail	2												1		3
Green-winged Teal	20	30	100								100		150		400
Redhead															
Lesser Scaup															
Bufflehead															
Unidentified ducks						200				0		40		0	240
TOTAL Waterfowl*	74	42	400	0	0	5200	0	0	0	3	5000	380	391	2	8037-10,307[b]
Ruddy Duck		400	200		40		250	2000	1000	500	400	10	600	50	5450
Other Species															
American Avocet	1	40							10						51
Sabine's Gull		2	2												4

* Excluding Ruddy Duck

[a] Census at Lee Vining Creek 23 September: Mallard -10, Green-winged Teal -5, American Coot -12

[b] On 22 September (one day after this census) there were about 6500 ducks at Wilson/Mill Creek, of which 90% were Shovelers; not clear if these had been flushed from Sammann's Spring earlier in day; lakewide total ≈ 6500-10,000 Shovelers.

APPENDIX I, Table 1.

Waterfowl at Mono Lake, CA Date: 11 October 2001 Survey: Aerial Observers: J. Jehl, P. DeWitt

Species	LV Ck.	Ranch Cove	Rush Ck	So Tufa	So Shore	Sammann's	Warm Sp	NE Shore	Blk Pt E	Blk Pt	Wilson Ck	Mill Ck	Co Park	W Shore	Other	Total
Waterfowl																
Canada Goose								[1]								
Gadwall																
American Wigeon																
Mallard			+					+			+					
Cinnamon Teal																
Northern Shoveler									[500]		+					
Northern Pintail																
Green-winged Teal			+						[200]		+		50			50
Redhead																
Lesser Scaup																
Bufflehead																
Unidentified ducks			50		15[a]	100	30		40		500					735
TOTAL Waterfowl*	0	0	50	0	15[a]	100	30	0	40	0	500	0	50	0	0	785
Ruddy Duck	60	300							5100[b]				50	900	500	6910
Other Species																
Great Blue Heron	2															2
American Avocet						50±			[1]							50+

* Excluding Ruddy Duck , + = present

Numbers seen from shore later in the day [in brackets] not included in totals

[a] All on Pond 1

[b] Mostly over rocks between Black Point and landbridge. Counts are minimun due to confusion with grebes

APPENDIX I, Table 1.

Waterfowl at Mono Lake, CA   Date: 12-13 October 2001   Survey: Boat   Observers: J. Jehl

Species	LV Ck.	Ranch Cove	Rush Ck	So Tufa	So Shore	Sammann's	Warm Sp	NE Shore	Blk Pt E	Blk Pt	Wilson Ck	Mill Ck	Co Park	W Shore	Other	Total
Date	12	12	12	12	13	13	13	13	12	12	12	12	12	12		
Waterfowl																
Canada Goose						1										1
Gadwall		2	10													12
American Wigeon																
Mallard		6	500			65							+			571+
Cinnamon Teal																
Northern Shoveler			750										+			750+
Northern Pintail																
Green-winged Teal			100			60							+			160+
Redhead																
Lesser Scaup																
Bufflehead																
Unidentified ducks		20	200			10	10		400	10			20			670
TOTAL Waterfowl*	0	28	1560	0	0	136	10	0	400	10	0	0	20	0	0	**2164**
Ruddy Duck	2	450	200	40	400	200		0	5000+	400	50		250	400	300	7692+
Other Species																
White Pelican					1											1
American Coot						1			1							2
Sabine's Gull**	2		1										2			5

* Excluding Ruddy Duck

** All juveniles

APPENDIX I, Table 1.

Waterfowl at Mono Lake, CA   Date: 31October 2001   Survey: Boat   Observer J. Jehl

Species	LV Ck.	Ranch Cove	Rush Ck	So Tufa	So Shore	Sammann's	Warm Sp	NE Shore	Blk Pt E	Blk Pt	Wilson Ck/ Mill Ck	Co Park	W Shore	Other	Total
Waterfowl															
Canada Goose															
Brant														1	1
Gadwall														1	1
American Wigeon															
Mallard	5		150	3		30					100		20		308
Cinnamon Teal															
Northern Shoveler	75	10	20								400				505
Northern Pintail	2					2					4				8
Green-winged Teal	2	30		2		30					200		100		364
Redhead															
Lesser Scaup	2														2
Bufflehead															
Unidentified ducks	3	10	30						10	1				3	57
TOTAL Waterfowl*	89	50	200	5	0	62	0	0	10	1	704[a]	0	120	5	1246
Ruddy Duck		60		100	50	100	20	50	400	500	400	300	500	100	2580
Other Species															
Double-crested Cormorant		1													1
Western Grebe			1						1			1			3[b]
American Coot		20													20
Bonaparte's Gull			4												4

* Excluding Ruddy Duck

[a] 98% of birds at Wilson Creek

[b] Three Western Grebes captured; all unable to dive well; released on Grant Lake

APPENDIX I, Table 1.

Waterfowl at Mono Lake, CA   Date: 21 November 2001   Survey: Aerial   Observers: J. Jehl, P. DeWitt

Species	LV Ck.	Ranch Cove	Rush Ck	So Tufa	So Shore	Sammann's	Warm Sp	NE Shore	Blk Pt E	Blk Pt	Wilson Ck/ Mill Ck	Co Park	W Shore	Other	Total
Waterfowl															
Canada Goose															
White-fronted Goose									3						3
Gadwall															
American Wigeon							1	3							4
Mallard	50						30		20						100
Cinnamon Teal															
Northern Shoveler															
Northern Pintail						10									10
Green-winged Teal						40	1					200	30		271
Redhead															
Lesser Scaup															
Bufflehead															
Unidentified ducks					24				20		5				49
TOTAL Waterfowl*	50	0	0	0	24	50	32	3	43	0	5	200	30	0	437
Ruddy Duck	100	5	100												205
Other Species															
American Avocet													6		6
California Gull				10	3		8		100	1					122

* Excluding Ruddy Duck

Grebes are gone. Few Ruddies (good count)

APPENDIX I, Table 1.

Waterfowl at Mono Lake, CA   Date: 22-23 November 2001   Survey: Boat (incomplete)   Observers J. Jehl, D. Jehl

Species	LV Ck.	Ranch Cove	Rush Ck	So Tufa	So Shore	Sammann's	Warm Sp	NE Shore	Blk Pt E	Blk Pt	Wilson Ck/ Mill Cr	Co Park	W Shore	Other	Total	Comments
date	23	23	23	23	22					23	23	23	23			
Waterfowl																
Canada Goose			14												14	
Ross' Goose				1											1	
Gadwall	2											2*	4		8	* cripples
American Wigeon																
Mallard	4	4													8	
Cinnamon Teal																
Northern Shoveler	4														4	
Northern Pintail	2														2	
Green-winged Teal	5										175		8		188	
Redhead																
Lesser Scaup				1											1	
Bufflehead																
Unidentified ducks		5								5					10	
TOTAL Waterfowl*	17	9	14	2	see below	ND	ND	ND	ND	5	175	2	12	0	236	
Ruddy Duck	30	20	10	300						280	30	20	180	10	880	

* Excluding Ruddy Duck

Shore based observations on 22 November: South Shore Pond 1: Mallard, 16; Bufflehead, 2; Ruddy Duck, 2

APPENDIX I

TABLE 2. Results of waterfowl censuses at freshwater ponds on the north shore of Mono Lake, CA, 2001.

Date: 26 May 2001

Time: 1400-1500 Observer(s): J. Jehl, B. White

	Dechambeau Ponds					County Ponds		Other	Total
Species	1	2	3	4	5	1	2		
Waterfowl									
Canada Goose						2 + 3y			2
Gadwall	2 (1pr)	2 (1pr)					2 (1pr)		6
American Wigeon									
Mallard									
Cinnamon Teal				4					4
Northern Shoveler									
Northern Pintail									
Green-winged Teal									
Redhead									
Lesser Scaup									
Bufflehead									
Unidentified ducks									
TOTAL Waterfowl*	2	2	0	4	0	2	2	0	12
Ruddy Duck									
Other Species									
Snowy Egret				1					1
American Coot			4	12					16
Black-necked Stilt				3					3
California Gull						300			300

* Excluding Ruddy Duck

APPENDIX I, Table 2.

Waterfowl at freshwater ponds. Date: 3 July 2001

Time: 1800 Observer(s): J. Jehl, B. White

	Dechambeau Ponds					Co Ponds		Other	Total
Species	1	2	3	4	5	1	2		
Waterfowl									
Canada Goose									
Gadwall			1+11y[a]	1+9y[a]			2		4
American Wigeon									
Mallard									
Blue-winged Teal				2(♂,♀)			4(2pr)		6
Cinnamon Teal							15		15
Northern Shoveler									
Northern Pintail									
Green-winged Teal									
Redhead									
Lesser Scaup									
Bufflehead									
Unidentified ducks									
TOTAL Waterfowl*	0	0	1+B	3+B	0	0	21	0	25
Ruddy Duck									
Other Species									
Black-crowned Night Heron							1		1
Osprey							1		1
American Coot	2+3y	2+2B	1						5+
Greater Yellowlegs							2	2	4
California Gull							200	200	400
Yellow-headed Blackbird	50-100								50-100

* Excluding Ruddy Duck

[a] Ducks @ 5 days on pond 3, 2 days on pond 4

American Coot broods on pond 2: one 5 small, one 4 larger

APPENDIX I, Table 2.

