APPENDIX D

DWORSHAK SUMMER OPERATIONS

INTRODUCTION

In accordance with the NOAA Fisheries 2000 Biological Opinion, Dworshak summer operations in 2004 consisted of drafting the reservoir from 1600 feet on June 30th to 1520 feet on September 19th and adjusting the temperature of Dworshak water releases from June 23 through September 21. To assist the Technical Management Team (TMT) in making recommendations on how to manage the cool water releases from Dworshak reservoir, the Reservoir Control Center (RCC) Water Quality Unit completed analyses that provided an estimate of how long water temperatures could be maintained at 43^{o} F and 45^{o} F and the availability of the desired temperature water throughout spill season. These analyses were submitted to the TMT at the June 23rd, June 30th ; July 7th, July 26th and August 4th meetings.

This report describes the calculations and supporting information used to develop the analyses, actual operations, final results, a comparison to the previous four years of Dworshak summer operations and conclusion.

Calculations for 2004 Dworshak Cool Water Releases

The determination of how long water could be released at temperatures of 45^{o}F or 43^{o}F was performed using the same type of mass and temperature balance calculations as those employed during 2003 Dworshak summer operations (see Appendix D of the 2003 Dissolved Gas and Water Temperature Monitoring Report at: http://www.nwd-wc.usace.army.mil/tmt/wq/tdg_and_temp/2003/ for more detailed information on the 2003 mass and temperature balance calculations.) The mass and temperature balance program was modified so the program could easily be run when flow rates varied frequently and some assumptions were modified. The modification of assumptions resulted from various lessons that were learned, which is discussed in the following section. The amounts of water needed to maintain a specific temperature were calculated and then compared with what temperature water was available. Based on the calculations described in this appendix, it was estimated that 45^{o} F water releases from Dworshak could be maintained throughout the entire summer operations, a total of 11 weeks.

These calculations used two pieces of information, which included the Dworshak reservoir temperature profiles and gross storage table figures. The Dworshak temperature profiles shown in Figure D-1 were derived from resistance thermal devices (RTDs), embedded in the face of the dam at the time of construction. The RTDs are also called fixed temperature strings. On May 19, 2004 a new floating temperature string was installed in the forebay of Dworshak dam by the buoy restriction, which is about 200 ft upstream of the dam. The floating string physically floats and collected temperature data at 0.5 m; 1.5m; 3m; 5m; 10m and multiples of 5 to 50 m and then multiples of 10 to 80m and then 100 m. Water temperatures measured at varying depths of the reservoir provided a profile of the reservoirs' thermal stratification. The profiles from the fixed temperature strings were used in these calculations and real time operations. The new floating temperature string had water temperatures that were generally slightly warmer then the fixed temperature strings, especially in the upper 10 meters. The new floating temperature string profiles are being compared against the fixed RTD temperatures profiles, which are regularly used for Dworshak operations.

Gross storage tables, which are available through the Corps' Reservoir Control Center, show the volume of water stored at the various elevations at the different projects. The gross storage information was cross-referenced with the temperature profiles to determine the volume of warm or cool water was available for temperature augmentation.

Lessons Learned from Water Temperature Calculations:

There are several lessons learned during the 2004 Dworshak summer operations that affect the COE, RCC, Water Quality Team calculations of water temperature releases from Dworshak. They are:

- In the past, the Water Quality Unit used the assumption that water is pulled into the turbines over a 40 ft water temperature range. This was a widely accepted idea that was based on the fact that the selector gates open to a 40 ft swath. Because of this assumption, water temperatures were averaged and used in the calculations. We have learned that this assumption was erroneous. According to Brian Moentenich, design engineer with the COE Portland District Hydrologic Design Center, the water flows into the turbines in a laminar manner and the temperatures should not be averaged across any vertical depth. The force the turbines excrete to pull water dramatically decreases within a short distance of the turbine intake. The affect of the idea that flow is laminar into the turbines becomes very important when only one unit is operating since model predictions can be tested against measured values. This happened during September 2004 flow augmentation.
- Water must be pulled 35ft below the surface or lower to prevent the units from cavitating.
- It is necessary to run the mass and temperature balance calculations weekly with the most current Dworshak temperature profile data available to be able to have an accurate estimate of cool water availability.
- Solar radiation and the amount of precipitation may significantly affect the water temperature profiles in the Dworshak reservoir. As a result, the mass and temperature balances findings calculated at the beginning of the summer operations changes as the reservoir temperature profiles change.
- Generally speaking, 45^{o} F water releases from Dworshak can be maintained throughout the summer operations for 11 weeks.
- It is easier for Dworshak operators to control outflow water temperatures at lower temperatures like 45^{o} F than higher temperatures like 48^{o} F or warmer. As a result it is easier to physical maintain 45^{o} F water releases for many weeks than the 47 or 48^{o} F water releases.

Actual Operations And Final Results:

The management of Dworshak outflows during the summer of 2004 was similar to operations that have occurred in recent years. In order to more fully characterize the results of this year's operations, this report will compare the operations that occurred in

2004 to the operations that occurred in the years 2000-2003. Table D-1 provides a numerical listing of dates and outflow rates from Dworkshak Reservoir for the years 2000-2004. Table D-2 provides a numerical listing of dates and outflow temperatures from Dworshak over the same time period. Outflow temperatures and flow rates for these years are depicted in graphical form in Figure D-6. Table D-3 shows the accumulative precipitation % of Normal. Figure D-4 shows Lower Granite tailwater temperatures for the years 2000 – 2004. The following is a discussion of the 2004 actual operations and the resultant Lower Granite tailwater temperatures with a five years operations comparison.

