Responses to FERC Additional Information Request WQ-1

Dissolved Oxygen Augmentation

Final Report

Idaho Power Company

Hells Canyon Project
FERC No. P-1971-079

February 2005

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ATTACHMENTS

SCHEDULE A: ADDITIONAL INFORMATION REQUEST WQ-1 DISSOLVED OXYGEN AUGMENTATION

Time Required: 9 months

In exhibit E of your license application, you propose to implement the following DO measures:

1. Inject oxygen into the transition zone or upper end of the lacustrine zone of Brownlee reservoir to supplement DO by 1,450 tons annually;
2. Install and operate turbine-venting systems in units 1 through 4 at the Brownlee development; and
3. Investigate, and install and operate, if practical, a system to inject oxygen or atmospheric air into water passing through unit 5 at the Brownlee development.

However, you do not provide enough specific information on the design and operation of the system that would be used to inject oxygen into Brownlee reservoir or detailed results on the effects of your turbine aeration testing. We need additional information about these proposed measures in order to evaluate the economic costs, resource benefits, and potential secondary effects (e.g., elevated total dissolved gas levels) of your proposal. Accordingly, please provide the following information after consultation with the ODEQ, IDEQ, and NOAA Fisheries.

(a) A report that presents the methods and results of hub-baffle aeration testing that you performed on Brownlee unit 4 in 2001 as referenced on page 47 of your Application for Certification Pursuant to Section 401 of the Clean Water Act for the Relicensing of the Hells Canyon Hydroelectric Project. These results should include an assessment of the effects of the baffles on both DO and total dissolved gas levels, if they were both monitored.

(b) A conceptual design and operational plan for the proposed reservoir aeration system. The plan should include consideration and evaluation of alternative locations, system designs, and augmentation schedules that are designed to maximize system efficiency and water quality benefits to important aquatic resources, including fall chinook spawning.

(c) A detailed estimate of design, construction, and operating costs, and any future capital costs for major overhaul or equipment replacement, as well as any anticipated effects on project generation and power benefits. Please provide your estimate of capital and operating costs and any effects on project generation or dependable capacity by year over the term of the next license, assuming a 30-year license.

(d) An assessment of the effects of reservoir aeration and turbine venting on levels of DO, total dissolved gas, ammonia, pH, and mercury and organo-chlorine compounds. Since there is uncertainty regarding how long it will take to fully implement the Total Maximum Daily Loads (TMDLs) that will affect the amount of nutrients that are delivered from upstream sources, please conduct your analysis for two scenarios: 1) with full attainment of nutrient load allocations from upstream TMDLs; and 2) with no improvement from upstream TMDLs.

This assessment should include the following:

(i) A plot of simulated hourly DO levels below Hells Canyon dam from January 1 through December 31 for each of the 5 representative years (1992, 1994, 1995, 1999, and 1997).

(ii) Semi-monthly plots (February, April, June, August, October, and December) of simulated DO isopleths in Brownlee reservoir for each of the 5 representative years (1992, 1994, 1995, 1999, and 1997). These plots should be similar in format to the plots that you provided in figures 13 and 26 of Technical Appendix E.2.2-2, except that each plot should be provided in a full-page, black-and-white format.

(iii) A qualitative evaluation of the potential effects on water temperatures, total dissolved gas levels, ammonia levels, pH levels, and concentrations of mercury and organo-chlorine compounds in the waters discharged from Hells Canyon dam for each of the 5 representative years (1992, 1994, 1995, 1999, and 1997).

Each of these graphs should be provided in a full-page, black-and-white format to ensure that all data series are visible in both hard copy and in electronic formats. To facilitate side-by-side comparisons, please provide the same graphs for your current and proposed operations[1] without implementation of reservoir aeration or turbine venting and without improvements from meeting other TMDL loading allocations. Please use the same scale and format that you use in the graphs that you provide in your response to parts (e)(ii) through (e)(iv) of AIR OP-1.

Include comments from the consulted entities and your response to their comments with your filing.

1. INTRODUCTION

This report presents analysis requested by the Federal Energy Regulatory Commission (FERC) to provide additional information on proposed reservoir and turbine aeration systems in response to the additional information request (AIR) WQ-1 relative to dissolved oxygen (DO) augmentation. In 2003, the Idaho Department of Environmental Quality (IDEQ) and Oregon Department of Environmental Quality (ODEQ) jointly developed the *Snake River–Hells Canyon Total Maximum Daily Load* (TMDL) (ODEQ and IDEQ 2003) for the Snake River between river miles (RM) 409 and 188. The Idaho Power Company (IPC), as well as other stakeholders with property interests adjacent to and upstream from the river segment that is the subject of the TMDL, participated in the TMDL development process. The TMDL contains load allocations for the Hells Canyon Complex (HCC) for various water quality parameters, including DO, but recognizes that DO concentrations in the Brownlee Reservoir and the Snake River are closely linked to and influenced by nutrient concentrations. As a consequence, the TMDL, in implementing a watershed approach, assigned total phosphorus load allocations to pollutant sources for the Snake River upstream of the HCC (RM 409–335) and a dissolved oxygen load allocation for Brownlee Reservoir (RM 335–285). In this manner, the TMDL recognized that pollutant sources upstream of the HCC were responsible for those water quality problems occurring upstream and not for water quality problems that would otherwise occur if the waters flowing into the HCC met water quality standards. Conversely, the TMDL recognized that the HCC was responsible for those water quality problems related exclusively to impoundment effects that would occur if inflowing water met water quality standards.[2]

The TMDL was approved by the U.S. Environmental Protection Agency in September 2004, and IPC was assigned a load allocation of 1125 tons/yr of oxygen to be applied from the first of July through the first

---

[1] In AIR OP-2, Current Operations Scenarios, we ask you to determine whether your proposed operations are the same as your current operations.

[2] SR-HC TMDL [July 2003], page 450.

week of September (Julian days 182–247) in Brownlee Reservoir. The reservoir aeration system proposed by IPC is designed to augment DO consistent with this load allocation. In IPC's final license application (FLA), IPC proposed to inject 1450 tons/yr of oxygen into Brownlee Reservoir in an effort to address IPC's anticipated TMDL load allocation. This proposal was consistent with the load allocation assigned to IPC in the draft TMDL. However, the final TMDL reduced that load allocation to 1125 tons/yr.[3] IPC recognizes that the proposed measures, while providing DO supplementation consistent with IPC's TMDL load allocation, may not completely address DO issues within, or perhaps below, the HCC. IPC's proposed measure is, however, consistent with the watershed approach to overall Snake River water quality utilized by the Clean Water Act (CWA) and the respective DEQ's in the development of the TMDL. That TMDL, while contemplating that measures intended to achieve the load allocations assigned to the respective stakeholders would be implemented concurrently, recognized that due to the size and complexity of the watershed above the HCC that significant water quality improvement would not occur for several years after full implementation.[4] While IPC has moved forward with plans for full implementation of its TMDL responsibility, it cannot address the effects of other anthropogenic influences in the watershed on water quality. Incremental improvements in DO both within and below the HCC should occur as the TMDL is implemented. In the interim, the water quality deficiencies of the Snake River cannot be balanced on the back of the HCC.

Consistent with the oxygen load allocation assigned to IPC by the final SR-HC TMDL of 1125 tons/yr, all information in this AIR relates to that load allocation rather than the 1450 tons/yr contained in the draft TMDL and IPC's FLA.

2. RESPONSES

2.1. Response to WQ-1(a)

The specific report requested is dated 2001 and presents results of testing conducted in 2000. In August 2000, Mobley Engineering Inc., in cooperation with IPC, conducted tests on Brownlee unit 4 to determine the effectiveness of hub baffles installed on the runner to induce airflow from the vacuum breaker line (Attachment 1). Premodification or "baseline" tests on unit 4 were conducted on August 14 and 15. The

---

[3] This change was in apparent recognition that the methodology used in the Draft TMDL did not account for other sources of oxygen, such as natural aeration from the atmosphere, nor the reduced sediment oxygen demand that will result from the improved water quality of flows into the reservoir as the other measures in the Draft TMDL are implemented.

[4] "Due to the extraordinary size and complexity of the SR-HC watershed, its hydrology, and the various factors that affect the implementation of control strategies, it was determined that a time frame of approximately 50 to 70 years will be required to implement all necessary control strategies and fully attain SR-HC TMDL targets." *Id.*, pg.448.

turbine was dewatered, and baffles were added over each thrust relief opening on the hub. On August 18 and 19, postmodification tests were conducted.

During September 2004, IPC's Power Production Department conducted additional tests on Brownlee unit 4 to determine the effect of baffles on efficiency and airflow at various wicket gate settings. The first set of tests was conducted with baffles installed, and a second test was conducted without the baffles. This evaluation was conducted using similar techniques as in the 2000 tests conducted by Mobley Engineering and included measurements of headwater and tailwater elevations, turbine discharge, wicket gate position, and airflow.

Testing in 2004 showed negligible differences in efficiency and airflow with or without baffles (Appendix A). Closer examination of the turbine drawings revealed that vacuum breaker air does not exit where the baffles were installed. Instead, the vacuum breaker air enters the head cover and exits from the runner cone. Therefore, installation of baffles cannot induce additional airflow into the turbine given the configuration of units 1 through 4 at the Brownlee Powerhouse. The Mobley Engineering report on the 2000 testing (Attachment 1) must be interpreted with consideration of the 2004 findings.

IPC included the proposed turbine modification using baffles on units 1 through 4 in the FLA with the expectation that some benefit might be derived from this relatively low cost alternative.[5] However, the results of 2004 testing indicate that the proposed turbine venting would not provide DO benefits in the discharge. As such, IPC is withdrawing that proposed measure.

Notwithstanding IPC's position that the TMDL defines its responsibility for DO, IPC has investigated other alternatives to augment DO conditions. One such alternative is the installation of a turbine aeration system that would include blowers at unit 1 through 4 at Brownlee Powerhouse. Information relative to this alternative is included in this report. Although IPC is not proposing these measures, the information is included to illustrate that while there are alternatives to the previously proposed turbine venting, they are not without significant cost. Given that these measures would address DO responsibilities beyond those assigned to IPC in the TMDL, IPC should not be expected to incur those additional costs.

In order to begin the CE-QUAL-W2 model runs necessary to address the AIRs in the timeframe allotted an assumption on the effects of proposed turbine aeration at Brownlee was necessary early in the process. Therefore, in the CE-QUAL-W2 modeling a 1 mg/L DO increase in Brownlee discharge was assumed

---

[5] Baffles have effectively been used on other projects, specifically with the Tennessee Valley Authority. This option was originally presented as a result of low construction and installation cost compared to the potential benefit of increased dissolved oxygen. Baffles are relatively easy to install by simply dewatering the unit and welding pre-fabricated 'hub baffles' over the exit of the vacuum breaker line on the turbine runner hub. Installation of baffles was estimated around $20,000 per unit. Additionally, this is a passive type venting system, so it would have been generally maintenance free with minimal efficiency loss.

when DO was below 6 mg/L, and a 0.33 mg/L increase assumed with DO was above 6 mg/L. This assumption was based on preliminary estimates of the effects of blower installation on unit 5 (only operating when discharge DO fell below 6 mg/L), information at that time on baffle installation (i.e. 2001 Mobley engineering report) and preliminary information on blowers for units 1–4. By the time baffle installation was determined to be ineffective sufficient time did not remain to refine the assumption of a 1 mg/L increase in DO.

2.2. Response to WQ-1(b)

IPC has proposed to implement the TMDL oxygen allocation by oxygen injection into the transition zone or upper end of the lacustrine zone of the reservoir. The oxygen requirement for IPC identified in the approved TDML is 1125 tons/yr. This response addresses FERC's request for additional information on the conceptual location, design, and operational plan for the proposed reservoir aeration system.

The conceptual reservoir aeration system would employ a porous hose line diffuser design originally developed for the Tennessee Valley Authority (TVA) (Mobley 1997, Mobley and Brock 1995). Systems employing this design are currently operating at six TVA hydropower projects, Duke Energy and Pennsylvania Power and Light hydropower projects, and the U.S. Army Corps of Engineers Richard B. Russell Dam, as well as five water supply reservoirs (Mobley et al nd). The porous hose line diffuser design has been successful in meeting goals of dissolved oxygen improvement and reduction of anoxic products in reservoirs (Mobley 1996).

To address FERC's request, water quality modeling using CE-QUAL-W2 is used to evaluate location and effects of the proposed aeration system. CE-QUAL-W2 is a two-dimensional (2D, laterally averaged) hydrodynamic water quality model. To incorporate reservoir aeration, some additional assumptions to the basic model package are required. The effects of the reservoir aeration system are modeled in CE-QUAL-W2 using customized coding developed for IPC. The coding allows oxygen to be added at a specified rate to a specified number of model cells for a range of days. The desired amount of oxygen per year is converted into a kilogram per day rate (i.e., 1125 tons/yr equals 15,727 kg/day over the 65 days included from Julian day 182 to 247), and that mass is added equally into the specified model segments and layers.

Three model segments are aerated, representing 1.8 miles of diffusers centered near river mile (RM) 325. Eight layers of these segments are aerated, representing 40 ft (12.2 m) of depth. The layers specified begin slightly off the bottom, representing the ability to float the diffuser line from anchors (Mobley 1997). The number of layers aerated represents the predicted distribution of oxygen absorption through the water column as bubbles rise. At the anticipated depths and oxygen flow rates, the oxygen is expected to be dissolved within this depth (Attachment 3). Oxygen is equally distributed through all the specified segments and layers. Modeling indicates that the oxygen will be approximately equally distributed throughout this depth and along the diffuser lines (Attachment 3). To represent rising bubbles, the coding also includes a factor by which vertical mixing between model layers can be increased. This factor is set to increase mixing slightly since the diffuser design at the oxygen flow rates are anticipated to cause relatively little mixing.

2.2.1. System Location

Under current conditions (before upstream water quality improvements from TMDL allocations are realized), the most extensive low DO concentrations in Brownlee Reservoir are found in the transition zone and the metalimnion and hypolimnion of the lacustrine zone. During medium to low flow years (1995 and 1992, respectively), extensive hypoxic (< 2.0 mg/L) and anoxic (< 0.5 mg/L) conditions develop in the transition zone. The most extreme hypoxia that IPC has measured in the transition zone occurred on July 20, 1990, shortly after a large fish kill in the upper segment of the reservoir. Extremely low DO levels (< 1 mg/L) extended to the surface at RM 324.4 in the transition zone (Figure 1). On this date, DO below 3 mg/L throughout the water column occurred upstream of RM 324.4 for approximately 3 miles. This episode of low DO throughout the water column in approximately 10 miles of Brownlee Reservoir led to the mortality of at least 28 white sturgeon (*Acipenser transmontanus*) and several other species. While collecting these measurements, IPC biologists observed dead fish throughout the upper reach of the reservoir (RM 337 to RM 317), including white sturgeon, catfish, crappie, and suckers (Myers et al. 2003). Although this episode in 1990 was extreme, IPC has measured low DO (< 4 mg/L) at or near RM 325 in other years. Summarized profile data collected over 13 years through the water column at RM 325 show that anoxic conditions are common in low flow years, while in higher flow years, this area remains relatively well oxygenated (Table 1).

The conceptual system location would be centered near RM 325 and cover approximately 1.8 miles of reservoir (Figures 2 and 3). This conceptual location was identified to provide improved habitat for fish, specifically white sturgeon, by extending adequate oxygen levels into the upstream end of the transition zone and prevent extreme hypoxic conditions from developing in this area. Several other factors in locating the system were also evaluated: 1) water depth for system efficiency 2) the need to install the oxygen facility on a concrete pad designed to vendor specifications and applicable safety regulations (CGA G-4.4, NFPA 50), 3) the requirement that liquid oxygen delivery via truck must include a concrete spill apron at the fill pipe connection, and 4) the need for the facility to be located where it is clear of overhead power lines and provides a suitable turnaround area for delivery trucks. The location was sited based on available flat terrain for a facility approximately 100 by 150 feet and other criteria previously mentioned. Very few siting locations exist in the upper end of the transition zone.

Model results show that, with the 1125 tons/yr applied from Julian day 182 to 247, oxygen levels are increased in the vicinity of the diffusers with little increases seen downstream (Figures 5–20). In low flow years (1992), some anoxia can occur upstream of the diffusers and, in very extreme cases (i.e., 1990), potentially extend to the surface and interrupt continuous habitat. Moving the system farther upstream of the proposed location was determined to be undesirable because of decreasing oxygen transfer efficiency with shallower water and the very low frequency of extreme hypoxic conditions occurring upstream of the proposed location. Placement of the system farther downstream, under current conditions, has potential to create an area of high DO near the diffusers that is surrounded by hypoxic water. In fact, this potential appears to be possible in low flow years even at the proposed location when aerating at 1125 tons/yr (Figures 5 and 6).

In higher flow years, the benefits of aerating at this location are less apparent because hypoxia does not develop as strongly. Measured data indicate that DO problems are common in this area in low flow years, while low DO was generally not measured in medium-high and high flow years (1999 and 1997, respectively). Model results for July 1999 and 1997 show limited hypoxic conditions developing near the system, with the majority developing downstream (Figures 17–20). In these models, low DO near the bottom in a small volume is alleviated with aeration while the majority of the water column is already at acceptable DO levels.

White sturgeon are considered a species of special concern by the state of Idaho. Lepla et al. (2003) suggested that poor water quality, specifically low DO levels, is the primary factor contributing to low condition factors of 11 white sturgeon captured in the upstream end of Brownlee Reservoir (approximately RM 335–325) in August 1997 (Lepla et al. 2003). Sturgeon habitat suitability indices (HSI) were developed by Lepla and Chandler (2003) on a scale of 0 to 1 (0 = unsuitable and 1 = most suitable) to evaluate habitat conditions for Snake River white sturgeon based on temperature and DO levels. HSI computed from CE-QUAL-W2 results show that aeration at the proposed location in low flow years may provide a larger area of benefit than apparent with only DO concentration results (Figures 21−34). Relatively small increases in DO can translate to large increases in habitat suitability for sturgeon. In July 1992 and 1994, the small DO increases seen near diffusers and downstream (Figures 5 and 6) translated to a relatively large volume in the transition zone that improved from an HSI below 0.5 (without aeration) to above 0.8 (with aeration) (Figures 21 and 22). HSI results in 1999 and 1997 showed acceptable conditions for sturgeon in the system vicinity without aeration (Figures 33 and 34).

The DO load allocation for Brownlee Reservoir was developed following extensive analysis of medium flow conditions (i.e., 1995) in the Snake River (IDEQ and ODEQ 2003). This analysis also assumed that upstream water quality improvements from other TMDLs would be fully realized. Due to significant uncertainty in timing and magnitude of upstream improvements, IPC's proposed location and goal for reservoir aeration has been developed to implement this allocation in a way that will provide the most benefit under current conditions.

It is anticipated that, as upstream improvements occur under TMDL implementation, benefits may be realized by moving the system farther downstream to supplement metalimnetic DO, where the largest DO deficits are predicted to occur after upstream improvements are made. Although relocating the system may be feasible in this situation, locating the system in an appropriate area under current conditions is important because specifics of the system design (i.e., liquid oxygen storage and distribution, diffuser system anchor weight and line length) make relocating the system yearly very difficult. Any relocation considered with this system should be a result of long-term TMDL improvements in inflow water quality and not annual variability in water quality based on flow conditions.

In conclusion, the line-diffuser system appears to be the most efficient system for distributing this amount of oxygen in the transition zone. However, annual relocation is not practical based on the configuration of the system.

2.2.2. Conceptual Design

This section presents conceptual design of the reservoir aeration system. The system is broken into two facilities, including the oxygen supply facility and the reservoir diffuser system.

2.2.2.1. Oxygen Supply Facility

The use of pure oxygen gas for supply of the diffusers was evaluated for this system. The use of compressed air was not evaluated because, compared with the first option, it would require significantly higher expense for the installation of approximately five times the number of diffusers to handle air. Additionally, total dissolved gas concerns are intensified by the application of air bubbles at high pressures in the reservoir, providing high levels of nitrogen adsorption.

To supply pure oxygen, a variety of systems are available including liquid oxygen delivery or self-contained generation. The use of self-contained generation was eliminated because of capital cost, electrical requirements, and location.

An oxygen supply facility would be located near the distribution site on flat terrain. The facility would consist of an oxygen storage tank, vaporizers, a pressure-regulating assembly, control valves, distribution piping, and truck access. The site would be screened and fenced.

The system capacity would be sized to place oxygen at the following two design criteria: 1) 34.6 tons/day (equivalent to 2250 tons/yr when applied for 65 days) and 2) 17.3 tons/day (equivalent to 1125 tons/yr when applied for 65 days). Based on oxygen transfer efficiencies (OTE) around 85% and a safety factor of 1.15, the amount of liquid oxygen delivered to the site would be increased to 46.8 tons/day and 23.4 tons/day.

An experienced gas supplier would provide a liquid oxygen tank (Figure 35), ambient air vaporizers (Figure 36), a pressure-regulating assembly (Figure 37), cryogenic piping, and control valves. Supply piping from the facility to the reservoir would be routed across the Snake River Road. Supply piping would measure approximately 1000 feet, be placed in a trench, and be routed in a protective carrier pipe. This carrier pipe provides protection from UV light and vandalism. The oxygen flow setting would be manual. Electric power (110V) and an alarm system are typically required at the facility.

The gas supplier would provide truck deliveries of liquid oxygen to the system during regular operational hours. For the two design criteria established, truck deliveries would be three trucks every day and three trucks every two days, respectively. To provide a two-day minimum storage, a 20,000-gallon tank is the smallest size that should be supplied. However, based on location, a larger tank would be more suitable to the operation because it would provide delivery flexibility for liquid oxygen deliveries. Therefore a 50,000-gallon tank is proposed.

2.2.2.2. Reservoir Diffuser System

The reservoir diffuser system is described in Attachment 3, “Dissolved Oxygen Augmentation in the Transition Zone,” and summarized below.

Mobley Engineering, Inc., has provided a detailed conceptual design for an oxygen diffuser system for the Brownlee Reservoir transition zone. The line diffuser design is well suited for the transition zone, and the conceptual design for this application uses standard line diffuser details to efficiently place oxygen in the water depths available. The diffuser system for the transition zone would place 17.3 to 34.6 tons of oxygen per day into the reservoir. Two diffuser lines would be routed upstream of the oxygen supply facility to place oxygen directly into approximately 2 miles of the reservoir. Supply lines from the oxygen supply facility would be routed in a trench under the road and then underwater to the deepest part of the reservoir.

There are several advantages of the line diffuser design:

- It is a proven system. Such systems are currently in operation at nine hydropower installations.
- Its high OTE minimizes operating costs. The OTE would range from 85% to 90% at depths available at the proposed location.

- It provides a wide range of oxygen flow rates while maintaining OTE and uniform distribution.
- It can be supplied with oxygen supplied from a cryogenic tank.
- The conceptual design provides for two diffusers to allow control of oxygen input distribution over approximately two river miles.

2.2.3. Conceptual Operational Plan

The TMDL specifies a time frame during which calculations showed the need for DO augmentation (i.e. Julian day 182–247). However, the TMDL provides for flexibility in this time frame and suggests that aeration should be implemented so that it coincides with the actual time periods when DO problems occur and where it will provide the most benefit to aquatic life. Given the significant interannual variability in Brownlee water quality conditions, the aeration system could be operated differently depending on conditions to maximize benefits. At RM 325 (approximately the center of the proposed location for the diffuser system), anoxic conditions occur in July of low flow years and also in recent (2003) medium-low flow years. Anoxic conditions have not been measured at RM 325 in higher flow years (Table 1). Based on our current understanding, oxygen dynamics in the transition zone are largely determined by flow conditions. However, we recognize that, although flow conditions appear to be a strong driver, there remains some risk that isolated and infrequent hypoxic conditions may develop even in higher flow years. Specifically, Table 1 shows one instance of low DO (2.05 mg/L) measured in a medium-high flow year (1998).

Not incorporating the flexibility provided for in the TMDL could result in aerating at 1125 tons/yr in years when a DO problem in the vicinity of the aeration system does not occur. Also, modeling indicates that, in low flow years, aerating at the 1125 tons/yr could create an isolated area of oxygenated water surrounded by hypoxic conditions (Figures 5 and 6). IPC's conceptual operational plan for the aeration system includes implementation of the TMDL allocation in a way that would allow more oxygen to be injected in years when the problem is likely to occur and none or less when the problem is unlikely to occur. Table 2 shows how the allocation could be applied to meet the allocation on a 10-year average basis. DO and sturgeon HSI results with aeration of 2250 tons/yr in low and medium-low flow years show that improvements are larger in the vicinity of the diffusers and move farther downstream than with aeration at 1125 tons/yr (Figures 38–45). Applying the allocation using this conceptual approach or a similar approach results in larger benefits in years when there are potential DO problems. Our current understanding may allow for the problem to be anticipated in low flow years, but the specific time of the year when it occurs is much more difficult to predict. Therefore, our current conceptual operational plan includes operation in the TMDL window (Julian day 182–247). However, moving this window to start and end earlier may be warranted based on historical data and model results (see section 2.4.2).

Although model results are useful for evaluating relative comparisons among scenarios, much uncertainty exists as to whether modeled benefits from aeration would be realized upon implementation. CE-QUAL-W2 is a complex model incorporating numerous water quality processes, but processes that are not included in the model would affect aeration. Recently collected data in the transition zone of Brownlee Reservoir shows the potential for a significant oxygen demand near the sediment resulting from chemical products of anoxic conditions (Table 3). Oxygen-demanding products released from anoxic sediment (including sulfide, ferrous iron, and methane) are not specifically included in CE-QUAL-W2. It is uncertain at this time how extensive oxygen demand from these materials would be when aeration began and at what rates these substances would continue to be produced during aeration.

2.3. Response to WQ-1(c)

2.3.1. Turbine Aeration by Forced-Air Blowers

Recent analysis indicates turbine venting proposed for units 1-4 will not be effective in increasing DO levels in the Brownlee discharge. Although IPC is not proposing forced air blowers (see section 2.1), IPC has analyzed replacing the proposed turbine venting system on units 1–4 with forced air blowers similar to that proposed on unit 5 to illustrate that while there are alternatives to the turbine venting IPC originally proposed, they are not without significant cost (See Attachment 2). As a result of installing such a blower system, some turbine efficiency would be lost, thus reducing generation capability. In addition, the blower motors consume power, and annual maintenance would need to be performed.

2.3.1.1. Capital Costs

Direct capital costs are summarized below for a 1 mg/L increase in DO. Capital construction costs are discussed in “Dissolved Oxygen Augmentation Using Forced Air” (Attachment 2). Indirect construction costs associated with installing the blower system include the Allowance for Funds Used During Construction (AFUDC). The estimated AFUDC is capitalized interest based on the predicted construction cost and duration of the installations. It is estimated construction would take three to four months to install blowers on units 1–4 and approximately 1 month to install blowers on unit 5. An annual AFUDC rate of 7.24% was used to estimate the interest that would be capitalized. The total direct capital costs and AFUDC are summarized below:

	Units 1–4	Unit 5
Direct capital construction costs (current dollars)	$ 3,088,000	$ 944,000
AFUDC	46,559	5,695
Total Investment	**$ 3,134,559**	**$ 949,695**

For capital costs (current dollars) to gain a 2 mg/L increase in DO, refer to “Dissolved Oxygen Augmentation Using Forced Air” (Attachment 2).

2.3.1.2. Annual Costs

Annual costs consist of operation and maintenance costs, including power consumption, as well as generation loss costs associated with turbine efficiency loss. These costs are summarized below for a 1 mg/L increase in DO assuming the blowers operate when the simulated discharge from Brownlee is below 6 mg/L. Estimated annual operating and generation loss costs were calculated based on 15-minute flows for five proposed operation flow years: 1992 (low flow year); 1994 (median low flow year); 1995 (approximate median flow year); 1999 (median high flow year); and 1997 (high flow year). The 15-minute flows for proposed operations for each of these inflow years was the flow calculated by the CHEOPS model for the other HCC relicensing studies currently underway. Costs are based on 2/3 of the flow through units 1–4 and 1/3 of the flow through unit 5, matching the CHEOPS model assumptions used for other HCC relicensing studies currently underway. The 15-minute power values were based on a monthly peak and off-peak wholesale power cost projection for 2005. Maintenance costs are discussed in “Dissolved Oxygen Augmentation Using Forced Air” (Attachment 2), while generation loss and operating costs are shown in Table 4. Annual costs are summarized below:

	Units 1–4	Unit 5	Total
Average annual maintenance costs (current dollars)	$ 40,000	$ 10,000	$ 50,000 *
Average annual operating costs (current dollars)	169,000	85,000	254,000
Average annual generation loss costs (current dollars)	253,000	126,400	379,400
Total average annual costs (current dollars)	**$ 462,000**	**$ 221,400**	**$ 683,400**

* (See Attachment 2)

For a 2 mg/L increase in DO, average annual costs would be twice the amount indicated. Per “Dissolved Oxygen Augmentation Using Forced Air” (Attachment 2), two blowers at each unit would be required to generate the additional increase in DO rather than a single blower, thus, requiring twice the power, generation loss, and efficiency loss for the units.

The annual operation costs were escalated at a current trend forecast rate of consumer price inflation (2.5%). To annualize the values, the 30-year escalated stream of expenses was averaged. Annual estimates for property insurance and property taxes were included in the annual cost estimates as well.

2.3.1.3. Estimated Total Costs

The 30-year total and annualized costs for each of the blower options include estimates for the following items that were mentioned previously: operation and maintenance expenses; property taxes; insurance costs; and lost generation (opportunity) costs. In addition to these cost components, the annual cost of capital for each system is included in the overall cost estimates described below. The annual cost of capital represents levelized costs over an assumed 30-year period, and is the Applicant's estimated annual revenue requirement. A discount rate of 7.20%, per IPC's 2004 Integrated Resource Plan was used to calculate the levelized cost of capital for blower systems.

In Millions $

	Cost of Capital			Expense Components						Totals	
	Total Investment (including AFUDC)	**Present Value Cost of Capital**	**Levelized Cost of Capital**	**30 Year Maintenance**	**30 Year Operating Cost (Power Consumption)**	**30 Year Lost Generation**	**30 Year Property Taxes**	**30 Year Insurance**	**30 Year Average Annual Expenses**	**Annualized Costs**	**30 Year Cash Flow**
Units 1–4	3.1	4.0	**0.3**	1.8	7.5	7.6	0.7	0.1	**0.6**	**0.9**	**20.8**
Unit 5	0.9	1.2	**0.1**	0.4	3.8	3.8	0.2	0.0	**0.3**	**0.4**	**9.1**

2.3.2. Reservoir Aeration

2.3.2.1. Capital Costs

IPC's proposed aeration system in the transition zone includes direct capital costs to install the liquid oxygen system and reservoir diffuser system. Costs associated with the reservoir aeration system are described in "Dissolved Oxygen Augmentation in the Transition Zone" (Attachment 3). Direct construction costs (itemized in Table 5) and AFUDC associated with the liquid oxygen supply system are summarized below:

	Reservoir Aeration and Oxygen Supply System
Direct capital construction costs (current dollars)............	$ 1,817,448
AFUDC..	22,019
Total Investment..	**$ 1,839,467**

2.3.2.2. Annual Costs

Annual costs for the reservoir diffuser system are mainly the costs for purchasing and delivering liquid oxygen. Some minor inspection costs and life cycle costs of the diffusers themselves are also included in the annual costs. Oxygen costs were estimated at $200 per ton for liquid oxygen delivered to the transition zone. Depending on local resources and availability in the area, this cost may fluctuate significantly from year to year. O & M costs associated with the reservoir diffuser system are summarized below and are included in the itemized estimate in Table 6.

	Reservoir Aeration and Oxygen Supply System
Average annual O & M costs (current dollars)................	$ 402,500

The annual O & M costs were escalated at a current trend forecast rate of consumer price inflation (2.5%). To annualize the values, the 30-year escalated stream of expenses was averaged. Annual estimates for property insurance and property taxes were included in the annual cost estimates as well.

2.3.2.3. Estimated Total Costs

The 30-year total and annualized costs for the reservoir diffuser system include estimates for the following items: O & M expenses; property taxes; and insurance costs. In addition to these cost components, the annual cost of capital for each system is included in the overall cost estimates identified in the following table. The annual cost of capital represents levelized costs over an assumed 30-year period, and is the Applicant's estimated annual revenue requirement. A discount rate of 7.20%, per IPC's 2004 Integrated Resource Plan was used to calculate the levelized cost of capital for blower systems.

In millions $

Cost of Capital			Expense Components				Totals	
Total Investment (including AFUDC)	**Present Value Cost of Capital**	**Levelized Cost of Capital**	**30 Year O&M Cost**	**30 Year Property Taxes**	**30 Year Insurance**	**30 Year Average Annual Expenses**	**Annualized Costs**	**30 Year Cash Flow**
1.8	2.3	**0.2**	17.9	0.4	0.1	**0.6**	**0.8**	**20.2**

2.4. Response to WQ-1(d)

This section presents simulated DO levels in Brownlee Reservoir and Hells Canyon discharge. FERC's AIR specifically requested that reservoir aeration, turbine aeration, and inflowing water quality improvements from upstream TMDLs be incorporated into the modeling. Some additional assumptions to the basic CE-QUAL-W2 model package are required to represent turbine and reservoir aeration. In the following model results, aeration was applied in all years at 1125 tons/yr (15,727 kg/day) over the 65 days from Julian day 182 to 247 at the proposed location discussed previously. Assumptions specific to the modeling of aeration have also been previously discussed.

In order to begin the CE-QUAL-W2 model runs necessary to address the AIRs in the timeframe allotted an assumption on the effects of proposed turbine aeration at Brownlee was necessary early in the process (See section 2.1). When Brownlee discharge DO is below 6 mg/L, the total benefit added to the modeled Brownlee discharge is 1 mg/L. When simulated discharge DO is above 6 mg/L, 0.33 mg/L is added when

DO is below saturation. The 0.33 mg/L assumption is based on air aspirated during normal operation of units 1 through 4 (without any modifications) and described in more detail in Appendix A. When the addition of this amount would increase DO above saturation, then only the amount needed to reach saturation is added to modeled discharge DO. The resulting discharge DO at Brownlee is then linked to the Oxbow model and run through the rest of the complex.

Long-term TMDL improvements were modeled for all the representative years using calculations described in Myers et al. 2003. A total phosphorus (TP) concentration target of 70 µg/L has been established for the upstream reach of the Snake River as part of the TMDL (IDEQ and ODEQ 2003). Dissolved phosphorus and organic phosphorus sources were reduced in the Brownlee Reservoir model inflows to simulate how the reservoir would respond to the TP target. With inflow water quality improvements and the associated decrease in organic matter (OM) loading, sediment oxygen demand (SOD) should also decrease over the long term. The proposed TP reduction and resulting SOD improvements were simulated to assess the reservoir's response to potential long-term water quality improvements in inflow. Simulated discharge from Brownlee Reservoir was then used to simulate improved conditions in Oxbow and Hells Canyon reservoirs.

To simulate the TP target, dissolved phosphorus and organic phosphorus (organic matter, including algae) were reduced from the baseline boundary conditions such that inflowing TP levels did not exceed 70 µg/L. After watershed management actions are implemented to meet the target, total organic matter (TOM) loads and sedimentation were expected to decrease. As loads decrease and existing TOM decays through natural processes, SOD decreases. Response to these long-term improvements was simulated by reducing SOD to 0.1 g O_2/m^2/day throughout the reservoir. This SOD is more typical of naturally occurring SOD levels (Cole and Wells 2002). For the lower reservoirs, discharge from the upstream reservoir was used as the inflow boundary condition and SOD was reduced to Brownlee levels (0.1 g O_2/m^2/day).

2.4.1. Response to WQ-1(d)(i)

Figures 46 through 50 show simulated Hells Canyon discharge DO levels from January 1 through December 31 for each of the five representative years. Simulated DO levels are shown without reservoir or turbine aeration; with reservoir and turbine aeration; and with the combination of long-term upstream TMDL improvements, reservoir aeration, and turbine aeration.

2.4.2. *Response to WQ-1(d)(ii)*

Figures 51 through 155 show semimonthly DO isopleths of the whole reservoir under proposed operations with and without aeration and under the assumption that TMDL conditions are met upstream. In the lower flow years, under current conditions, hypoxic conditions may develop earlier than the start of TMDL window (Julian day 182) (Figures 53 and 67). Incorporation of an earlier start date for aeration may warrant further consideration, but at this time, this change has not been extensively evaluated. When upstream TMDL improvements are realized, conditions in the reservoir may improve dramatically (Figures 121–155).

2.4.3. *Response to WQ-1(d)(iii)*

Qualitative evaluation of the potential effects of reservoir aeration and turbine venting on water temperature, TDG, ammonia, pH, mercury, and organochlorine compounds in water discharged from Hells Canyon Dam was specifically requested in the AIR. This section reviews reservoir processes related to anoxic conditions in the transition zone and presents potential effects of reservoir and turbine aeration on discharge levels.

2.4.3.1. Ammonia

A major pathway for ammonia production is heterotrophic bacterial decomposition of organic matter where ammonia is generated as a primary end product. Under anoxic conditions in the water and sediments, bacterial nitrification of ammonia to nitrate and nitrite ceases and ammonia accumulates. When overlying water is anoxic, the capacity of sediments to absorb ammonia is greatly reduced and ammonia is released (Wetzel 2001). The combination of these processes results in accumulation of ammonia (and other anoxic products, including inorganic phosphorus and dissolved metals) throughout the year in the hypolimnion and deeper areas of the transition zone.

Aeration should reduce the release and accumulation of ammonia from sediments and water column decay in the vicinity of the reservoir diffusers. Modeling suggests that, under current conditions, DO levels in Brownlee and Hells Canyon discharges are unlikely to be noticeably increased from reservoir aeration in the upstream end of the transition zone. However, aeration would suppress ammonia accumulation in the transition zone, and ammonia levels in the discharge could be reduced when stored water from the transition zone is discharged during drawdown.

2.4.3.2. Mercury and Organochlorines

The cycling of mercury (Hg) among its many pools and forms in aquatic systems is complex. Inorganic mercury (InHg) and highly toxic, bioaccumulative methylmercury (MeHg) compounds are partitioned among sediment, water, and biota pools in both organic/inorganic and dissolved/particulate forms. The majority of InHg is typically stored in sediments (Meili 1997). Concentrations of MeHg and proportions of MeHg to InHg depend on the balance of methylation, demethylation, and chemical stabilization in the system. MeHg is formed by methylation of InHg in the presence of organic matter. Methylation is thought to be a microbial process highly dependent on methanogenic and sulfate-reducing bacteria in anoxic conditions, although it can also occur in oxic conditions (Miskimmin et al. 1992). Demethylation, which is also controlled directly by microbial activity or abiotically by sunlight, is highest in oxic photic zones (Meili 1997).

Organic matter concentrations and cycling exert strong control on the transport and transformations of Hg in aquatic systems. Concentrations of MeHg and total Hg typically increase with the concentration of dissolved organic carbon (Driscoll et al. 1994). Other important parameters influencing the cycle include concentrations and redox states of iron, manganese, chloride, and sulfur compounds.

Methylation appears highest in layers of the water column and sediments with steep redox gradients and high microbial activity (i.e., the metalimnion of eutrophic lakes and top centimeters of sediment). Oxic sediments can be a sink for InHg and MeHg while anoxic sediments can be a source. A buildup of MeHg is often seen in anoxic water where conditions slow demethylation and anoxic sediments increase MeHg release.

Similar to mercury, organochlorine compounds are strongly associated with sediments. Lack of oxygen is a common limiting factor in biodegradation of organic compounds. Degradation rates are generally slower under anoxic conditions (Maier et al. 2000). Oxic conditions can increase levels of microorganisms, which in turn increase degradation rates. Contaminants that have low water solubility or are strongly sorbed to sediments are less available for uptake by microorganisms and thus less bioavailable. When sediments have high OM levels and anoxic conditions prevail, degradation may be limited.

Mercury exists in sediments of the transition zone and throughout the Snake River (Myers et al. 2003). If the proposed porous-hose line diffusers are positioned off the bottom of the reservoir, sediment disturbance from operation may be minimal. If sediments are not disturbed, mercury concentrations downstream should not be increased. Aeration would reduce the volume of anoxic water and decrease the area of anoxic sediments, thereby reducing MeHg production. Because organochlorine compounds are strongly associated with the sediment, if sediments are not disturbed, organochlorine compounds should not be redistributed downstream.

2.4.3.3. pH

In natural waters, pH is governed mainly by interaction of H+ ions arising from dissociation of H_2CO_3 (carbonic acid) and from OH ions produced during hydrolysis of HCO_3^- (bicarbonate) and from organic decomposition (Wetzel 2001). Carbonic acid is formed from hydration of dissolved CO_2 where equilibrium exists with CO_2, H_2CO_3, and CO_3^{2-} (carbonate). When this equilibrium is shifted by removal of CO_2 (e.g., from photosynthesis) or addition of CO_2 (e.g., microbial respiration), pH can be shifted. Vertical patterns of pH in eutrophic waters can be strong due to photosynthetic removal of CO_2 in the photic zone (raising pH) and CO_2 generation from heterotrophic decay of organic matter, nitrification of ammonia, and oxidation of sulfide (lowering pH). These processes, combined with other decomposition processes, result in a decrease in pH in anoxic waters such as those in the metalimnion or hypolimnion. These patterns are especially pronounced in Brownlee Reservoir due to high inflowing organic loads and high primary productivity.

In the vicinity of the diffusers, pH would likely be increased from current conditions due to elimination of anoxic conditions. When water stored in the transition zone is discharged during drawdown, pH in Hells Canyon discharge could be increased by reservoir aeration.