Waterfowl at freshwater ponds.

Date: 28 July 2001

Time: 1630-1830 Observer(s): J. Jehl

	Dechambeau Ponds					Co Ponds		Other	Total
Species	1	2	3	4	5	1	2		
Waterfowl									
Canada Goose									
Gadwall			3 +B			1 +B	9 +B		13
American Wigeon									
Mallard									
Cinnamon Teal							6		6
Northern Shoveler							3		3
Northern Pintail							1 +B		1
Green-winged Teal									
Redhead									
Lesser Scaup									
Bufflehead									
Unidentified ducks									
TOTAL Waterfowl*	0	0	3	0	0	1	19	0	23
Ruddy Duck		1							1
Other Species									
Black-crowned Night Heron							3		3
American Coot		4 +B		3 +B		1			8
Blk-necked Stilt						17			17
California Gull						150	200		350

* Excluding Ruddy Duck

Dechambeau

Pond 2: American Coot 2 broods

Pond 3: Gadwall 3 broods: brood 1: 10 @ 600 g; brood 2: 5 @ 400 g; brood 3: 7 @ 100 g

Pond 4: American Coot 6 young

County

Pond 1: Gadwall: one brood of 9, 150-200 g

Pond 2: Gadwalll 6 broods: brood1: one of 9, 500-600 g; broods 2+3: 2 broods, total 13 yg; broods 4+5: 2 broods, total 21 small (200 g) yg; brood 6: one brood, age & size uncertain. Northern Pintail brood of 3

APPENDIX I, Table 2.

Waterfowl at freshwater ponds. Date: 23 August 2001

Time: 1700-1830 Observer(s): J.R. Jehl, J.D. Jehl

	Dechambeau Ponds					Co Ponds		Other	Total
Species	1	2	3	4	5	1	2		
Waterfowl									
Canada Goose									
Gadwall	4 + B	2 + B		3		5(?) + B			14 + B
American Wigeon									
Mallard		1		2			38		41
Cinnamon Teal									
Northern Shoveler							40		40
Northern Pintail		1		2			2		5
Green-winged Teal	2	1		2			3		8
Redhead									
Lesser Scaup									
Bufflehead									
Unidentified ducks									
TOTAL Waterfowl*	6	5	0	9	0	5	83	0	108
Ruddy Duck		1							1
Other Species									
American Coot		40	4						44
Wilson's Phalarope							70		70
Killdeer							3		3
small sandpipers							2		2

* Excluding Ruddy Duck

Pond 1: One brood, two young @ 500 g

Pond 2: Two broods totaling nine young

Co Pond 1: Several broods, including 38 adults and young

APPENDIX I, Table 2.

Waterfowl at freshwater ponds.

Date: 6 September 2001

Time: 1840-1925 Observer(s): J. Hite

	Dechambeau Ponds					Co Ponds		Other	Total
Species	1	2	3	4	5	1	2		
Waterfowl									
White-fronted Goose	1								1
Canada Goose									
Gadwall	4		2	22		11	14		53
American Wigeon									
Mallard	3	2					6		11
Blue-winged Teal				2			(2**)		2
Cinnamon Teal							6		6
Northern Shoveler									
Northern Pintail							9		9
Green-winged Teal									
Redhead									
Lesser Scaup									
Bufflehead									
Unidentified ducks									
TOTAL Waterfowl*	8	2	2	24	0	11	35	0	82
Ruddy Duck									
Other Species									
Eared Grebe						1			1
American Coot		37 (4juv)	6 (3juv)	4					47

* Excluding Ruddy Duck

** Probably same birds from Dechambeau Pond 4

APPENDIX I, Table 2.

Waterfowl at freshwater ponds. Date: 23 September 2001

Time: 1700 Observer(s): J. Jehl

	Dechambeau Ponds					Co Ponds		Other	Total
Species	1	2	3	4	5	1	2		
Waterfowl									
Canada Goose									
Gadwall						3**	4**		7
American Wigeon									
Mallard							45		45
Cinnamon Teal									
Northern Shoveler							2		2
Northern Pintail	4						1		5
Green-winged Teal							2		2
Redhead									
Lesser Scaup									
Bufflehead									
Unidentified ducks				1					1
TOTAL Waterfowl*	4	0	0	1	0	3	54	0	62
Ruddy Duck									
Other Species									
American Coot	5	32	5	10					52

* Excluding Ruddy Duck

** All juveniles (local?)

APPENDIX I, Table 2.

Waterfowl at freshwater ponds.

Date: 12 October 2001

Time: 1600-1700 Observer(s): J. Jehl

	Dechambeau Ponds					Co Ponds		Other	Total
Species	1	2	3	4	5	1	2		
Waterfowl									
Canada Goose									
Wood Duck						1			1
Gadwall						2			2
American Wigeon				2					2
Mallard				3					3
Cinnamon Teal									
Northern Shoveler									
Northern Pintail				1					1
Green-winged Teal						4			4
Redhead									
Ring-necked Duck						1			1
Lesser Scaup									
Bufflehead									
Unidentified ducks									
TOTAL Waterfowl*	0	0	0	6	0	8	0	0	14
Ruddy Duck									0
Other Species									
American Coot		32		105					137

* Excluding Ruddy Duck

APPENDIX I, Table 2.

Waterfowl at freshwater ponds.

Date: 30 October 2001

Time: 1530-1645 Observer(s): J. Jehl

	Dechambeau Ponds					Co Ponds		Other	Total
Species	1	2	3	4	5	1	2		
Waterfowl									
Canada Goose									
Gadwall							2		2
American Wigeon									
Mallard									
Cinnamon Teal									
Northern Shoveler									
Northern Pintail									
Green-winged Teal									
Redhead									
Ring-necked Duck				1♀					1
Lesser Scaup									
Bufflehead				3					3
Unidentified ducks									
TOTAL Waterfowl*	0	0	0	4	0	0	2	0	6
Ruddy Duck				7					7
Other Species									
Eared Grebe		2 juv							2 juv
American Coot	55	45	1	40					141

* Excluding Ruddy Duck

APPENDIX I, Table 2.

Waterfowl at freshwater ponds. Date: 23 November 2001

Time: 1530-1630 Observer(s): J. Jehl

	Dechambeau Ponds					Co Ponds		Other	Total
Species	1	2	3	4	5	1	2		
Waterfowl									
Canada Goose									
Ross' Goose	2								2
Gadwall									
American Wigeon									
Mallard									
Cinnamon Teal									
Northern Shoveler									
Northern Pintail									
Green-winged Teal									
Redhead									
Ring-necked Duck				1					1
Lesser Scaup									
Bufflehead									
Unidentified ducks									
TOTAL Waterfowl*	2	0	0	1	0	0	0	0	3
Ruddy Duck				1					1
Other Species									
Eared Grebe				1		2			3
American Coot				85					85

* Excluding Ruddy Duck

Appendix II.

Common and Latin names of birds used in this report

APPENDIX II.

Common and Latin names of birds used in this report. Nomenclature follows the American Ornithologist's Union. 1998. Check-list of North American Birds, 7th ed. American Ornithologist's Union, Washington, DC.

Common Loon	*Gavia immer*
Pied-billed Grebe	*Podilymbus podiceps*
Eared Grebe	*Podiceps nigricollis*
Western Grebe	*Aechmophorus occidentalis*
Clark's Grebe	*Aechmophorus clarkii*
American White Pelican	*Pelecanus erythrorhynchos*
Double-crested Cormorant	*Phalacrocorax auritus*
Great Blue Heron	*Ardea herodias*
Cattle Egret	*Bubulcus ibis*
White-faced Ibis	*Plegadis chihi*
White-fronted Goose	*Anser albifrons*
Snow Goose	*Chen caerulescens*
Ross's Goose	*Chen rossii*
Canada Goose	*Branta canadensis*
Brant	*Branta bernicla*
Gadwall	*Anas strepera*
American Wigeon	*Anas americana*
Mallard	*Anas platyrhnchos*
Blue-winged Teal	*Anas discors*
Cinnamon Teal	*Anas cyanoptera*
Northern Shoveler	*Anas clypeata*
Northern Pintail	*Anas acuta*
Green-winged Teal	*Anas crecca*
Canvasback	*Aythya valisineria*
Redhead	*Aythya americana*
Ring-necked Duck	*Aythyacollaris*
Lesser Scaup	*Aythya affinis*
Bufflehead	*Bucephala albeola*
Common Merganser	*Mergus merganser*
Red-breasted Merganser	*Mergus serrator*
Ruddy Duck	*Oxyura jamaicensis*
American Coot	*Fulica americana*
Killdeer	*Charadrius vociferus*
Black-necked Stilt	*Himantopus himantopus*
American Avocet	*Recurvirostra americana*
Wilson's Phalarope	*Phalaropus tricolor*
Red-necked Phalarope	*Phalaropus lobatus*
California Gull	*Larus californicus*

Appendix III.

Coordinates of sectors (GPS) used in waterfowl surveys

APPENDIX III.