Water Release Temperatures:

The water release temperatures from Dworshak during the 2004 summer operations ranged from 42.8 to 54.5^{o}F with an average of 45.6^{o}F. Table D-2 provides the water release temperature ranges (as calculated from the maximum and minimum) and averages for the time periods between June 23 and September 21, 2004. The temperature averages varied between 42.8 to 54.5^{o}F. An average water temperature of 43.3 ^{o}F was maintained for ten days from July 26 through August 4, 2004. This was the lowest Dworshak water release temperature maintained voluntarily during the last five years Dworshak summer operations. This factor alone makes the 2004 summer operations unique.

As Table D-2 shows numerically and Figure D-6 shows graphically, an overall trend towards cooler water being released from Dworshak reservoir during summer operations is observed. The impact of this trend toward cooler Dworshak water temperature releases had the overall impact of decreasing the amount of greater than 40^{o}F water in the reservoir. Comparing the temperature profile charts can show the extent and potential significance of the decrease of greater than 40^{o}F water in the reservoir. As Figure D-1 shows that 1374ft is the lowest elevation where greater than 40^{o}F water could be found in September. In 2003, it was at 1324 ft and in 2002 it was at 1324 ft and in 2001 it was at 1399ft. Since the elevation in September at which the greater than 40^{o}F water can be found varies from 1324 to 1399 ft and the reservoir appears to “recover” by the next summer operations, the impact of lower release temperatures may depend more on environmental factors (e.g. summer inflow rates and temperatures, weather conditions, etc.) than the manner in which outflow temperatures and rates are managed during summer operations. However, due to the limited data available, further investigation and modeling is required to elicit more reliable conclusions.

Water Release Outflow:

The water outflow from Dworshak during the 2004 summer operations ranged from 4.8 to 13.7 kcfs with an average of 9.8 kcfs. Table D-1 shows the outflow ranges, (as calculated from the maximum and minimum) and averages for the time periods between June 20 and September 21, 2004. The outflows varied between 2.2 kcfs at the beginning and end of summer operations to a maximum outflow of 13.7 kcfs. The 2004 average water outflow of 9.8 kcfs is close to the five-year average of 9.7 kcfs, so it is similar to the last five years and resultant downstream water temperature is shown. The river warms as it moves downstream. This conclusion matches what is seen in Table D-3 of the accumulative precipitation, which shows that 2004 water year was 101% of normal above Ice Harbor. The same correlation can be seen in the 2001 water year. During the low water year of 2001, the average outflow was lower than the five-year average by about 2 kcfs. This matches the accumulative precipitation for 2001 water year. As Table D-3 shows, the 2001 water year's accumulative precipitation above Ice Harbor was 48% of normal.

<u>Effects of Releases on Lower Granite:</u>
Dworshak outflow and cool water releases on the Snake River can be seen in most clearly at Lower Granite tailwater and appear to diminish as the water passes through subsequent projects on the Lower Snake River. Figures D-2 and D-3 show the Dworshak outflow and cool water releases on the Lower Granite and the four Lower Snake projects, respectively. Figure D-2 shows Lower Granite tailwater temperature, the dates when changes in Dworshak outflow temperature were made and what the changes were. Dworshak releases were maintained at 45 ^{o}F from July 1 – 26; and 43 ^{o}F from July 26 to August 4, 45 ^{o}F from August 4 – 25 and 45 ^{o}F to 47 ^{o}F through the rest of spill season, which lasted until September 21st. As Figure D-2 shows Lower Granite tailwater temperatures at or below the State water quality standard of 68^{o}F most of the time, which is good by comparison to the Anatone tailwater temperature. The Anatone tailwater temperature continued to rise to a high of 75 ^{o}F on July 24. The Anatone tailwater fluctuated from 72 - 75 ^{o}F between July 15 and August 22, 2004.

The Lower Granite tailwater stayed below the State water quality standard of 68 ^{o}F most of the time, except for 10 hours as Figure D-5 shows. The other Lower Snake projects did not during July and August, as Figure D-3 shows. Figure D-3 compares the Dworshak discharge and temperature against the Lower Snake River projects tailwater temperatures in 2004. Ice Harbor had the highest tailwater temperatures, which is to be expected since it benefits the least from the Dworshak cool water releases.

Figures D-4 through D-6 show a five-year comparison from 2000 to 2004. Comparing the 2004 summer operations with the previous four years suggest that the Dworshak 43 to 45 ^{o}F cool water releases produces two effects, which are:

1. The reduction in hours of exceedance of the State water quality standard of 68 ^{o}F at Lower Granite and the extent to which the standards were exceeded;
2. Cooler Lower Granite tailwater temperatures in September

Figure D-5 contains a 10-year statistical analysis of Lower Granite tailwater temperatures with the hours of exceedance and cumulative magnitude of exceedance for 1995 through 2004. The cumulative magnitude of exceedances is calculated by multiplying the number of hours that the 68 ^{o}F temperature standard was exceeded by the number of degrees above the measured water temperature above that standard. This value provides an indication of the degree to which the temperature standard was exceeded through the entire year. As Figure D-5 shows, during the 2004 Dworshak summer operations, there were only 10 hours when the State water quality standard of 68 ^{o}F was exceeded and the cumulative magnitude of exceedance is quite low. This suggests that the 2004 Dworshak summer operations were more effective in reducing Lower Granite tailwater temperature exceedances than previous years.