2.4.3.4. Total Dissolved Gas Levels

DO could be increased to supersaturated concentrations in the immediate vicinity of the diffusers. A measurement of total dissolved gas (TDG) in this area would show elevated TDG concentrations due to oxygen supersaturation. With supersaturated TDG caused from atmospheric air (primarily nitrogen), gas bubble disease in fish is a concern. However, supersaturated oxygen concentrations alone would have to be very high (approaching 300%) to cause gas bubble trauma in fish (Weitkamp and Katz 1980, Summerfelt et al. 2001). Under current conditions, oxygen demand from high inflowing organic matter loads would result in injected oxygen being used quickly. Modeling reservoir aeration shows that, under current conditions, the oxygen plume from aeration in the transition zone does not affect Brownlee discharge DO levels. Likewise, TDG levels in Brownlee or Hells Canyon discharge are not expected to be affected by reservoir aeration under current conditions.

Turbine aeration using blowers could elevate TDG in Brownlee discharge. However, modeling indicates that keeping the target DO increase to approximately 1 mg/L would maintain TDG levels below 110% saturation (Attachment 2). Slight elevation of TDG levels in Brownlee discharge is not expected to significantly elevate TDG below Hells Canyon Dam. At this time, there is some uncertainty regarding specific TDG levels that would result from blower operation.

2.4.3.5. Temperature

Reservoir water temperatures in the vicinity of the diffusers could be changed, compared with temperatures under current conditions, due to some mixing induced by oxygen bubbles. However, because induced mixing from the porous-hose line diffusers has been noted to be minimal (Mobley 1997), this effect is expected to be minimal. Water temperatures in Brownlee discharge are unlikely to be affected by the proposed reservoir aeration in the transition zone or by turbine aeration. Therefore, temperature in the discharge from Hells Canyon Dam is not expected to be affected by reservoir aeration.

3. CONSULTATION

Comments were requested on a draft version of this report provided to The National Marine Fisheries Service (NOAA Fisheries), Oregon Department of Environmental Quality (ODEQ) and Idaho Department of Environmental Quality (IDEQ). Comments were received from NOAA Fisheries and ODEQ following the provided 30-day commenting period (Attachment 4). ODEQ requested that it be clearly stated in this document that while a 30-day commenting period was provided, a collaborative forum for stakeholder discussion and input regarding the draft AIR response was not provided. Tight timelines for completing the work required in this AIR precluded the creation of such a forum. Nevertheless, consultation relative to this AIR is consistent with the guidelines outlined by FERC in its May 4, 2004 issuance of the AIRs.

3.1 Response to Comments Related to Turbine Aeration

Both ODEQ and NOAA fisheries requested clarification and specifics on the basis and implications of the turbine aeration assumptions incorporated into the CE-QUAL-W2 modeling. IPC has modified the text in section 2.1, 2.3, and 2.4 to clarify this assumption. ODEQ requested details on the development of the DO improvement and associated cost numbers for blower installation on units 1–4. Section 2.3 has been revised to incorporate final cost estimates and includes details on how annual costs of blower operations were calculated. Discussion is now included in section 2.3 describing the costs associated with further increments of DO improvement greater than 1 mg/L. In addition, Attachment 2 provides more information on the costs of blowers and predicted effects on TDG levels. NOAA fisheries noted that forced air blowers seem expensive compared to the oxygen injection system. Blowers have significant cost; however, Table 4 shows that per ton of oxygen blowers are less expensive than an oxygen injection system that would add a similar amount of oxygen.

ODEQ stated that the TMDL did not "evaluate IPC's DO impact to the Snake River downstream of the HCC" and because of this IPC should consider DO improvement measures to address DO in the lower river. It is not clear what "IPC DO impacts in the lower river that are not provided for by complying with the TMDL load allocation alone" ODEQ is referencing. IPC's data and analyses provided in the FLA clearly indicate that seasonal low dissolved oxygen levels within and downstream of the HCC are the result of organic matter processing in Brownlee Reservoir. IPC's responsibility for degraded DO conditions in Brownlee Reservoir was assessed as 1125 tons of DO. Given that DO conditions downstream of the Brownlee Reservoir discharge improve as water passes through both Oxbow and Hells Canyon reservoirs, and then continues to improve downstream of Hells Canyon Dam, it is unclear what negative impacts, beyond the degradation of DO in Brownlee Reservoir, could be attributed to the HCC. IPC was proposing turbine aeration as a potential low cost method of providing relatively immediate downstream DO improvements because it appeared that necessary watershed improvements may be very expensive and require considerable time to implement. However, as stated above, IPC's proposed turbine venting will not provide DO benefits in the discharge.

3.2 Response to Comments Related to Reservoir Aeration

Both ODEQ and NOAA Fisheries generally supported IPC's conceptual system design that incorporates operational flexibility and uses liquid oxygen. However, there are concerns about the proposed design related to the difficulty of relocation, ease of repair and potential for bio-fouling. Text has been added to section 2.2.1 to clearly state the limited capabilities of the proposed system to be relocated on an annual basis. Attachment 3 to this document briefly presents the diffuser manufacture's approach and experience with bio-fouling related diffuser problems. The manufacturer states that although bio-fouling is a problem, seasonal operation of the diffusers would function to clear and clean the porous hose diffuser. The manufacturer also states that repairs to the porous hose diffuser can be readily made in-situ without divers by re-floating sections of the diffuser line.

NOAA fisheries expressed concern related to the effectiveness of the aeration system immediately following implementation due to high sediment oxygen demand. There is considerable uncertainty involved in assessing the benefits that may be expected immediately following implementation. IPC recognizes that high sediment oxygen demand has potential to limit effectiveness. Further, circulation induced increases in near sediment velocities from aeration have potential to increase sediment oxygen demand from current conditions. Vertical entrainment of reduced materials including dissolved nutrients and metals, and increased release rates of these substances could also occur. However, sediment oxygen demand in Brownlee Reservoir is largely a legacy issue of years of degraded water quality inflows to the reservoir. IPC believes that the TMDL appropriately allocated IPC's DO responsibility as 1125 tons/yr. This allocation was not identified to diminish in the future as sediment oxygen demand decreases. It would not be equitable or appropriate to require IPC to initially inject additional oxygen to offset legacy pollution from upstream sources.

NOAA Fisheries commented that although the conceptual location and operational plan for transition zone aeration would “nominally meet the mandated TMDL requirement” it doesn’t appear to affect discharge DO levels. The proposed conceptual system would allow IPC to fully meet it’s TMDL DO allocation of 1125 tons/yr. IPC disagrees with the characterization that fully implementing its load allocation defined in the TMDL “nominally meets the mandated TMDL requirement.” Simply because overwhelming pollution loads may limit the extent of downstream effects of IPC’s aeration system until substantive upstream water quality improvements are realized should not be used to marginalize IPC’s full implementation of its load allocation.

ODEQ requested that simulated hourly DO percent saturation below Hells Canyon Dam be included in Figures 46 through 50. FERC’s AIR specifically requested DO “levels” be presented but did not specifically request percent saturation. Sufficient time was not available to incorporate ODEQ’s request.

4. LITERATURE CITED

Cole, T. M., and S. A. Wells. August 2002. CE-QUAL-W2: A two-dimensional, laterally averaged, hydrodynamic and water quality model. Version 3.1. user manual. U.S. Army Corp of Engineers, Washington, DC. Instruction Report EL-02-1.

Driscoll, C. T., C. Yan, C. L. Schofield, R. Munson, and J. Holsapple. 1994. The mercury cycle and fish in the Adirondack lakes. Environmental Science Technology 28:136–143.

Idaho Department of Environmental Quality (IDEQ) and Oregon Department of Environmental Quality (ODEQ). 2003. Snake River–Hells Canyon total maximum daily load (TMDL). Idaho Department of Environmental Quality, Boise Regional Office, Boise, ID and Oregon Department of Environmental Quality, Pendleton office, Pendleton, OR. 480 p.

Lepla, K., and J. A. Chandler. 2003. Physical habitat use and water quality criteria for Snake River white sturgeon. In: K. Lepla, editor. Chapter 2, Status and habitat use of Snake River white sturgeon associated with the Hells Canyon Complex. Technical appendices for new license application: Hells Canyon Hydroelectric Project. Idaho Power Company, Boise, ID. Technical Report E.3.1-6.

Lepla, K., J. A. Chandler, and P. Bates. 2003. Status and Habitat use of Snake River white sturgeon associated with the Hells Canyon Complex. In: K. Lepla, editor. Chapter 1, Status and habitat use of Snake River white sturgeon associated with the Hells Canyon Complex. Technical appendices for new license application: Hells Canyon Hydroelectric Project. Idaho Power Company, Boise, ID. Technical Report E.3.1-6.

Maier, R. M., I. L. Pepper, and C. P. Gerba. 2000. Environmental microbiology. Academic Press, San Diego, CA. 585 p.

Meili, M. 1997. Mercury in lakes and rivers. Pages 21–52 in: A. Sigel and H. Sigel editors. Metal ions in biological systems. Volume 34, Mercury and its effects on environment and biology. Marcel Dekker, New York, NY. 603 p.

Miskimmin, B. M., J. W. M. Rudd, and C. A. Kelly. 1992. Influence of dissolved organic carbon, pH, and microbial respiration rates on mercury methylation and demethylation in lake water. Canadian Journal of Fisheries and Aquatic Sciences 49:17–22.

Mobley, M. H. and W. G. Brock. 1995. Widespread oxygen bubbles to improve reservoir releases. Lake and Reserv. Manage. 11:231-234.

Mobley, M. H. and W. G. Brock. 1996. Aeration of reservoirs and releases using TVA porus hose line diffuser. http://www.tva.gov/environment/water/rri_papers.html. Accessed on November 1, 2004. 6 pages

Mobley, M. H. 1997. TVA reservoir aeration diffuser system. In: Proceedings of the conference Waterpower; 1997; Atlanta, Georgia. Waterpower. Technical paper 97-3. 10 pages. Accessable at http://www.loginetics.com/pubsm/Aeration.html. Accessed on November 1, 2004.

Mobley, M. H., R. J. Ruane and E. D. Harshbarger. nd. “And then it sank…” the development of an oxygen diffuser for hydropower. http://www.loginetics.com/pubsm/Aeration.html. Accessed on November 1, 2004. 12 pages.

Myers, R., J. Harrison, S. K. Parkinson, B. Hoelscher, J. Naymik, and S. E. Parkinson. 2003. Pollutant transport and processing in the Hells Canyon Complex. Technical appendices for new license application: Hells Canyon Hydroelectric Project. Idaho Power Company, Boise, ID. Technical Report E.2.2-2.

Summerfelt, S., J. Bebak-Williams, and S. Tsukuda. 2001. Controlled systems: Water reuse and recirculation. Pages 285–395 in: G.A.Wedemeyer, editor. Fish hatchery management. 2nd edition. American Fisheries Society, Bethesda, MD.

Weitkamp, D. E., and M. Katz. 1980. A review of dissolved gas supersaturation literature. Transactions of the American Fisheries Society 109:659–702.

Wetzel, R. G. 2001. Limnology: lake and river ecosystems. 3rd edition. Academic Press, San Diego, CA. 1006 p.

This page was left blank intentionally.

Table 1. Summary of measured profile transition zone DO collected in July at or near RM 325, 1991−2003.

Year	Flow Conditions	Mean (Range) DO mg/L	Dates Sampled
1991	Low	2.78 (0.15–5.12)	7/9, 7/23
1992	Low	4.82 (0.22–9.64)	7/7, 7/21
1993	Medium	9.29 (5.43–13.61)	7/8, 7/22
1994[a]	Low	6.17 (3.52–10.82)	7/11
1995	Medium	10.71 (9.06–15.11)	7/5, 7/17
1996	Medium-high	10.81 (8.38–12.84)	7/2, 7/17
1997	High	10.02 (8.97–12.13)	7/9, 7/22
1998	Medium-high	7.18 (2.05–11.33)	7/8, 7/22
1999	Medium-high	10.69 (7.86–13.78)	7/7, 7/28
2000	Medium	7.22 (5.58–10.17)	7/6
2001	Low	2.33 (0.09–4.55)	7/12, 7/25
2002	Low	4.13 (0.19–7.01)	7/1
2003	Medium-low	3.78 (0.21–10.04)	7/23

[a] Data collected at RM 323, none collected at RM 325 in 1994.

Table 2. Summary of measured profile transition zone DO collected in July at or near RM 325, 1991−2003, and an example of the aeration allocation implementation approach using a 10-year average concept.

Year	Flow Conditions	Mean (Range) DO mg/L	Dates Sampled	Example Aeration Level Tons/Year	10-Year Average Aeration Level
1991	Low	2.78 (0.15–5.12)	7/9, 7/23	2250	
1992	Low	4.82 (0.22–9.64)	7/7, 7/21	2250	
1993	Medium	9.29 (5.43–13.61)	7/8, 7/22	1125	
1994[a]	Low	6.17 (3.52–10.82)	7/11	2250	
1995	Medium	10.71 (9.06–15.11)	7/5, 7/17	1125	
1996	Medium-high	10.81 (8.38–12.84)	7/2, 7/17	0	
1997	High	10.02 (8.97–12.13)	7/9, 7/22	0	
1998	Medium-high	7.18 (2.05–11.33)	7/8, 7/22	0	
1999	Medium-high	10.69 (7.86–13.78)	7/7, 7/28	0	
2000	Medium	7.22 (5.58–10.17)	7/6	1125	1012.5
2001	Low	2.33 (0.09–4.55)	7/12, 7/25	2250	1012.5
2002	Low	4.13 (0.19–7.01)	7/1	2250	1012.5
2003	Medium-low	3.78 (0.21–10.04)	7/23	2250	1125.0

[a] Data collected at RM 323, none collected at RM 325 in 1994.

Table 3. Concentrations of selected constituents measured in the transition zone on July 23, 2003.

River Mile	Depth (m)	Ammonia (mg/L)	Sulfide (mg/L)	Methane (mg/L)	Dissolved Iron (mg/L)	Dissolved Manganese (mg/L
305	0.3	0.13	na	na	<0.01	<0.01
305	25.0	0.07	<0.05	0.0007	<0.01	<0.01
305	48.0	0.69	<0.05	0.58	<0.01	
310	0.3	0.10	na	na	<0.01	<0.01
310	20.0	0.04	<0.05	0.008	<0.01	<0.01
310	36.0	1.48	0.80	1.20	0.03	0.68
315	0.3	0.08	na	na	<0.01	<0.01
315	18.0	0.22	na	na	<0.01	<0.01
315	25.0	0.51	<0.05	0.34	<0.01	0.13
320	0.3	<0.01	na	na	<0.01	<0.01
320	16.0	0.49	0.09	0.21	<0.01	0.24
320	25.0	1.62	0.95	1.70	<0.01	0.81
325	0.3	0.02	na	0.04	<0.01	<0.01
325	10.0	0.13	na	0.06	<0.01	<0.01
325	18.0	0.37	<0.05	0.18	<0.01	0.25
330	7.0	0.03	na	na	<0.01	<0.01

Note: “na” indicates that a sample was not collected for this parameter. The symbol < indicates that the results were less than detection limits.

Table 4. Summary of generation loss and operating costs for a forced-air blower system.

Design Year	Days of Operation (JD)	Annual Generation Loss—Efficiency Loss ($)	Annual Operating Cost–Blowers ($)	Total Annual Operating/ Loss Cost ($)	Oxygen Added From Blowers (tons)
1992—low water year	148–338, 340–341*, 342–345	348,000	210,000	558,000	3914
1994—medium-low water year	158–310, 314, 316, 317, 318–319, 323, 324–326, 332–333*, 336, 337, 341, 342, 343–346*	369,000	231,000	600,000	4133
1995—medium water year	185–194*, 195–306, 315, 316	379,000	262,000	641,000	4230
1999—medium-high water year	182–286, 287–293*, 294–307, 311, 313−323, 333–337	466,000	303,000	769,000	5305
1997—high water year	188–194*, 196, 197−202, 203, 204−255, 256, 257, 261–270, 271, 280−281*, 286–287, 306–307, 308	335,000	264,000	599,000	3780
Average		**379,400**	**254,000**	**633,400**	**4272**

Table 5. Summary of capital construction costs for reservoir aeration system.

CAPITAL CONSTRUCTION COSTS					
Item	**Units**	**Quantity**	**Unit Price**	**Extended Cost**	**Total**
Liquid Oxygen Supply					
50,000 Gal. Liquid Oxygen Storage Tank	EA	1	$485,000	$485,000	
Ambient Vaporizers (56K cont 100k peak Rating)	EA	4	$31,000	$124,000	
Switching Assembly	EA	1	$9,000	$9,000	
Regulator Assembly	EA	1	$5,000	$5,000	
Pressure Reducing Station	EA	1	$10,000	$10,000	
Miscellaneous Piping	LS	1	$5,000	$5,000	
Labor	LS	1	$10,000	$10,000	
Shipping & Crane	LS	1	$35,000	$35,000	
Subtotal:					*$683,000*
Reservoir Diffuser System					
Reservoir Diffusers	LF	12200	$60.66	$740,000	
Manifold and Supply Piping Costs	LS	1	$95,000	$95,000	
Subtotal:					*$835,000*
Site Improvements					
Unloading Apron	SF	150	$7.00	$1,050	
Concrete Pad (Vaporizers)	SF	1500	$5.00	$7,500	
Tank Footing Supports	EA	2	$15,000	$30,000	
Miscellaneous Grading	LS	1	$10,000	$10,000	
Screen Fence	LF	320	$12.00	$3,840	
Site Lighting / Power Improvements	LS	1	$10,000	$10,000	
Subtotal:					*$62,390*
SUBTOTAL					***$1,580,390***
Contingency	LS	15%			$237,058
TOTAL CAPITAL COSTS					**$1,817,448**

Table 6. Summary of operation and maintenance construction costs for reservoir aeration system.

OPERATING & MAINTENANCE COSTS (Annual)					
Item	**Units**	**Quantity**	**Unit Price**	**Extended Cost**	**Total**
Liquid Oxygen Supply					
Liquid Oxygen Delivery	Tons	1525	$200.00	$305,000	
Subtotal:					*$305,000*
Reservoir Diffuser System					
Annual Inspection	YR	1	$5,000	$5,000	
10-Yr Life Cycle	YR	0.1	$150,000	$15,000	
Subtotal:					*$20,000*
Miscellaneous					
Start-Up	LS	1	$15,000	$15,000	
Shut-Down	LS	1	$10,000	$10,000	
Subtotal:					*$25,000*
SUBTOTAL					*$350,000*
Contingency	LS	15%			$52,500
TOTAL OPERATING AND MAINTENANCE COSTS					$402,500

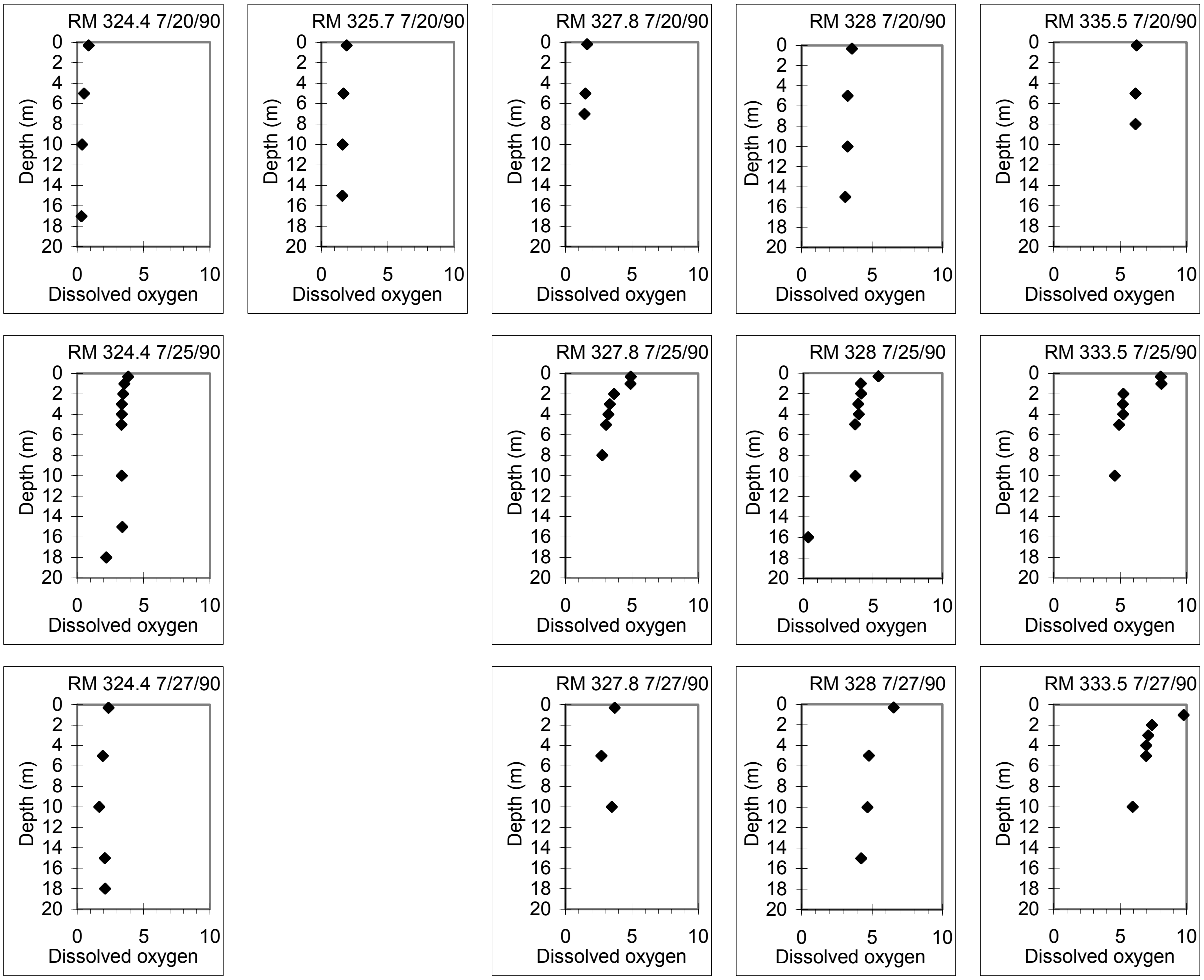


Figure 1. DO (mg/L) profiles measured in the upper end of the transition zone in 1990.

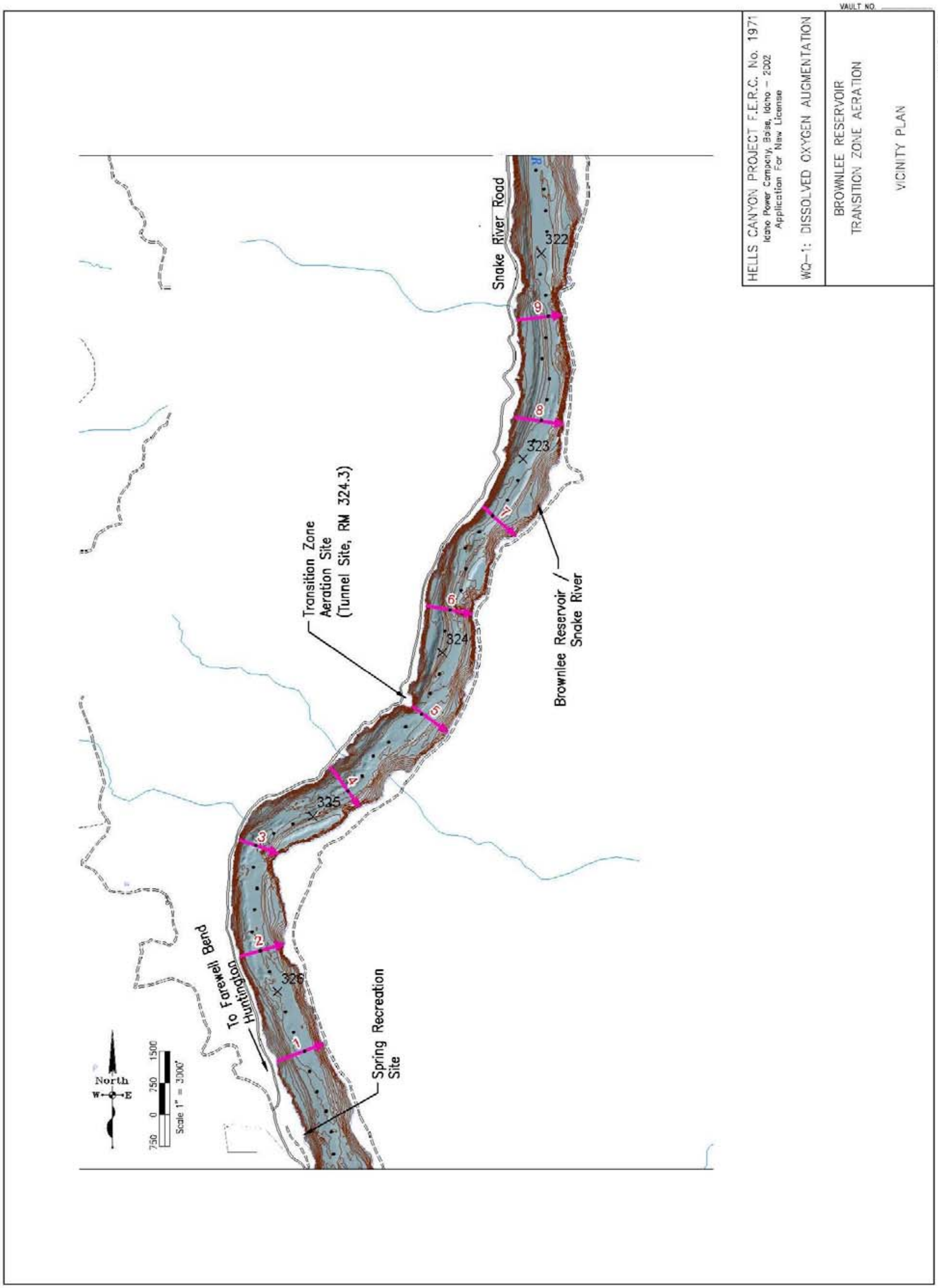


Figure 2. Vicinity plan.

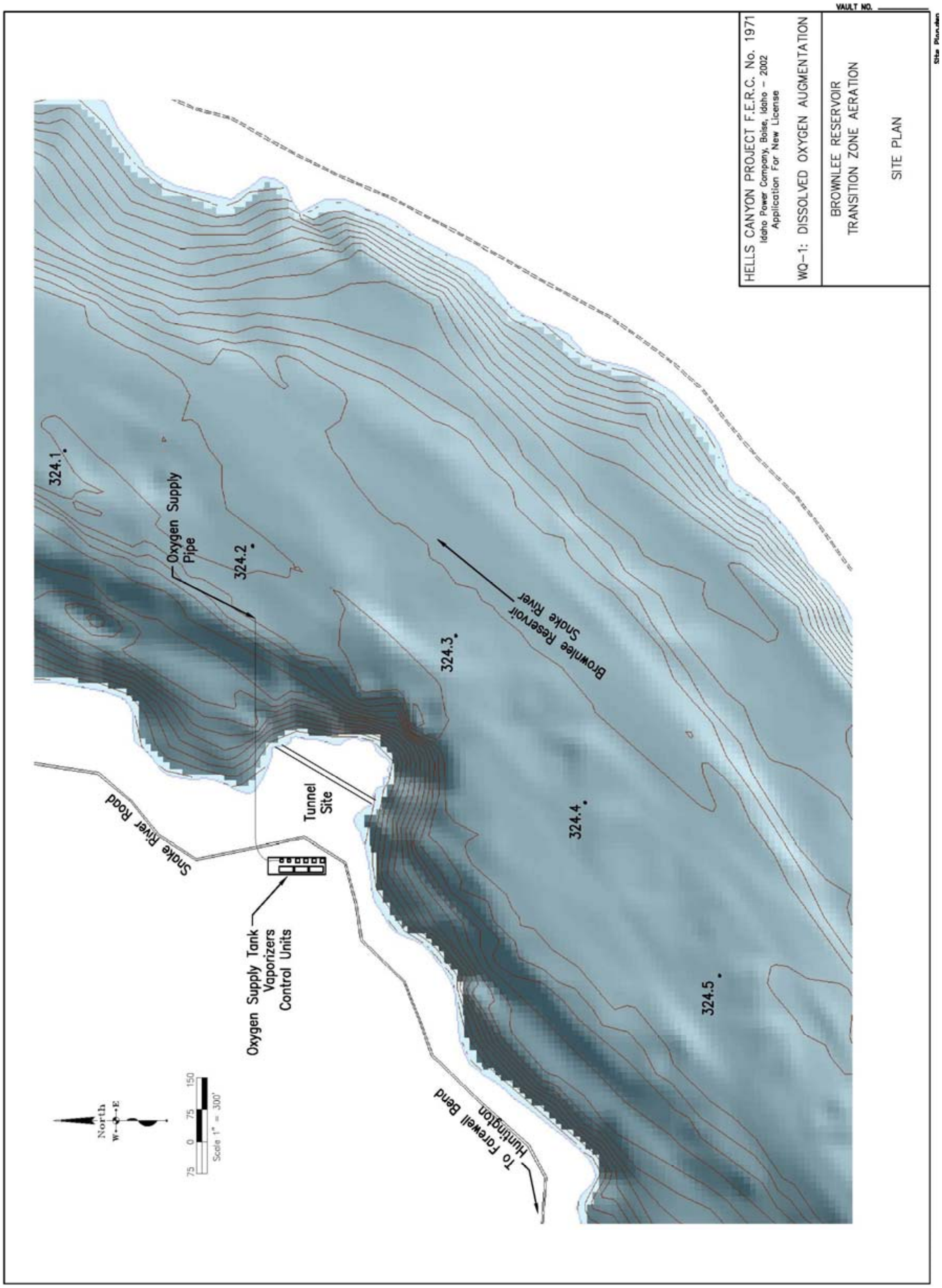


Figure 3. Site plan.

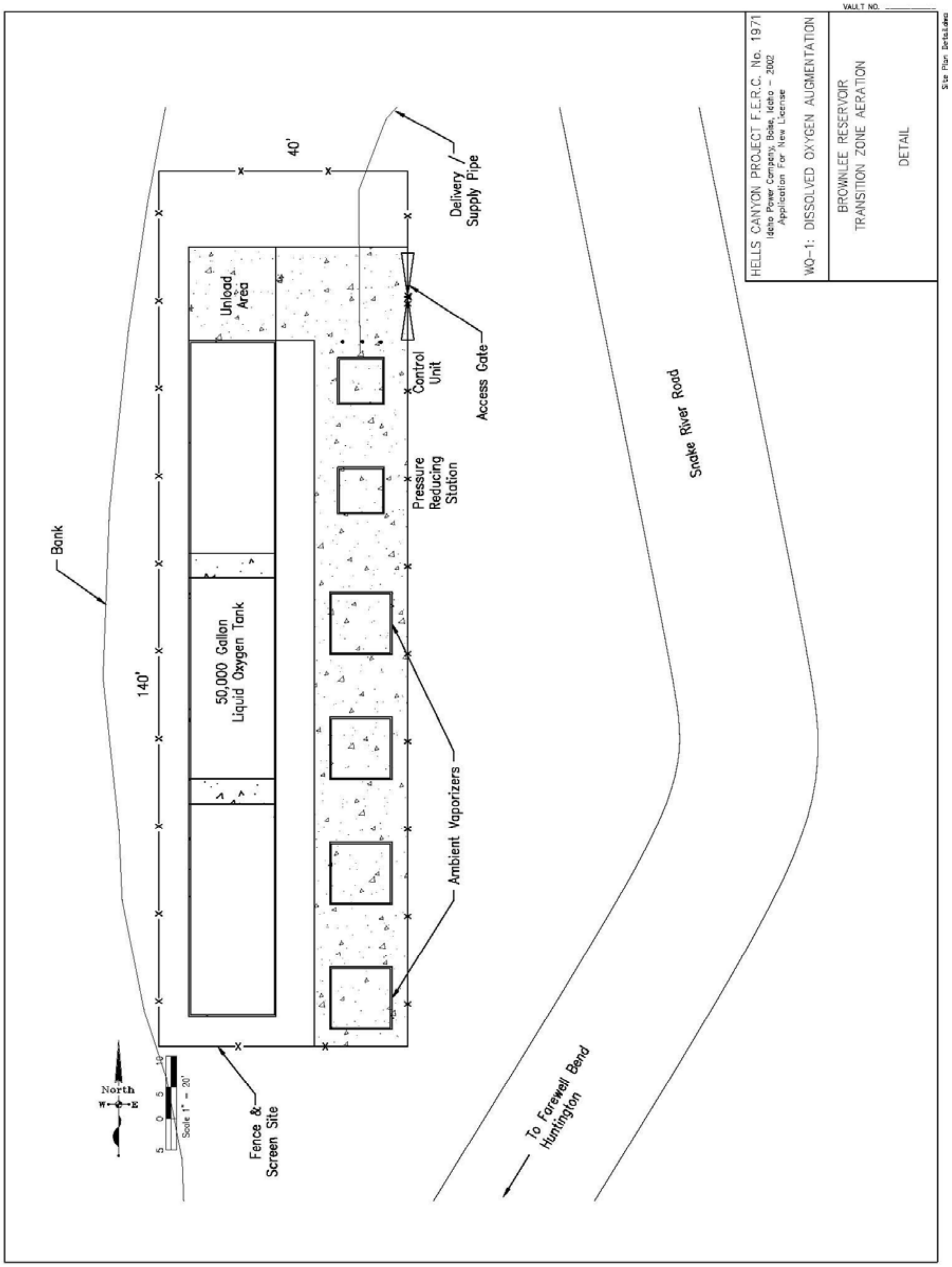


Figure 4. Site detail.

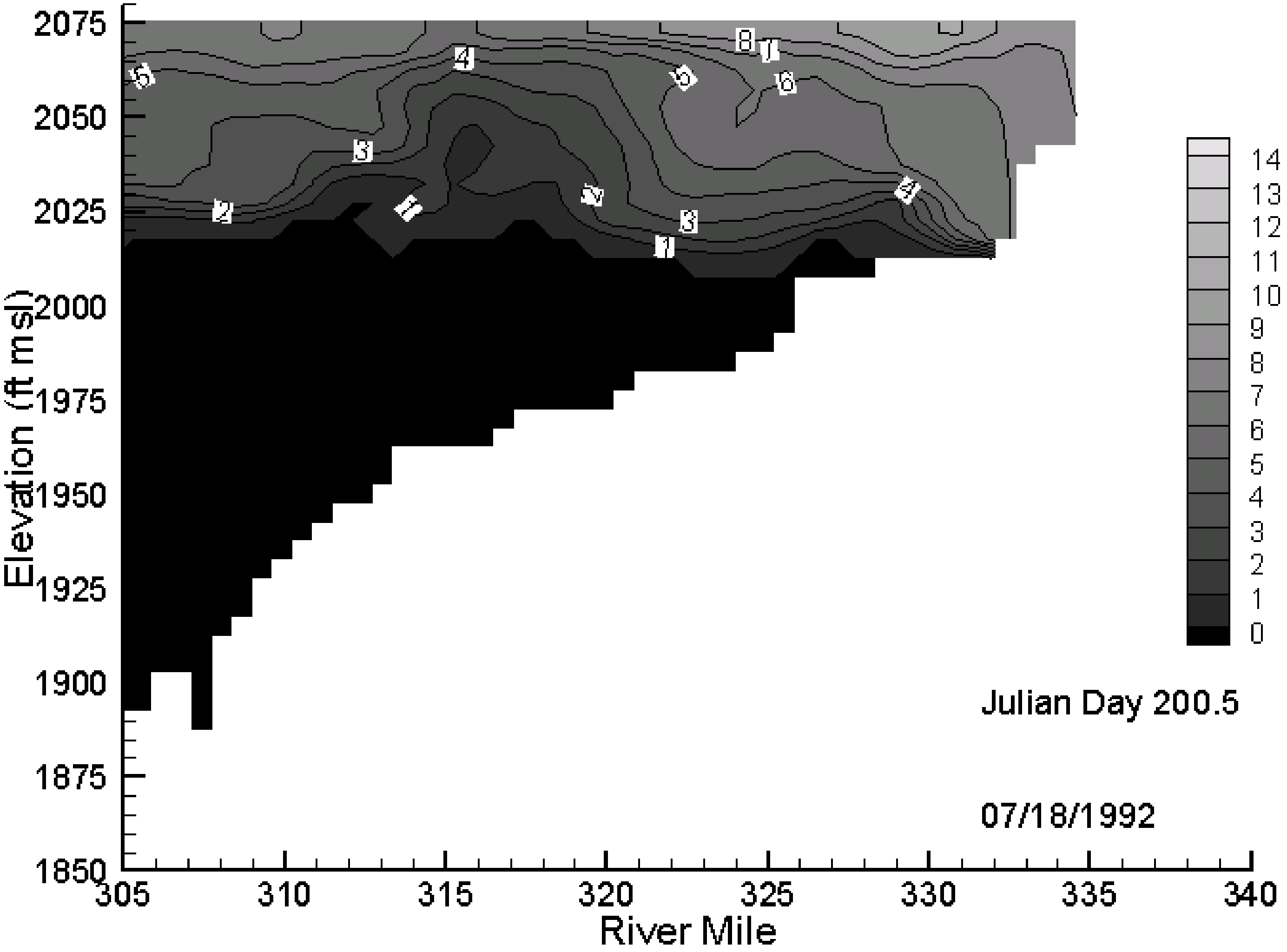


Figure 5. Simulated 1992 (low flow year) DO (mg/L) isopleth for the Brownlee transition zone under proposed operations.

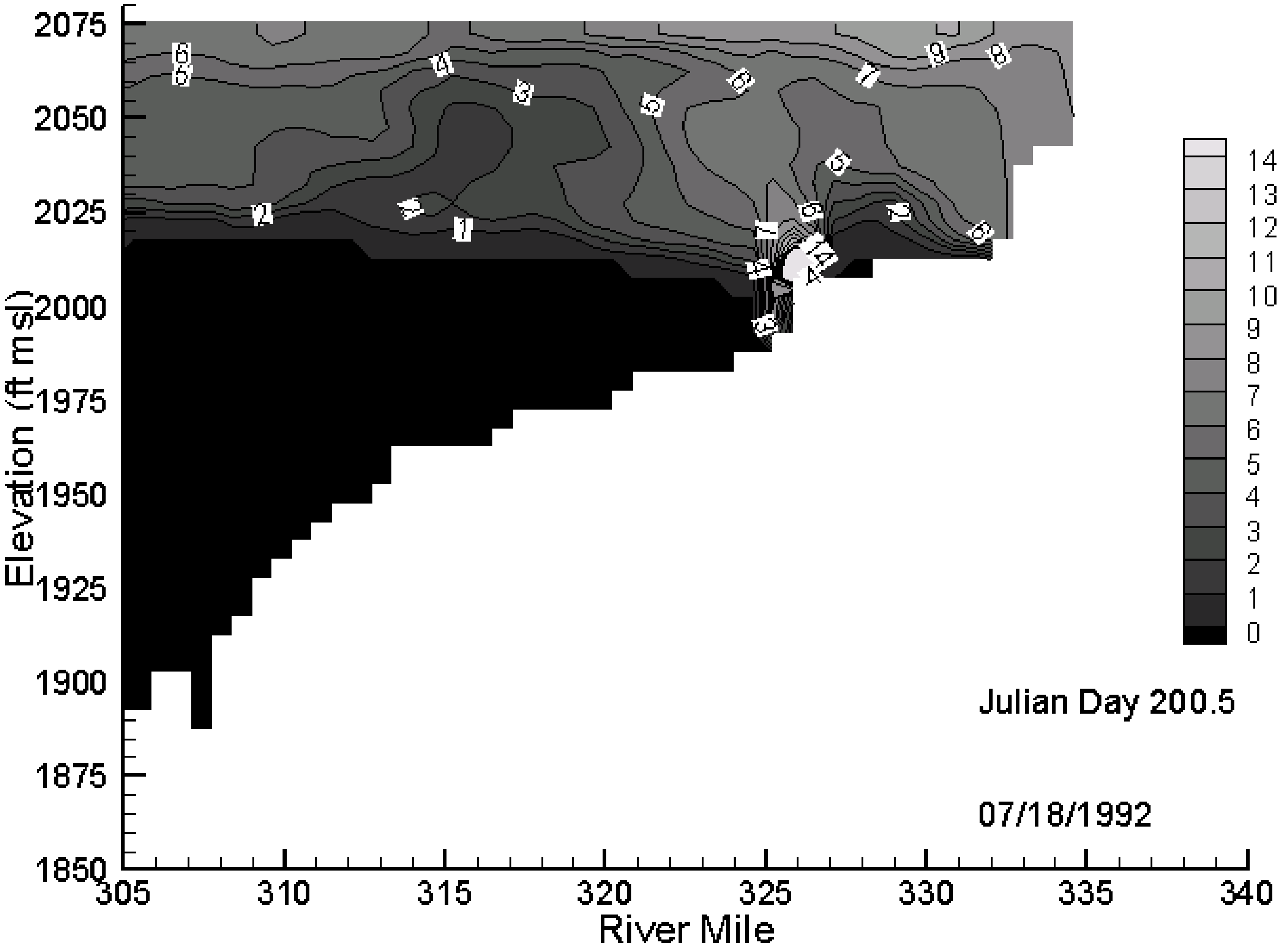


Figure 6. Simulated 1992 (low flow year) DO (mg/L) isopleth for the Brownlee transition zone under proposed operations with 1125-tons/yr aeration at the proposed location.