Coordinates determined with Garmin 45 GPS and have not been confirmed by other methods.

Area	Coordinates Start	Coordinates End	Description
1 Lee Vining	37°58'859" 119°07'028"	37°58'301" 119°05'829"	400 m E of DWP dock to N end of Lee Vining Tufa
2 Ranch Cove	37°58'301" 119°05'829"	37°57'322" 119°03'915"	N end of Lee Vining Tufa to Tufa formation on E corner of Ranch Cove
3 Rush Creek	37°57'322" 119°03'915"	37°56'079" 119°02'357"	Tufa formation on E corner of Ranch Cove to base of Rush Creek Delta
4 South Tufa	37°56'079" 119°02'357"	37°56'860" 118°59'811"	Base of Rush Creek Delta to Monument Rock
5 South Shore	37°56'860" 118°59'811"	37°56'287" 118°59'172"	Monument Rock to large tufa in lake
6 Sammann's Springs	37°56'287" 118°59'172"	37°59'059" 118°55'278"	Large tufa in lake to eastern shore of lake beyond Sammann's Spring tufa grove (SE corner of lake)
7 Warm Springs	37°59'059" 118°55'278"	38°02'824" 118°55'711"	Eastern shore of lake beyond Samman's Spring tufa grove (SE corner of lake) to end of continuous marsh vegetation
8 NE Shore	38°02'824" 118°55'711"	38°04'394" 118°59'730"	End of marsh, west along barren beach to start of vegetation
9 Black Point East	38°04'394" 118°59'730"	38°02'311" 119°03'784"	Start of marsh vegetation to SW corner of land bridge
10 Black Point	38°02'311" 119°03'784"	38°00'973" 119°06'939"	All of Black Point from SW corner of land bridge to NW corner near Wilson Creek

Area	Coordinates Start	Coordinates End	Description
11 Wilson Creek	38°00'973" 119°06'939"	38°00'956" 119°07'260"	West base of Black Point to mid way between Wilson-Mill Creek mouth
12 Mill Creek	38°00'956" 119°07'260"	38°00'810" 119°07'789"	Mid way between Wilson-Mill Creek mouth to middle of Old Mill Creek Delta
13 County Park	38°00'810" 119°07'789"	38°00'638" 119°08'828"	Old Mill Creek Delta, west past Danberg Beach to Mono Inn
14 West Shore	38°00'638" 119°08'828"	37°58'859" 119°07'028"	Mono Inn along W Shore, then east to 400 m west of LADWP boat launch

Appendix IV.

Photos of waterfowl habitat

FIGURE 1. Gadwall broods at Pond 1, South Shore, 30 July 2001.

FIGURE 2. Pond 3, South Shore, 30 July 2001. Already very low; this and other ponds on the South Shore dried by August, thus providing no habitat for migrating waterfowl.

FIGURE 3. Gadwall and American Coots at Dechambeau 2: August 2001

FIGURE 4. Shoreline at Sammann's Spring, late September 2001.

FIGURE 5. Marsh habitat just inland from shore, Sammann's Spring, late September 2001.

FIGURE 6. Marsh habitat, Sammann's Spring, late September 2001. The areas away from the shoreline are dried out and provide no habitat for waterfowl.

FIGURE 7. Shoreline and marsh habitat east of Black Point attracted small numbers of waterfowl in autumn 2001.

FIGURE 8. Pools and marshes at the Wilson Creek mouth provide the best waterfowl habitat at Mono Lake.

FIGURE 9. Pools and marshes at the Wilson Creek mouth.

FIGURE 10. Pools and marshes at the Wilson Creek mouth.

FIGURE 11. Brushy areas adjacent to meadows at Wilson Creek mouth are used by nesting Gadwalls.

FIGURE 12. Two American Coots off the mouth of Mill Creek. Thick brush comes to the shore and provides little habitat for waterfowl.

FIGURE 13. Mouth of Mill Creek, showing the paucity of waterfowl habitat.

FIGURE 14. Shoreline east of mouth of Mill Creek.

FIGURE 15. Mouth of Rush Creek, 23 November 2001.

FIGURE 16. Mouth of Rush Creek, 23 November 2001.

Appendix V.

Foot damage in Gadwalls at Mono Lake, California

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FOOT DAMAGE IN GADWALLS AT MONO LAKE, CALIFORNIA

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Abstract.—Gadwalls (*Anas strepera*) hatched at Mono Lake, California, exhibit two types of severe foot damage, one manifested by the formation of hard white nodules on the plantar surface, the other by necrosis, which results in deformed and eroded webs and, in extreme cases, loss of podotheca and toes. Unknown in Gadwalls elsewhere or in other waterbirds at Mono Lake, these conditions may be evident in ducklings only three weeks old. They presumably stem from infections incurred after ducklings abrade their feet on the harsh lake substrate. The causative agent(s) is unknown.

DAÑO EN LA PATA DE INDIVIDUOS DE *ANAS STREPERA* EN EL LAGO MONO, CALIFORNIA

Sinopsis.—Individuos de *Anas strepera* nacidos en el Lago Mono, California, exhiben dos tipos de daños en sus patas. Uno se manifiesta mediante la formación de nódulos blancos y duros en la planta de la pata y el otro por necrosis que da origen a deformación y daño a las membranas interdigitales y en casos extremos a la podoteca y los dedos. Esta condición, que no es conocida en otras poblaciones de esta especie o en otras aves del lago, es evidente en patitos de tres semanas de edad. Es probable que la infección ocurra en las aves jovenes que se raspan las patas con el duro sustrato del lago. Se desconoce el agente causante de la condición.

Mono Lake is a terminal and hypersaline lake at the western edge of the Great Basin in east-central California. Over the past two decades surface salinity has varied from about 70–95 g/l, whereas alkalinity has been stable at pH 9.8–9.9. Several species of ducks may nest around the periphery, but the only regular breeder is the Gadwall (*Anas strepera*), with a population of 20–30 pairs. A few (usually < 20) nonbreeding adults also summer and molt there in most years. Nesting takes place in late May–early August. As soon as the ducklings hatch, mostly in the first days of July, they are immediately led to the lake, and by the time they are several days old can be seen swimming along the margins. As the ducklings grow, broods wander farther from shore, and spend most of their time swimming on the open lake, returning sporadically to forage in the marshes. Fledging takes 50–53 days (Loekmoen et al. 1990; Leschack et al. 1997) and by mid September nearly all local birds have departed.

From 1985 through 1999, as part of a study of local waterfowl, I banded 254 Gadwalls (*Anas strepera*), which included 79 adults (mostly females attending broods), 172 locally hatched non-flying birds, and 3 of unknown age. I captured ducks by pursuing them with a small boat, which caused them to skitter over the surface for up to 1 km. When nearly overtaken, they can dive for 30 sec or so and swim vigorously under water, relying on wings and feet for propulsion. They are caught in a dip-net as they surface to breathe (Jehl and Yochem 1987).

The majority showed evidence of damaged feet, which took two forms, both of which were typically found in the same individual. The first was an apparent gout-like or arthritic condition, which involved the development of hard, white (calcareous?) nodules in joints on the plantar surface and to a lesser extent in any area where the foot might contact the substrate. The second and more dramatic was necrosis that resulted in the loss of tissue from the webs or toes. The onset of necrosis was signaled by the appearance of pin-head sized depigmented areas, which then eroded through the web forming 5–10 mm circular holes. In extreme cases, these expanded further to involve the loss of the entire webbing, distal phalanges, or even entire toes. Involvement was confined to the foot and in only one case extended as far proximal as the tarsometatarsal joint.

In 1996–1999, I documented the conditions in as many birds as possible using the following index:

0. Normal.
1. Slight. Eroded edges and or tiny holes in webbing; calcareous areas small (Fig. 1A).
2. Moderate. Moderate holes in webbing and/or edges deeply eroded; calcareous areas conspicuous (Fig. 1B).
3. Severe. Large holes in webbing, or webbing entirely gone; toes or entire foot may be deformed; in some cases distal phalanges or entire toe missing. Extreme cases also exhibited calcareous areas, but I rarely noted their extent because other damage was so extensive (Fig. 1C–F).

A few birds received intermediate rankings.

RESULTS

Twenty-three of 32 adults (72%) had evidence of necrosis, which in 17 (53%) cases was Moderate or Severe (Fig. 2). In ducklings the incidence was greater (83 of 96, 86%), but the severity was less (85 cases [88%] Normal to Moderate), because the condition is progressive. I observed damage in ducklings as young as 20 d old (body mass 250 g; age estimated from growth curves in Lokemoen et al. [1990]; these were the smallest I was able to catch without disrupting broods), and it was usually Slight to Moderate by Day 40–50 (Fig. 3). Damage varied among broods but was rather consistent within broods; in some broods young had only Slight (0–1) damage, whereas in others of the same age it might average Moderate to Severe (2–3). That active necrosis was not limited to ducklings was indicated by some adults that were sloughing large areas of podotheca, including one that had large gas blisters on gangrenous feet (Fig. 1E, F).