Figure D-4 shows the combined effects of using Dworshak water for flow augmentation and temperature control of Lower Granite tailwater during 2000 through 2004. As Figure D-4 shows, the Dworshak outflow temperature and flow produced a combined effect of lowering the Lower Granite tailwater temperature that is somewhat consistent, except during September. The average Lower Granite tailwater temperature during September 1-15 in 2004 was 63.8^{o}F, lower than the five-year average of 65.0 ^{o}F. This may be credited to higher Dworshak outflows as well as cooler temperatures releases in September than what was done during 2000 or 2001. It should be noted that the average Dworshak water release temperatures during 2004 were the lowest in the five years, yet the Lower Granite tailwater temperatures for July and August were about average. This suggests that Lower Granite tailwater temperatures would have been higher without the 45 ^{o}F Dworshak water releases.

TABLE D-1

2000 - 2004 OUTFLOW RANGE		
2004 - Dates	**Outflow Ranges (kcfs)**	**Avg. Flow (kcfs)**
6/20/2004	1.9	1.9
6/28 - 6/30	2.2 - 3.3	2.4
6/30 - 7/6	6. 3 - 7.4	7
7/6 - 7/12	7.4 - 9.7	9.5
7/12 - 7/23	11.2 - 11.8	11.5
7/23 - 7/26	13.6 - 13.7	13.6
7/26 - 8/8	5.8 - 12.0	11.5
8/8 - 8/31	9.4 - 10.5	10.5
9/1 - 9/14	5.8 - 7.1	7
9/14 - 9/19	4.7 - 5.8	5.1
9/19 - 9/20	2.3 - 2.5	2.5
9/21/04	1.7	1.7
7/1 - 9/15	**4.8 - 13.7**	**9.8**
2003 - Dates	**Outflow Ranges (kcfs)**	**Avg. Flow (kcfs)**
6/8/03	1.8	1.8
6/9 - 7/1	1.6 - 7.5	4.4
7/2 - 7/7	2.1 - 5.3	4.5
7/7 - 7/8	7.8 - 9.6	9.4
7/8 - 7/24	7.2 - 14.2	13.7
7/24 - 8/4	4.5 - 12.4	11.9
8/4 - 8/19	8.0 - 10.4	10.1
8/20 - 9/11	5.7 - 9.5	7.2
9/11 - 9/14	2.3 - 6.1	4.7
9/15/2002	1.6	1.6
7/1 - 9/15	**1.6 - 14.2**	**9.4**
2002 - Dates	**Outflow Ranges (kcfs)**	**Avg. Flow (kcfs)**
6/11/02	1.6 - 1.9	1.7
6/12 - 7/2	3.0 - 19.8	14.2
7/2 - 7/9	7.3 - 9.6	8.5
7/9 - 8/24	8.0 - 14.1	13.5
8/25 - 8/31	10.7 - 12.5	12
9/1 - 9/10	8.4 - 10.5	10.1
9/11/02	4.0 -7.1	5.5
9/12/02	1.5 - 2.3	1.6
7/1 - 9/15	**1.5 - 19.7**	**11.9**
2001 - Dates	**Outflow Ranges (kcfs)**	**Avg. Flow (kcfs)**
6/23 - 7/1	1.6 - 1.8	1.7
7/2 - 7/5	4.9 - 5.3	5
7/5 - 7/7	6.9 - 7.6	7
7/7 - 8/28	5.1 - 10.9	10.2
8/28/01	4.7 - 4.9	4.8
8/29/2002	2.4 - 2.5	2.5
8/30/2002	1.5 - 2.4	1.6
7/1 - 9/15	**0.1 - 10.9**	**7.7**
2000 - Dates	**Outflow Ranges (kcfs)**	**Avg. Flow (kcfs)**
6/13/2000	1.5 - 1.8	1.7
6/13 - 6/22	2.1 - 5.5	4.9
6/22 - 6/26	4.8 - 7.2	6
6/27 - 6/29	3.3 - 4.9	3.9
6/30 - 7/7	4.4 - 7.0	6.6
7/8 - 8/21	11.0 - 14.4	13.1
8/21 - 8/26	5.8 - 11.1	10.6
8/26 - 8/28	8.0 - 8.7	8.5
8/29 - 8/31	3.9 - 5.9	4.2
9/1/2000	1.5 - 2.5	1.6
7/1 - 9/15	**1.5 - 14.4**	**9.6**
Five Year Average	**1.9 - 14.6**	**9.7**