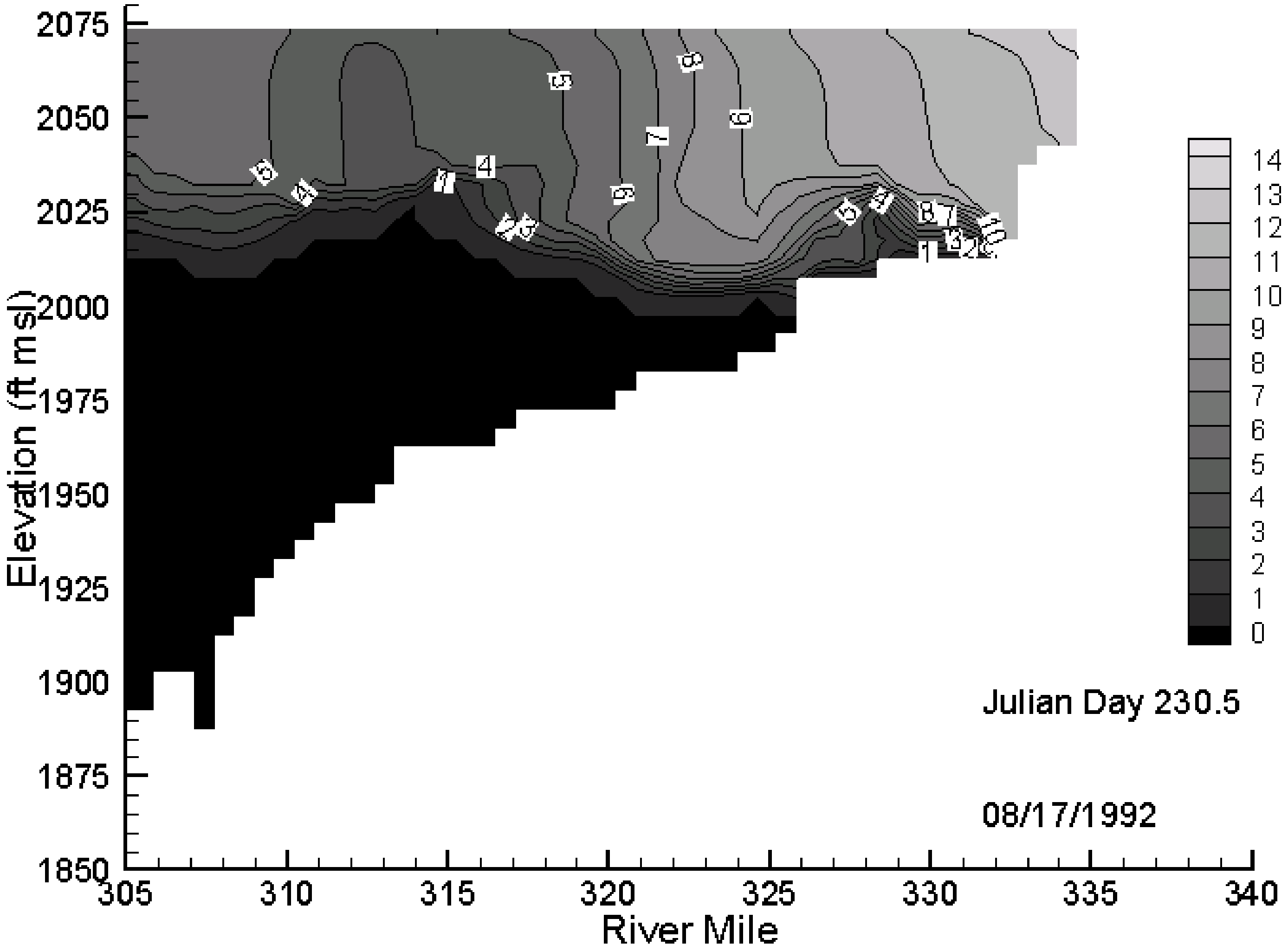


Figure 7. Simulated 1992 (low flow year) DO (mg/L) isopleth for the Brownlee transition zone under proposed operations.

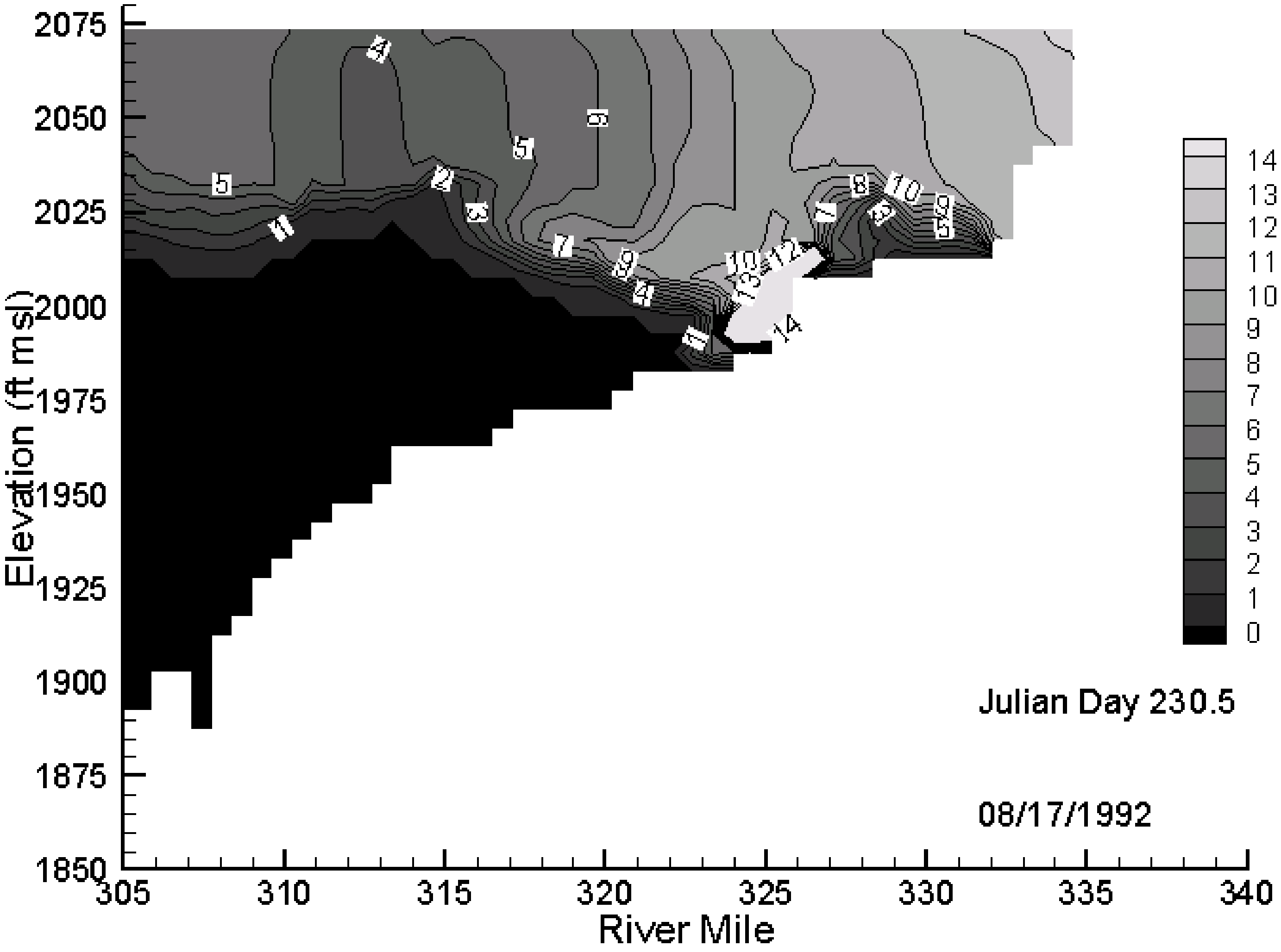


Figure 8. Simulated 1992 (low flow year) DO (mg/L) isopleth for the Brownlee transition zone under proposed operations with 1125-tons/yr aeration at the proposed location.

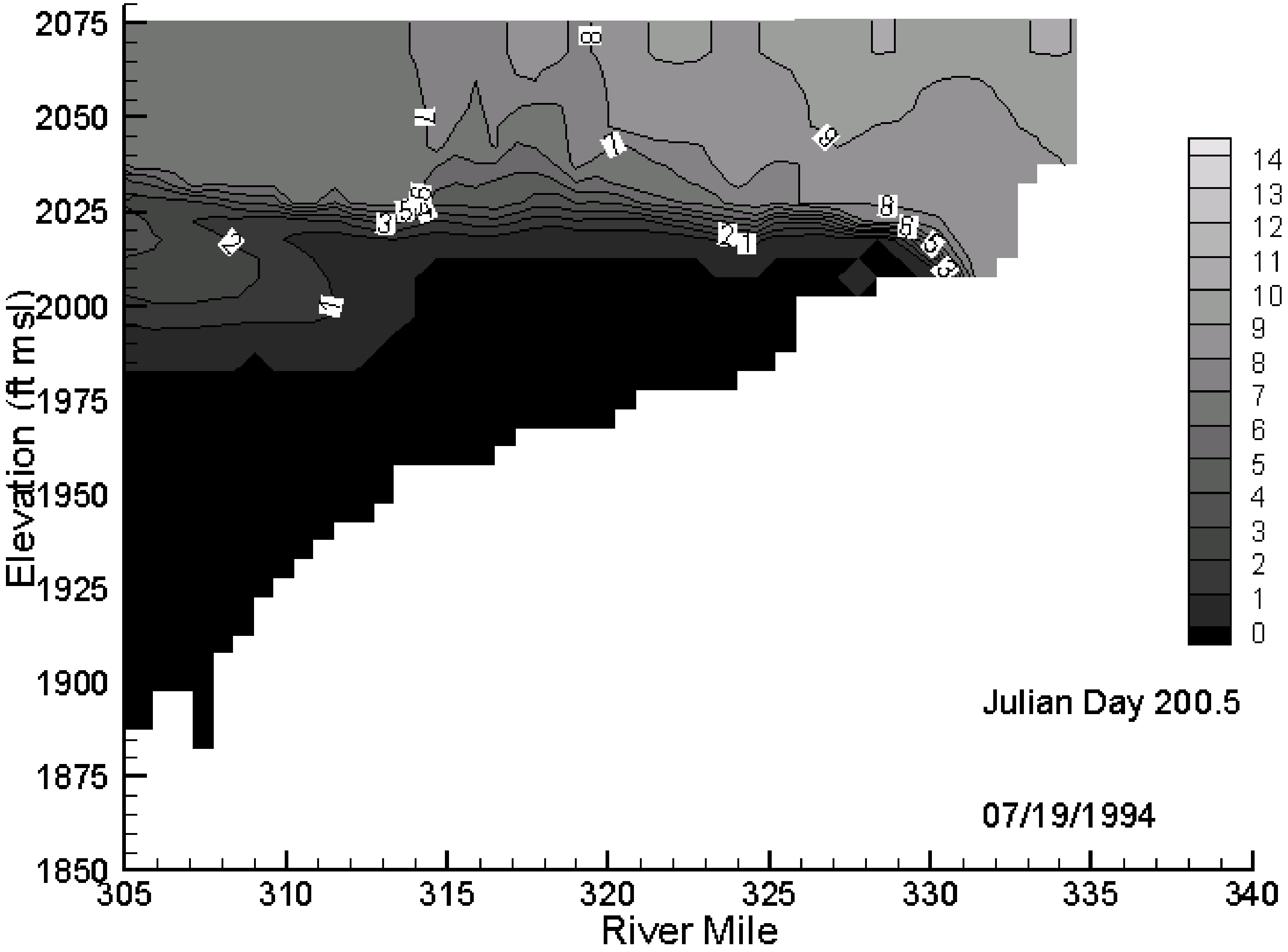


Figure 9. Simulated 1994 (medium-low flow year) DO (mg/L) isopleth for the Brownlee transition zone under proposed operations.

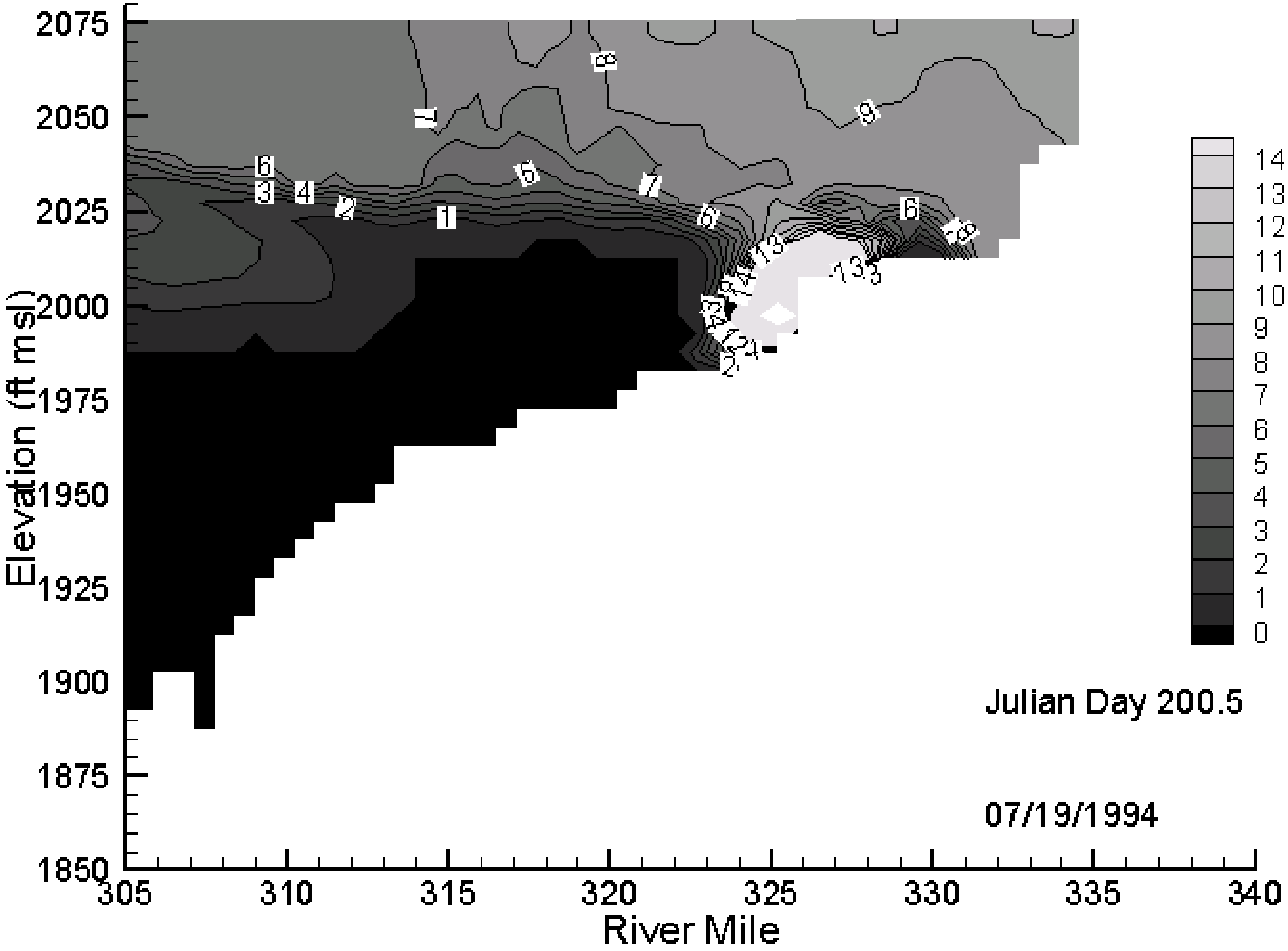


Figure 10. Simulated 1994 (medium-low flow year) DO (mg/L) isopleth for the Brownlee transition zone under proposed operations with 1125-tons/yr aeration at the proposed location.

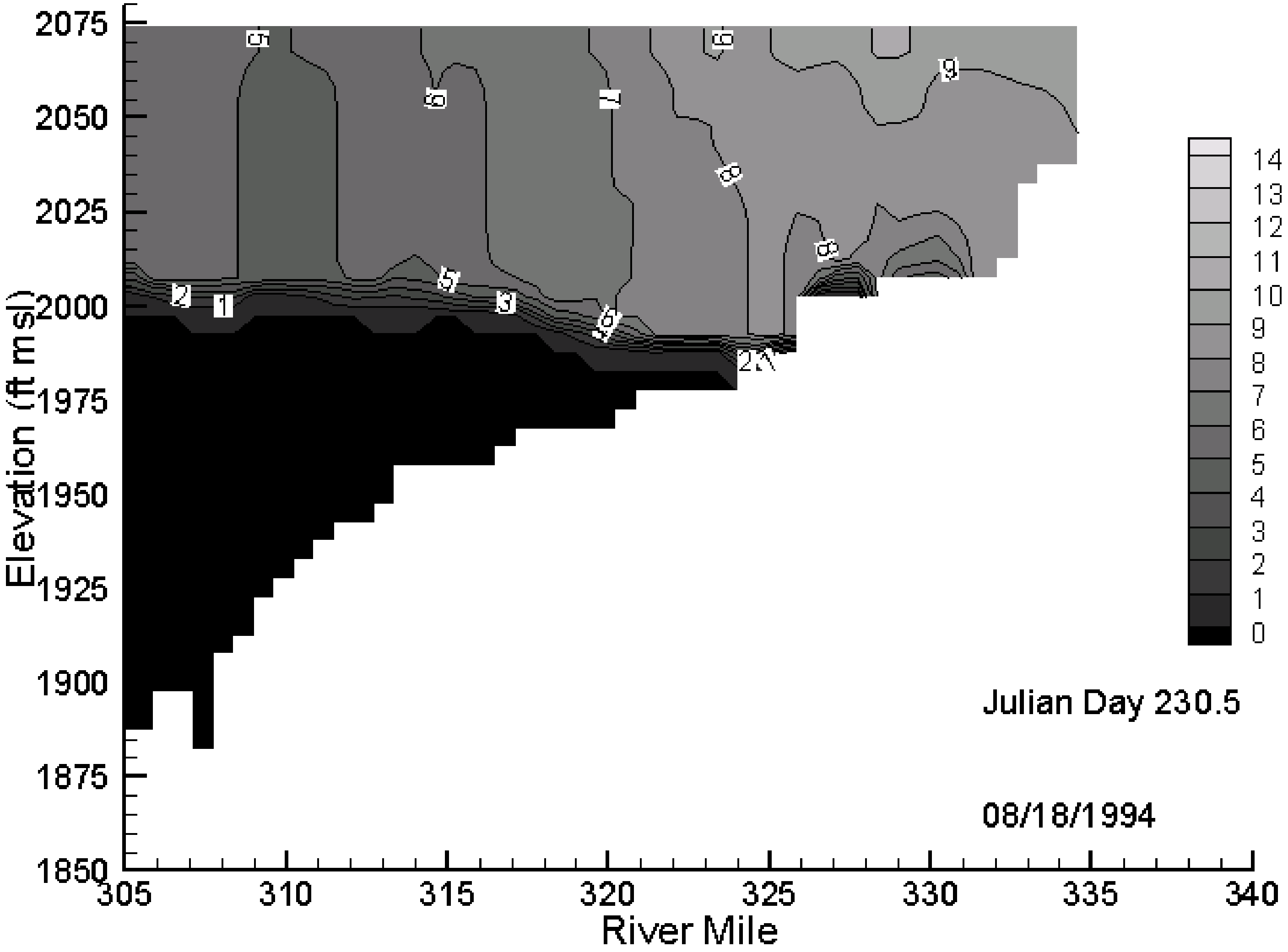


Figure 11. Simulated 1994 (medium-low flow year) DO (mg/L) isopleth for the Brownlee transition zone under proposed operations.

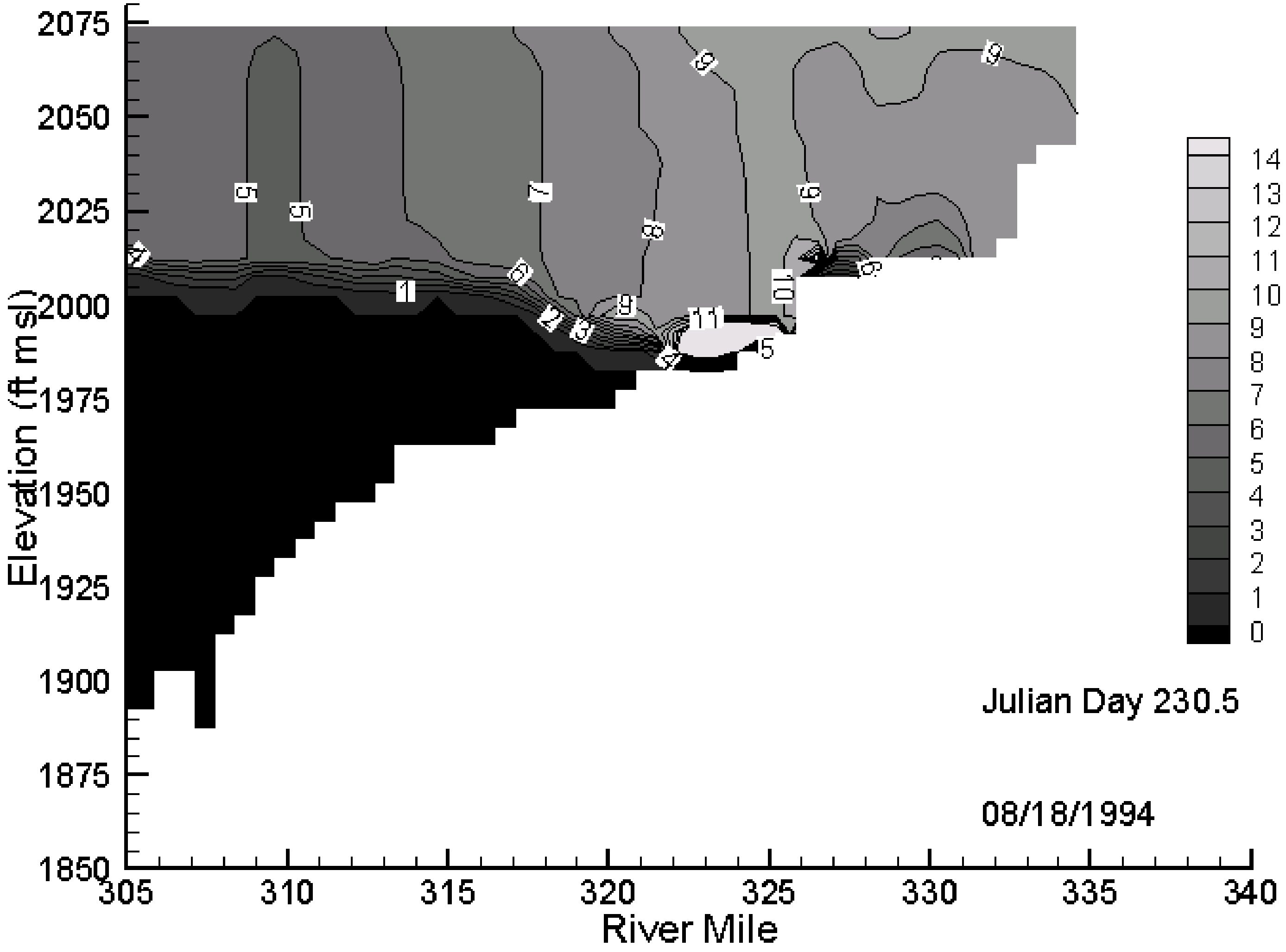


Figure 12. Simulated 1994 (medium-low flow year) DO (mg/L) isopleth for the Brownlee transition zone under proposed operations with 1125-tons/yr aeration at the proposed location.

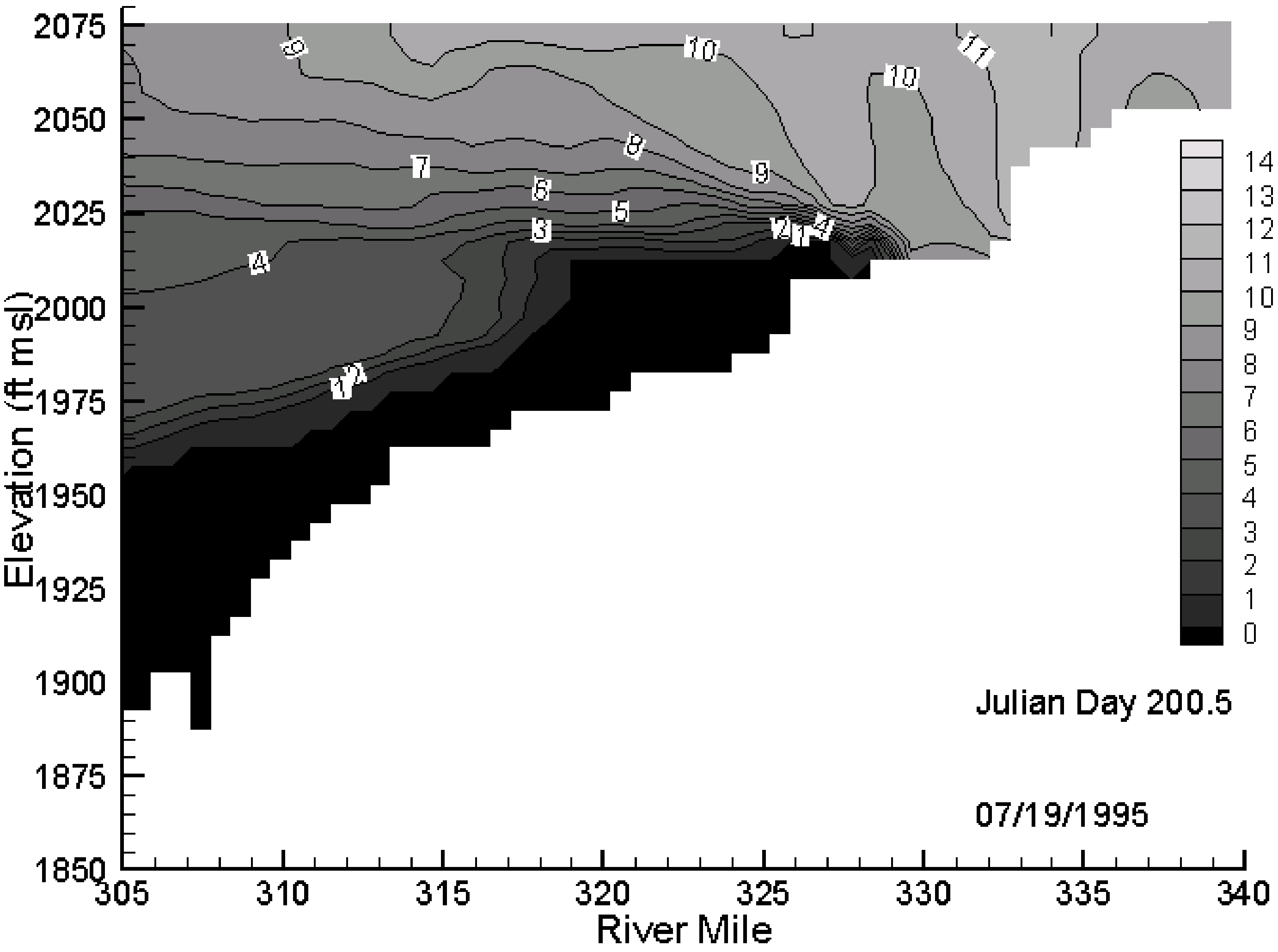


Figure 13. Simulated 1995 (medium flow year) DO (mg/L) isopleth for the Brownlee transition zone under proposed operations.

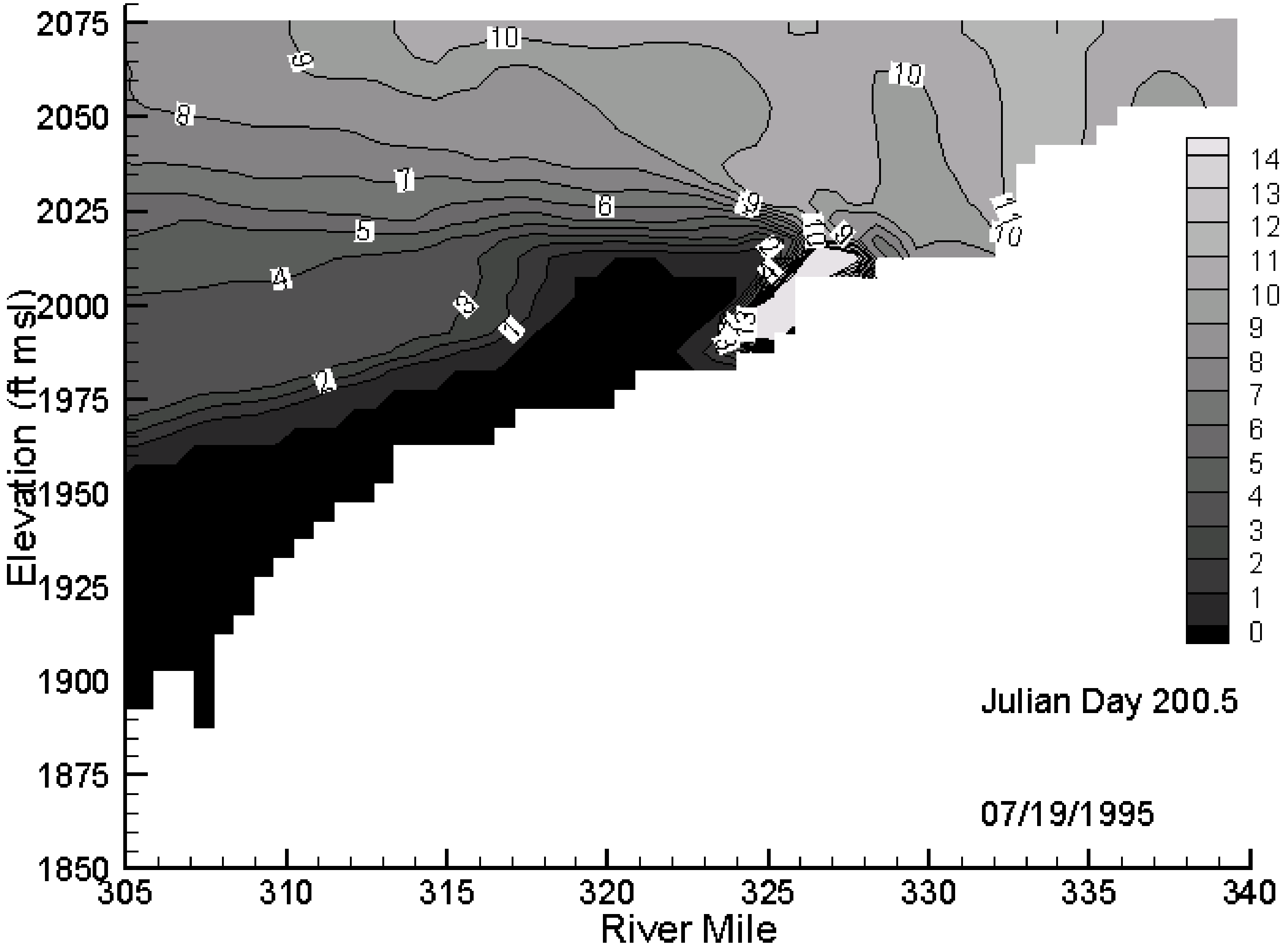


Figure 14. Simulated 1995 (medium flow year) DO (mg/L) isopleth for the Brownlee transition zone under proposed operations with 1125-tons/yr aeration at the proposed location.

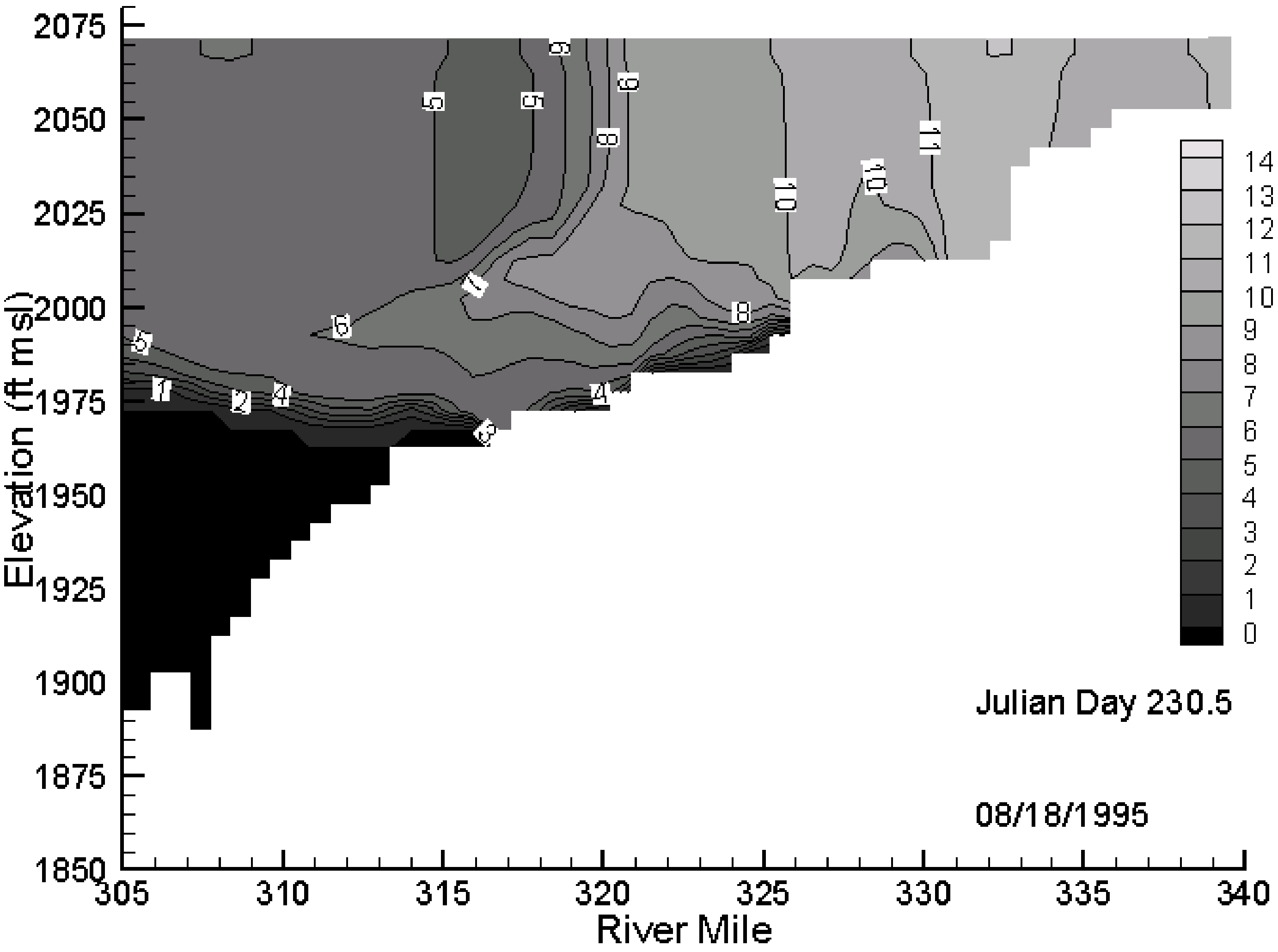


Figure 15. Simulated 1995 (medium flow year) DO (mg/L) isopleth for the Brownlee transition zone under proposed operations.

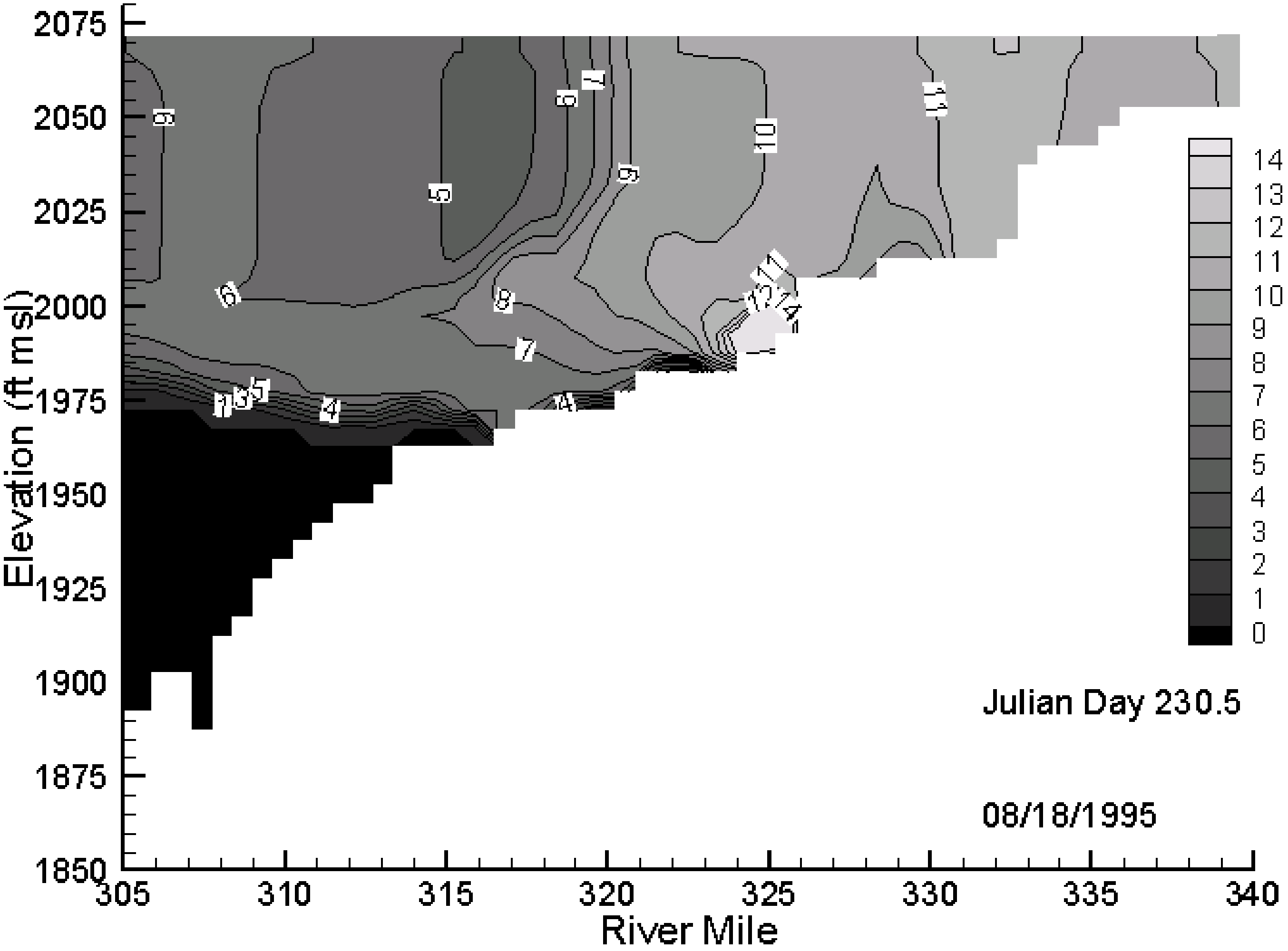


Figure 16. Simulated 1995 (medium flow year) DO (mg/L) isopleth for the Brownlee transition zone under proposed operations with 1125-tons/yr aeration at the proposed location.

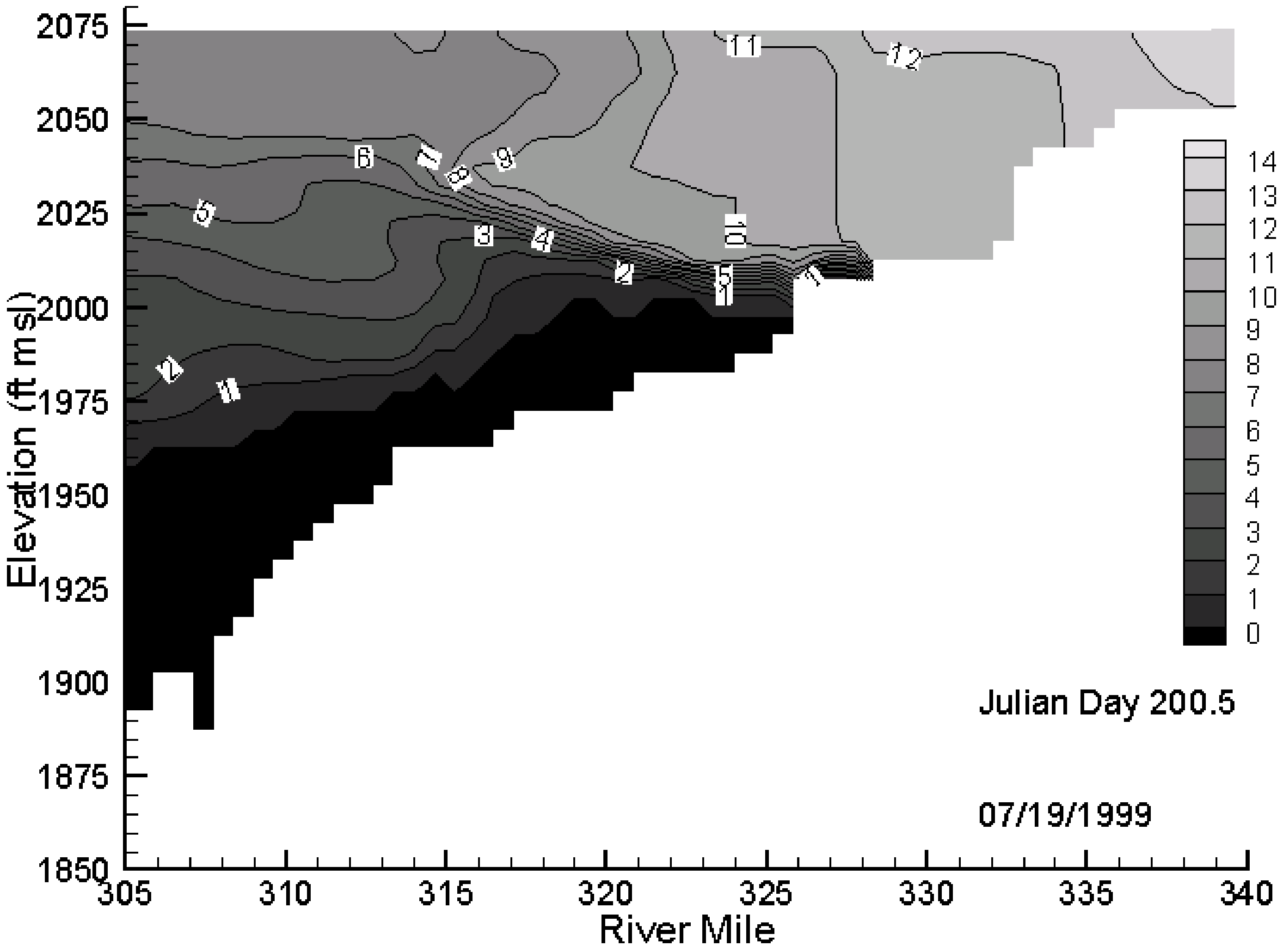


Figure 17. Simulated 1999 (medium-high flow year) DO (mg/L) isopleth for the Brownlee transition zone under proposed operations.