At my request, veterinarians from SeaWorld, San Diego, examined a severely crippled adult from Mono Lake, along with tissue samples from several flightless juveniles. Tissue samples included the nodules as well as early (depigmented areas on webs) to advanced sites of damage (the borders of holes, sloughing tissue). Lesions in the adult did not appear to be active. Two types of bacteria (*Staphylococcus epidermidis, S. sciuri*) and a probable dermatophyte (fungus) were cultured from a swab and biopsy of one foot. These organisms are considered part of the normal skin flora;

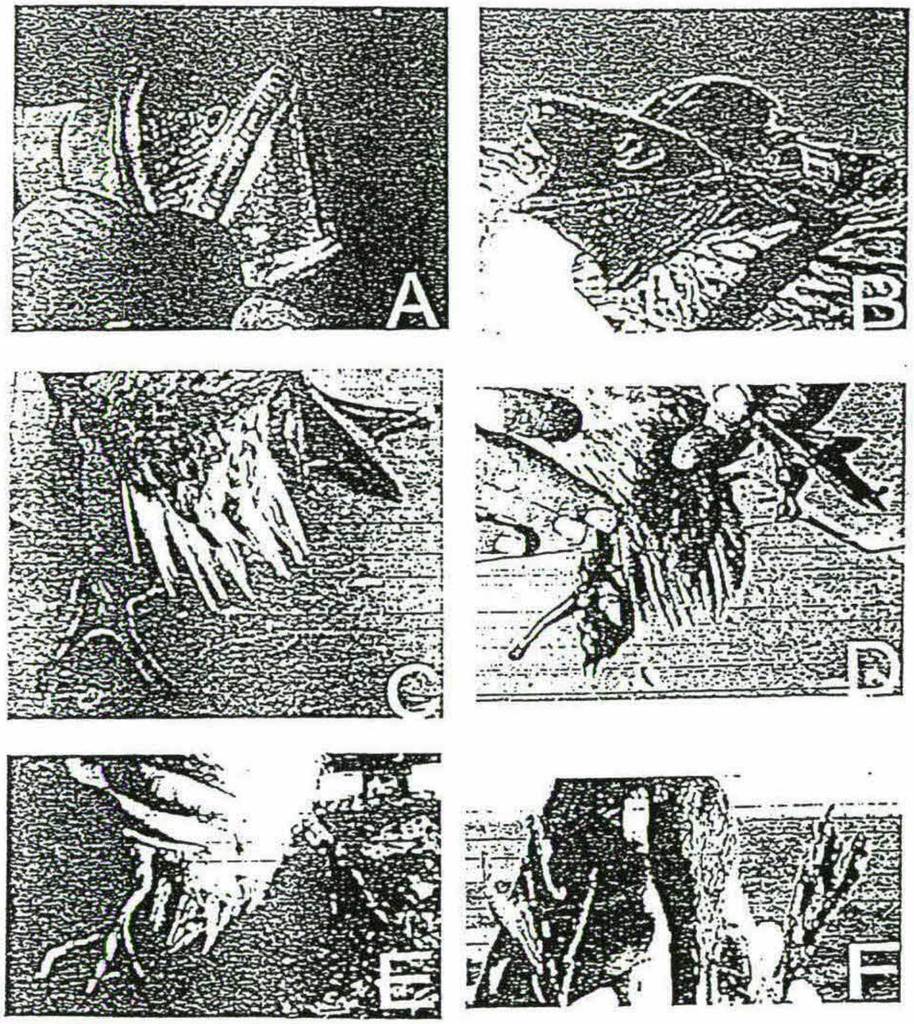

FIGURE 1. Categories of foot damage in Gadwalls. A. Slight: juvenile, 569 g, captured 29 July 1997. B. Moderate: juvenile, August 1997. C, D. Severe: adults. E, F. Dorsal and ventral views of an adult with Severe damage and gangrenous gas blisters, October 1998.

the bacteria can act as secondary invaders in damaged or diseased tissue. An inflammation on one foot was diagnosed as a granuloma. Histopathological studies of the young indicated non-specific inflammation; bacteria were present but could not identified (P. Yochem, pers. comm.).

DISCUSSION

The Gadwall is probably the commonest dabbling duck breeding at alkaline lakes in western North America. Although the species has been intensively studied in many areas (Leschack et al. 1997), individuals with

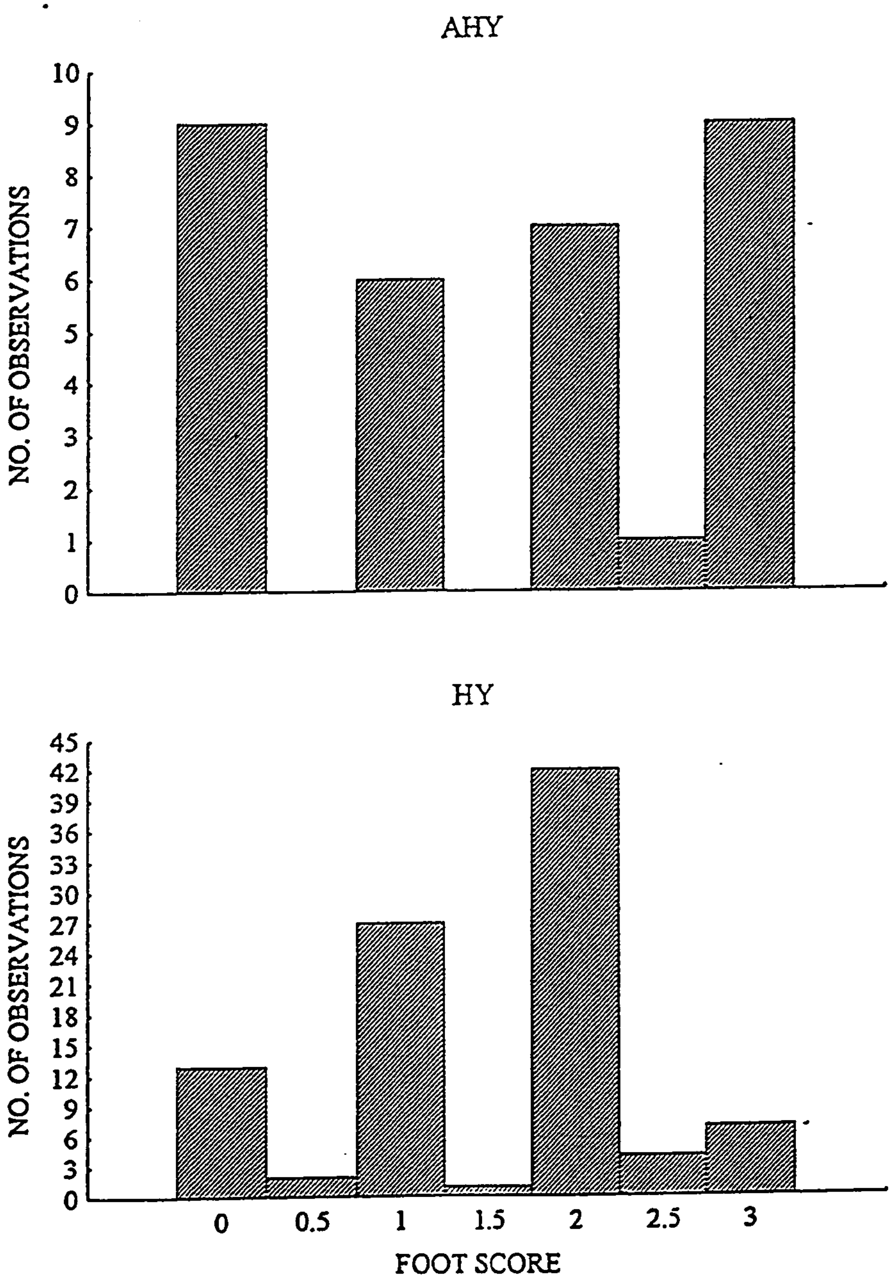

FIGURE 2. Frequency of necrotic foot conditions in Gadwalls at Mono Lake, California, 1996–1999. Top: adults (AHY). Bottom: ducklings (HY). Foot scores are defined in text.