TABLE D-2

2000- 2004 TEMPERATURE RANGES		
2004 - Dates	**Temperature Ranges (^{o}F)**	**Avg. Temp. (^{o}F)**
6/23 - 7/1	46.0 - 52.6	50.2
7/1 - 7/26	44.5 - 46.7	45.6
7/26 - 8/4	42.9 - 43.9	43.3
8/4 - 9/20	44.2 - 54.7	46.3
9/21/04	46.6 - 48.0	47.1
7/1 - 9/15	**42.8 - 54.5**	**45.6**
2003 - Dates	**Temperature Ranges (^{o}F)**	**Avg. Temp. (^{o}F)**
6/23 - 7/1	50.4 - 53.0	51.8
7/2 - 7/12	46.9 - 49.3	47.9
7/12 - 8/20	43.5 - 49.5	45.2
8/20 - 9/15	43.5 - 48.0	45.4
9/15/003	45.7 - 47.0	46.4
7/1 - 9/15	**43.5 - 53.1**	**45.7**
2002 - Dates	**Temperature Ranges (^{o}F)**	**Avg. Temp. (^{o}F)**
6/12 - 6/30	44.8 - 51.6	47
7/1 - 7/3	46.6 - 52.0	49.7
7/4 - 7/25	46.9 - 48.9	47.7
26-Jul	45.9 - 47.5	46.5
7/27 - 8/7	44.5 - 46.3	45.5
8/8 - 9/8	46.6 - 50.5	48.7
9/9 - 9/11	46.1 - 53.6	47.3
9/12/02	46.1 - 52.43	47.1
7/1 - 9/15	**44.4 - 53.6**	**47.8**
2001 - Dates	**Temperature Ranges (^{o}F)**	**Avg. Temp. (^{o}F)**
6/23 - 7/1	48.0 - 50.4	49.2
7/2 - 8/5	46.9 - 50.5	48.5
8/5 - 8/27	46.2 - 48.6	47.4
8/27 - 8/29	43.0 - 47.5	43.5
8/30/2001	43.0 - 44.4	43.6
7/1 - 9/15	**42.8 - 50.5**	**46.9**
2000 - Dates	**Temperature Ranges (^{o}F)**	**Avg. Temp. (^{o}F)**
6/23 - 6/30	49.3 - 55.0	52.5
7/1 - 7/10	47.7 - 49.8	48.3
7/10 - 7/14	45.3 - 48.6	47.2
7/14 - 8/29	46.6 - 53.2	48.2
8/29 - 9/1	50.4 - 52.0	51.1
9/1/2000	45.5 - 48.4	46.1
7/1 - 9/15	**45.3 - 53.4**	**48.9**
Five Year Average	**43.8 - 53.0**	**47.0**

TABLE D-3

Accumulative Precipitation % of Normal			
Year	**Grand Coulee Dam**	**The Dalles**	**Ice Harbor Dam**
2004	104	101	104
2003	80	85	89
2002	93	89	82
2001*	96	118	198
2000*	109	---	99

Normal is based on the 1971-2000 water supply year.

*Normal is based on the 1961-1990 water supply year.