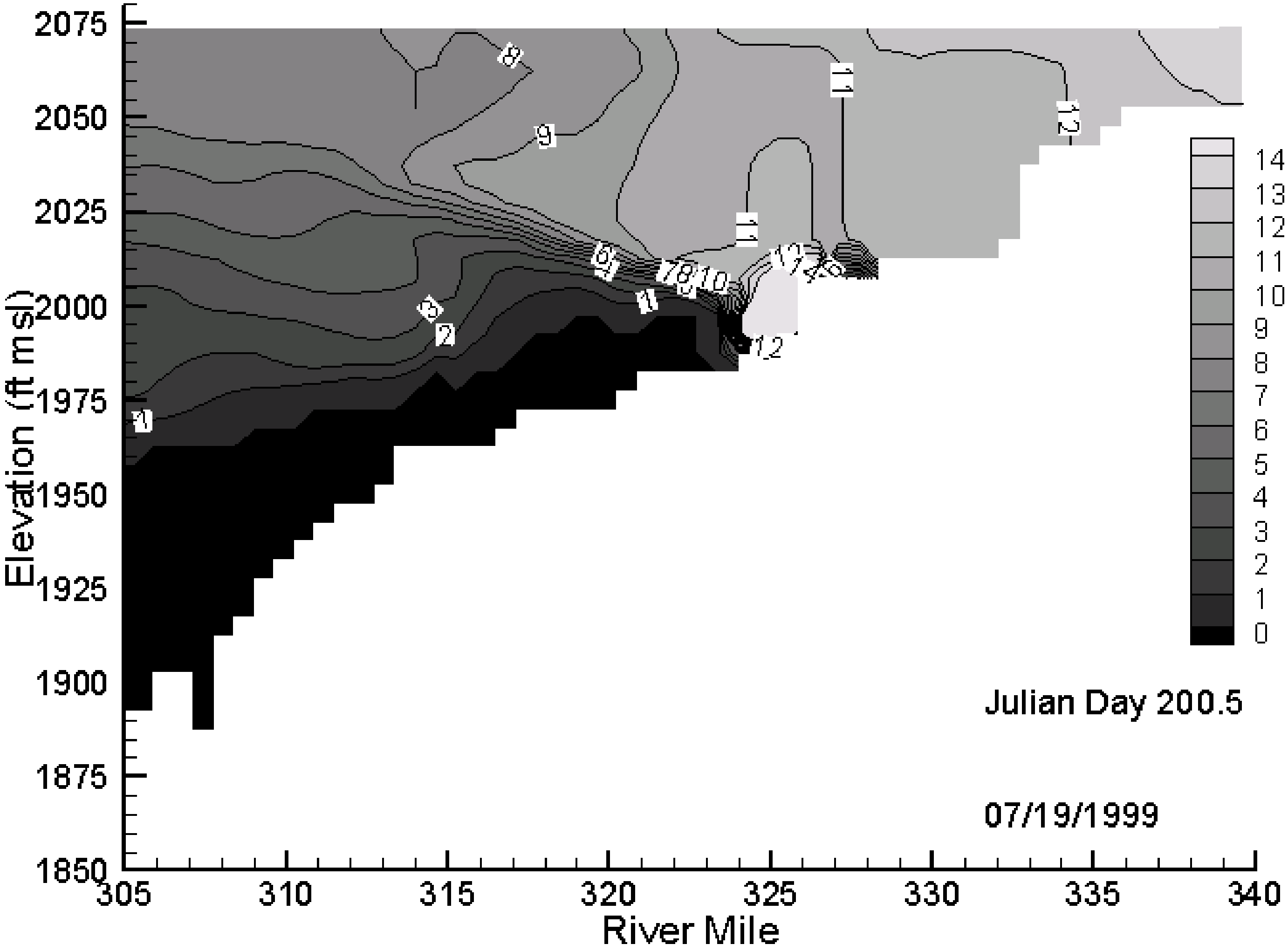


Figure 18. Simulated 1999 (medium-high flow year) DO (mg/L) isopleth for the Brownlee transition zone under proposed operations with 1125-tons/yr aeration at the proposed location.

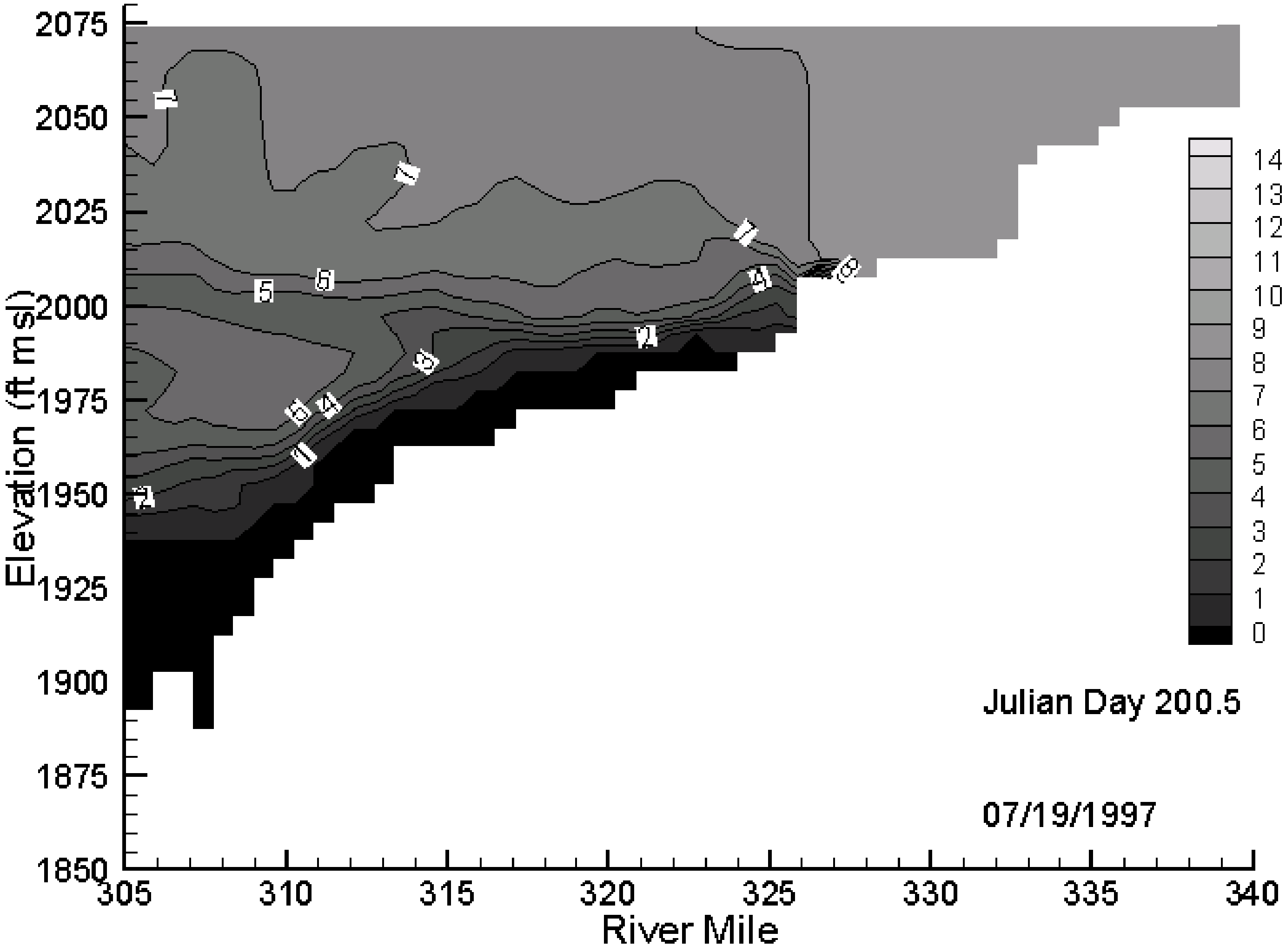


Figure 19. Simulated 1997 (high flow year) DO (mg/L) isopleth for the Brownlee transition zone under proposed operations.

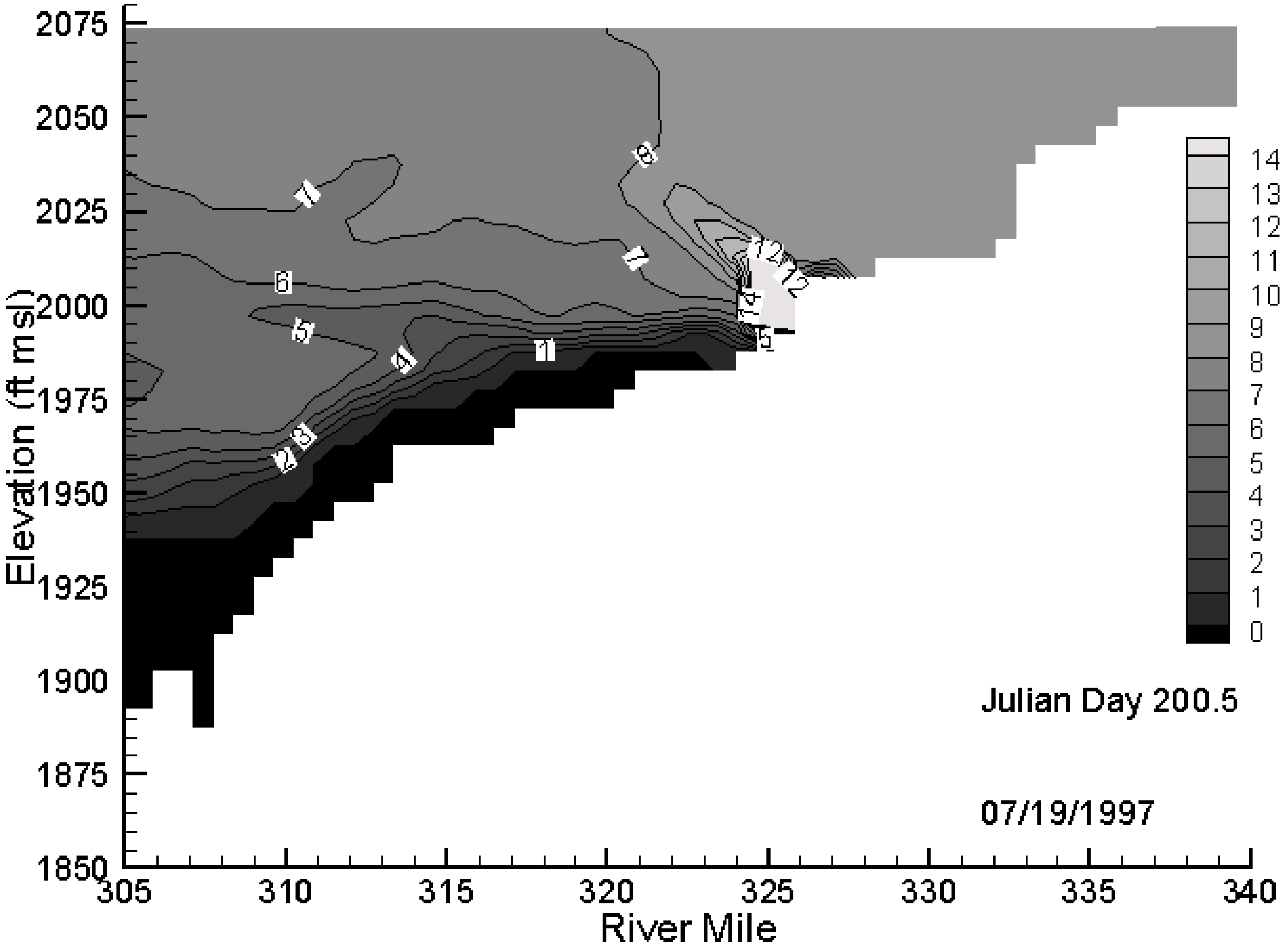


Figure 20. Simulated 1997 (high flow year) DO (mg/L) isopleth for the Brownlee transition zone under proposed operations with 1125-tons/yr aeration at the proposed location.

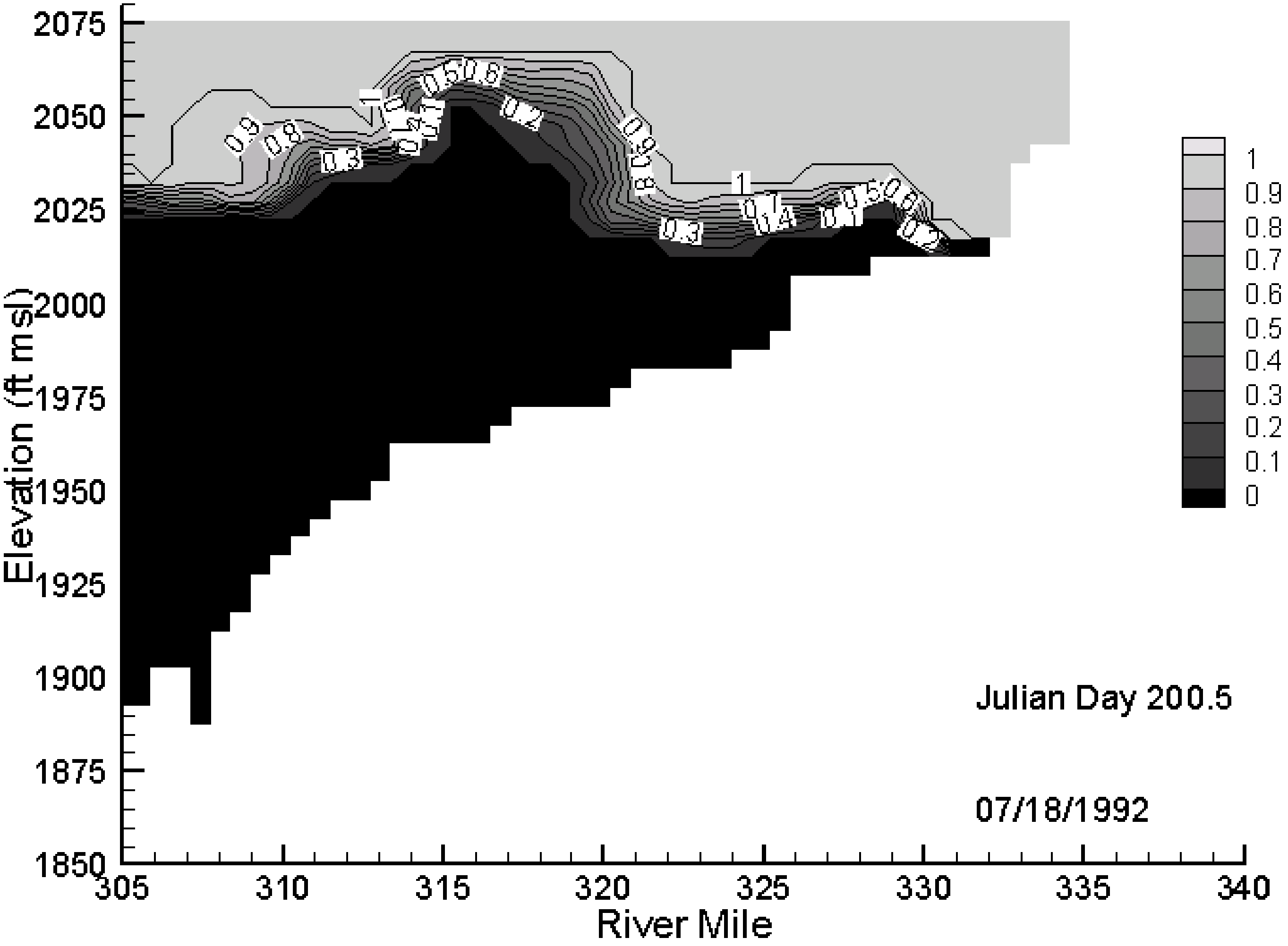


Figure 21. Simulated 1992 (low flow year) Sturgeon HSI isopleth for the Brownlee transition zone under proposed operations.

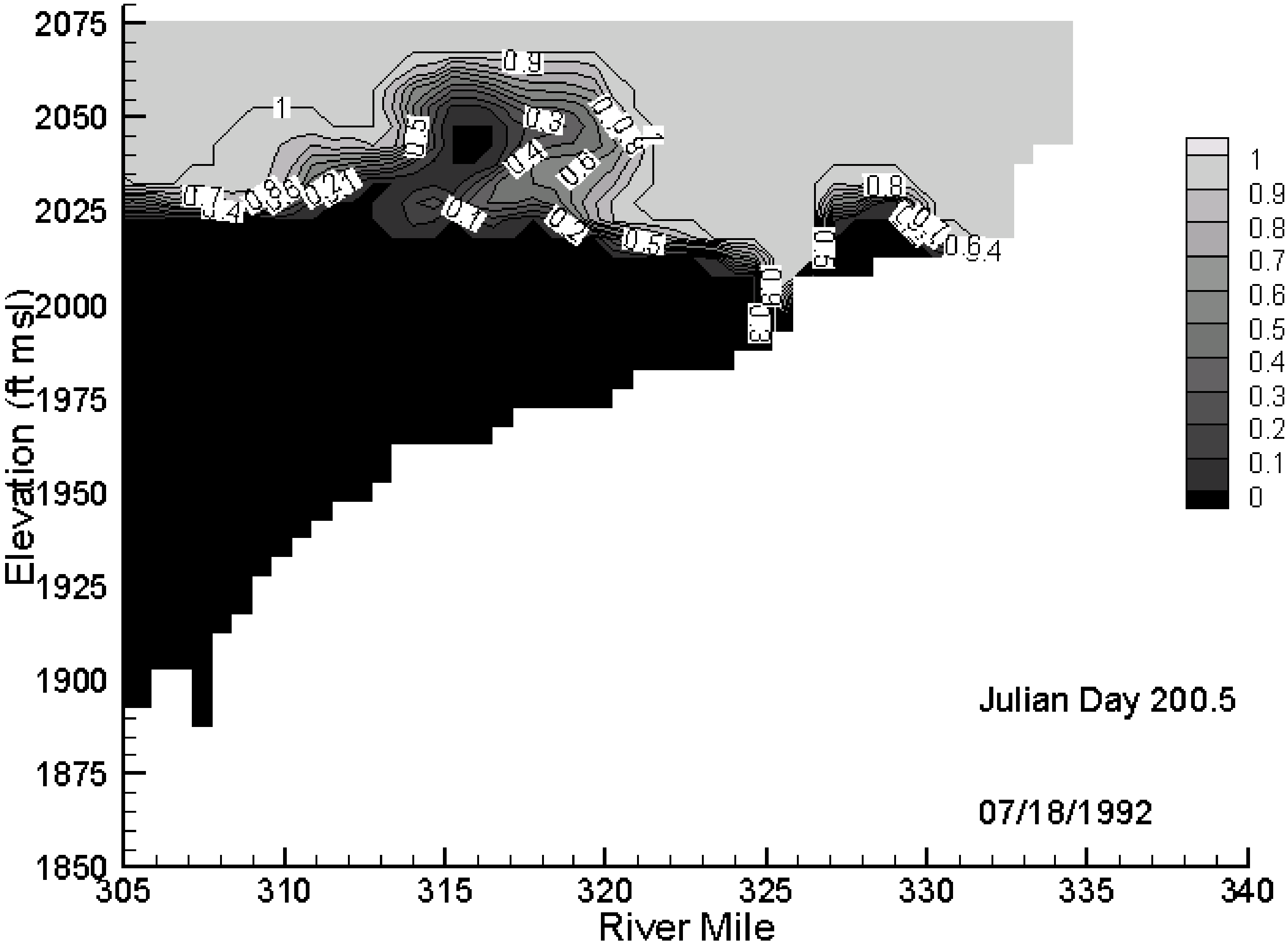


Figure 22. Simulated 1992 (low flow year) Sturgeon HSI isopleth for the Brownlee transition zone under proposed operations with 1125-tons/yr aeration at the proposed location.

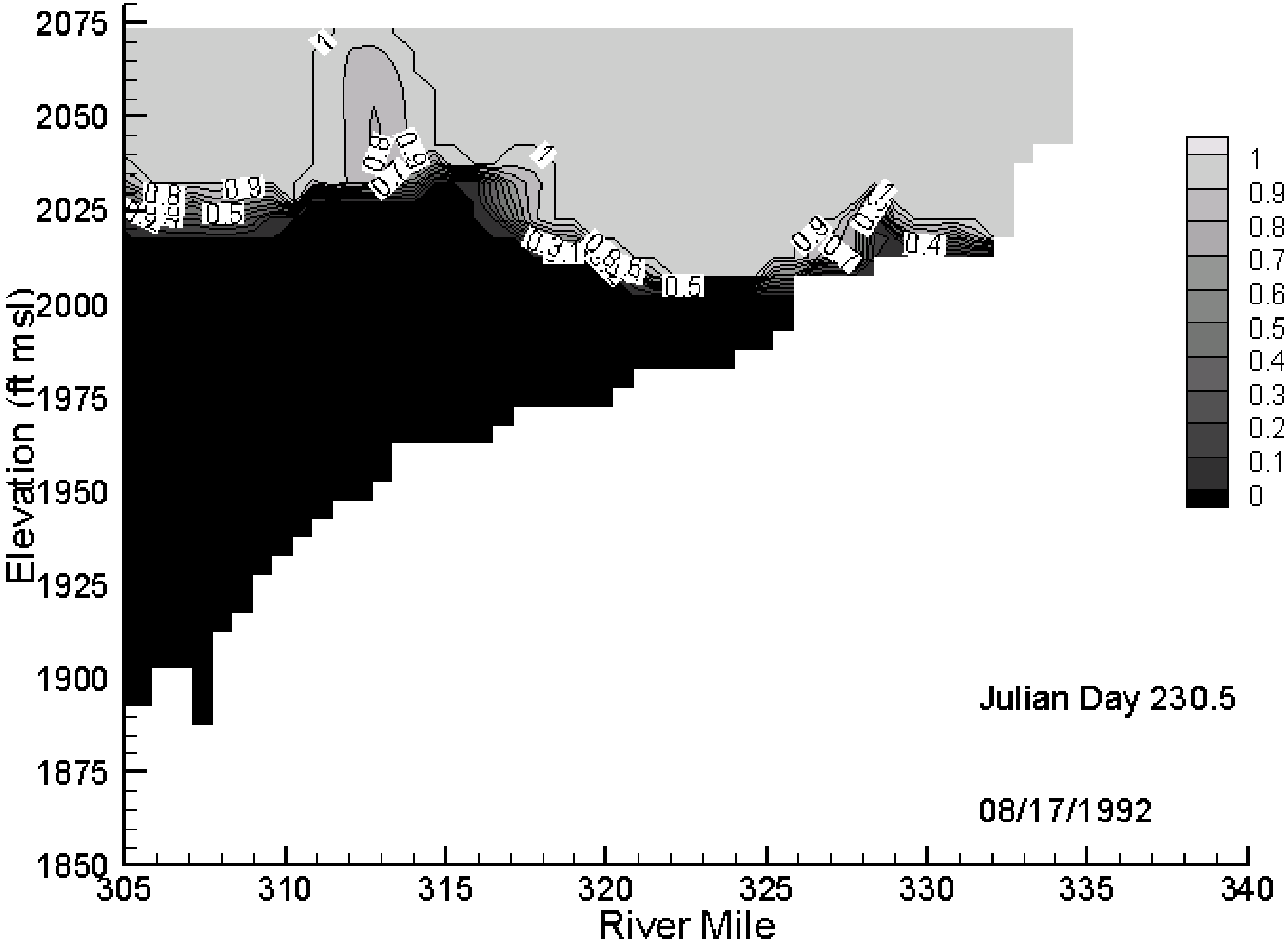


Figure 23. Simulated 1992 (low flow year) Sturgeon HSI isopleth for the Brownlee transition zone under proposed operations.

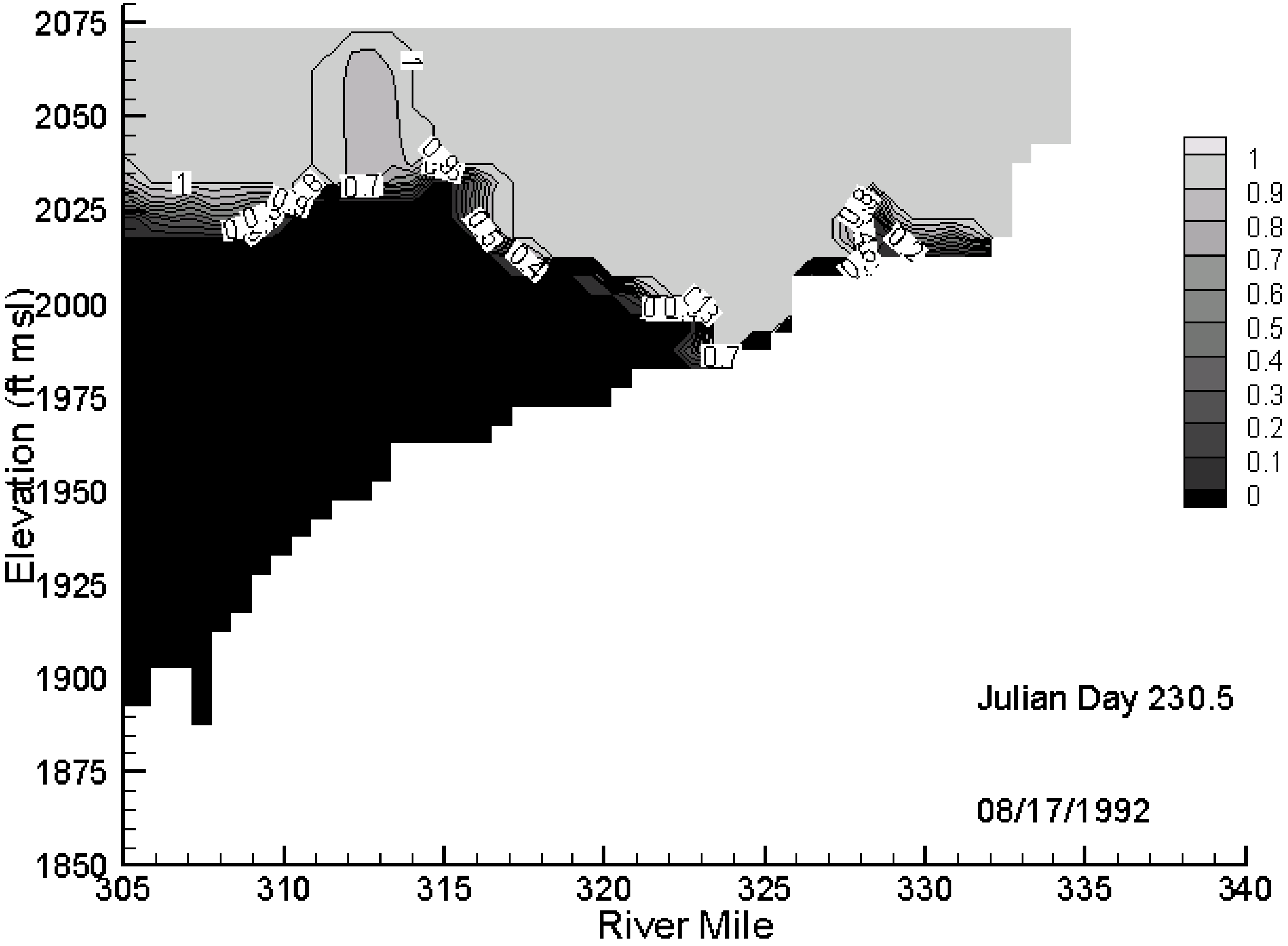


Figure 24. Simulated 1992 (low flow year) Sturgeon HSI isopleth for the Brownlee transition zone under proposed operations with 1125-tons/yr aeration at the proposed location.

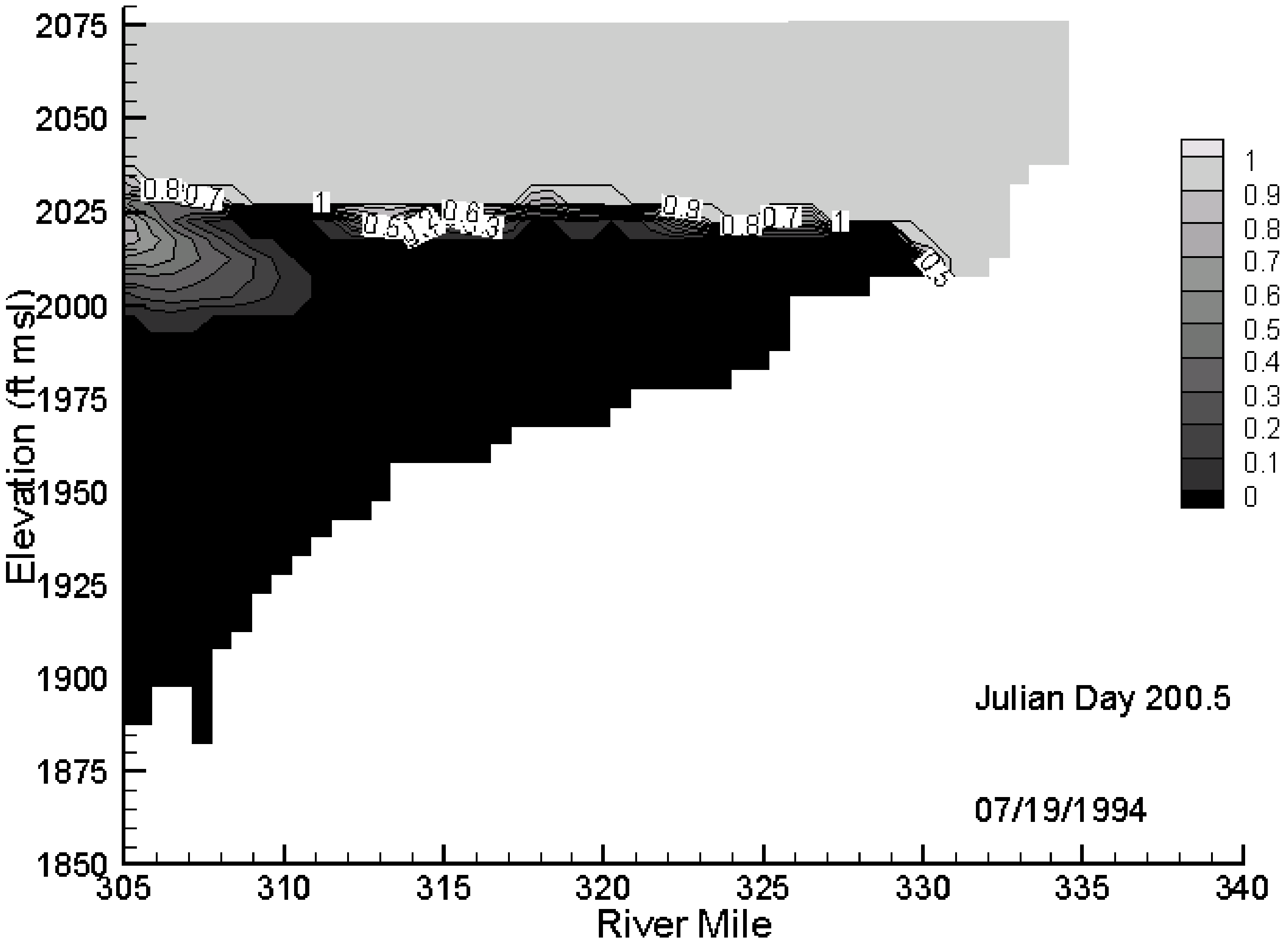


Figure 25. Simulated 1994 (medium-low flow year) Sturgeon HSI isopleth for the Brownlee transition zone under proposed operations.

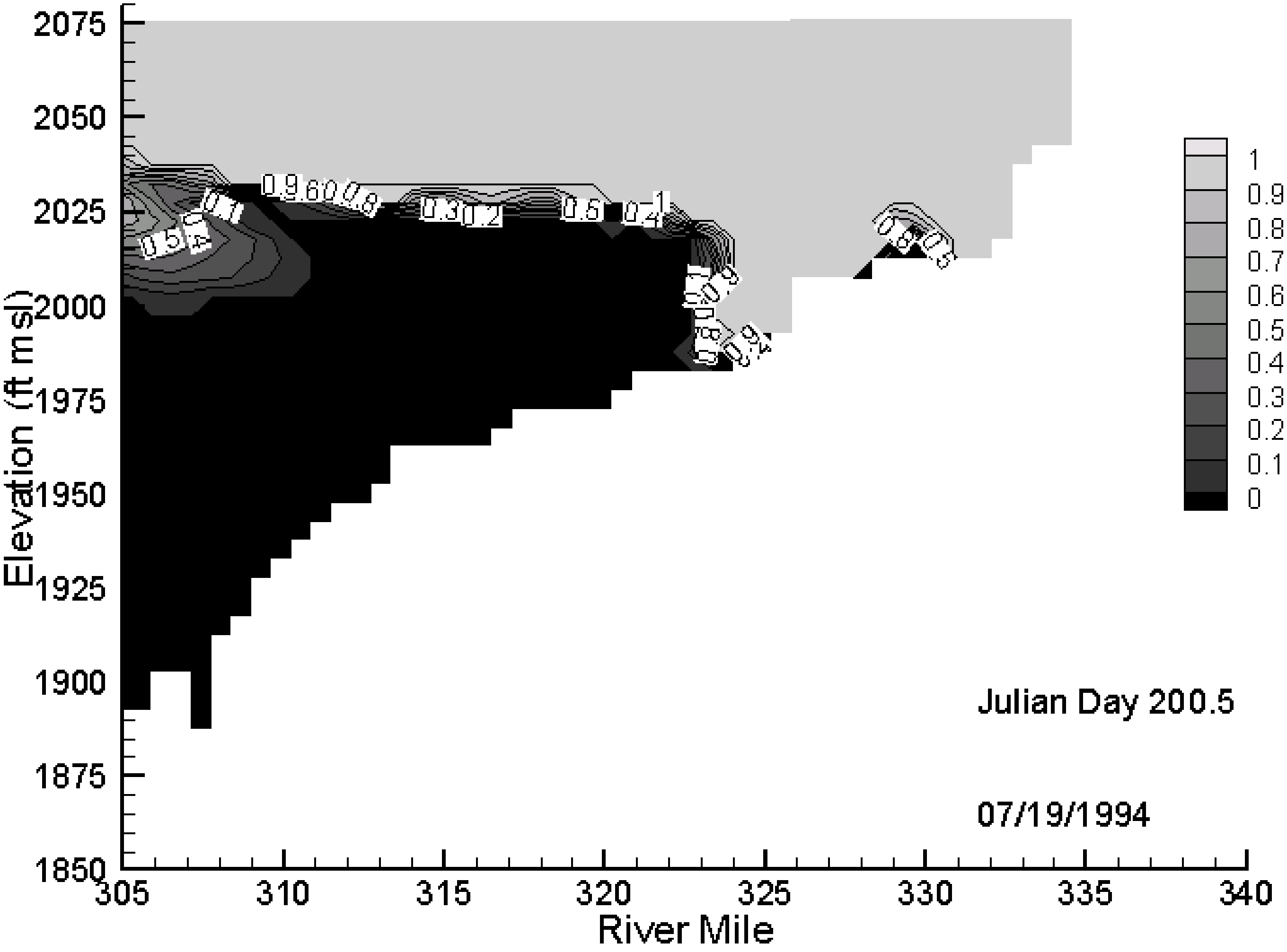


Figure 26. Simulated 1994 (medium-low flow year) Sturgeon HSI isopleth for the Brownlee transition zone under proposed operations with 1125-tons/yr aeration at the proposed location.

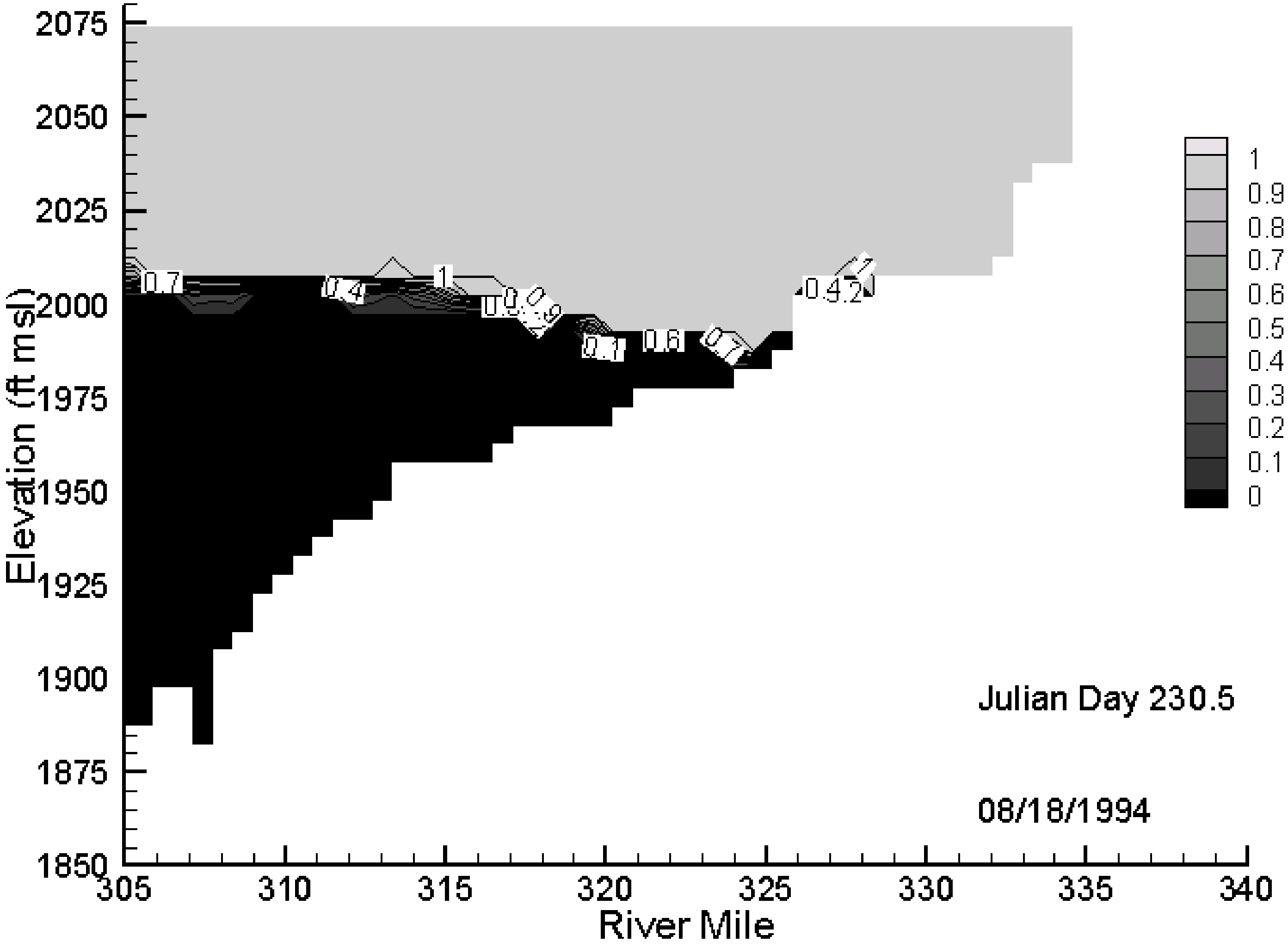


Figure 27. Simulated 1994 (medium-low flow year) Sturgeon HSI isopleth for the Brownlee transition zone under proposed operations.

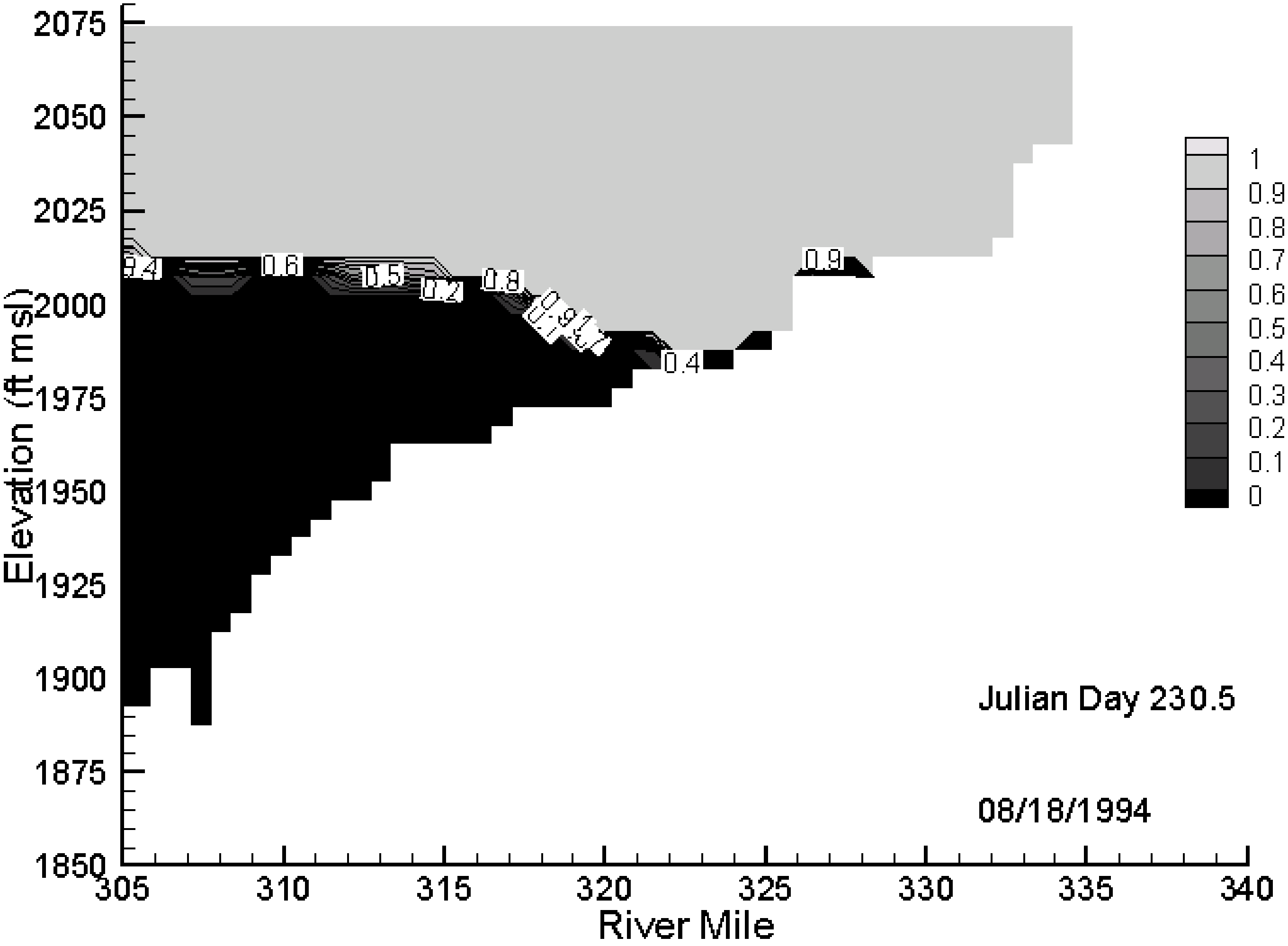


Figure 28. Simulated 1994 (medium-low flow year) Sturgeon HSI isopleth for the Brownlee transition zone under proposed operations with 1125-tons/yr aeration at the proposed location.