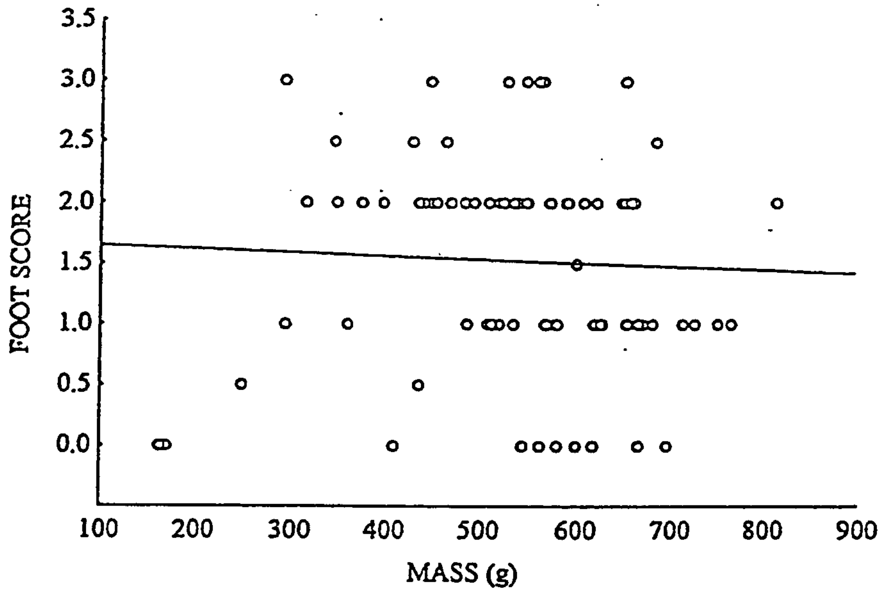

FIGURE 3. Relationship between body mass and severity of foot damage in Gadwall ducklings from Mono Lake, California. The approximate ages of birds are: 200 g = 20 days; 400 g = 40 days; 600 g = 60 days. Mass at fledging averages 597 g in females and 640 g in males (from Lokemoen et al. 1990). Foot scores are defined in text.

necrotic feet are evidently unknown except at Mono Lake. For example, the condition has not been noted at Summer Lake, Oregon (salinity < 10 g/l, pH 8.5–10.5), Malheur National Wildlife Refuge, Oregon, and Klamath National Wildlife Refuge, California/Oregon, where hundreds to several thousand young are banded annually (M. St. Louis, G. Ivey, and D. Mauser, respectively, pers. comm.). It also is not known from North Dakota, a major breeding area (G. Krapu, pers. comm.). Other common waterbirds at Mono Lake show no affliction, even though their feet are also submerged continuously for months (Jehl 1988; Jehl et al. 1999; Jehl, unpubl. data). These include California Gulls (*Larus californicus*), which nest there (thousands of young examined and banded over two decades), and staging Eared Grebes (*Podiceps nigricollis*, > 5000 examined; Jehl et al. 1999), Wilson's Phalaropes (*Phalaropus tricolor*, > 600 examined) and Ruddy Ducks (*Oxyura jamaicensis* > 100 examined).

How foot damage arises is unknown. It may be that necrosis originates when tiny ducklings scrape their tender feet as they shuffle to forage in shallow water, thus creating a route for infection. The Mono Lake bottom is highly abrasive, being composed largely of pumice sand, bits of lava and tufa fragments. (Young gulls also forage in the lake, but by swimming in water too deep to make contact with the substrate.) The infectious agent (if any) remains to be determined. Preliminary studies did not indicate active bacterial infection; viral and mycological studies have not been attempted (P. Yochem, pers. comm.). The harsh chemistry of Mono Lake, per se, is unlikely to be involved directly, except to impair healing, because the condition is not found at other lakes with similar environments. The origin of the white nodules is also enigmatic. The fact that it occurs along with necrosis in most individuals suggests a common origin.

Although foot damage can be severe, it does not appear to be debilitating, at least while birds are at Mono Lake. Broods are large (9–12), as is typical of Gadwalls, which indicates that maternal condition is good; even females with severely damaged feet fledge young. And if swimming and diving ability is impaired, it is not noticeable in birds pursued for banding, which remain highly mobile and challenging to capture. In addition, the survival of young seems good, as no banded ducklings have been found dead locally, and juveniles with foot damage have survived for at least three years (Jehl, unpubl. data). However, the greater severity of damage in adults shows that damage is progressive, and one may assume that the loss of entire webs or toes, or the presence of active gangrene, impairs survivorship.

Indications that these forms of foot damage are evidently endemic to and originates in ducklings at Mono Lake means that they can be regarded as a characteristic local marker. No locally banded Gadwalls have yet been recaptured at Mono Lake, but the high frequency of foot damage among adults of either sex suggests that the breeding population includes many locally produced birds. Although female dabbling ducks are more highly philopatric than males, the summer occurrence of damaged adult males suggests that some of them also return to Mono Lake to breed or molt.

ACKNOWLEDGMENTS

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TIME BUDGETS OF RUDDY DUCKS AT MONO LAKE, CALIFORNIA

Elizabeth Johnson and Joseph R. Jehl, Jr.

Hubbs-Sea World Research Institute
Technical Report 2002-331
February 2002

NOTICE

ABSTRACT

The Ruddy Duck is the dominant duck at Mono Lake. We studied its time-activity budgets from 21 September to 9 November 2001. This species was chosen because unlike other ducks, individuals are resident for long periods, rarely fly, confine their activities to a relatively small area, and stay near shore much of the day. This allows for extensive and unbiased observations from shore.

Using focal animal and scan sampling techniques, we found that Ruddy Ducks spend 47% of the day sleeping, 32% foraging, and 21% in other activities (swimming, preening, and loafing). They forage throughout the day but effort is greatest in early morning and late afternoon. This suggested that the ducks might spend appreciable time foraging after dark, which we confirmed (39%) using radiotelemetry. Our data on diurnal budgets are similar to those gathered at Mono Lake in 1997 and can be considered as representative of current conditions. Our data on nocturnal behavior are similar to the only previous study of this species.

INTRODUCTION

The desirability of re-establishing waterfowl populations to Mono Lake, CA is an integral part of the Restoration Plan adopted by the State Water Quality Resources Board. Time-activity budgets provide a technique to quantify behavior and help understand how species rely on particular habitats. Unfortunately, this technique cannot be applied to the majority of waterfowl species inhabiting Mono Lake because they are easily disturbed and fly out of sight. As a result, opportunities for observations can be so haphazard and unpredictable as to render studies of little value (Jehl 2001).

This is not the case for the Ruddy Duck (*Oxyura jamaicensis*), which is the dominant waterfowl species in fall. It uses the lake as a molting and staging area before migrating to wintering grounds. Peak numbers of four to five thousand occur in mid-October. The Ruddy Duck is amenable for study because some individuals remain at the lake for weeks or longer, during which period they rarely fly. Further, because most of their distribution and all of their foraging occurs within 100 m of shore in water less than 3 m deep, it is possible to make extensive and unbiased observations from land.

As part of a detailed study, we made observations and calculated time-activity budgets for Ruddy Ducks from 21 September to 10 November 2001. We compared our findings with the diurnal data collected at Mono Lake in autumn 1997 (Lin 1998) and nocturnal data from South Carolina in winter 1985-1986 (Bergan 1989).

METHODS

We used two methods to obtain time-activity budgets. Focal animal sampling involves choosing a duck at random and observing and recording all of its behaviors during a 30-minute period. Duration of each behavior was averaged by hour to determine the time spent in any activity. Scan sampling involves scanning a flock of birds and recording the percent of birds engaged in any particular activity at that time. Four scans were taken per hour of daylight and the results averaged to provide the amount of time spent performing each behavior. These two techniques provide independent measures of activity and in theory should agree. In actuality, scan sampling will underestimate foraging time because individuals that are underwater will be overlooked, whereas focal animal sampling may underestimate or overestimate activities performed infrequently (Altmann 1974).

We used focal animal sampling to provide information on dive times and foraging bout lengths. Dive times and interdive intervals were averaged for each period of the day (early morning, late morning, early afternoon, and late afternoon). We used median (rather than mean) duration to determine bout lengths because many bouts extended beyond the observational period and their entire duration was not determinable. Because a single individual could not be followed continuously, the number of foraging bouts per day could not be determined. To test for a seasonal shift in bout lengths, we calculated the mean for each month. Bouts that extended beyond the observational period were not used to determine the mean. Significant differences between months for both dive times and bout lengths were tested using t-tests.

To expand on previous data from Mono Lake we used radiotelemetry to examine nocturnal activity. On 21 – 22 September 2001 we fitted four male Ruddy Ducks with radio transmitters that were attached with both an adhesive and a harness to the back between the wings (Fig. 1). The transmitters had an expected range of 3 miles and a life of 3 months. We released the ducks at the Old Marina in the west end of the lake because this is a common place for Ruddy ducks to congregate and forage and because they can be detected from the adjacent highway. We also monitored the signals from two other high vantage points (Black Point, on the north side of Mono Lake, Panum Crater, on the south side) in case the ducks moved to other areas of the lake. This group of ducks reacted adversely to the transmitters, and we were unable to detect signals from three of them after a few hours. We suspect that they were able to remove the harnesses. We did receive a signal from the fourth transmitter. However, it was transmitting 100 m inshore near the County Park, the duck evidently having been killed and carried there by a predator.

FIGURE 1. Ruddy Ducks with radio transmitters attached.

Subsequently, on 12 October, we attached radio transmitters to four additional ducks (two males and two females) using adhesive only. They were again released at the Old Marina and the signals monitored from the same vantage points. These birds behaved normally and we were able to monitor their frequencies day and night through 14 October. The radios transmitted only in air, any interruption in the signal would indicate that the duck was submerged and, therefore, diving. Although radiotelemetry does not provide information on other activities, it allows us to estimate the degree to which Ruddy Ducks forage at night during this season. Details of observational periods are presented in Appendix 1.

Stomach contents of five Ruddy Ducks were examined to determine prey.

RESULTS

Ruddy Ducks are present at Mono Lake through most of the fall, arriving in late August and remaining into late November or December. They feed exclusively by underwater foraging in shallow areas, principally where the substrate is rocky and provides habitat for brine flies (J. R. Jehl, Jr. unpubl.). As a result, they are present near the shoreline for most of the day, feeding within 100 m of shoreline and then retreating offshore to rest.