FIGURE D-1
DWORSHAK TEMPERATURE PROFILES
January – October

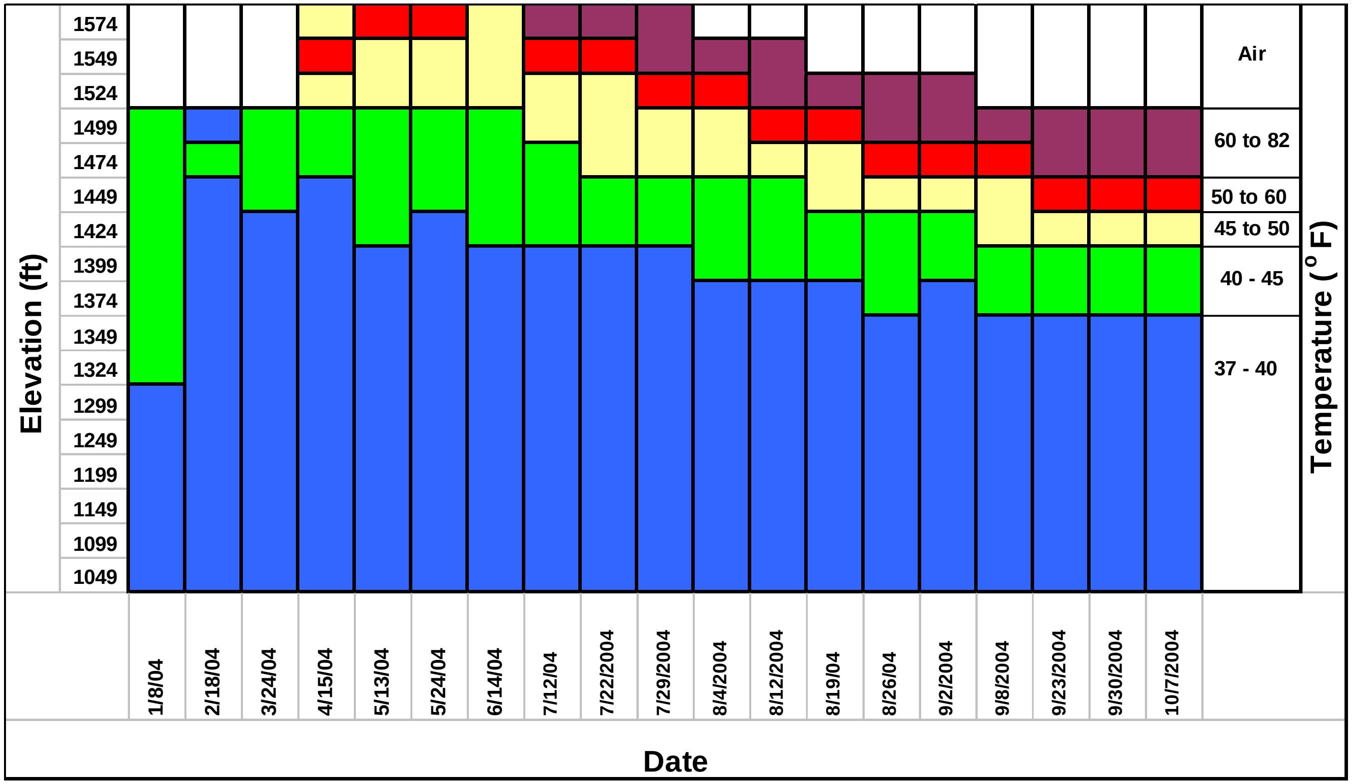


FIGURE D-2
Anatone, Lower Granite Tailwater