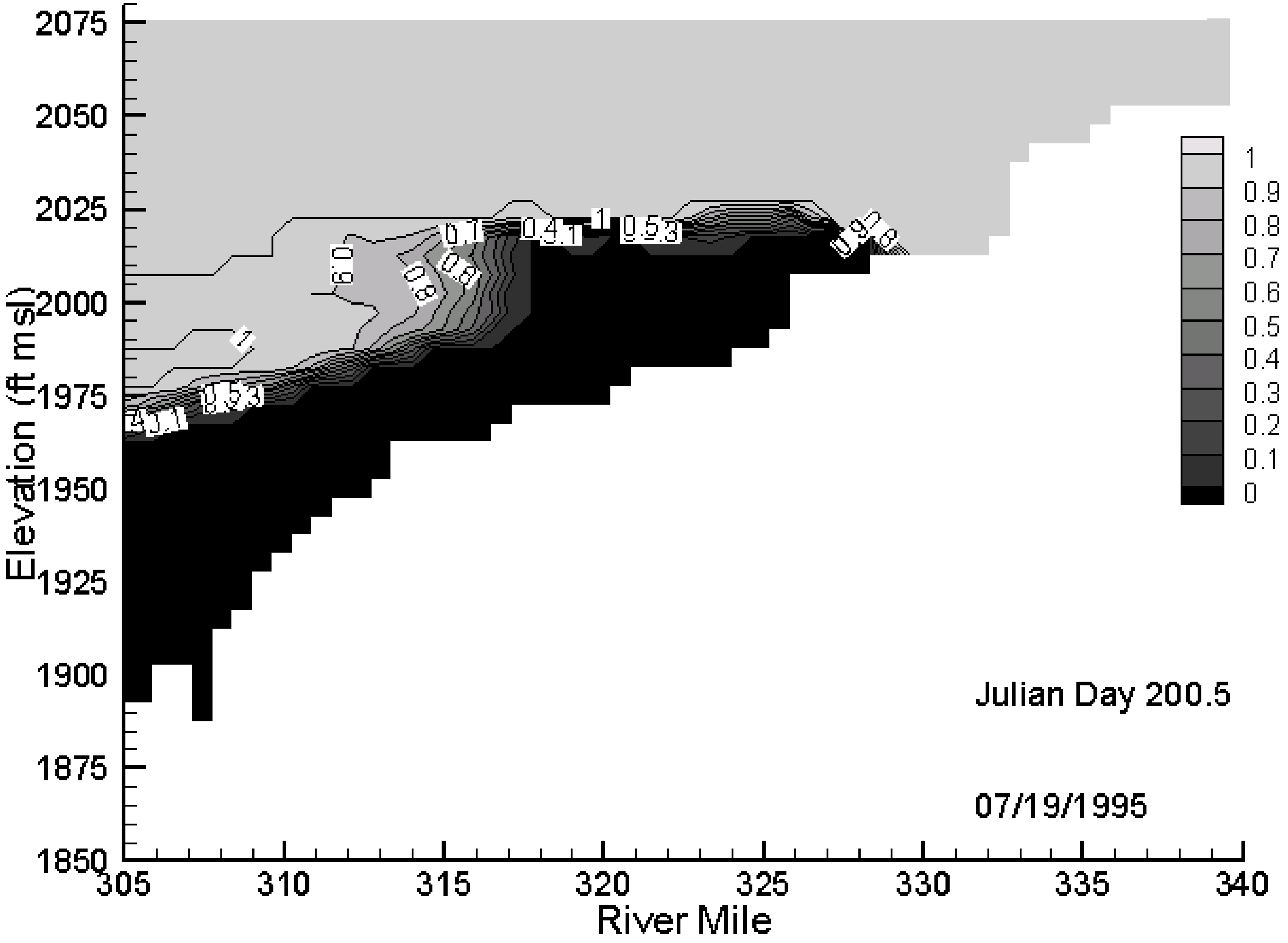


Figure 29. Simulated 1995 (medium flow year) Sturgeon HSI isopleth for the Brownlee transition zone under proposed operations.

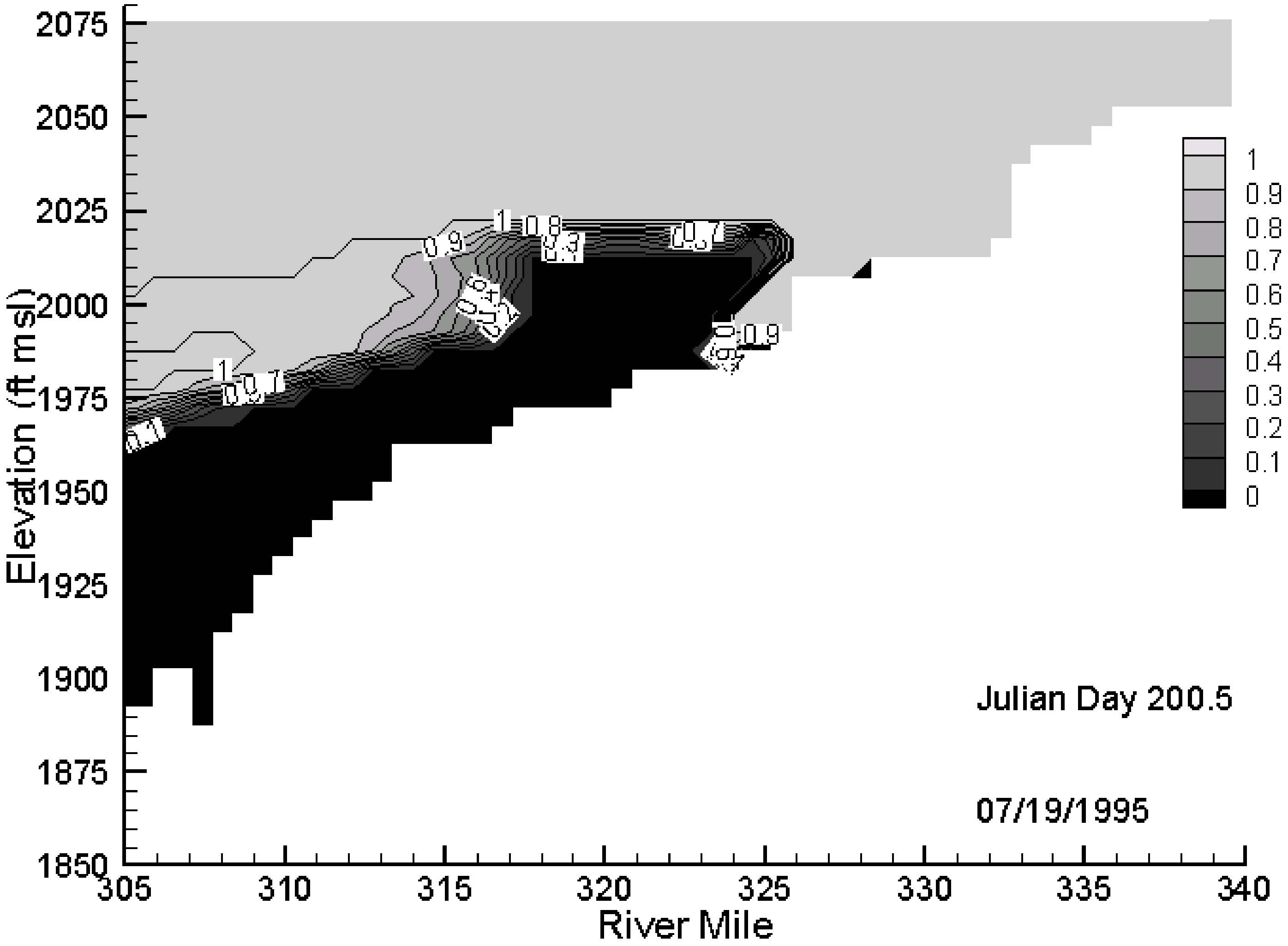


Figure 30. Simulated 1995 (medium flow year) Sturgeon HSI isopleth for the Brownlee transition zone under proposed operations with 1125-tons/yr aeration at the proposed location.

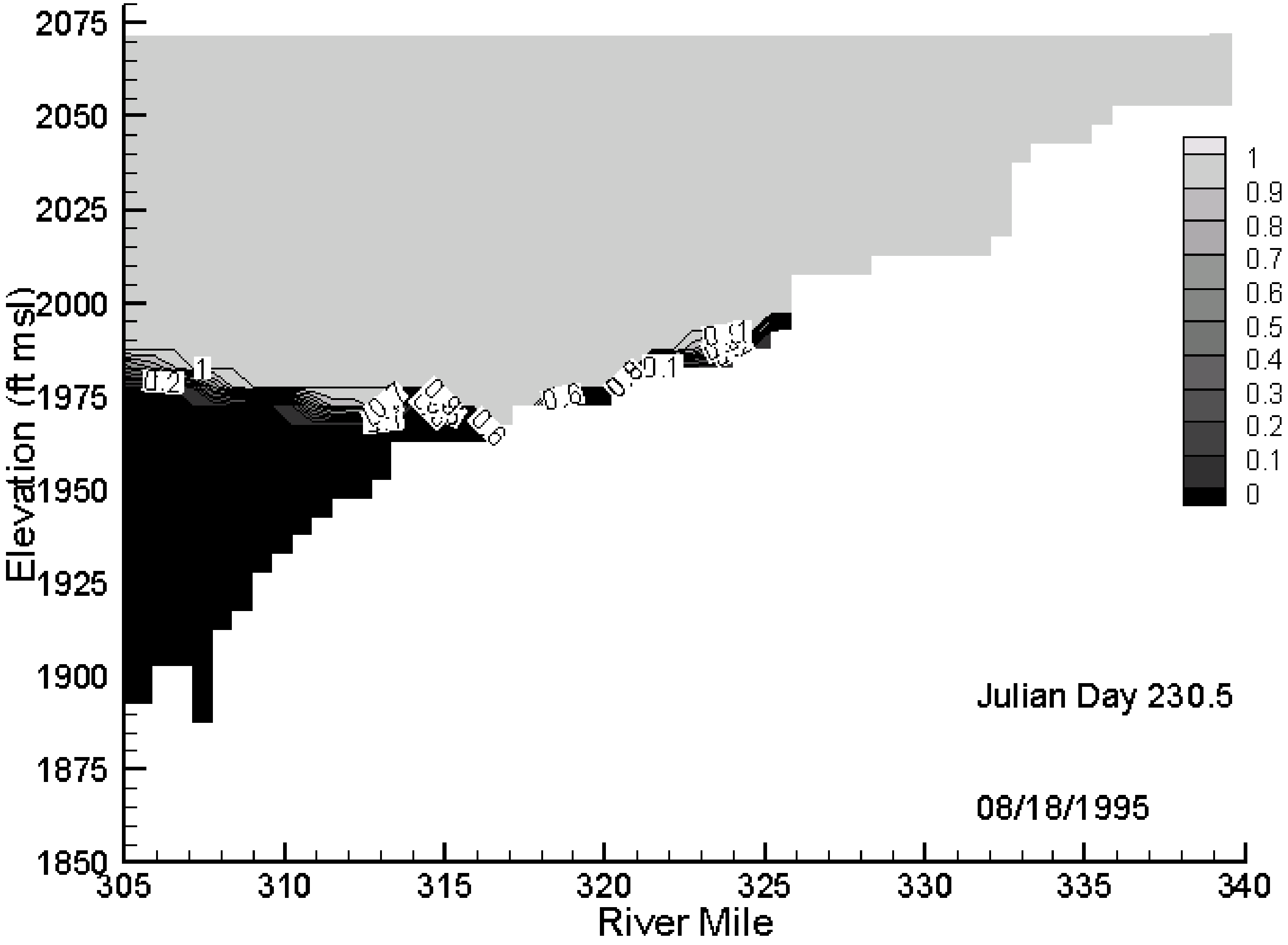


Figure 31. Simulated 1995 (medium flow year) Sturgeon HSI isopleth for the Brownlee transition zone under proposed operations.

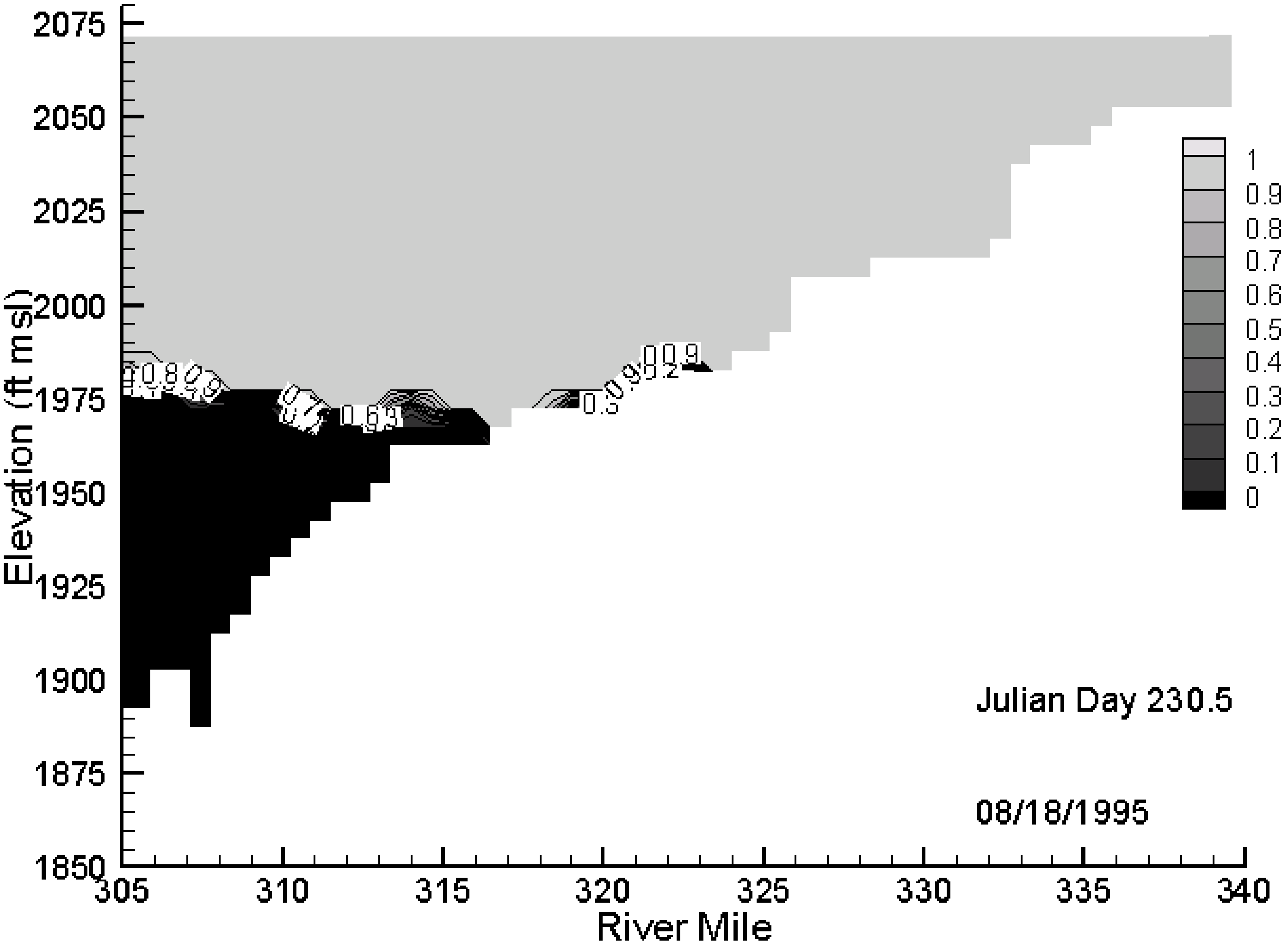


Figure 32. Simulated 1995 (medium flow year) Sturgeon HSI isopleth for the Brownlee transition zone under proposed operations with 1125-tons/yr aeration at the proposed location.

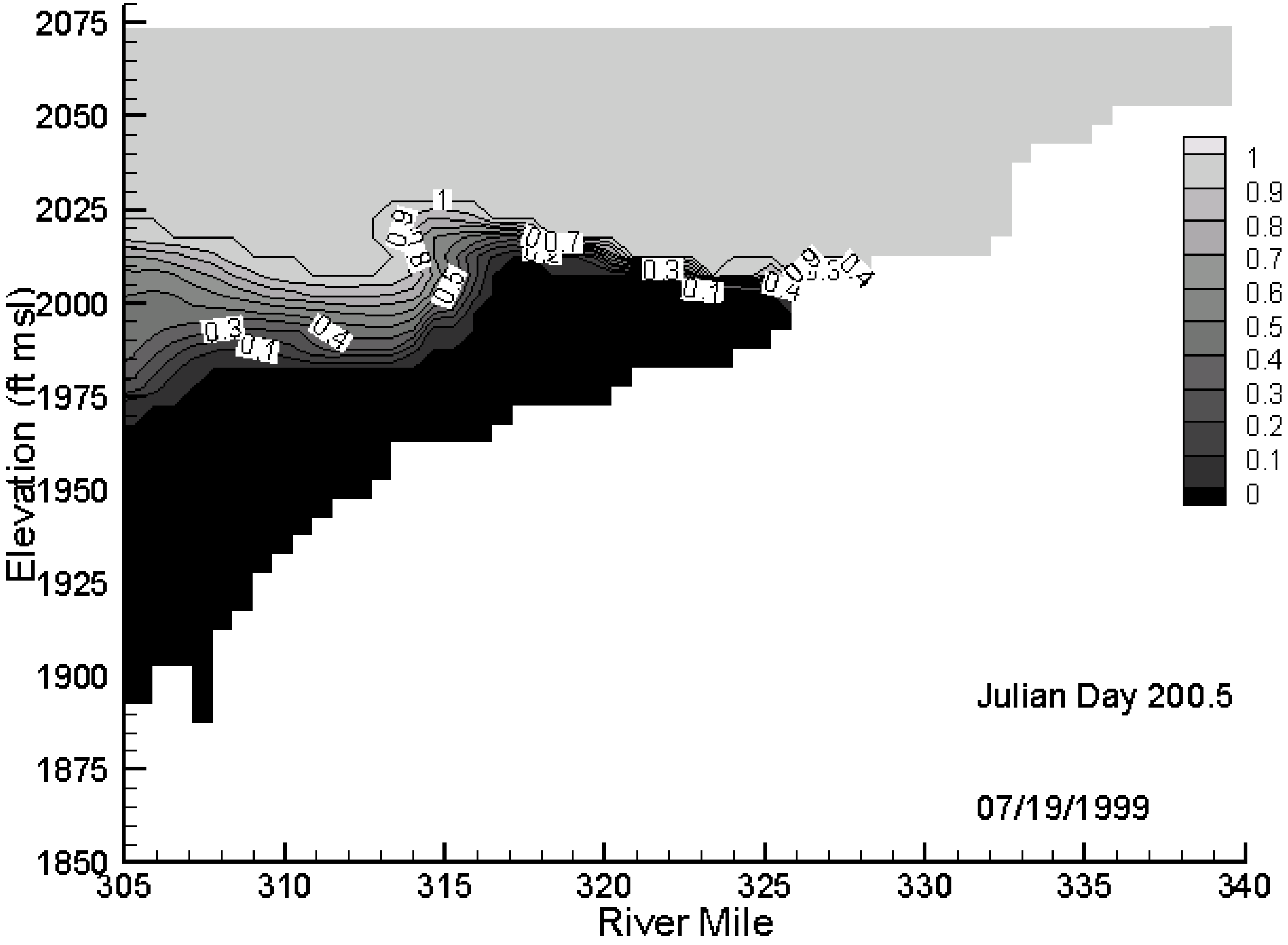


Figure 33. Simulated 1999 (medium-high flow year) Sturgeon HSI isopleth for the Brownlee transition zone under proposed operations.

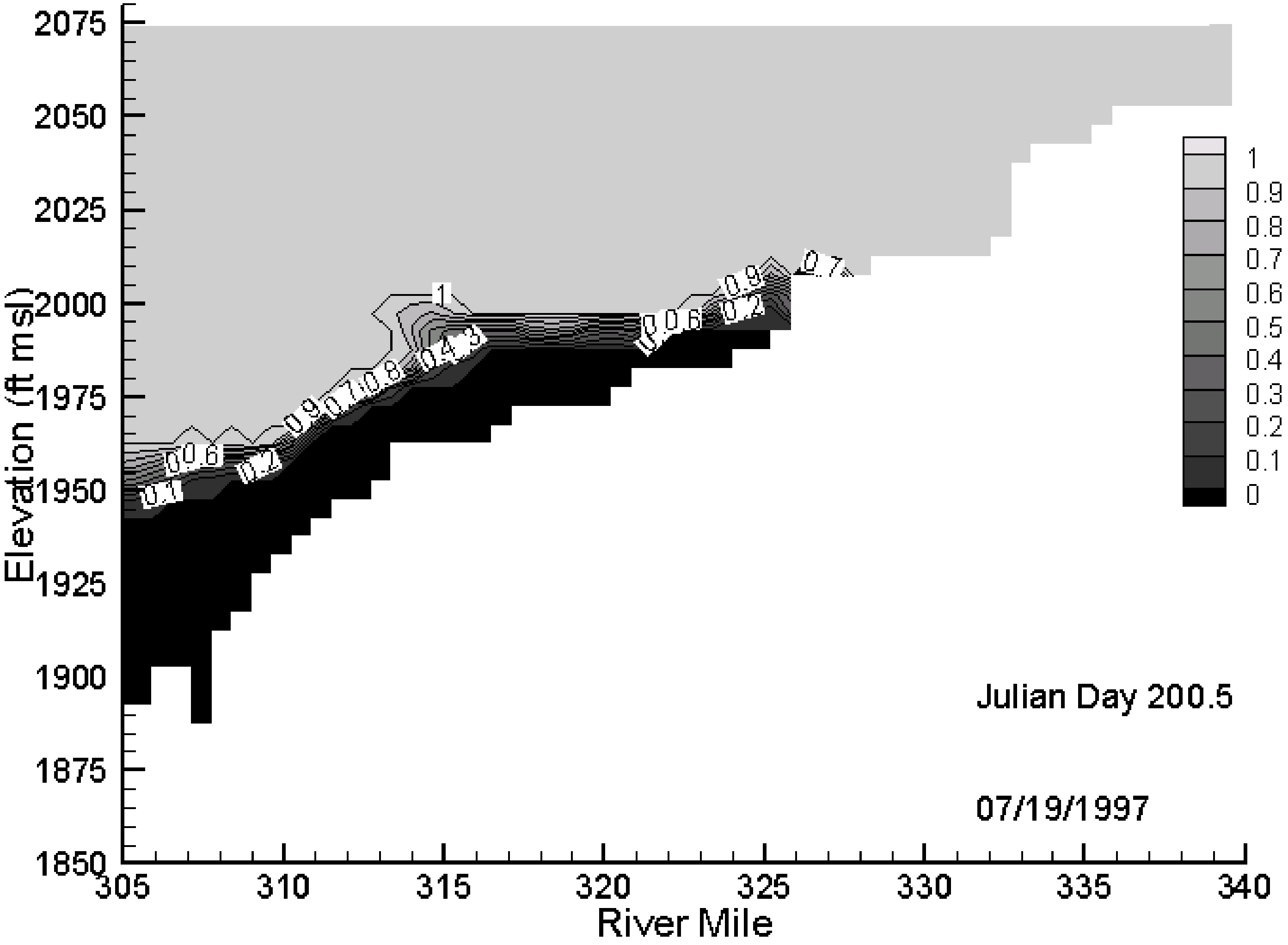


Figure 34. Simulated 1997 (high flow year) Sturgeon HSI isopleth for the Brownlee transition zone under proposed operations.

Figure 35. 50,000 gallon liquid oxygen storage tank.

Figure 36. Vaporizer/discharge piping.

Figure 37. Oxygen gas regulator assembly.

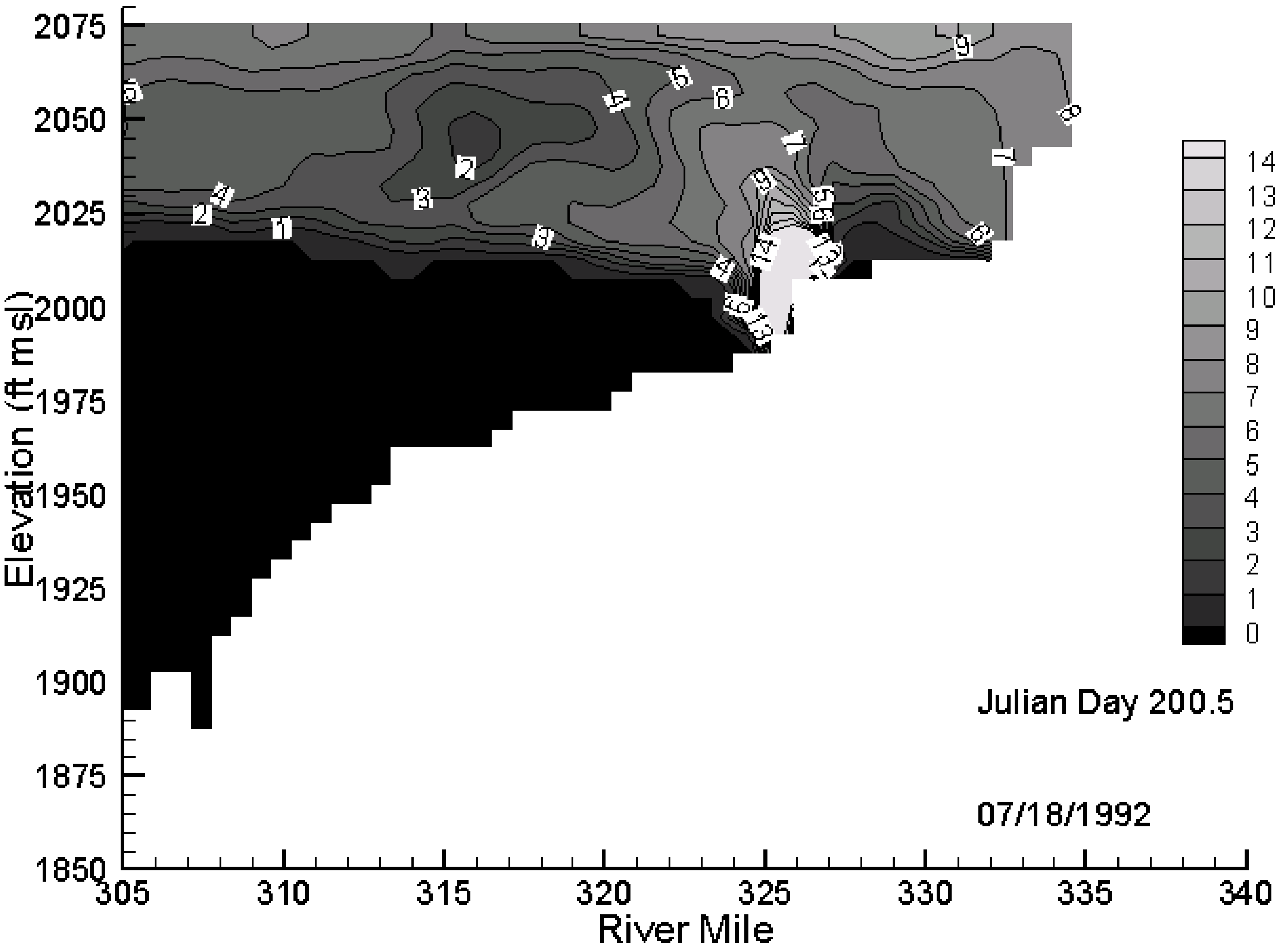


Figure 38. Simulated 1992 (low flow year) DO (mg/L) isopleth for the Brownlee transition zone under proposed operations with 2250-tons/yr aeration at the proposed location.

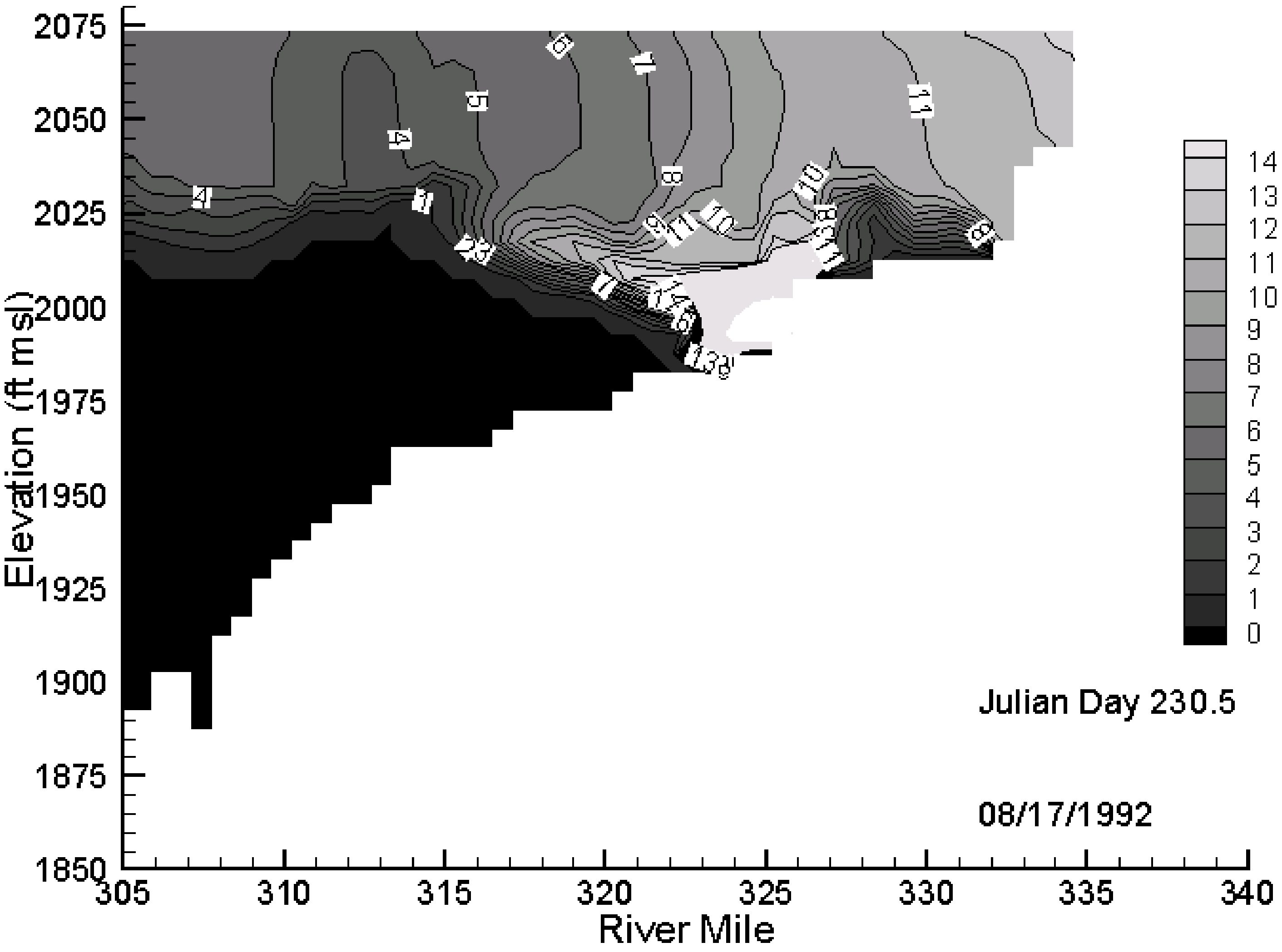


Figure 39. Simulated 1992 (low flow year) DO (mg/L) isopleth for the Brownlee transition zone under proposed operations with 2250-tons/yr aeration at the proposed location.

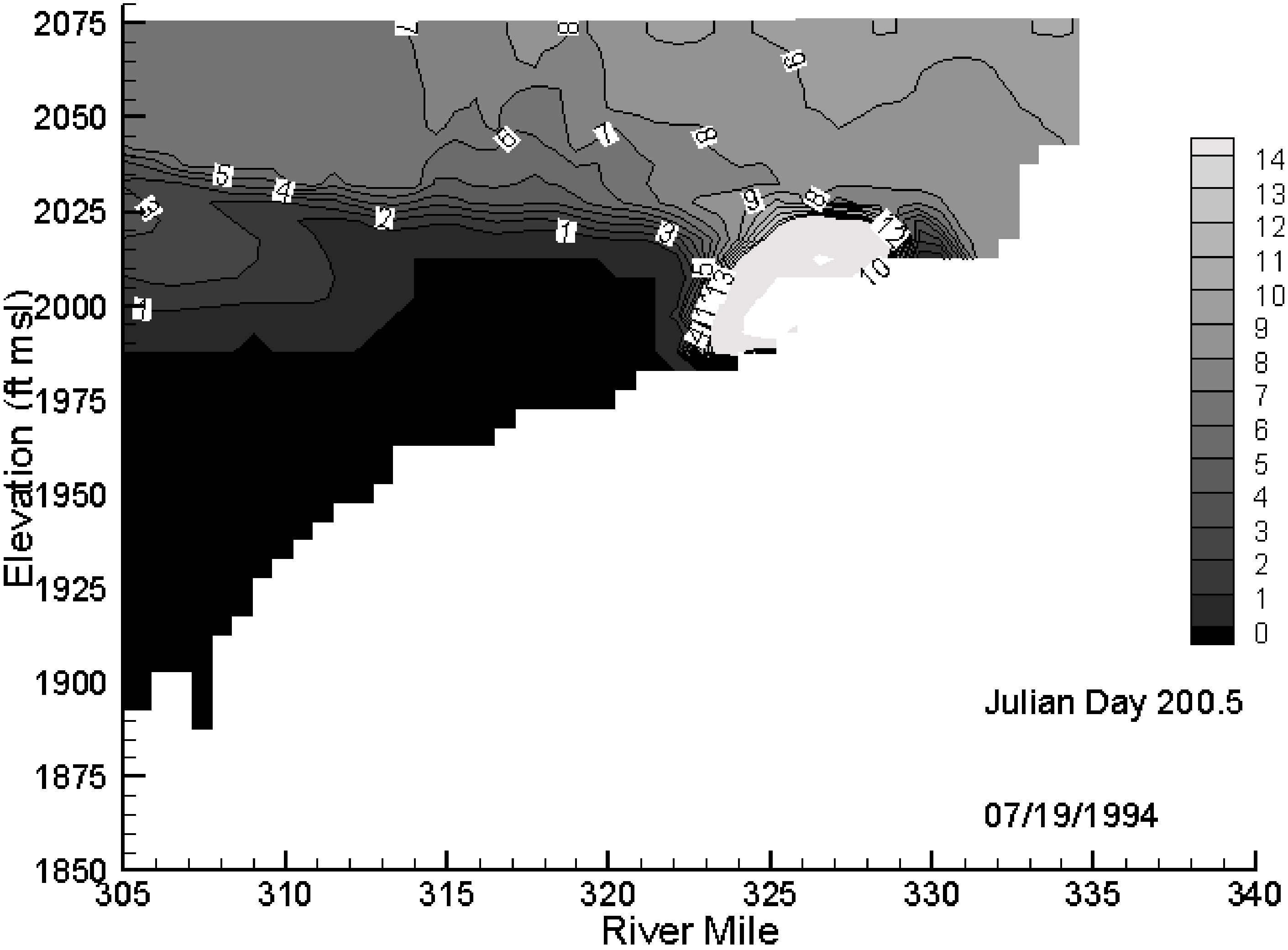


Figure 40. Simulated 1994 (medium-low flow year) DO (mg/L) isopleth for the Brownlee transition zone under proposed operations with 2250-tons/yr aeration at the proposed location.

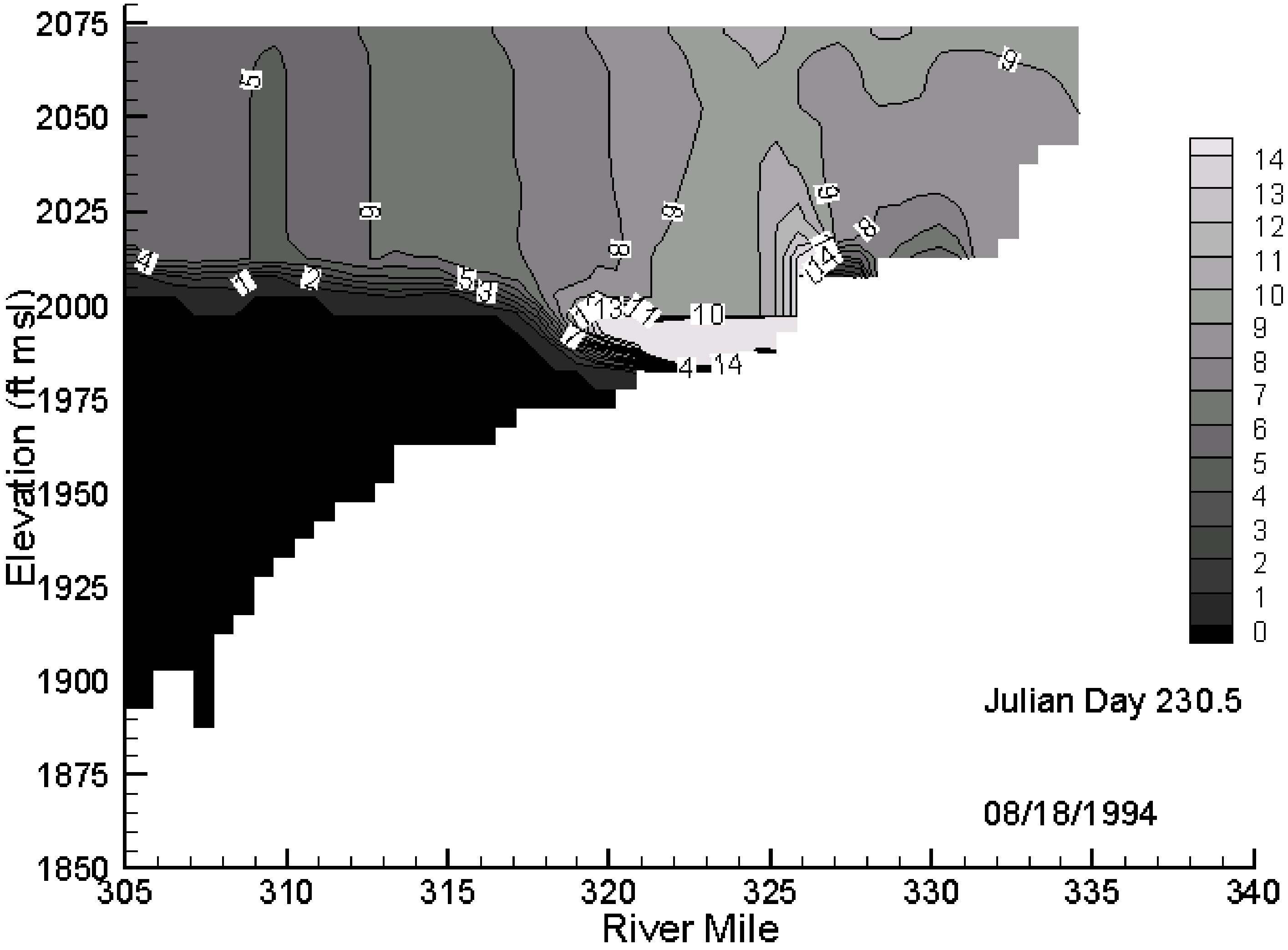


Figure 41. Simulated 1994 (medium-low flow year) DO (mg/L) isopleth for the Brownlee transition zone under proposed operations with 2250-tons/yr aeration at the proposed location.