Diurnal activity

The focal animal and scan sample techniques provided similar results (Fig. 2-5). Averaged over two months, the major daytime activities were sleeping (47%) and foraging (32%) (Fig. 6 and 7). Other activities (swimming, preening, and loafing) made up about 20% of the day and < 1% of time was spent alert, flying, or wing flapping. Any activity might be carried out at any time of the day. Feeding and resting were inversely related with some temporal variation. Foraging effort increased in the last few hours of daylight, 1600-1800 hours, and the first few hours of daylight (0600-0700 hours). In general, temporal differences in other activities are unlikely to be significant, considering the high variability within each hour.

Figure 2. Time-activity budget based on focal animal sampling for Mono Lake, October 2001.

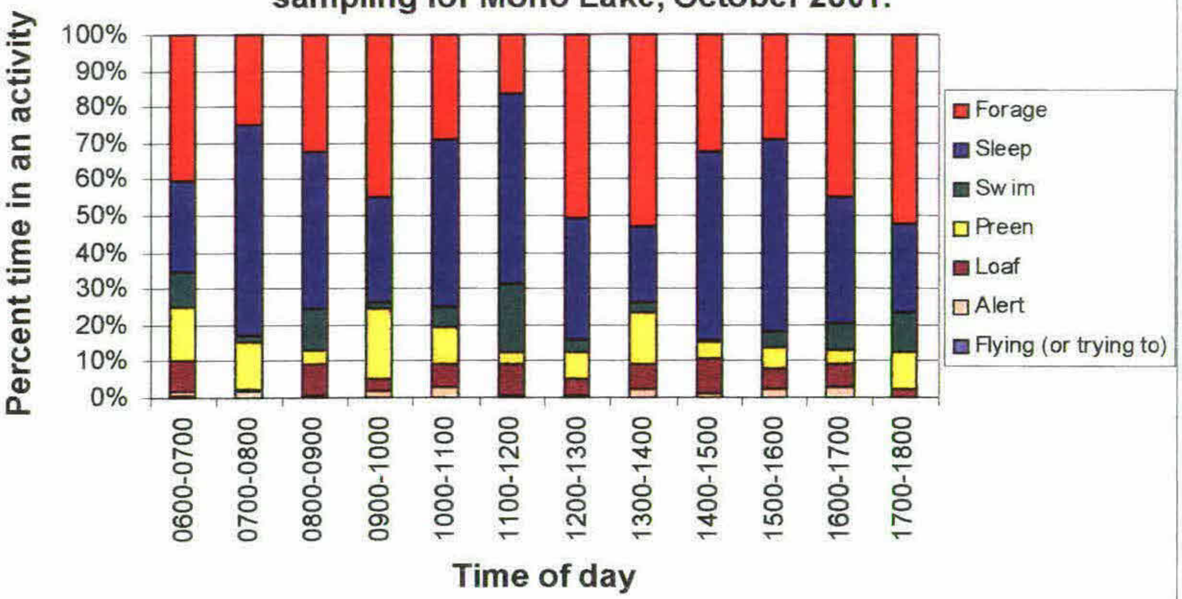
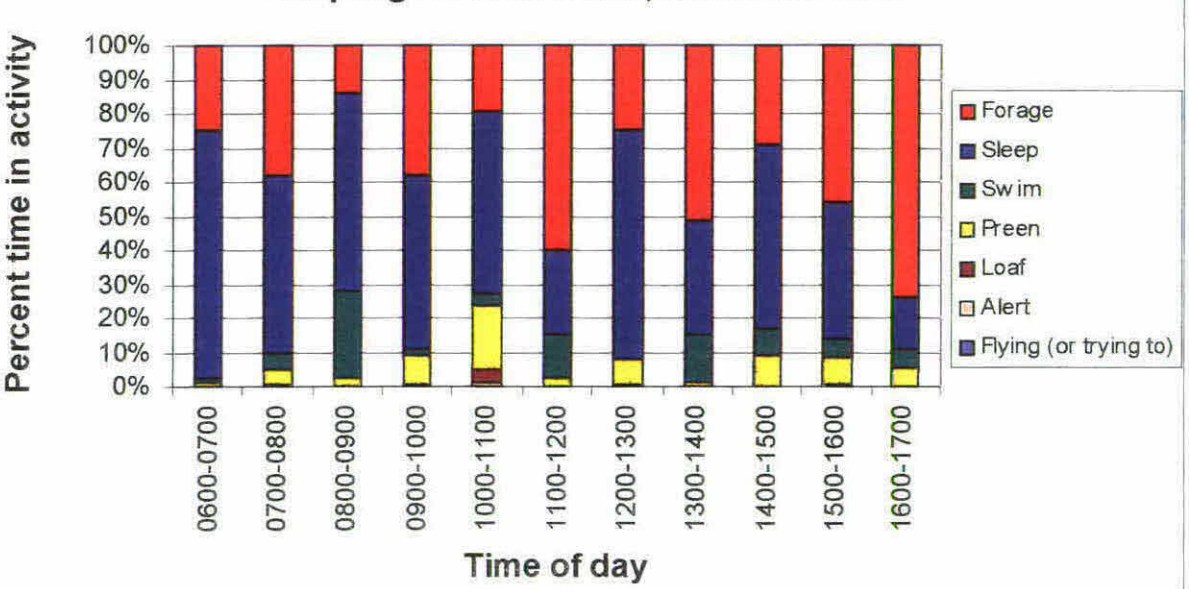


Figure 3. Time-activity budget based on focal animal sampling for Mono Lake, November 2001



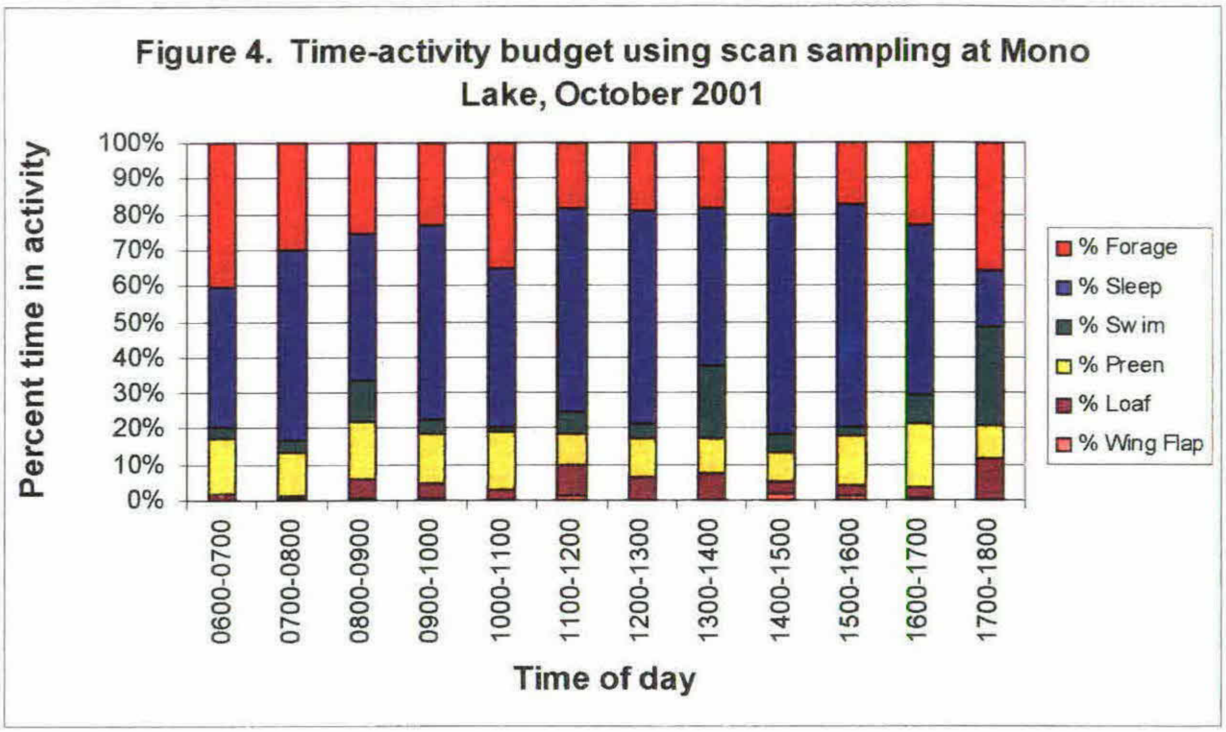


Figure 4. Time-activity budget using scan sampling at Mono Lake, October 2001
Percent time in activity
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0600-0700
0700-0800
0800-0900
0900-1000
1000-1100
1100-1200
1200-1300
1300-1400
1400-1500
1500-1600
1600-1700
1700-1800
Time of day
% Forage
% Sleep
% Sw im
% Preen
% Loaf
% Wing Flap