Hourly Temperature Data

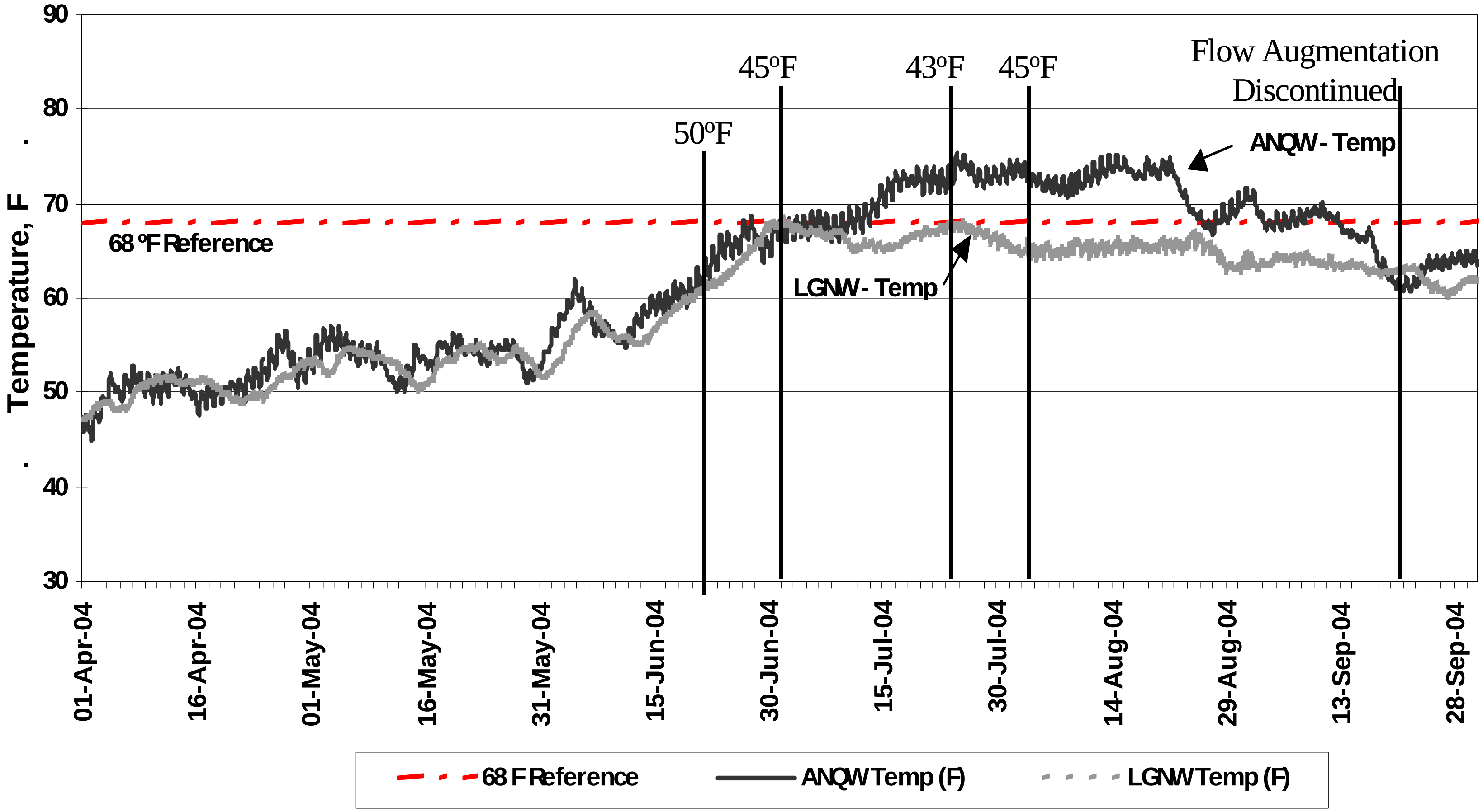
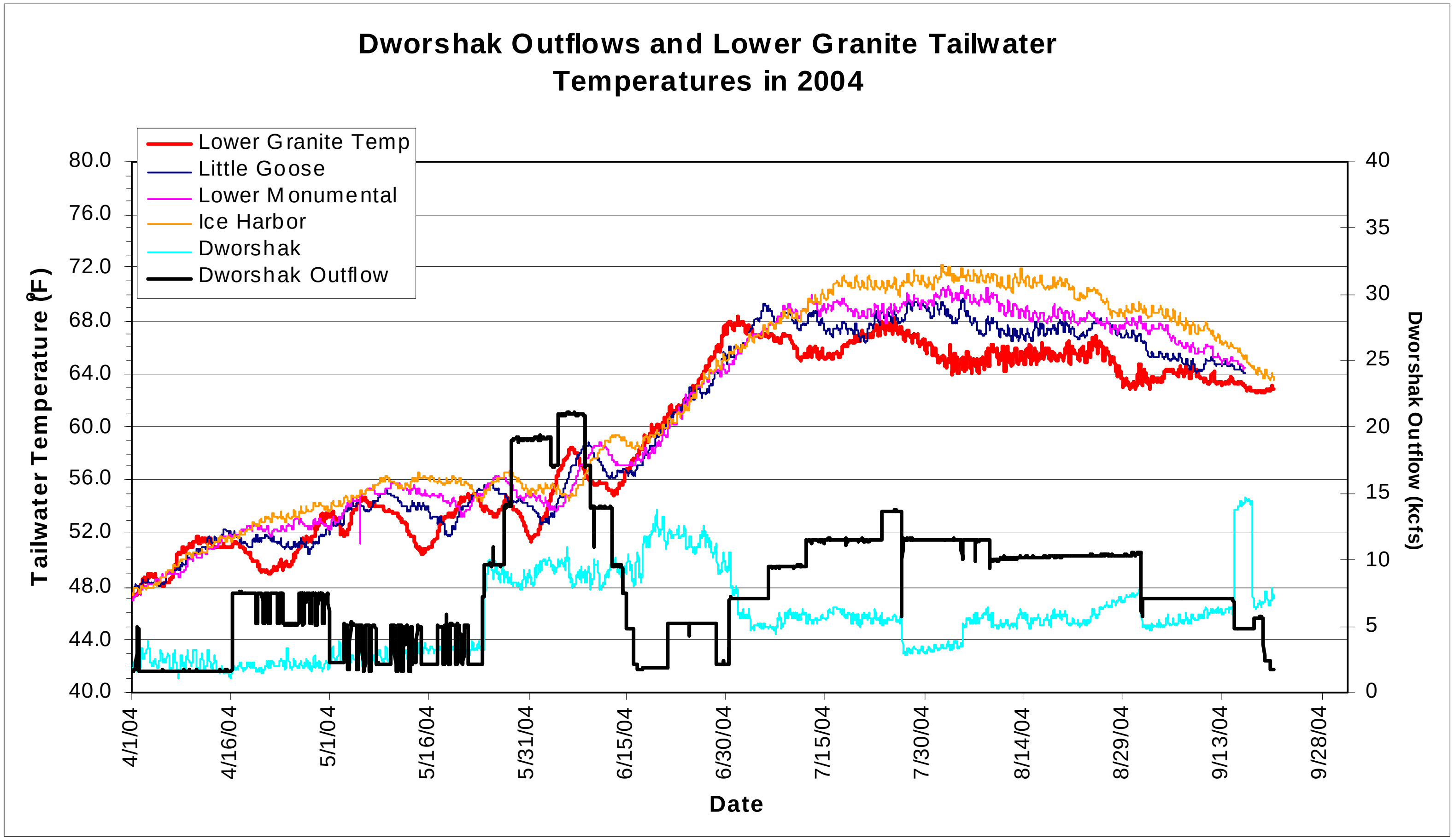
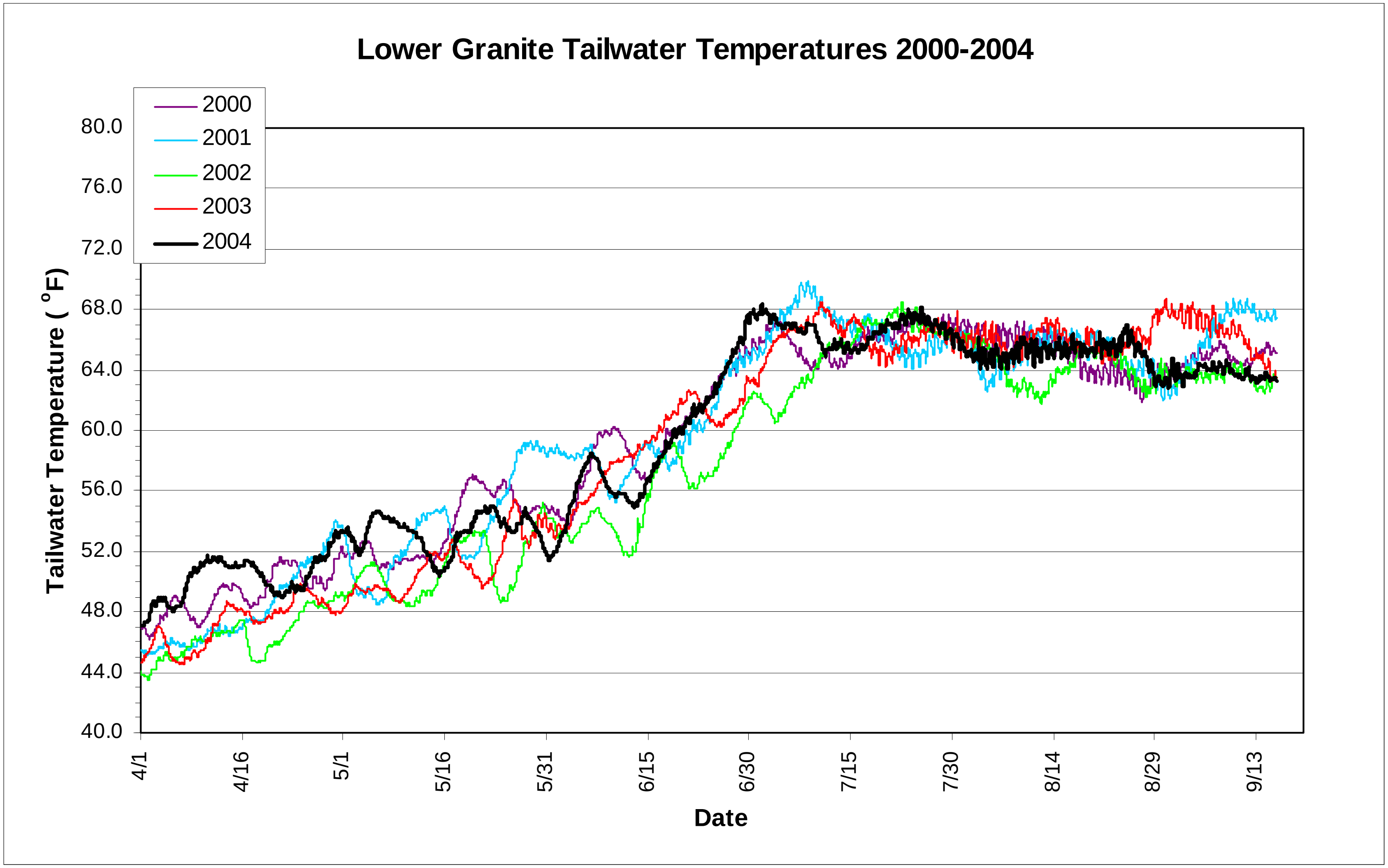