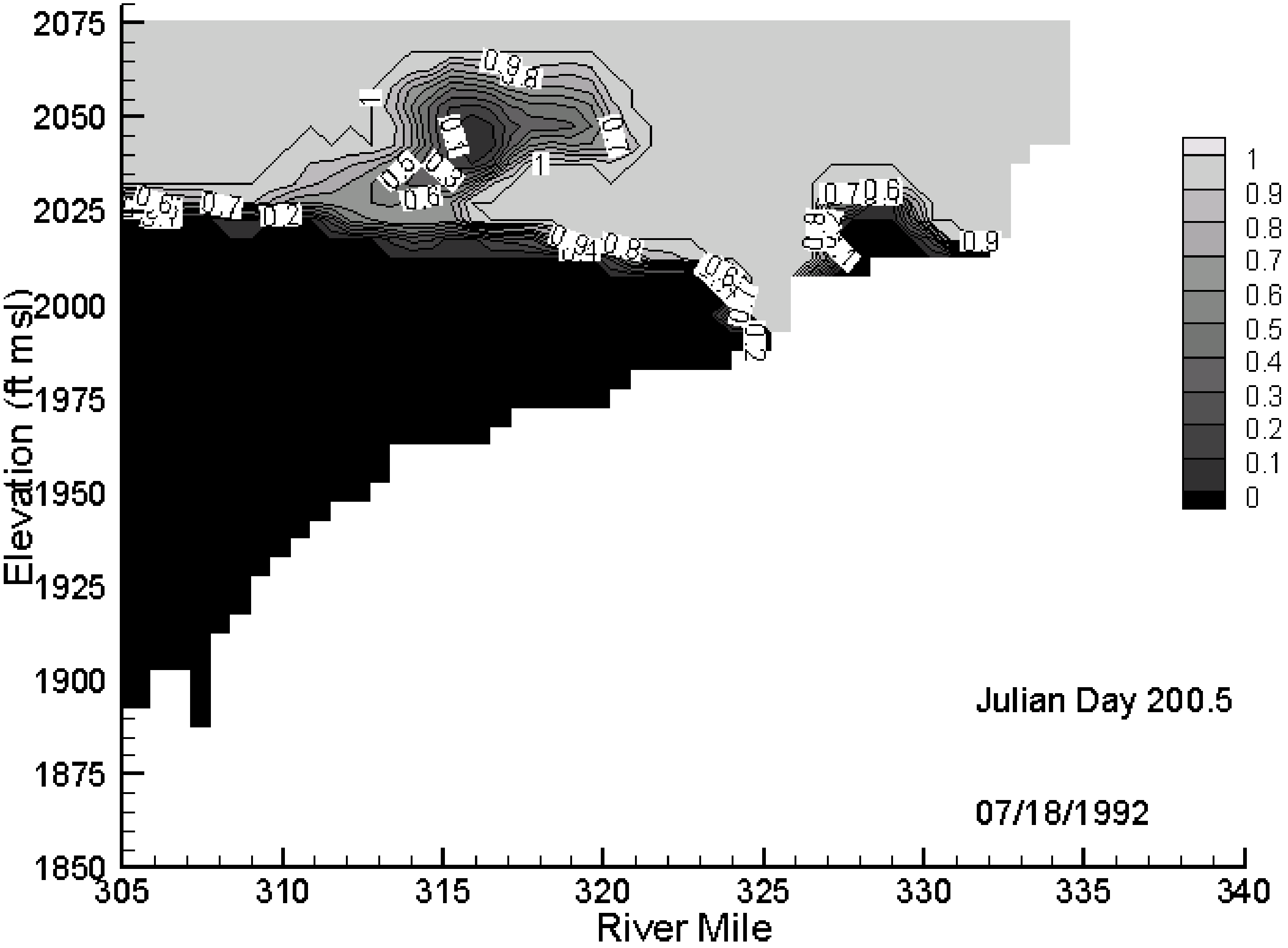


Figure 42. Simulated 1992 (low flow year) Sturgeon HSI isopleth for the Brownlee transition zone under proposed operations with 2250-tons/yr aeration at the proposed location.

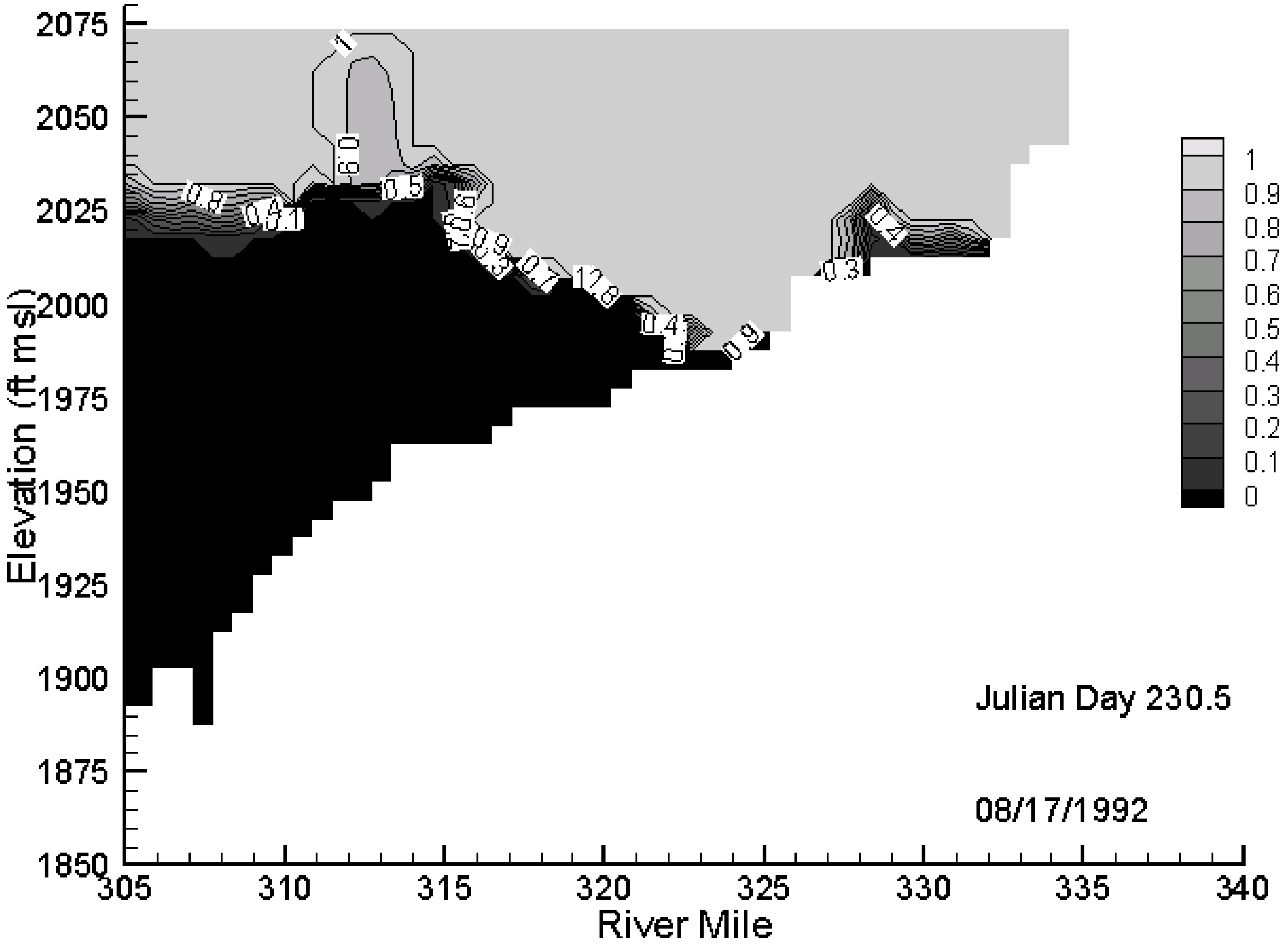


Figure 43. Simulated 1992 (low flow year) Sturgeon HSI isopleth for the Brownlee transition zone under proposed operations with 2250-tons/yr aeration at the proposed location.

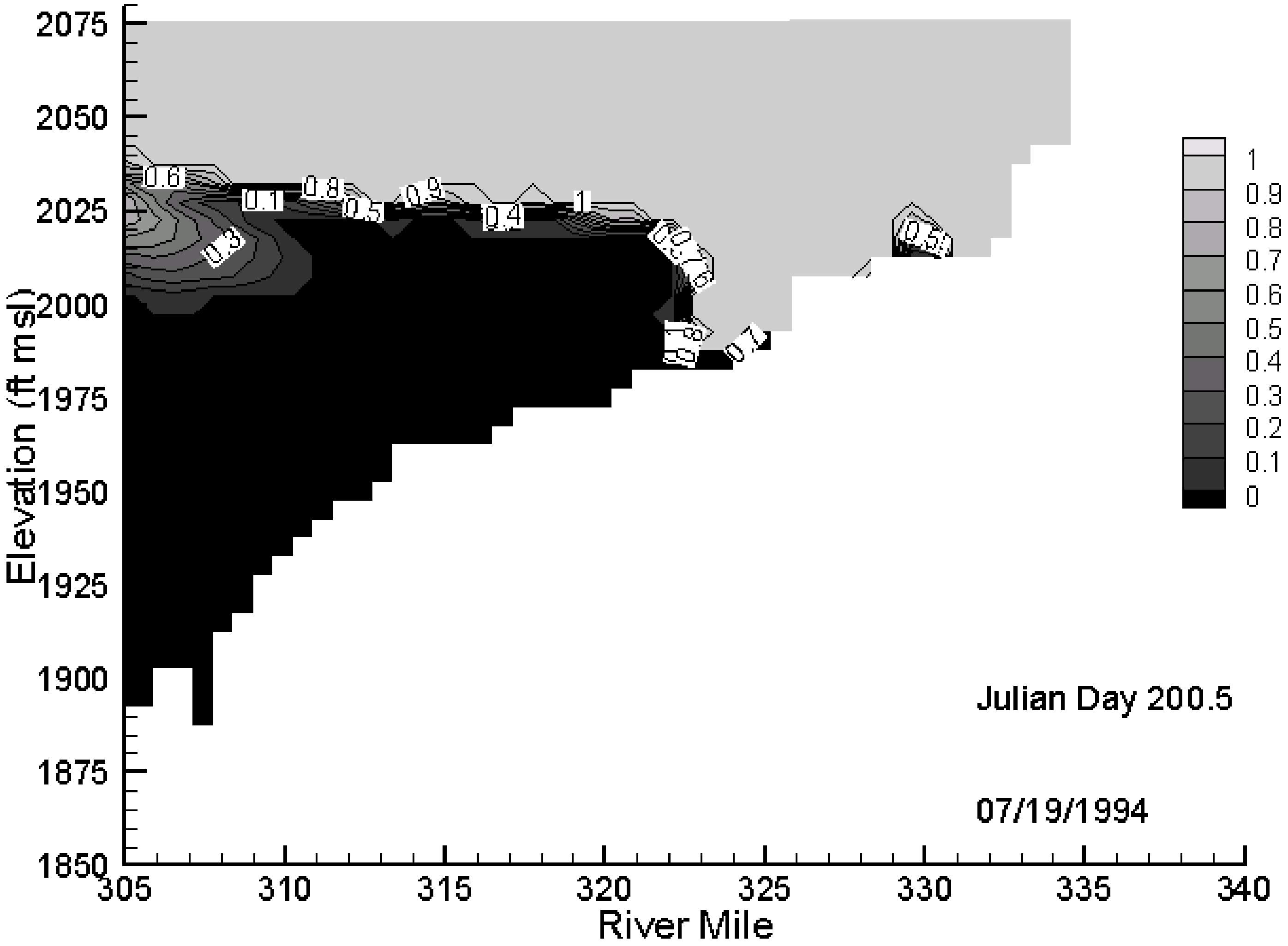


Figure 44. Simulated 1994 (medium-low flow year) Sturgeon HSI isopleth for the Brownlee transition zone under proposed operations with 2250-tons/yr aeration at the proposed location.

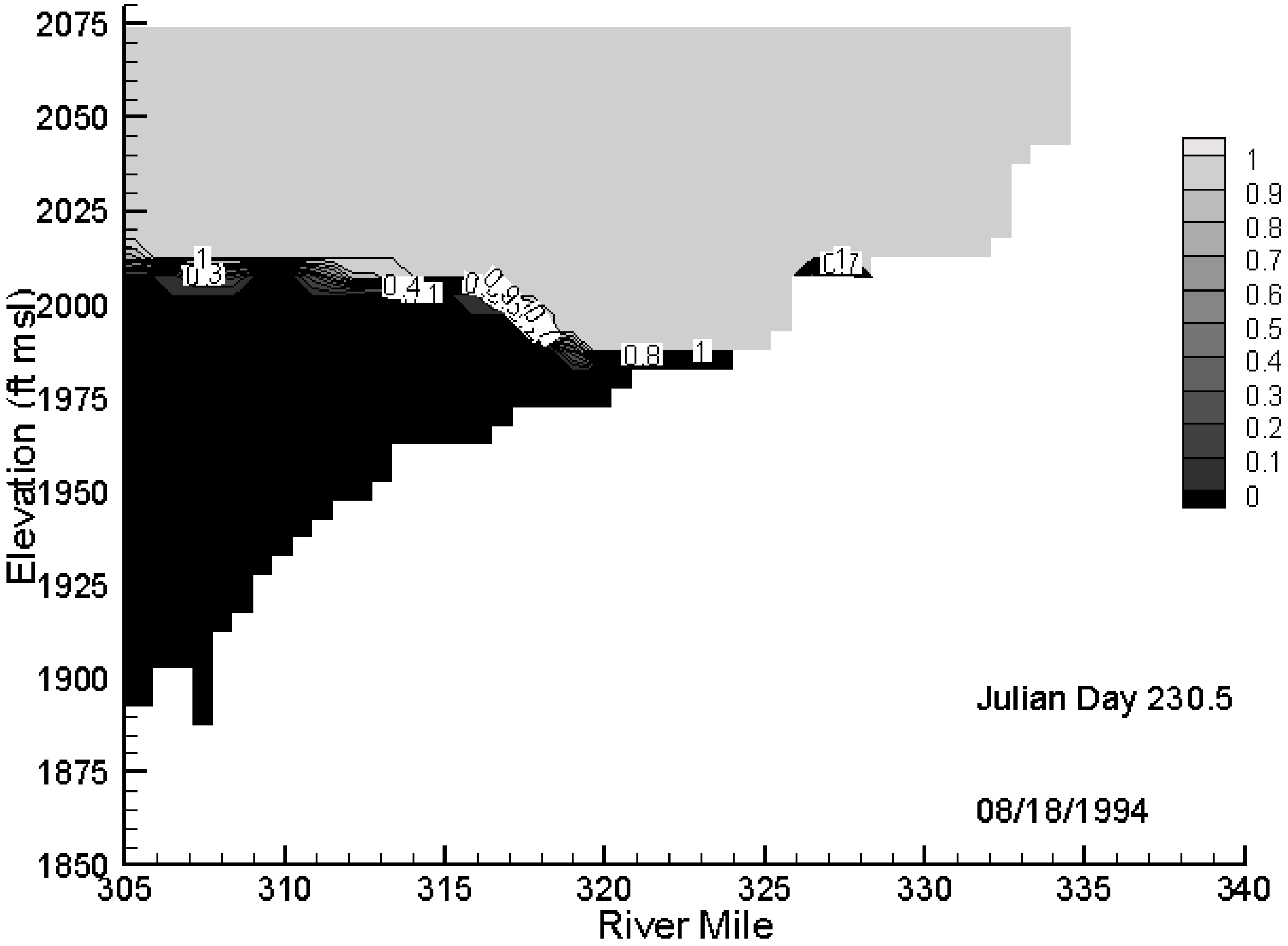


Figure 45. Simulated 1994 (medium-low flow year) Sturgeon HSI isopleth for the Brownlee transition zone under proposed operations with 2250-tons/yr aeration at the proposed location.

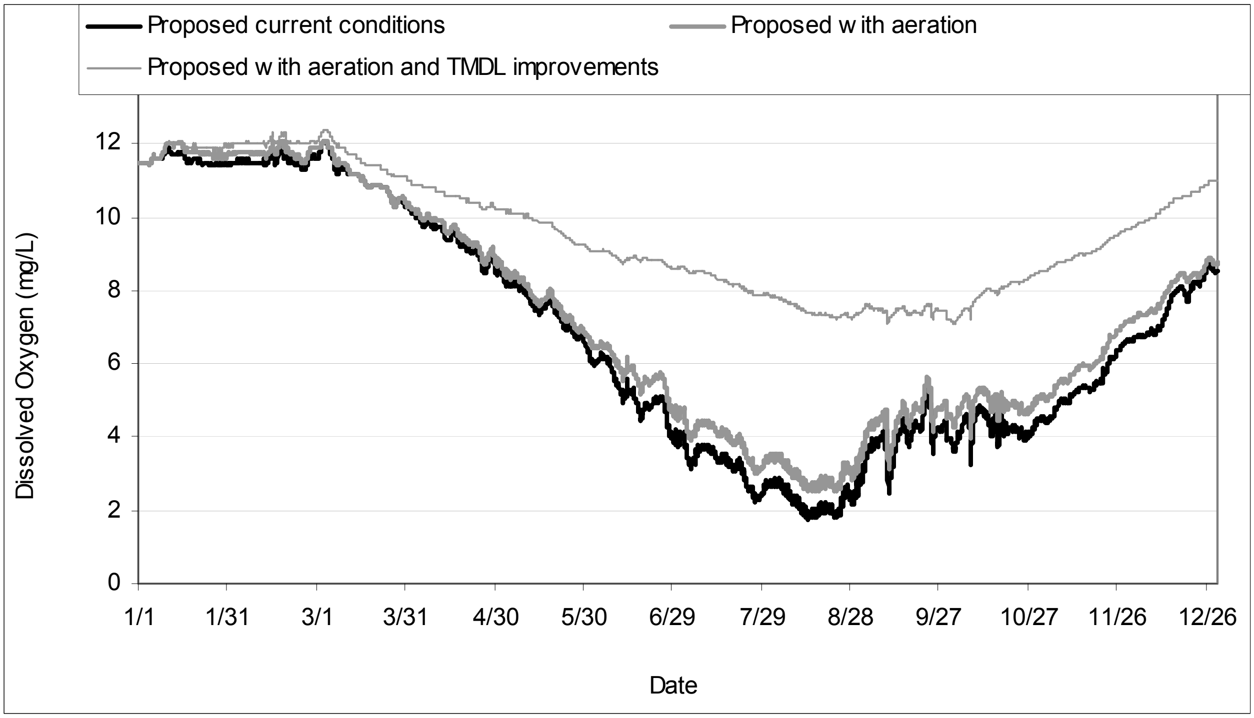


Figure 46. 1992 simulated hourly DO levels in Hells Canyon discharge under proposed operations with and without reservoir aeration and turbine aeration, and with full implementation of the TMDL.

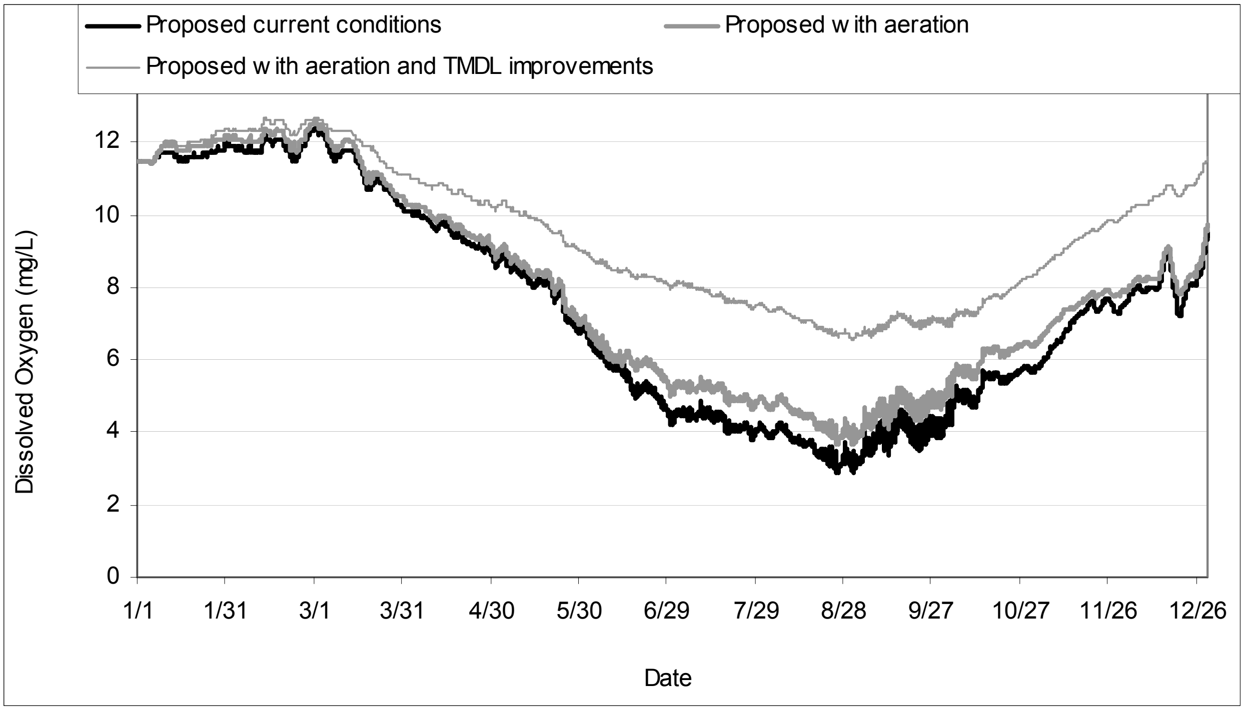


Figure 47. 1994 simulated hourly DO levels in Hells Canyon discharge under proposed operations with and without reservoir aeration and turbine aeration, and with full implementation of the TMDL.

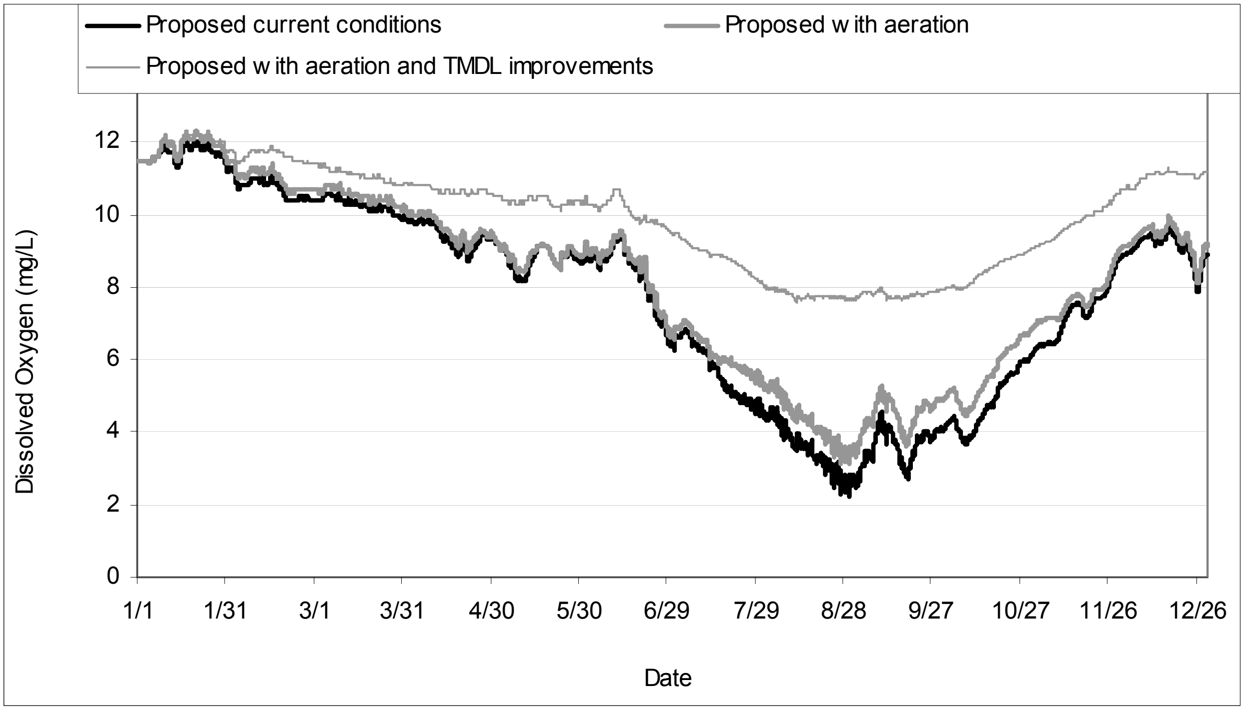


Figure 48. 1995 simulated hourly DO levels in Hells Canyon discharge under proposed operations with and without reservoir aeration and turbine aeration, and with full implementation of the TMDL.

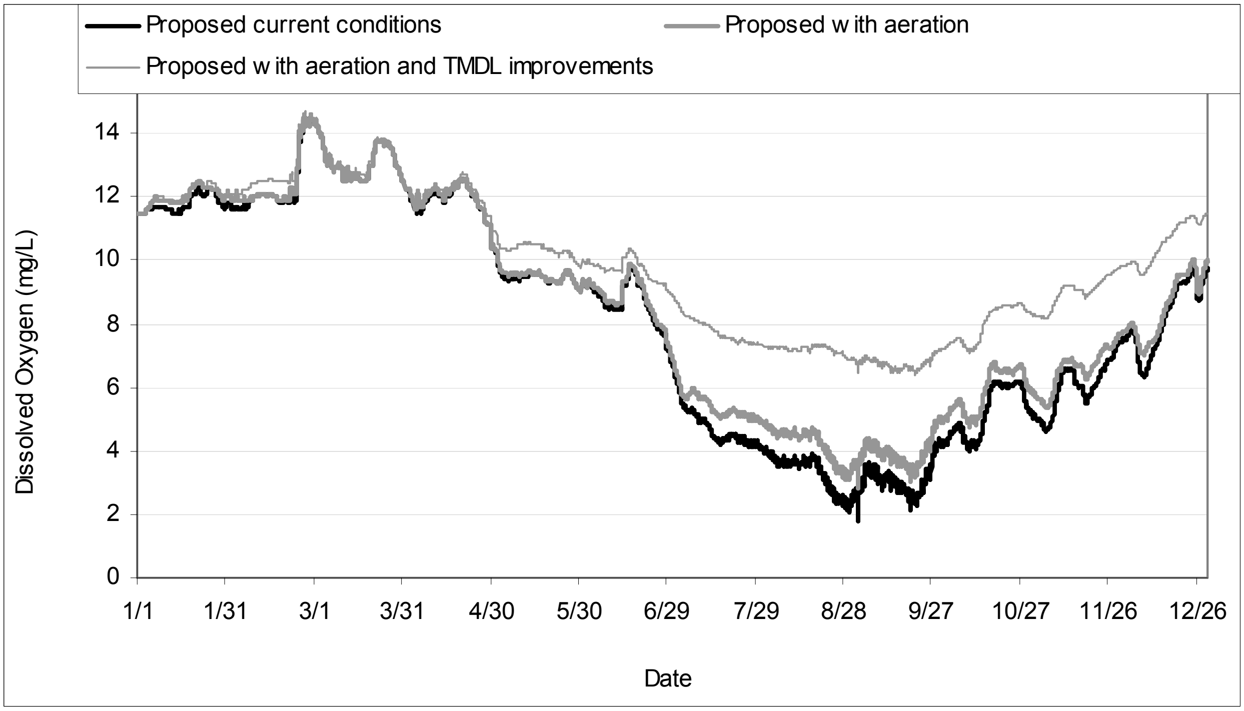


Figure 49. 1999 simulated hourly DO levels in Hells Canyon discharge under proposed operations with and without reservoir aeration and turbine aeration, and with full implementation of the TMDL.

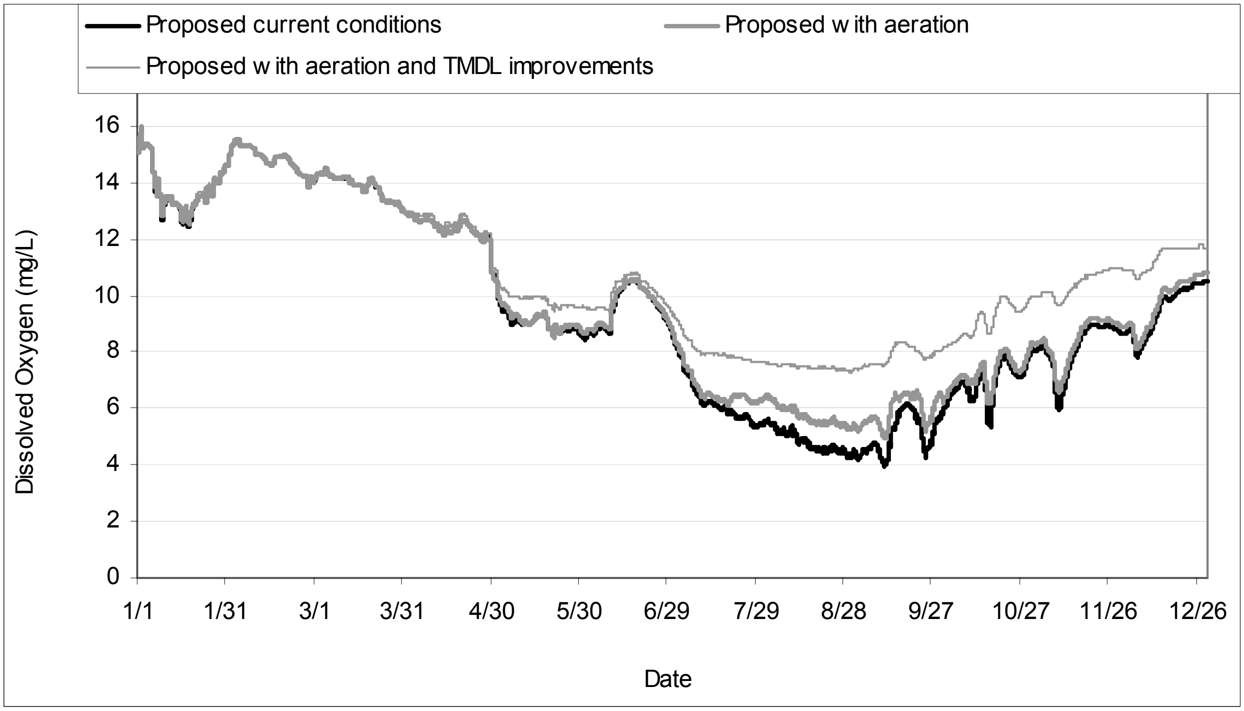


Figure 50. 1997 simulated hourly DO levels in Hells Canyon discharge under proposed operations with and without reservoir aeration and turbine aeration, and with full implementation of the TMDL.