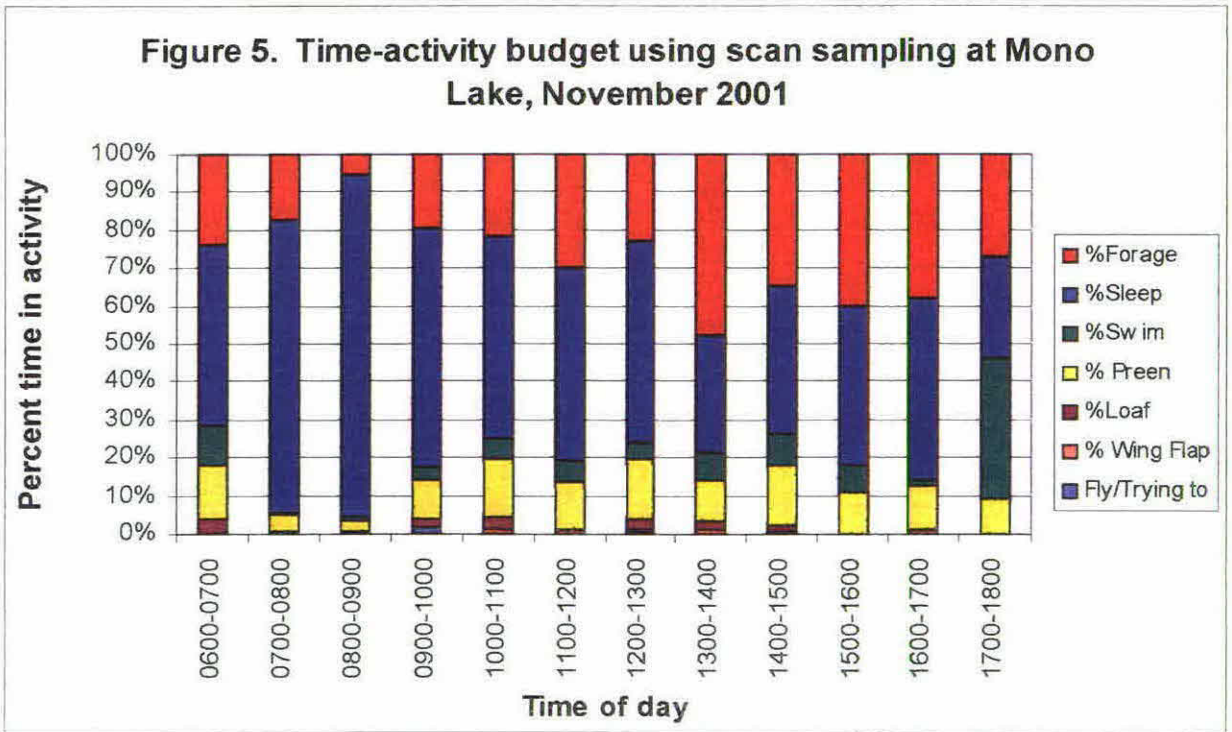


Figure 5. Time-activity budget using scan sampling at Mono Lake, November 2001
Percent time in activity
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0600-0700
0700-0800
0800-0900
0900-1000
1000-1100
1100-1200
1200-1300
1300-1400
1400-1500
1500-1600
1600-1700
1700-1800
Time of day
%Forage
%Sleep
%Sw im
% Preen
%Loaf
% Wing Flap
Fly/Trying to

Figure 6. Time-activity budget using focal animal sampling at Mono Lake, Averaged over October and November 2001

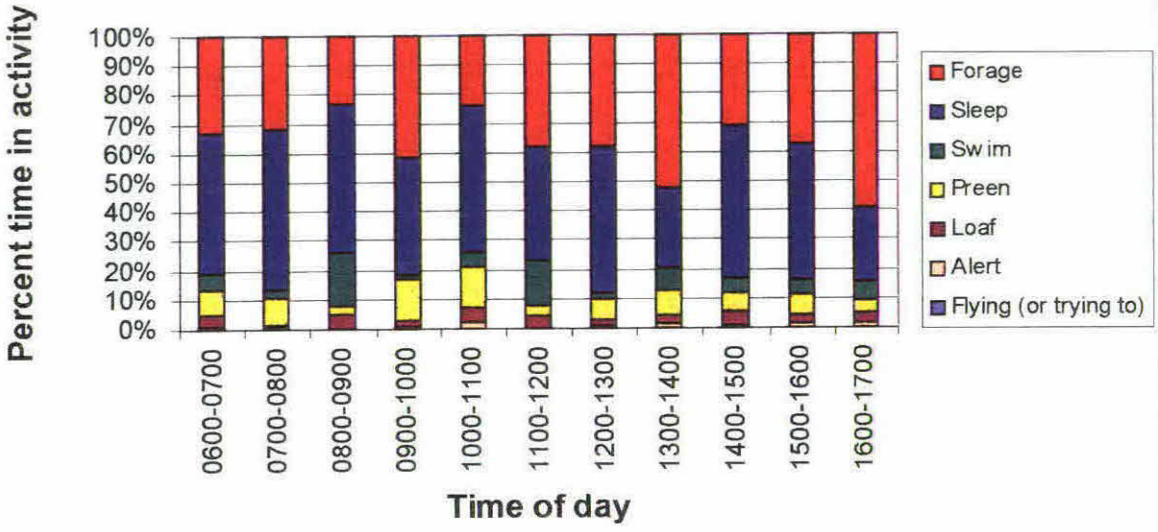
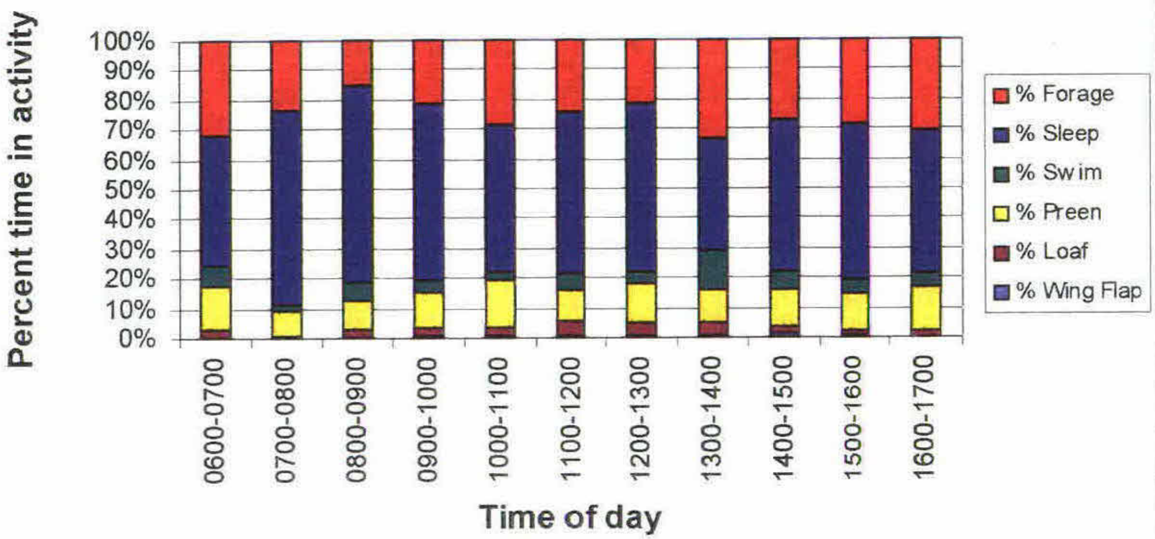


Figure 7. Time-activity budget using scan sampling at Mono Lake, Averaged over October and November 2001



We used focal animal sampling to provide further information on temporal variation in foraging (Tables 1 and 2). Dive lengths ranged from 21 to 38 seconds, with a significant increase in dive length during November ($P < 0.02$, Table 1). Interdive intervals ranged between 10 and 13 seconds with no daily or seasonal variations (Table 1). Dive bouts ranged from 20 – 40 minutes and tended to be longer in the late day and again were significantly longer in November ($P < 0.01$,Table 2).

TABLE 1. Diurnal Ruddy Duck dive times and interdive intervals, Mono Lake 2001.

Month	Time of Day	Number of birds observed	Average # of observations per bird	Average dive time (s)	Standard Error	Average interdive interval (s)	Standard Error
October	early morning (0600-0900)	9	23	25.44	1.42	12.34	0.95
	late morning (0900-1200)	6	21	29.01	1.93	12.61	1.49
	early afternoon (1200-1500)	9	25	23.80	1.93	10.42	0.56
	late afternoon (1500-1800)	6	30	26.82	1.54	11.54	0.53
November	early morning (0600-0900)	5	25	33.56	1.71	11.88	0.51
	late morning (0900-1200)	7	24	33.65	4.87	10.24	0.81
	early afternoon (1200-1500)	3	24	29.98	2.57	10.39	0.33
	late afternoon (1500-1800)	4	38	27.88	2.13	10.29	0.21

TABLE 2. Length of Ruddy Duck diurnal foraging bout, Mono Lake 2001

Month	Time of Day	Sample Size	Median forage bout (min)	Mean forage bout (min)
October	early morning (0600-0900)	8	19.5	20.1
	late morning (0900-1200)	5	20	
	early afternoon (1200-1500)	7	20	
	late afternoon (1500-1800)	6	34	
November	early morning (0600-0900)	5	33	36.7
	late morning (0900-1200)	5	23	
	early afternoon (1200-1500)	2	41	
	late afternoon (1500-1800)	4	34	

Nocturnal activity

Our data on nocturnal activity come from three of four birds released in mid-October, only one of which provided meaningful results (Table 3). Signals were received and monitored from 1825 to 2100 hours on 14 October. Two of these remained continuous, and therefore showed no indication of diving or foraging. Bird 3 (a male) had one diving bout of 48 minutes with an average dive time of 25.8 s and an average interdive interval of 8.6 s (Fig. 8). Frequencies were next monitored on 21 October, when the only signal received was from Bird 3. It was monitored on the nights of 21 and 22 October (Fig. 9 and 10). On 21 October, data were obtained from 1845 to 0615 (no data between 2200-2330), during which time there were four foraging bouts.