FIGURE D-3



Dworshak Outflows and Lower Granite Tailwater Temperatures in 2004
Lower Granite Temp
Little Goose
Lower Monumental
Ice Harbor
Dworshak
Dworshak Outflow
Tailwater Temperature (°F)
80.0
76.0
72.0
68.0
64.0
60.0
56.0
52.0
48.0
44.0
40.0
Dworshak Outflow (kcfs)
40
35
30
25
20
15
10
5
0
4/1/04
4/16/04
5/1/04
5/16/04
5/31/04
6/15/04
6/30/04
7/15/04
7/30/04
8/14/04
8/29/04
9/13/04
9/28/04
Date

FIGURE D-4



Lower Granite Tailwater Temperatures 2000-2004
2000
2001
2002
2003
2004
80.0
76.0
72.0
68.0
64.0
60.0
56.0
52.0
48.0
44.0
40.0
Tailwater Temperature (°F)
4/1
4/16
5/1
5/16
5/31
6/15
6/30
7/15
7/30
8/14
8/29
9/13
Date

FIGURE D-5

Lower Granite Tailwater Thermal Exceedances
(1995-2004)

Year	Hours of Exceedance	Average Number of Degrees an Exceedance is above the 68° F Water Temperature Standard	Standard Deviation (°F)	Exceedance Range (°F)	Cumulative Magnitude of Exceedance (Degree-Hours)
2004	7	0.23	0.13	68.0 – 68.36	2
2003	63	0.23	0.18	68.0 – 68.76	14
2002	17	0.25	0.13	68.0 – 68.54	4
2001	172	0.72	0.55	68.0 – 69.15	123
2000	0	N/A	N/A	N/A	0
1999	23	0.28	0.13	68.0 – 68.54	6
1998	981	1.75	1.34	68.0 – 72.5	1,721
1997	137	0.41	0.23	68.0 – 69.08	56
1996	526	1.17	0.64	68.0 – 70.70	613
1995	593	0.61	0.33	68.0 – 69.62	363

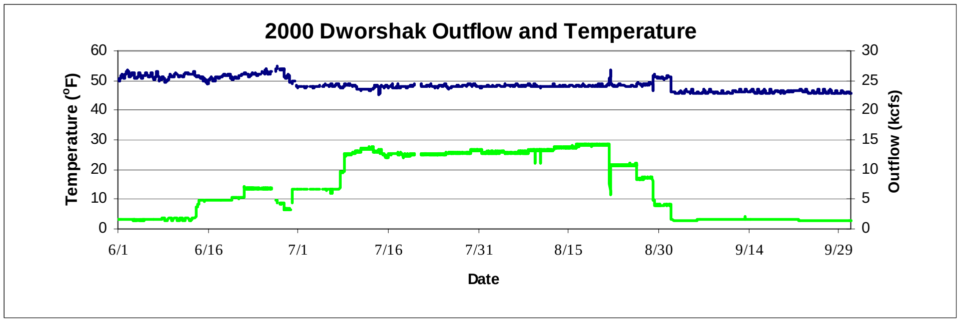
10-Year Statistics of Cumulative Magnitude of Exceedance

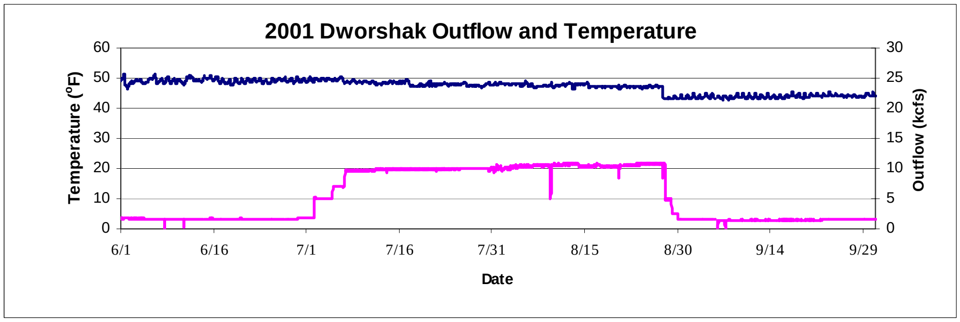
Hours of Exceedance
- Range: High = 981 hrs (1998)
  Low = 0 hrs (2000)
- Average 1995-1999: 452 hrs
- Average 2000-2004: 52 hrs
- 10-Year Average: 252 hrs