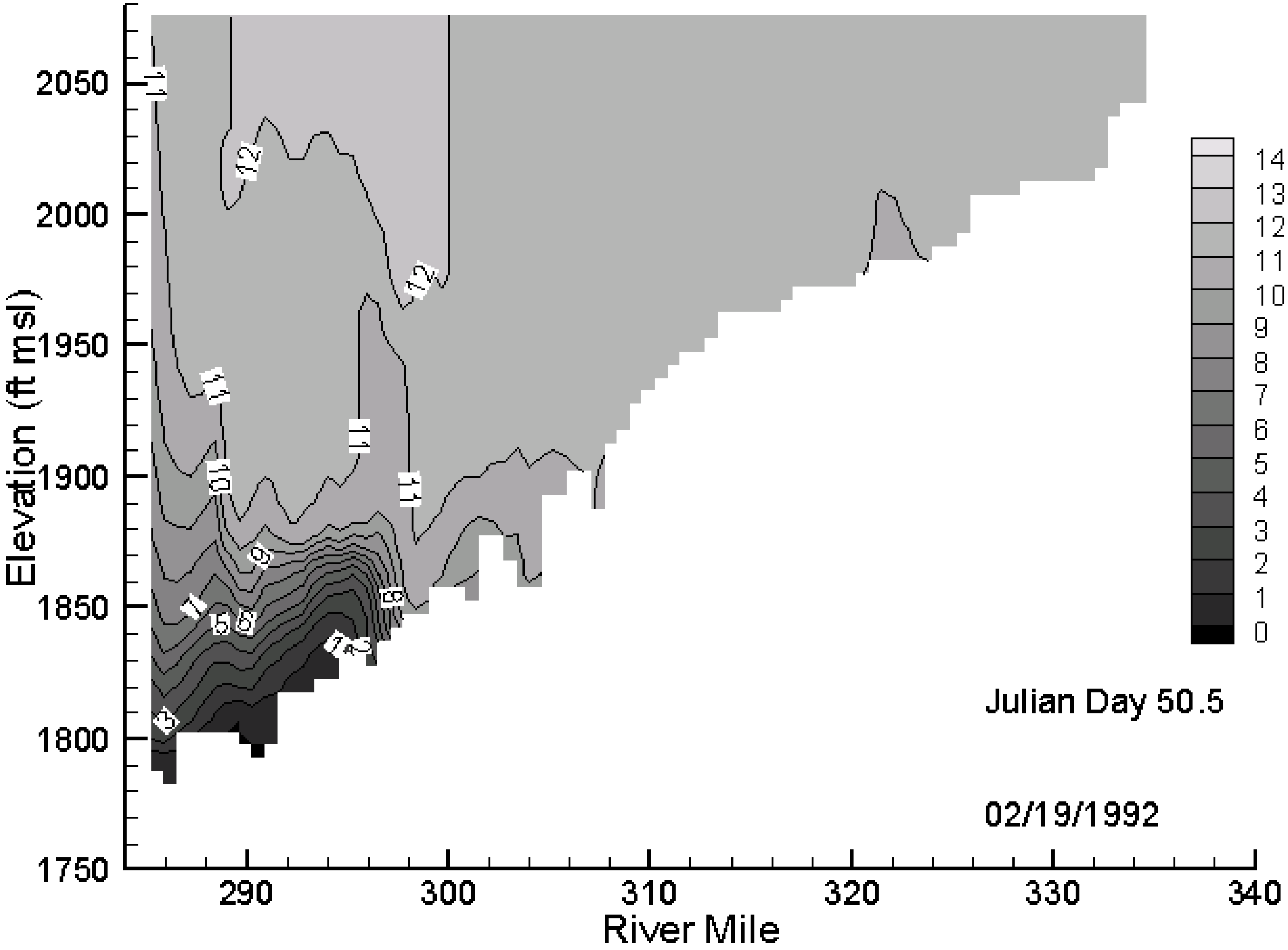


Figure 51. Simulated 1992 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

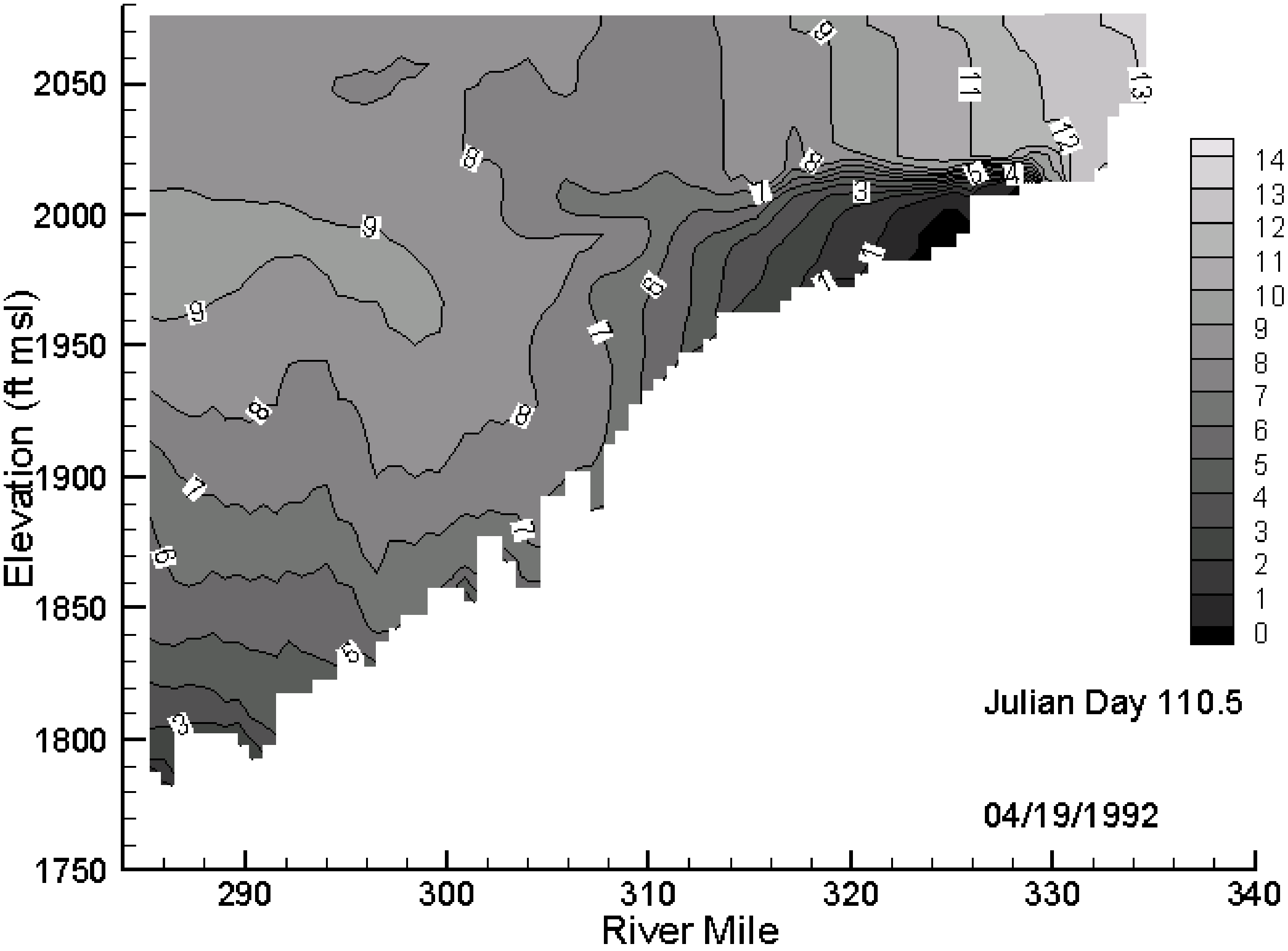


Figure 52. Simulated 1992 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

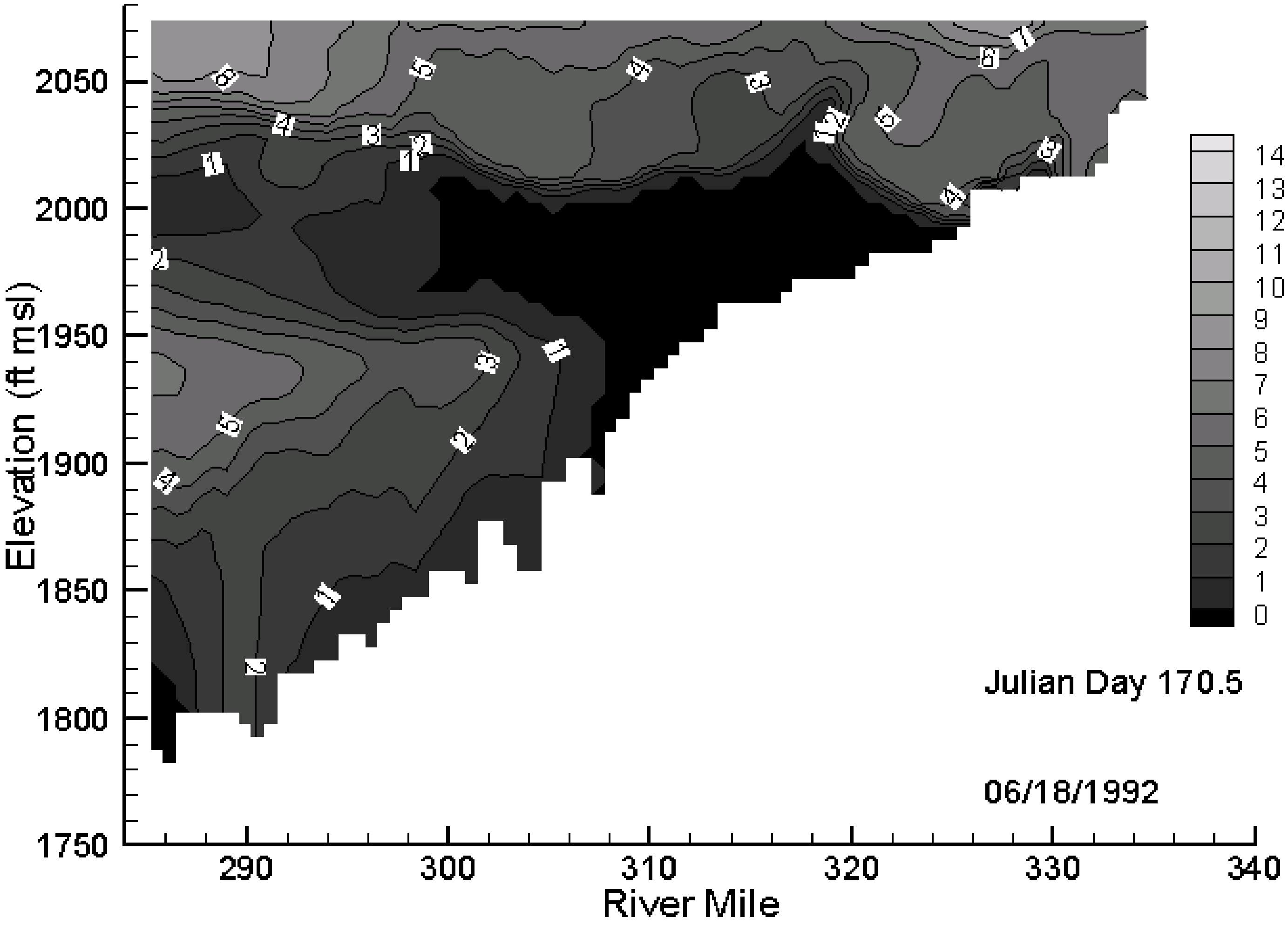


Figure 53. Simulated 1992 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

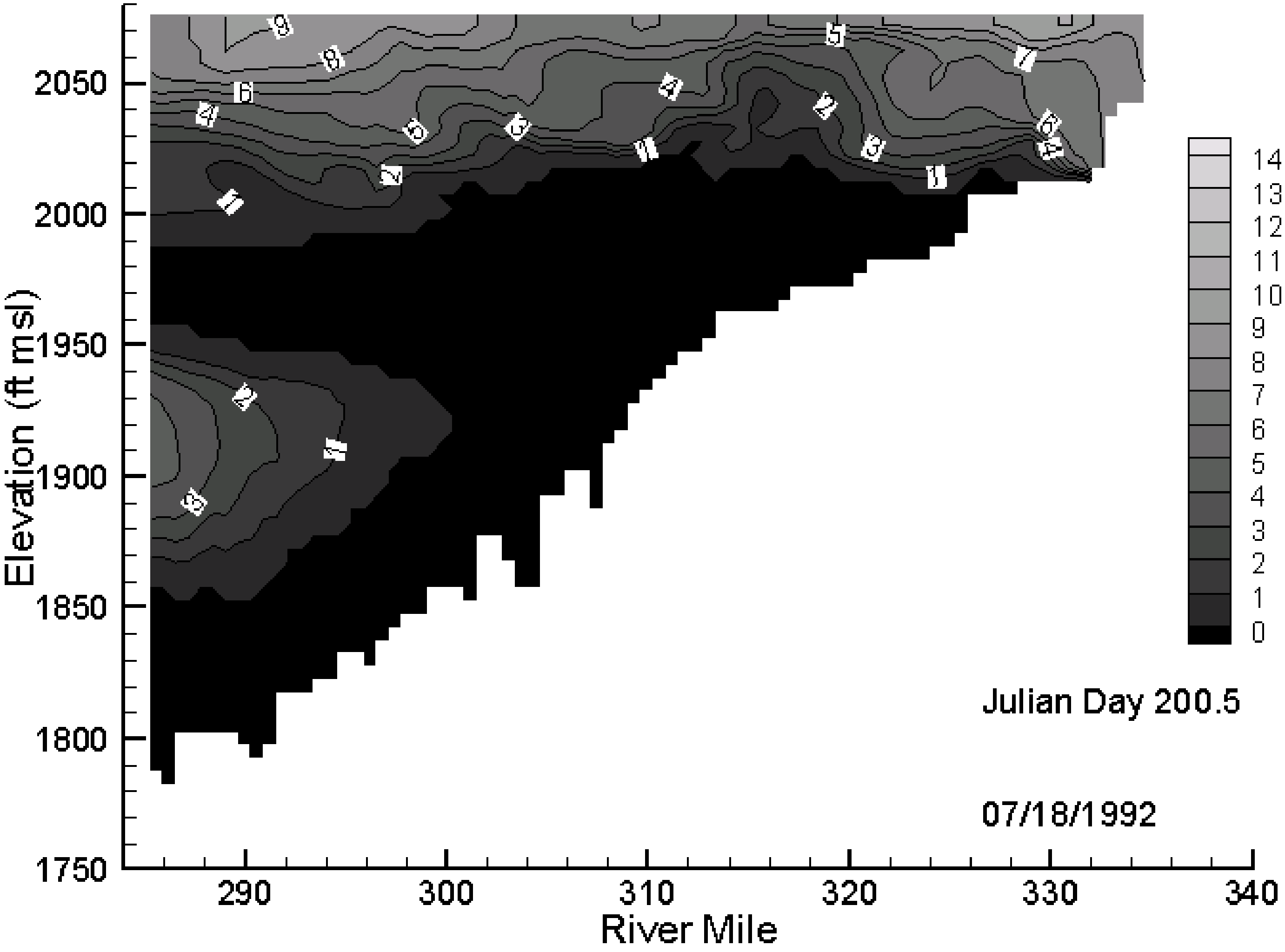


Figure 54. Simulated 1992 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

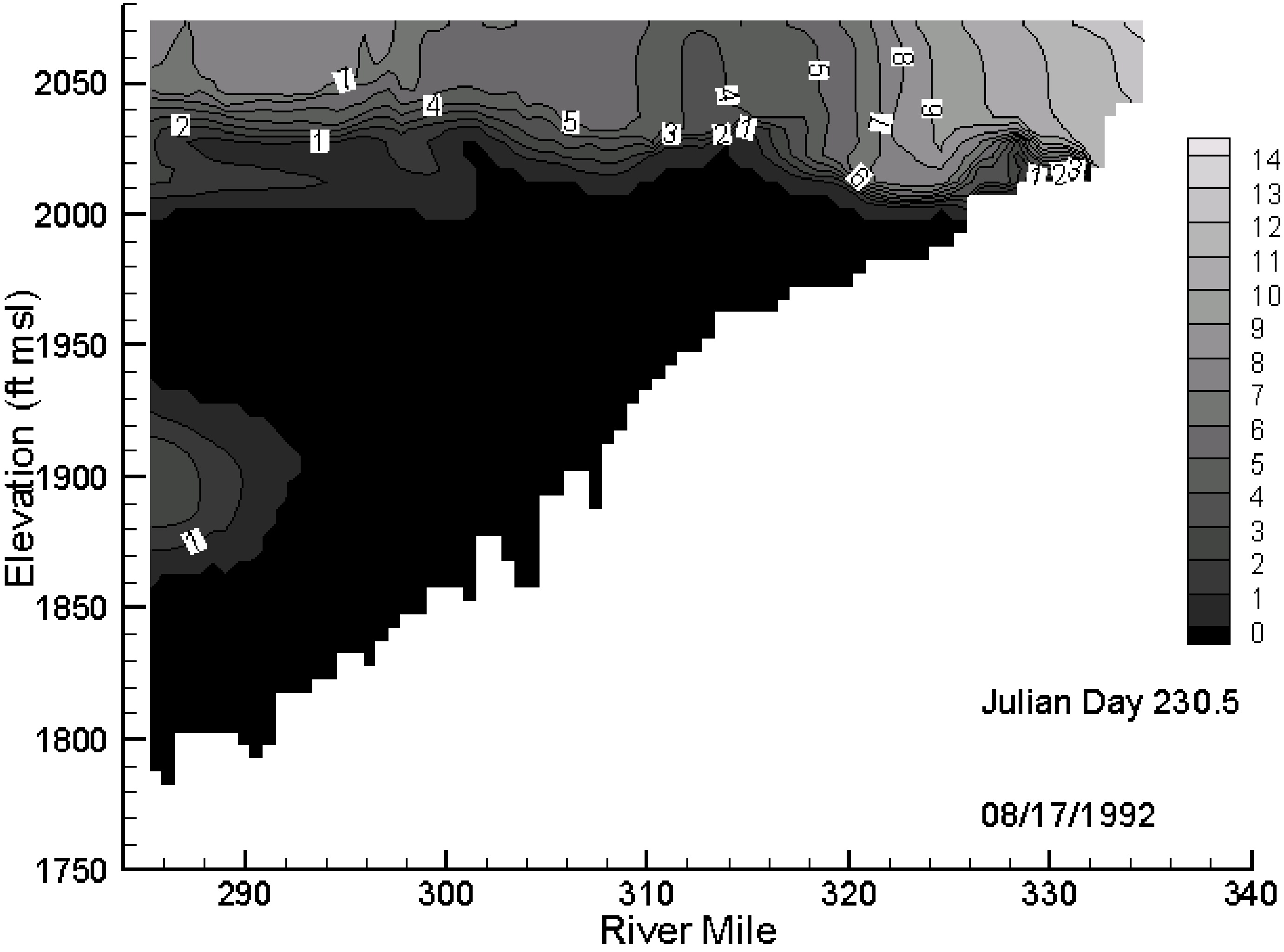


Figure 55. Simulated 1992 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

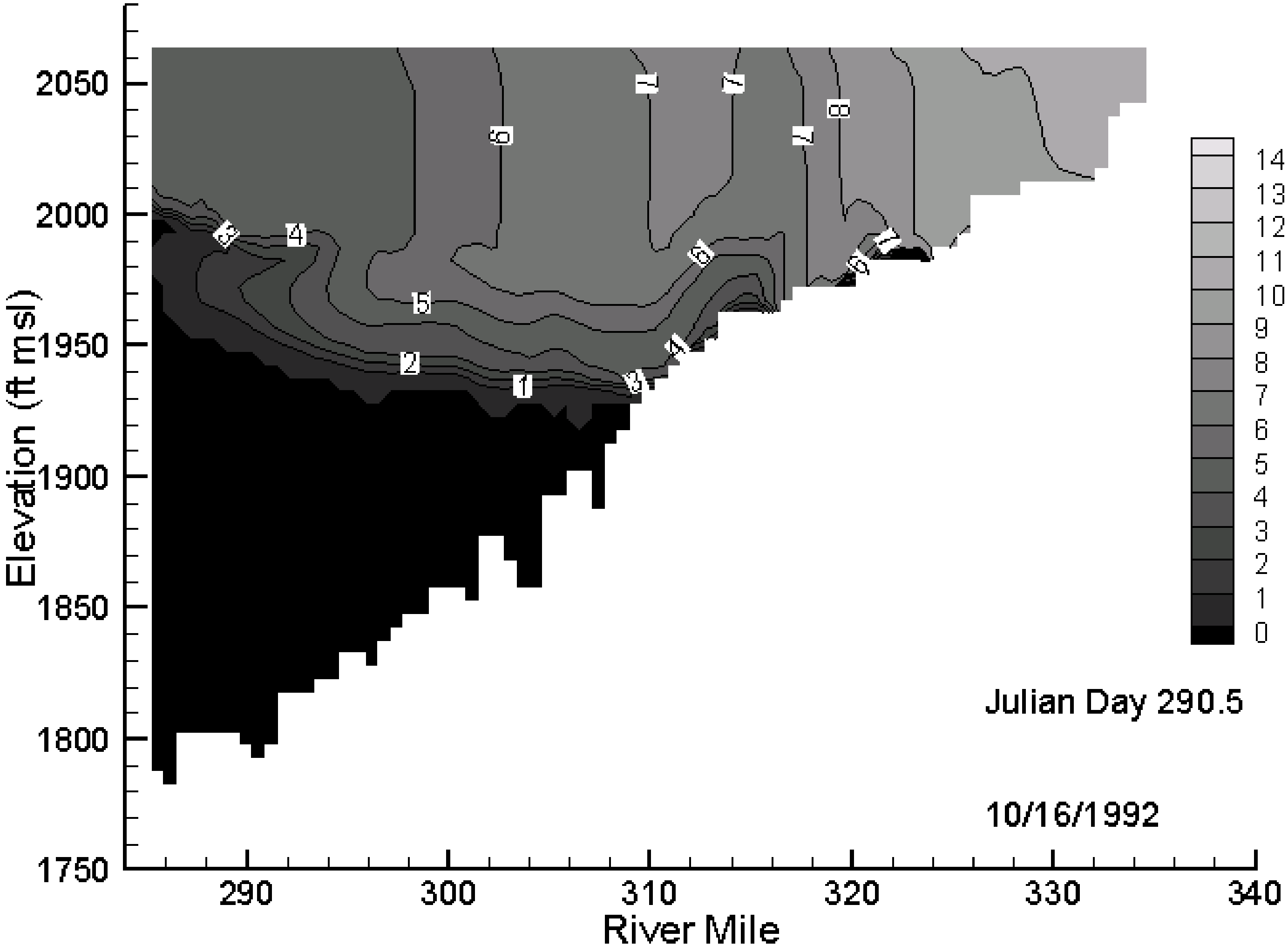


Figure 56. Simulated 1992 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

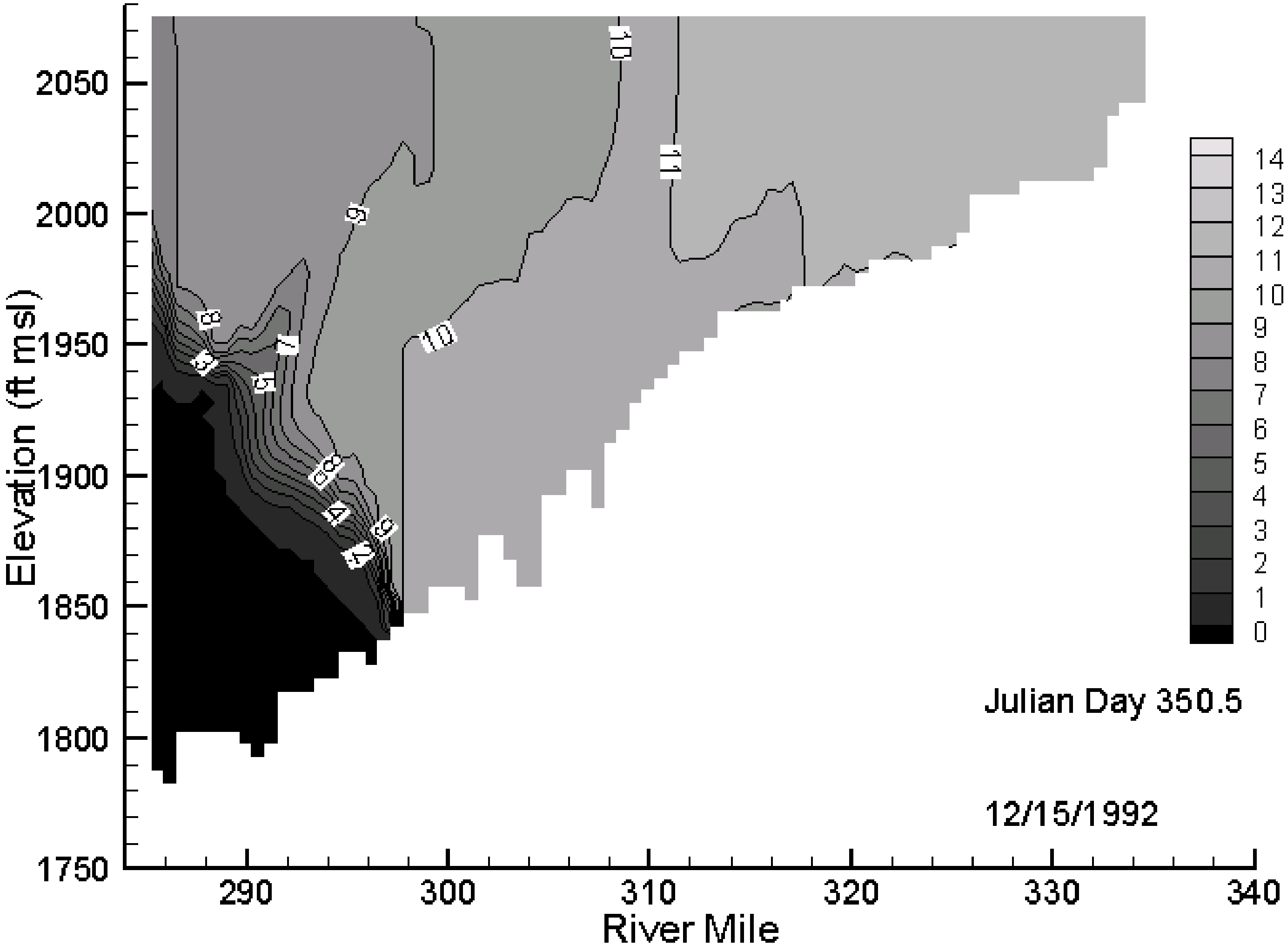


Figure 57. Simulated 1992 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

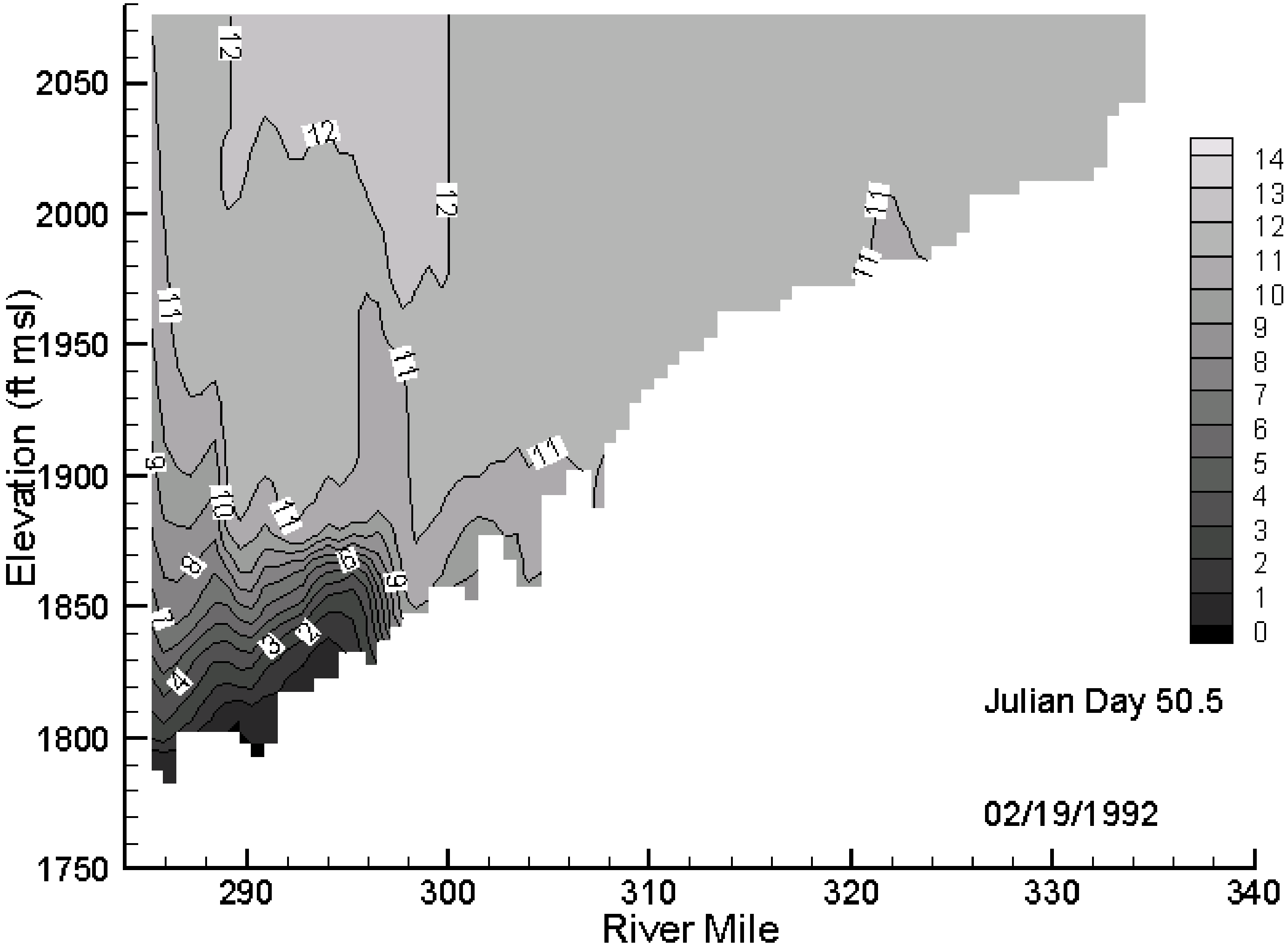


Figure 58. Simulated 1992 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

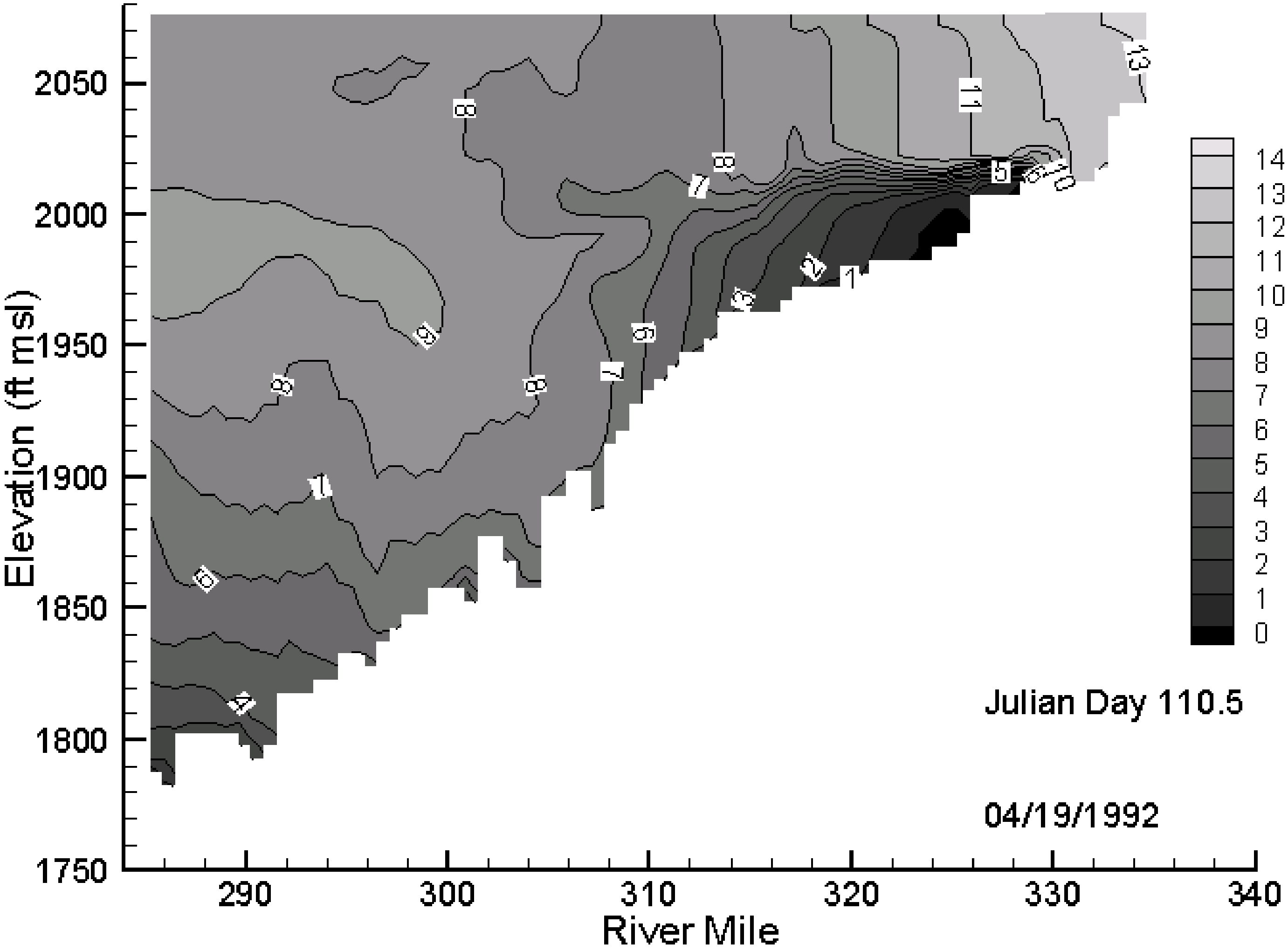


Figure 59. Simulated 1992 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

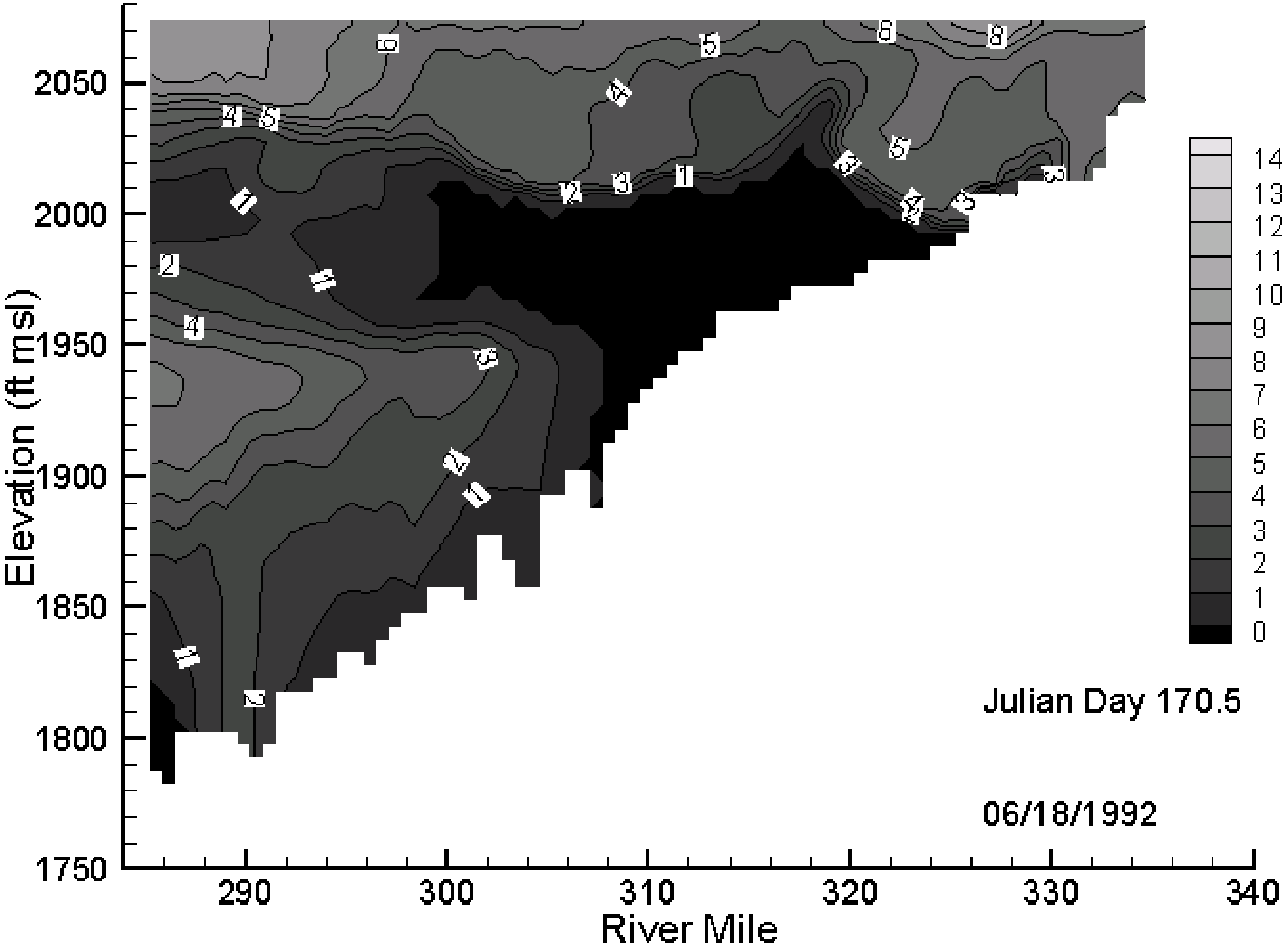


Figure 60. Simulated 1992 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

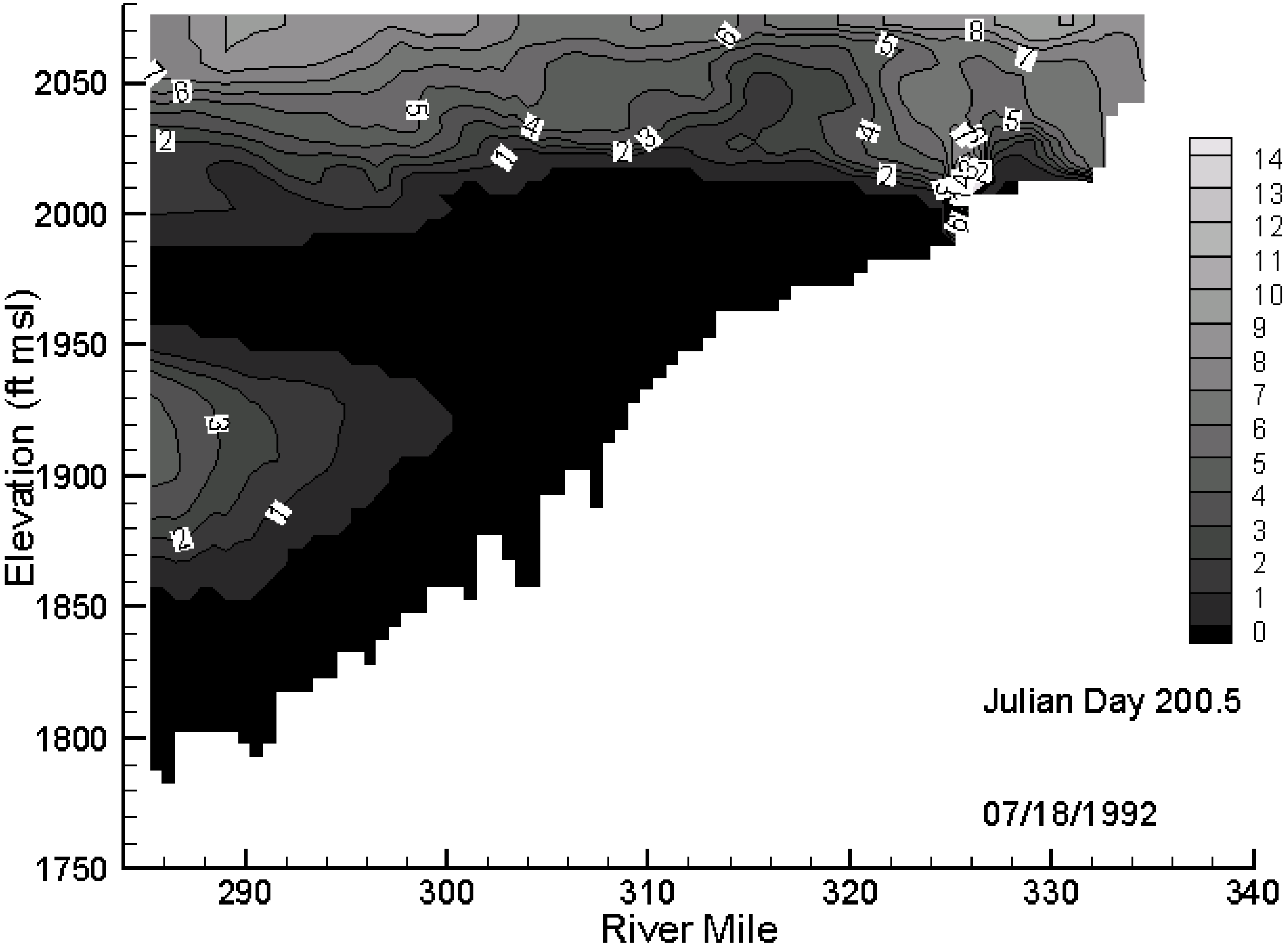


Figure 61. Simulated 1992 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

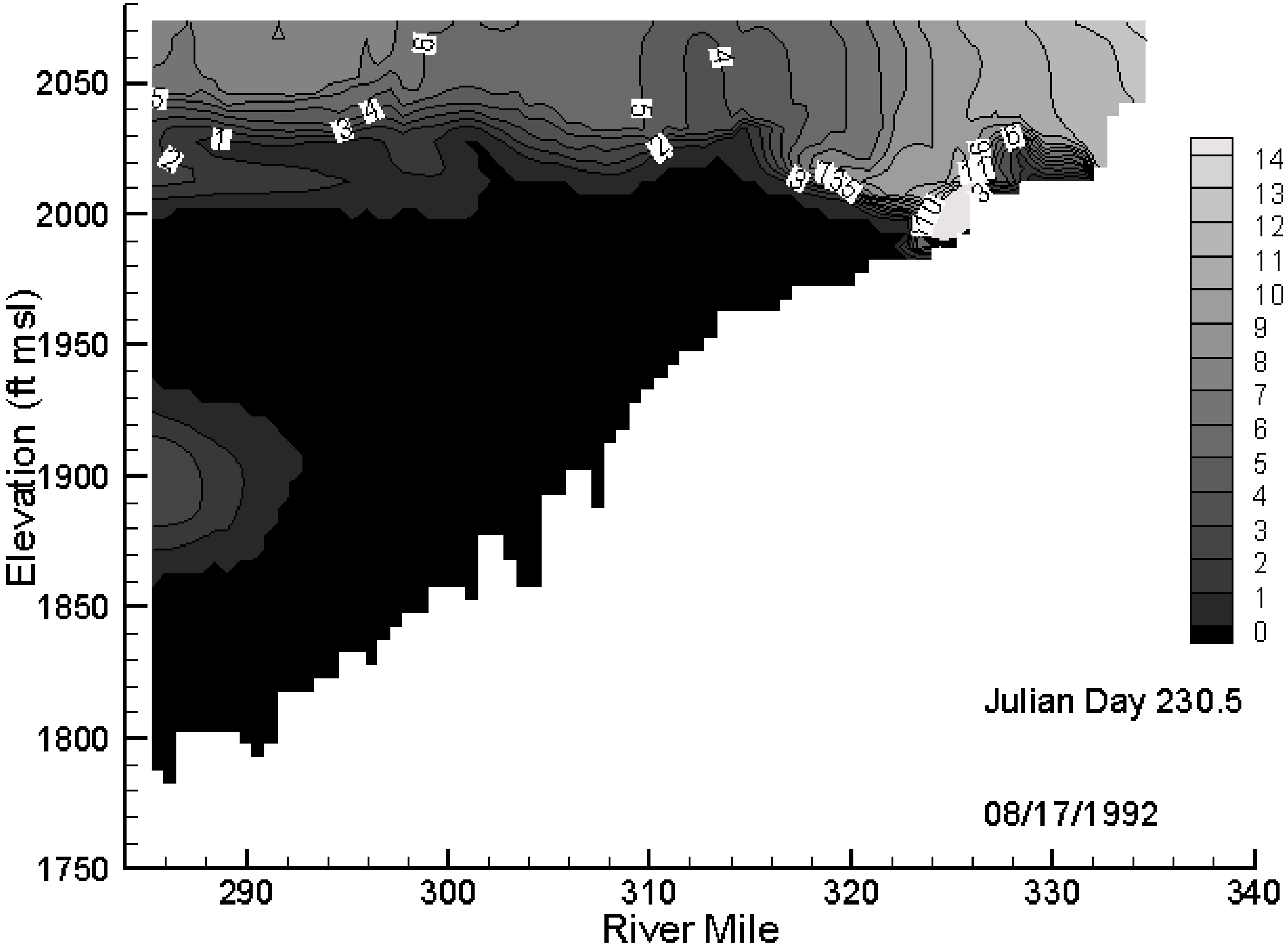


Figure 62. Simulated 1992 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

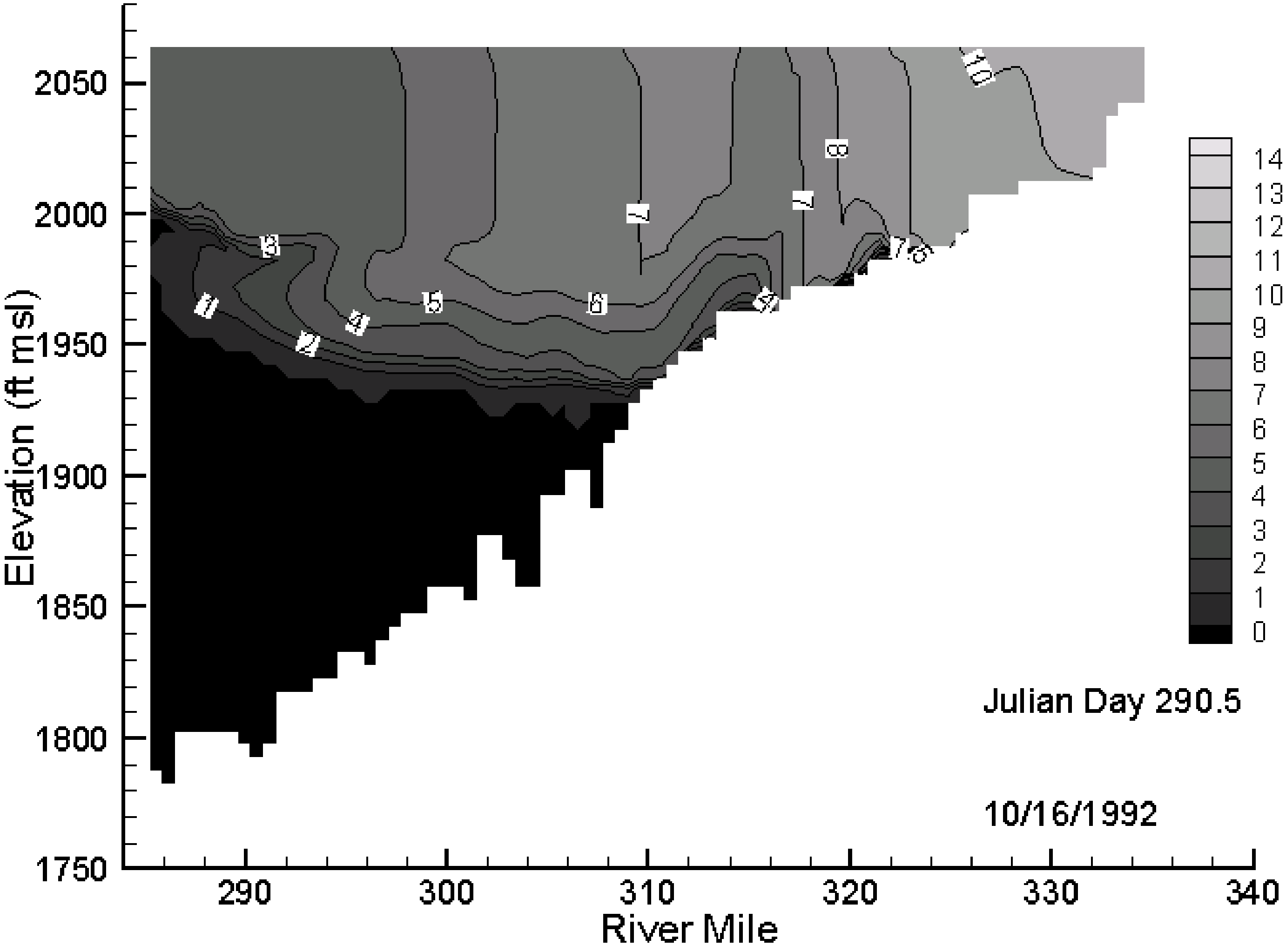