Figure 8. Nocturnal dive patterns of a Ruddy Duck, Mono Lake, 14 Octoer 2001.

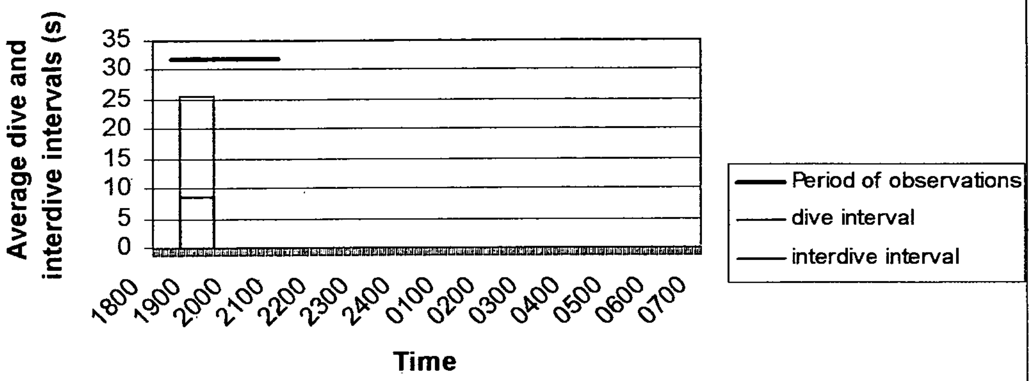


Figure 9. Nocturnal dive patterns of a Ruddy Duck, Mono lake, 21 October 2001

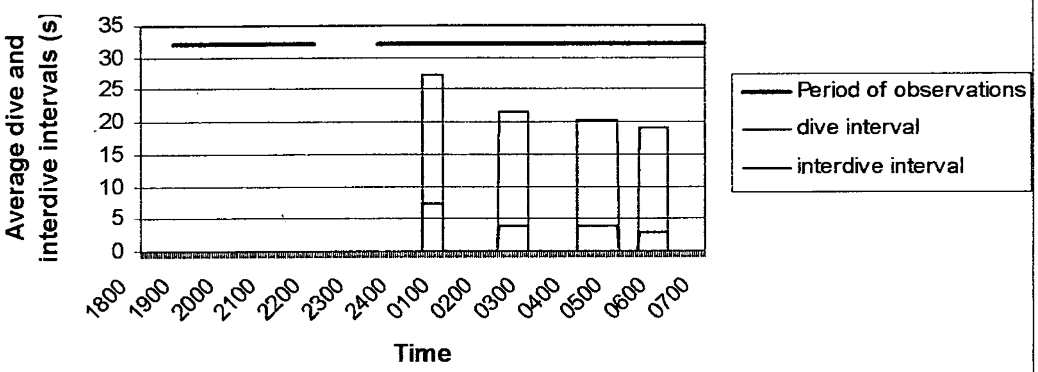


Figure 9. Nocturnal dive patterns of a Ruddy Duck, Mono lake, 21 October 2001

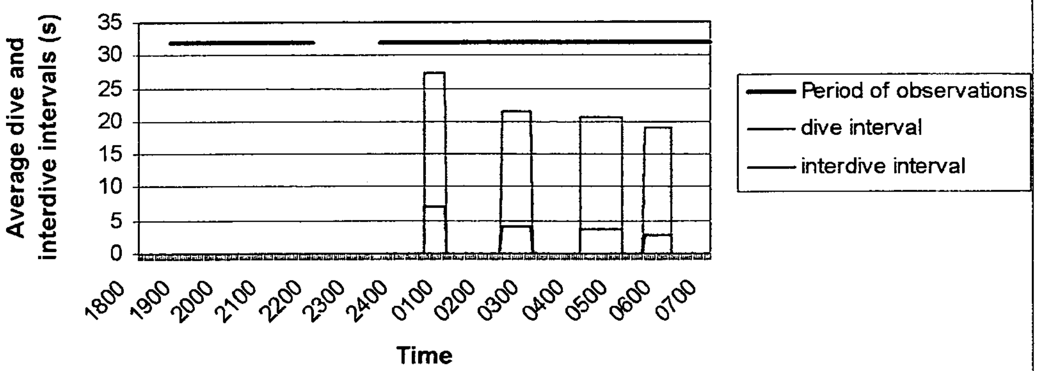


TABLE 3. Diving bout lengths and dive times for a radiotagged Ruddy Duck, Mono Lake, October 2001

14-Oct-01	**Signal**	**average dive (s)**	**average interval (s)**	**dive bout (min)**
1825-1840	Continuous			
1840-1928	Diving	25.8	8.6	48
1928-2100	Continuous			
21-Oct-01				
1845-2200	Continuous			
2200-2330	No data			
2330-2430	Continuous			
2430-0100	Diving	27.4	7.2	29
0100-0216	Continuous			
0216-0257	Diving	21.6	3.9	39
0257-0404	Continuous			
0404-0500	Diving	20.5	3.7	56
0500-0530	Continuous			
0530-0607	Diving	19.0	2.8	37
22-Oct-01				
2205-2259	Diving	22.9	5	>54
2259-2445	Continuous			
2445-0145	Diving	22.6	4.3	60
0145-0320	Continuous			
0320-0415	Diving	15.5	1.8	55
0415-0615	Continuous			
0615-0700	Diving	22.6	7.8	45

The early bouts had dives and interdive intervals similar to those obtained by day, but became shorter as the night progressed (Table 3). On 22 October (2205 to 0700) there were also four foraging bouts. Dive durations and intervals decreased over the night, then increased to daytime lengths by 0615 (Table 3). Nocturnal diving bouts were significantly longer ($P < 0.001$) than diurnal bouts, ranging from 29 – 60 minutes (Table 3). The next observations were on 8 to 10 November; no signals were detected.

Stomach contents

We examined stomachs of five Ruddy Ducks (four males and one female) collected in October. Two were empty and three contained brine fly larvae. This, and previous observations (J. R. Jehl, Jr.), indicate that Ruddy Ducks are foraging only on brine flies in the vicinity of hard substrate, such as tufa, in shallow areas of the lake.

DISCUSSION

Focal animal and scan sampling techniques showed that Ruddy Ducks spend the majority of the daytime hours sleeping and foraging (79%). Scan samples provide lower foraging efforts because this technique underestimates foraging. On the other hand, scan samples show an increase in swimming during the late daylight hours. This was not observed in the focal animal samples, perhaps because of the small sample sizes.

The results in 2001 are similar to the diurnal time-activity budgets obtained at Mono Lake in 1997, when foraging and sleeping combined made up about 70 – 85% of daytime activity (Lin 1998). Loafing, swimming and preening totaled 15 – 33%.

In this study there was a seasonal shift in foraging activity, as shown by longer dive durations and dive bout lengths from October to November. This probably reflects a decrease in prey availability over this period, because duck numbers at the lake decline. However, an increased foraging effort was not reflected in time-activity budgets. So it is possible that the increased lengths are coupled with a decrease in the number of bouts, resulting in no net change in foraging activity.

Studies in both 1997 and 2001 found that ducks became more active later in the day, as evidenced by increased time spent foraging and swimming and lengthened dive times. The reasons remain to be determined. In animals that are inactive at night, late afternoon "topping off" is not unusual. However, Ruddy Ducks forage at night, at about the same rates (Bergan et al. 1989) as during the day. In our study nocturnal activity was slightly higher (39% vs. 32%) and the duration of the dive bouts were longer during our month of nocturnal study (October). One possible explanation is that food becomes easier to obtain at night, because of changes in activity of prey. While we do not have information on circadian activity patterns in brine fly larvae (which were important prey in our samples), we suspect that if they were much more accessible after dark, duck foraging activities would peak at that time. Instead, in our small sample there was a hiatus in feeding activity between 1930 and 2400.

In the only other study of diurnal and nocturnal wintering activities, Bergan et al. (1989) used focal animal sampling. It was performed from January to April 1985 and November to March 1986 in South Carolina. They found that both male and female Ruddy ducks spend the majority of their day feeding (33-35%) and sleeping (38-42%). They also found that Rudy Ducks are quite active at night with feeding (35-38%), locomotion (37-32%), and sleeping (16-20%) as major activities. Their study, like ours, showed no seasonal variation in diurnal time-activity budgets but that Ruddy Ducks become more active late in the day and that activity continues into the night. The increased time spent foraging is accompanied by an increase in swimming and a decrease in sleeping.

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