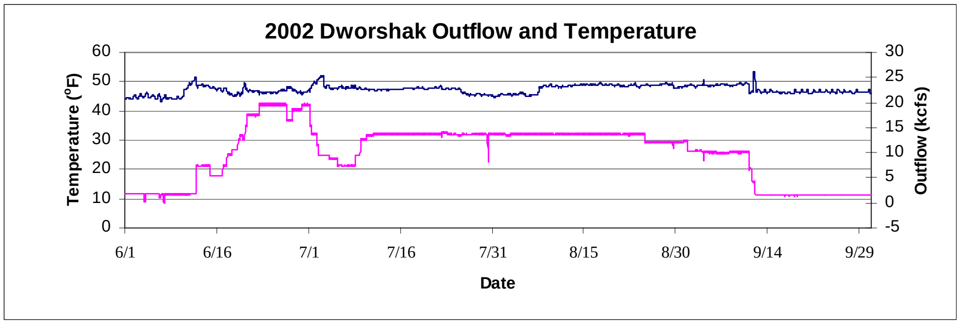
Cumulative Magnitude of Exceedance
- Range: High = 1,721 degree-hrs
  Low = 0 degree-hrs
- Average 1995-1999: 552 degree-hrs
- Average 2000-2004: 29 degree-hrs
- 10-Year Average: 290 degree-hrs

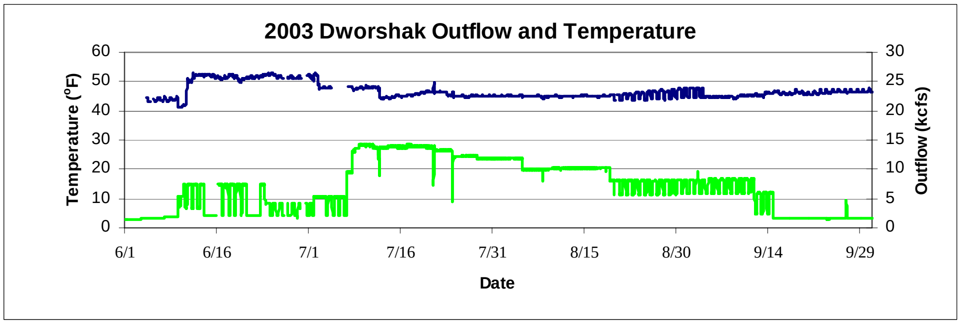
Cumulative Magnitude of Exceedance = $\sum$ (# of hours above 68° F)$_i$ x (Temp above 68° F)$_i$

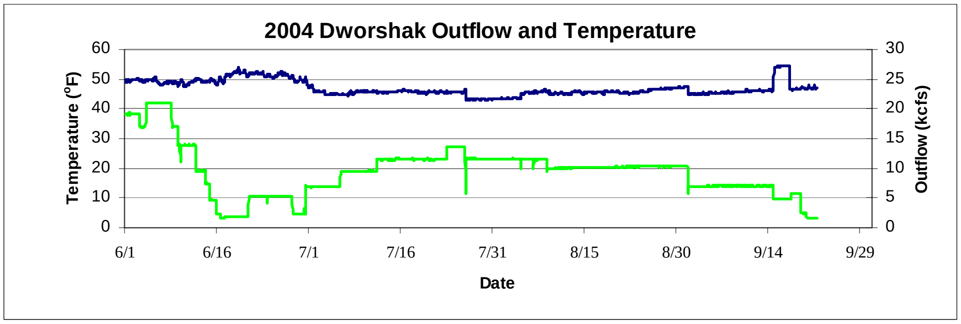
FIGURE D-6


2000 Dworshak Outflow and Temperature
Temperature (°F)
Outflow (kcfs)
0
10
20
30
40
50
60
0
5
10
15
20
25
30
6/1
6/16
7/1
7/16
7/31
8/15
8/30
9/14
9/29
Date


2001 Dworshak Outflow and Temperature
Temperature (°F)
Outflow (kcfs)
0
10
20
30
40
50
60
0
5
10
15
20
25
30
6/1
6/16
7/1
7/16
7/31
8/15
8/30
9/14
9/29
Date


2002 Dworshak Outflow and Temperature
Temperature (°F)
Outflow (kcfs)
0
10
20
30
40
50
60
-5
0
5
10
15
20
25
30
6/1
6/16
7/1
7/16
7/31
8/15
8/30
9/14
9/29
Date


2003 Dworshak Outflow and Temperature
Temperature (°F)
Outflow (kcfs)
0
10
20
30
40
50
60
0
5
10
15
20
25
30
6/1
6/16
7/1
7/16
7/31
8/15
8/30
9/14
9/29
Date


2004 Dworshak Outflow and Temperature
Temperature (°F)
Outflow (kcfs)
0
10
20
30
40
50
60
0
5
10
15
20
25
30
6/1
6/16
7/1
7/16
7/31
8/15
8/30
9/14
9/29
Date