Figure 63. Simulated 1992 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

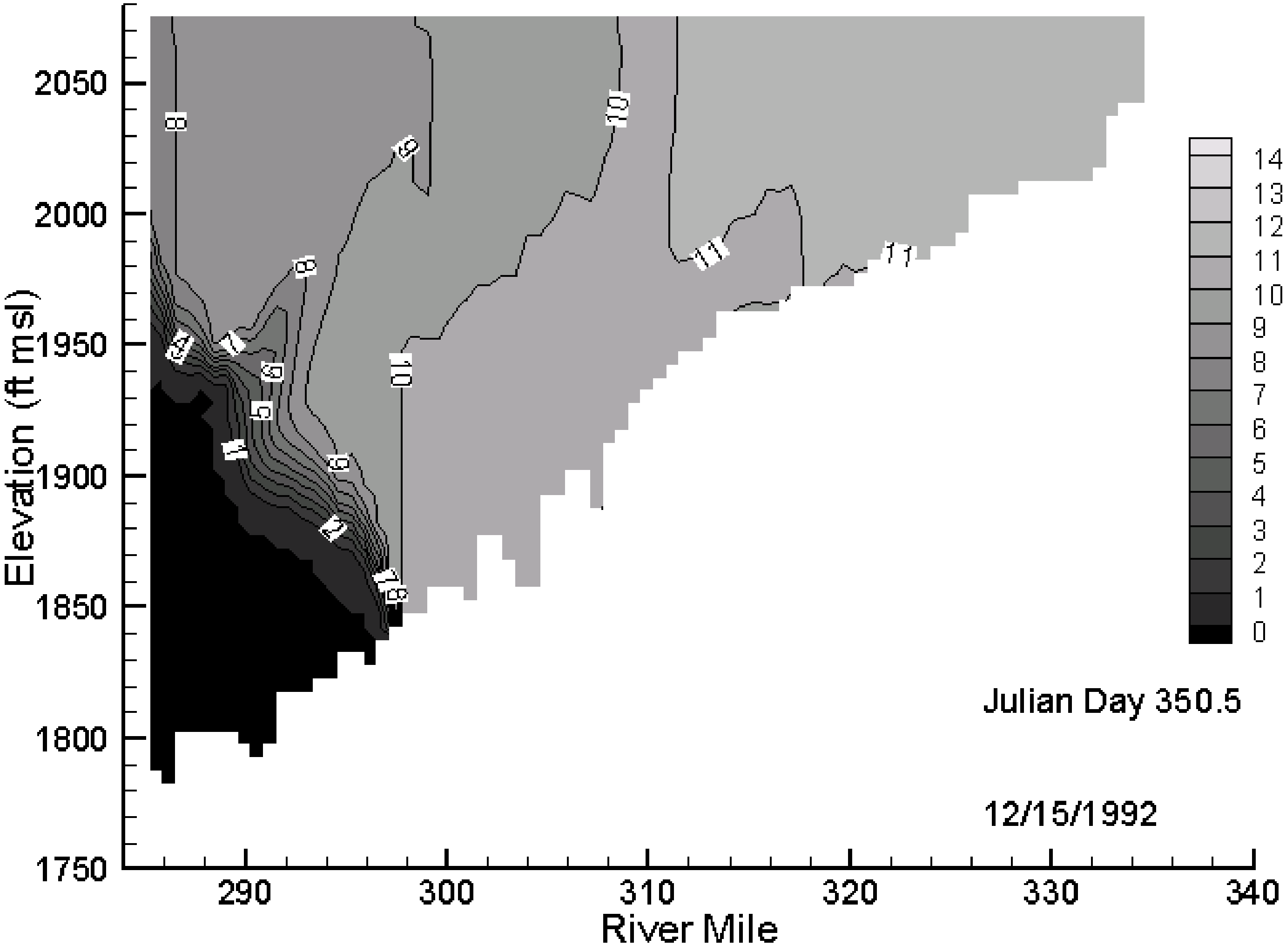


Figure 64. Simulated 1992 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

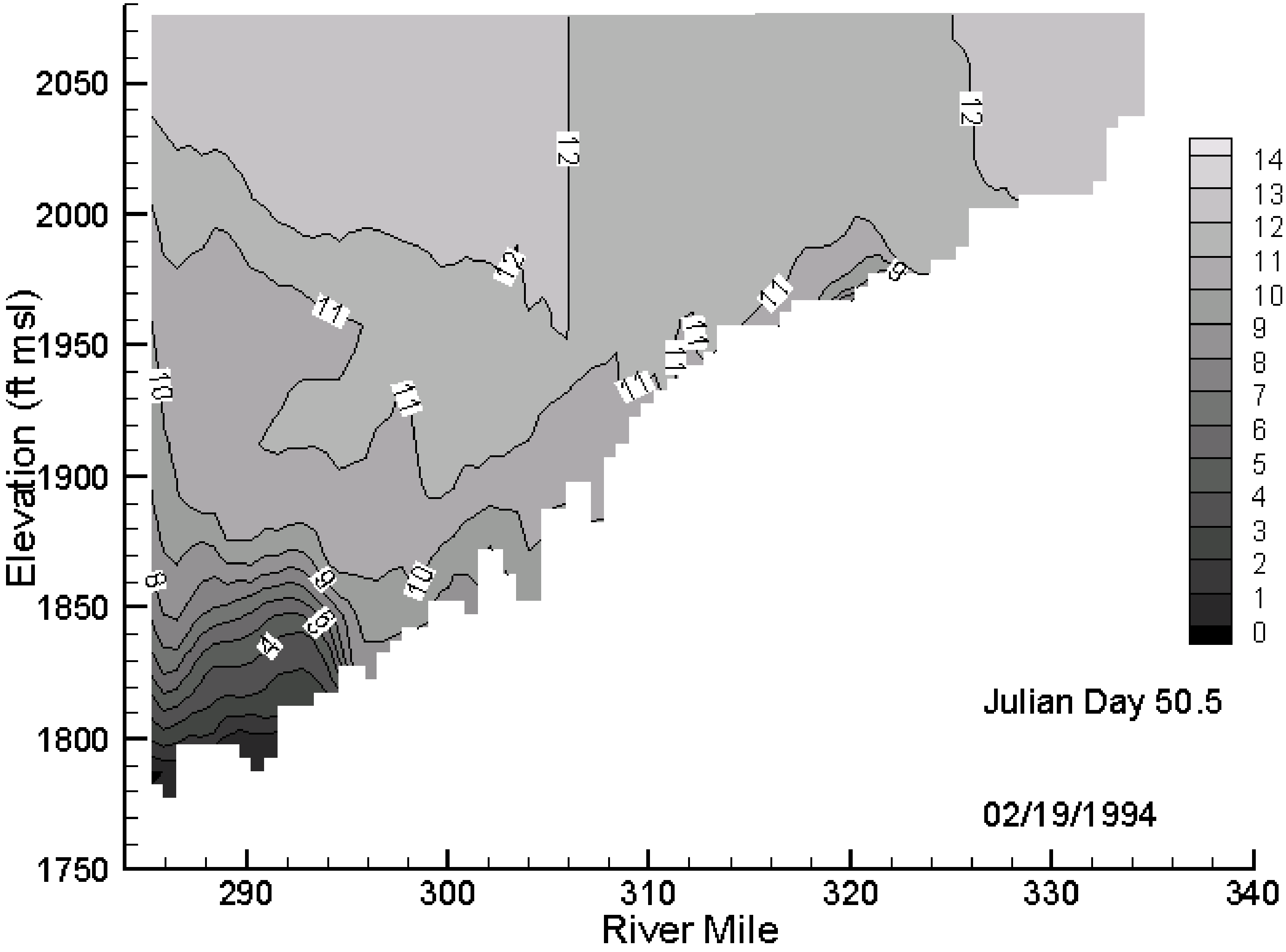


Figure 65. Simulated 1994 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

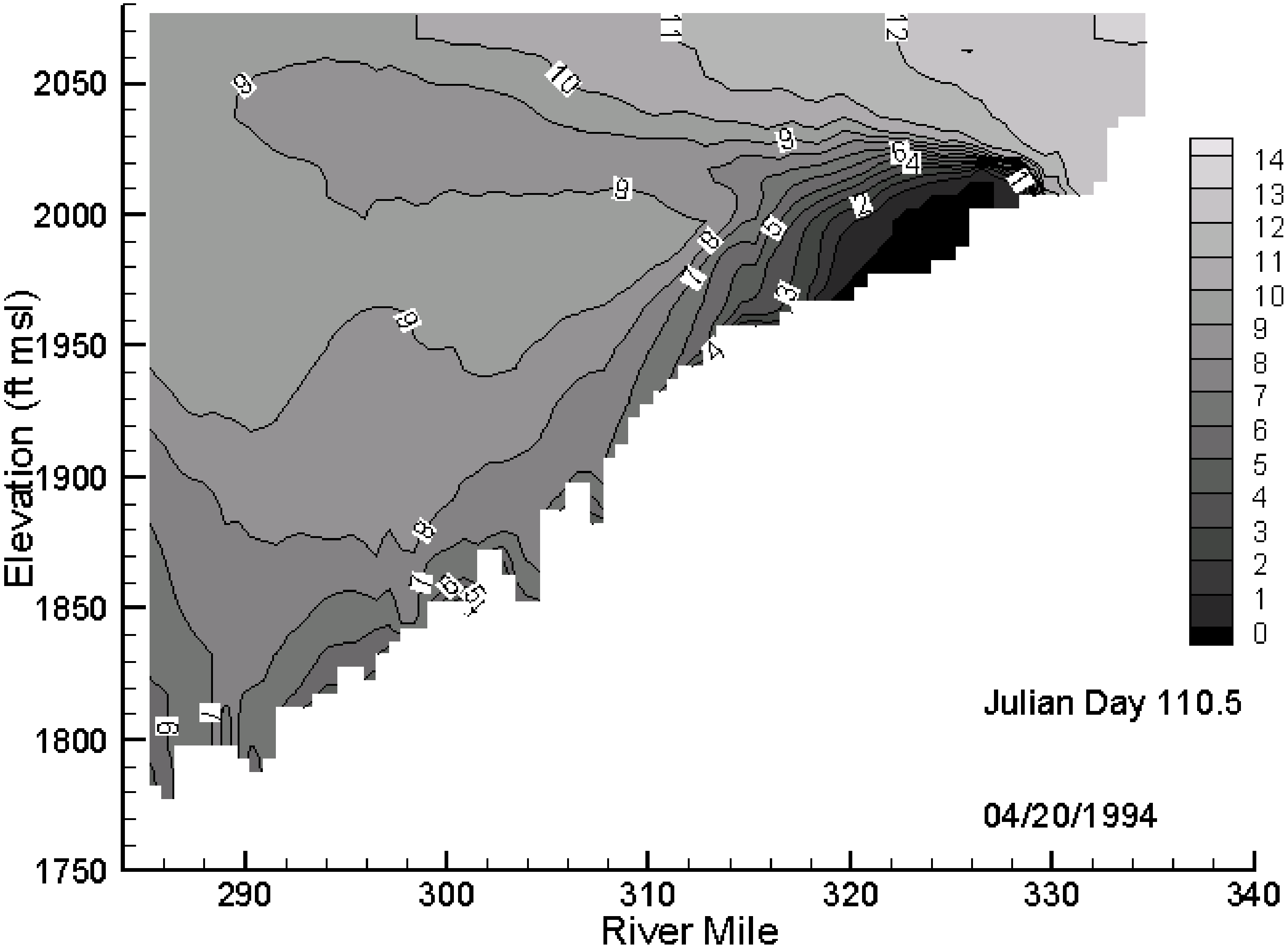


Figure 66. Simulated 1994 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

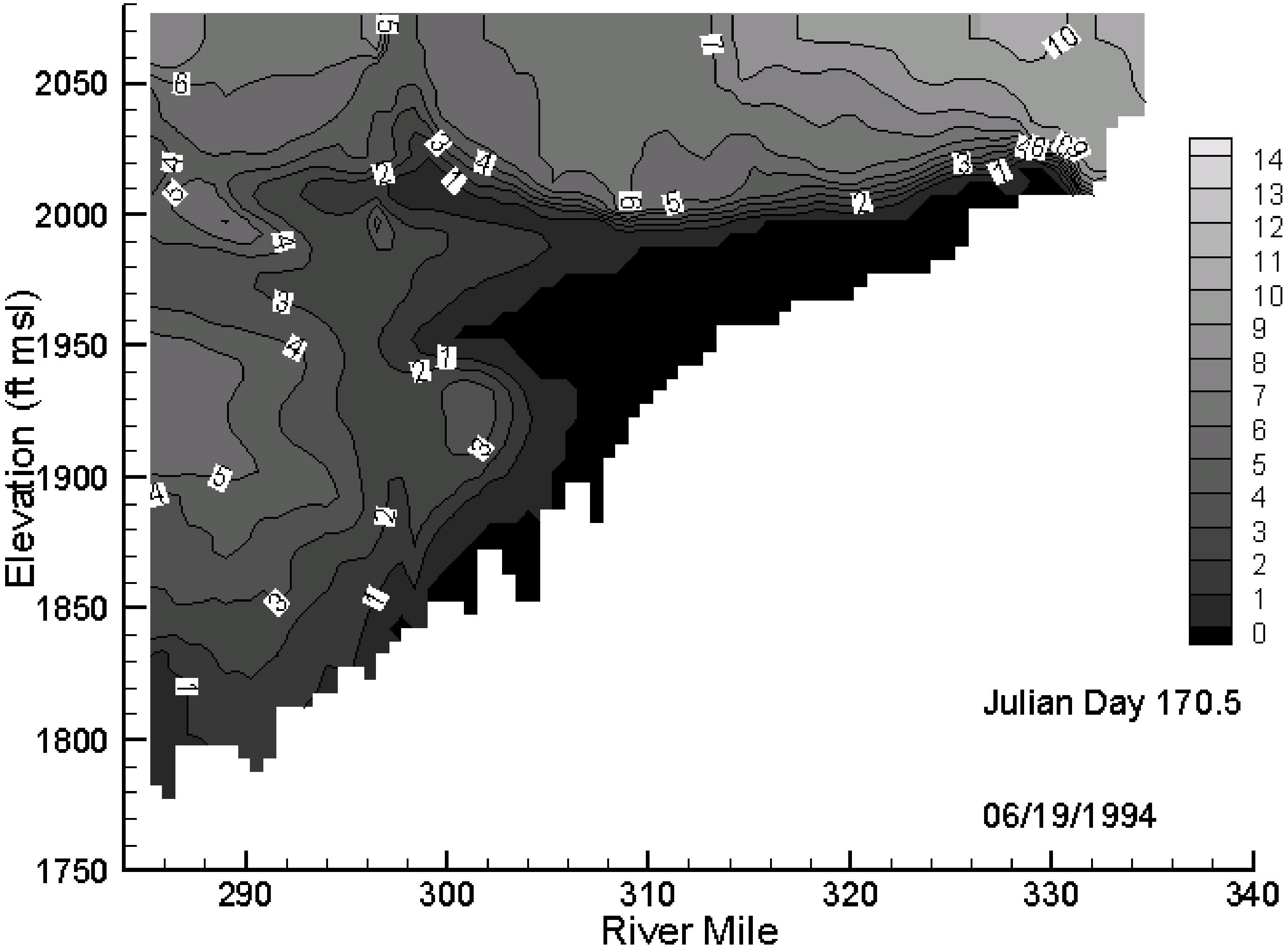


Figure 67. Simulated 1994 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

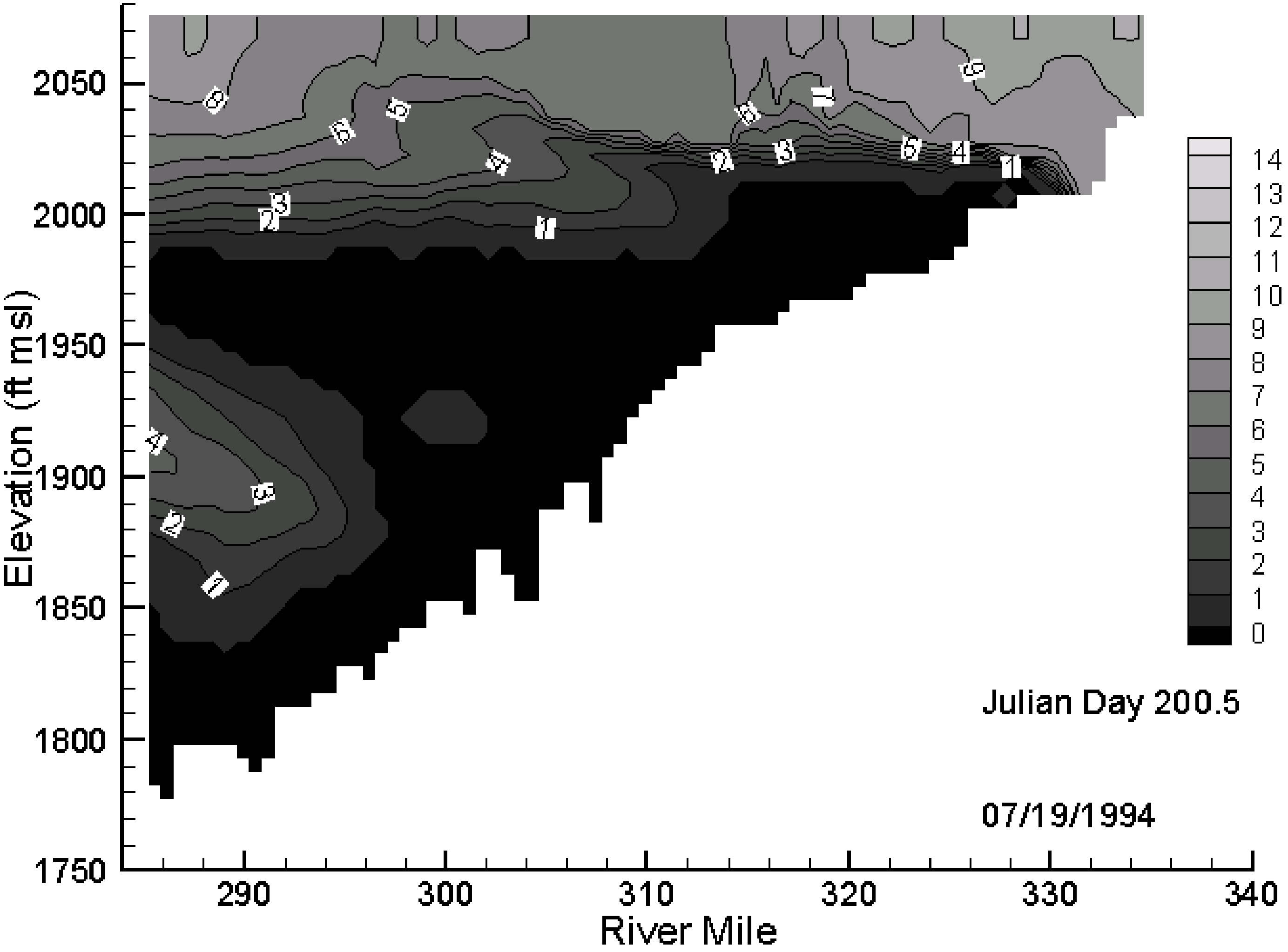


Figure 68. Simulated 1994 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

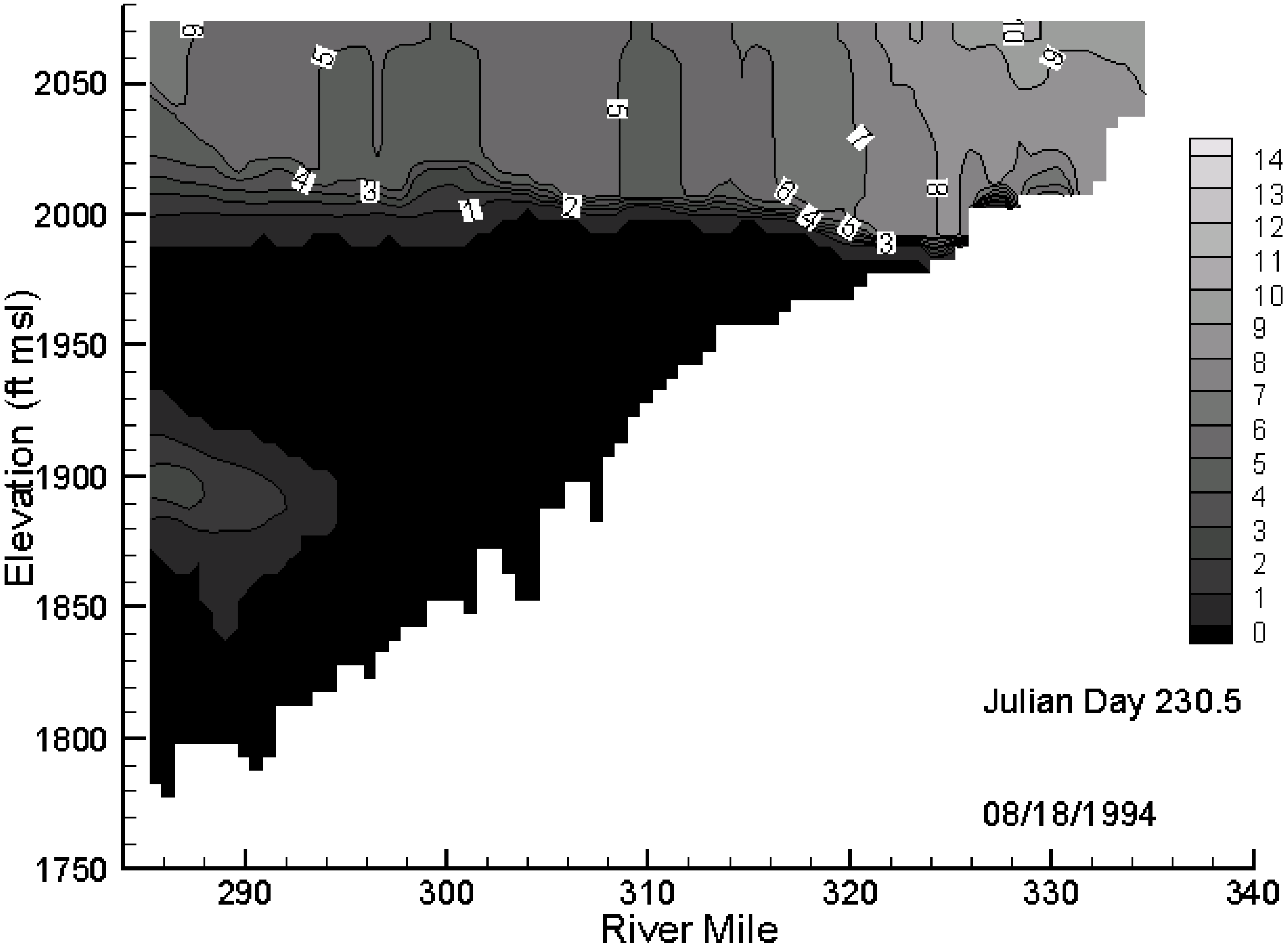


Figure 69. Simulated 1994 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

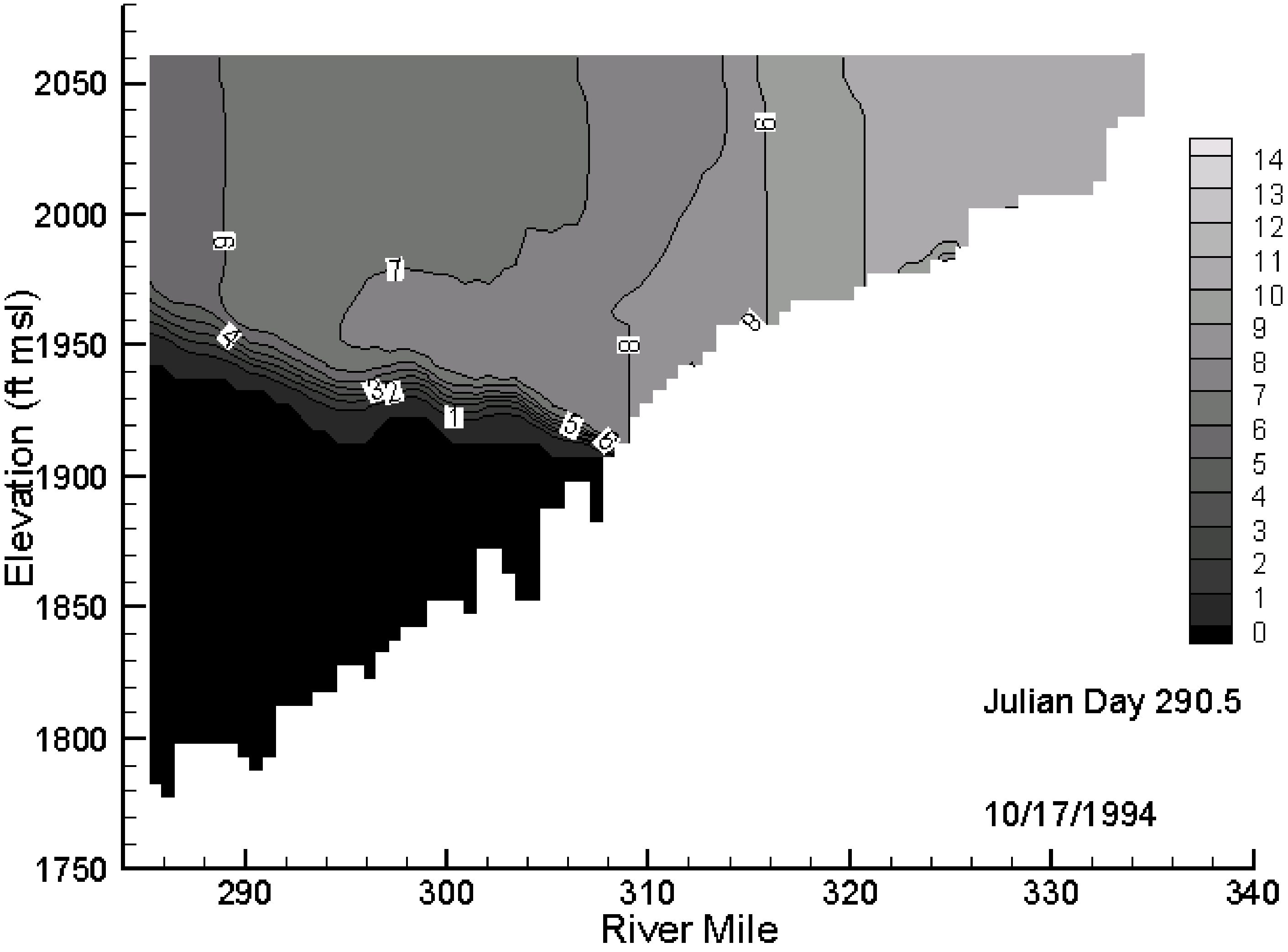


Figure 70. Simulated 1994 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

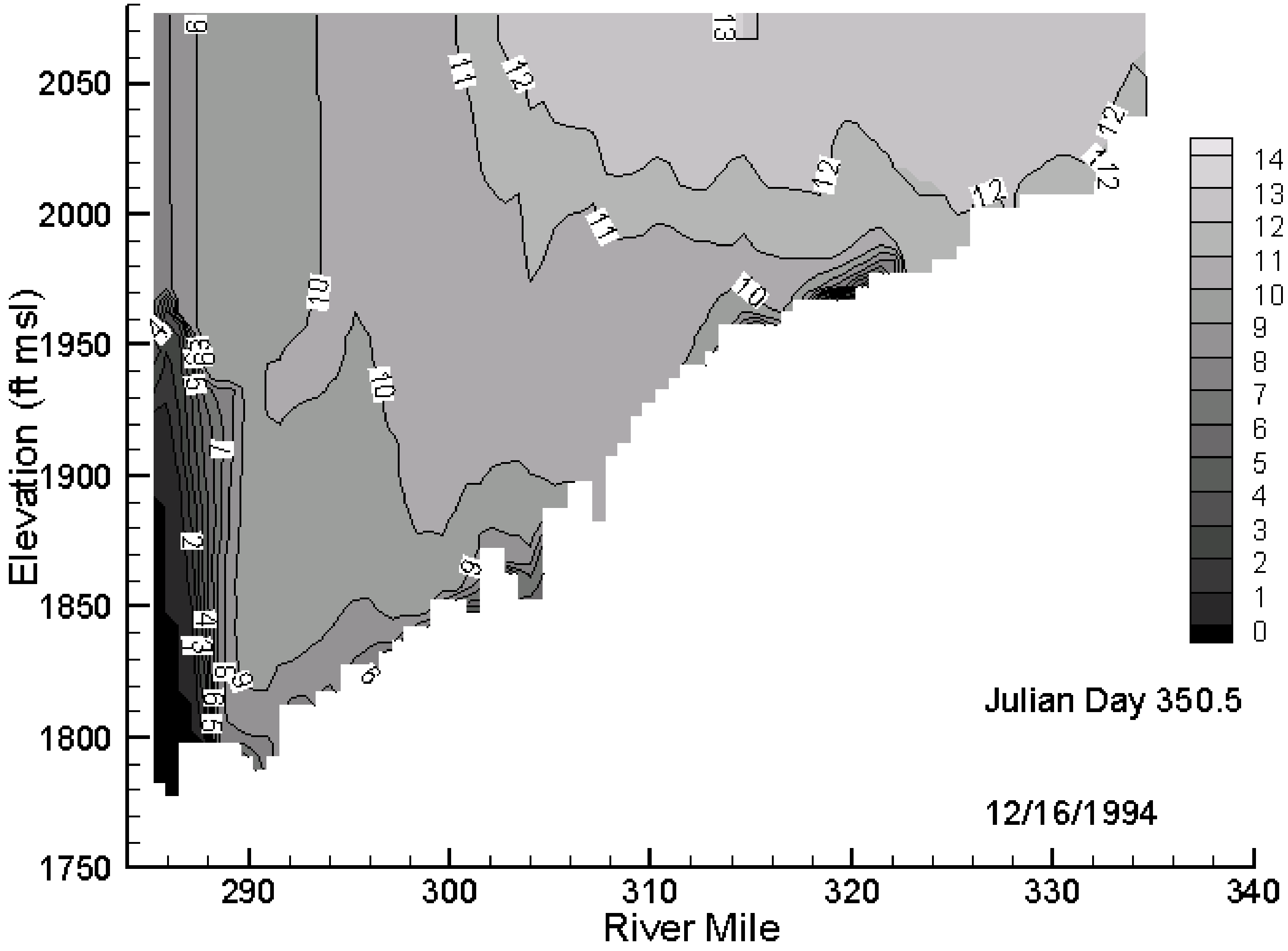


Figure 71. Simulated 1994 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

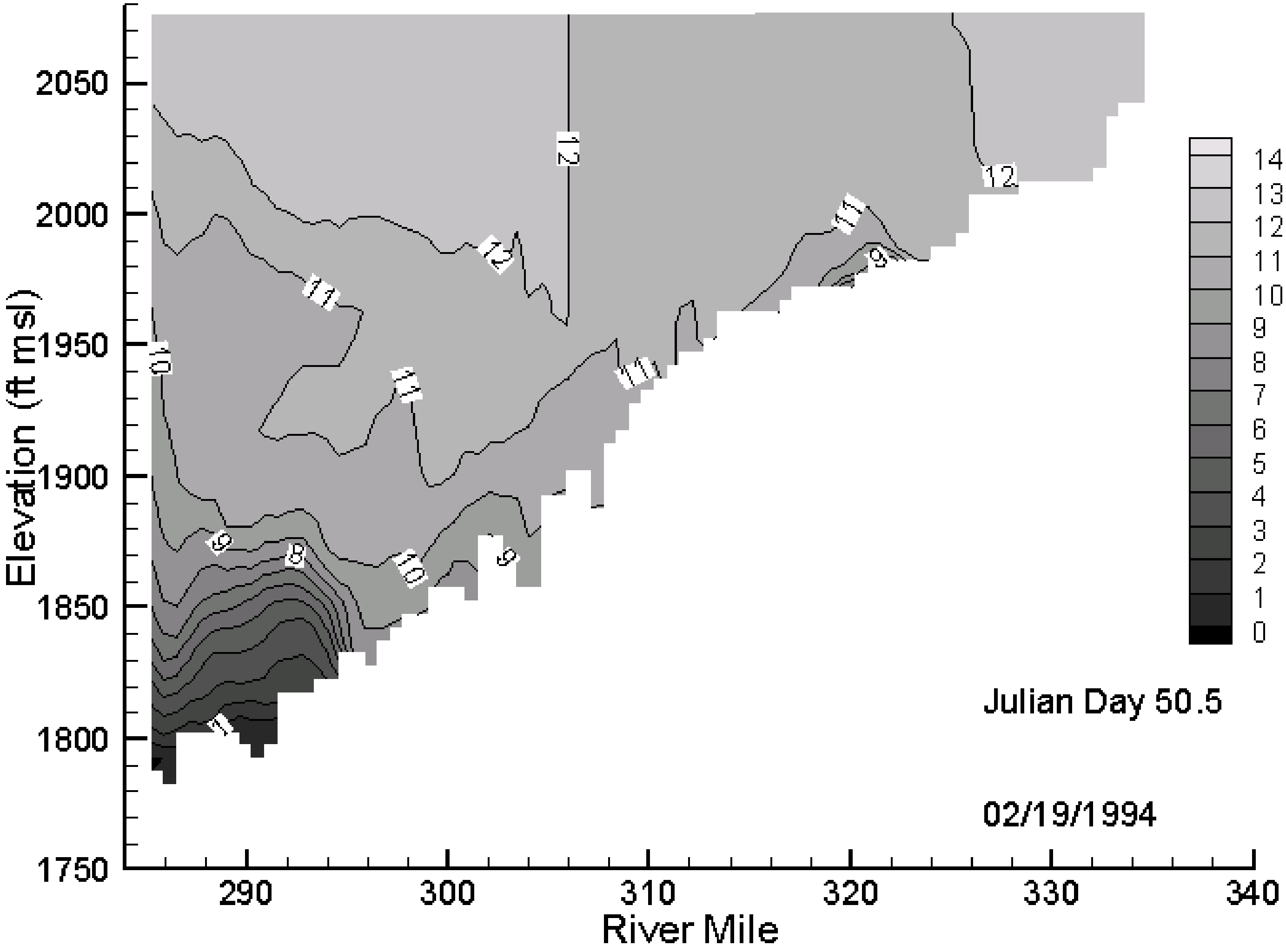


Figure 72. Simulated 1994 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

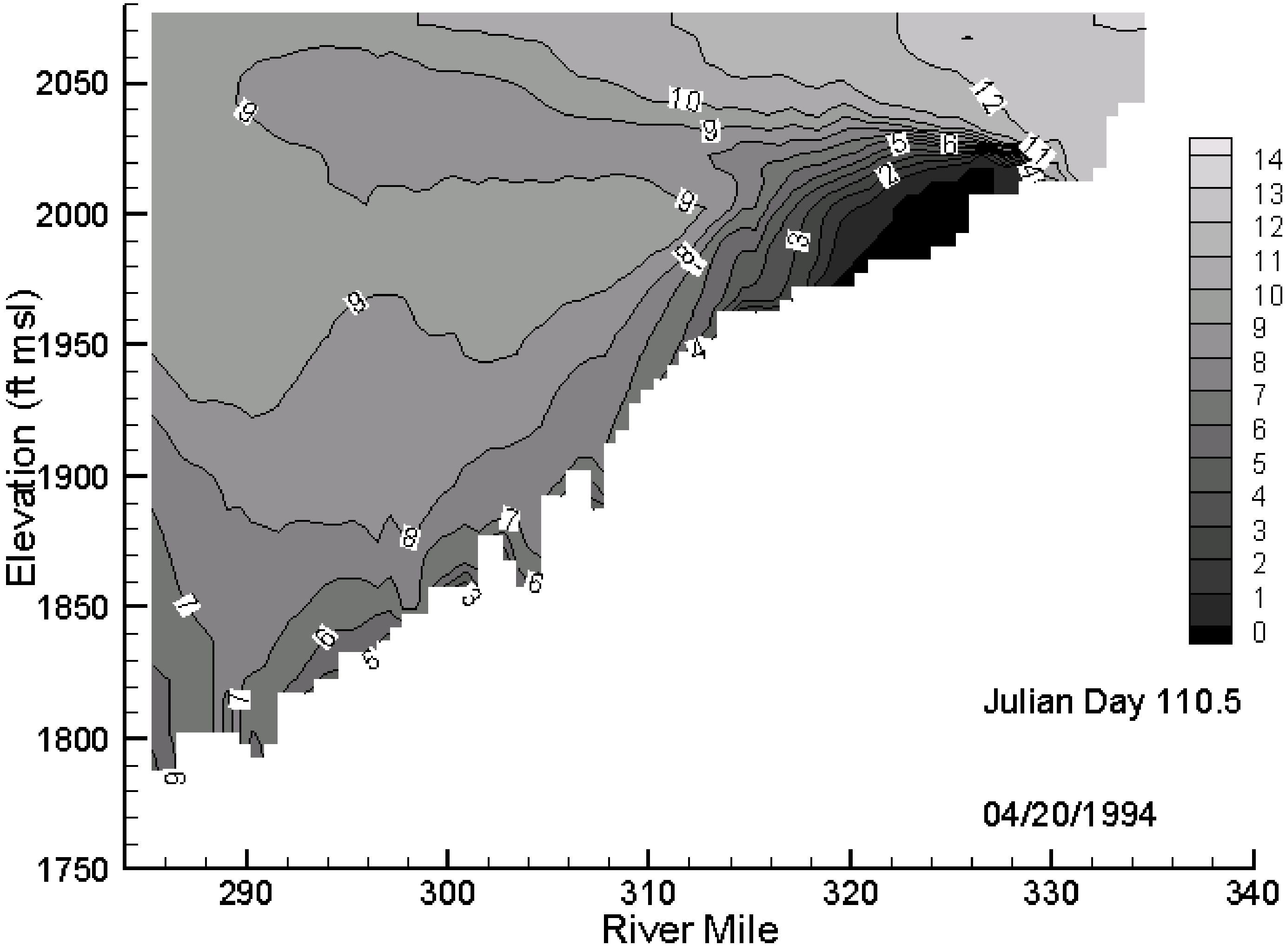


Figure 73. Simulated 1994 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

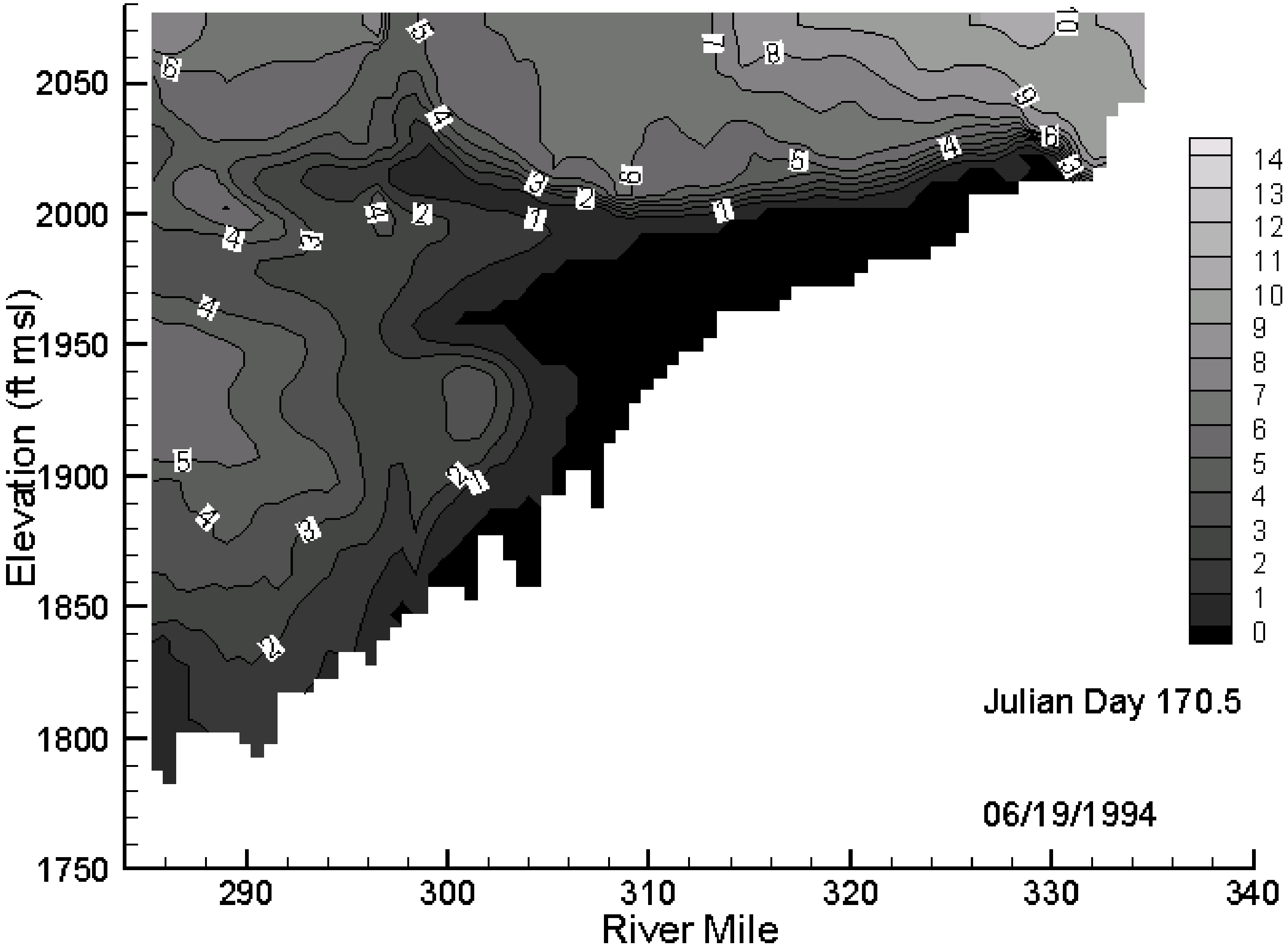


Figure 74. Simulated 1994 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

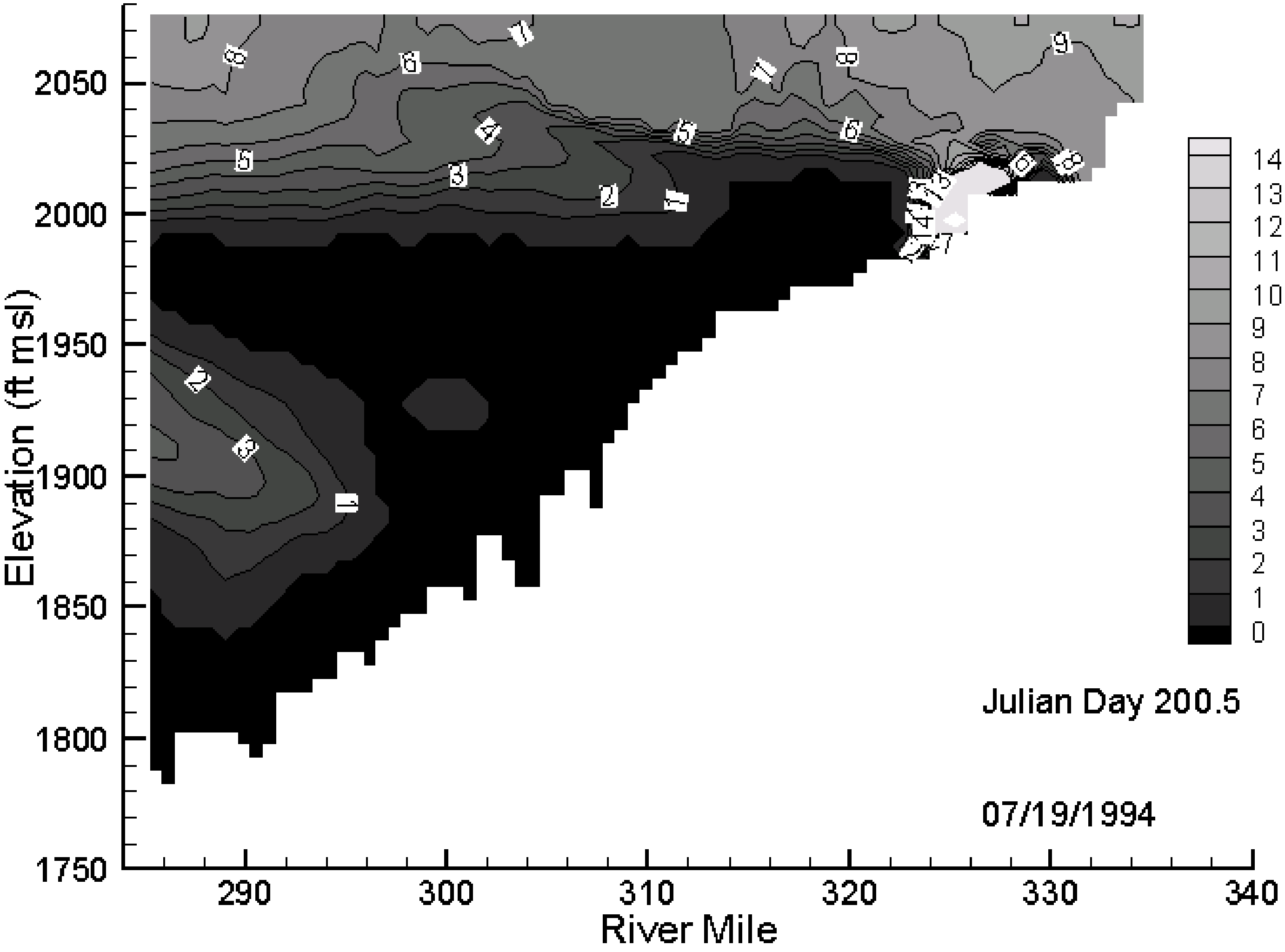


Figure 75. Simulated 1994 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

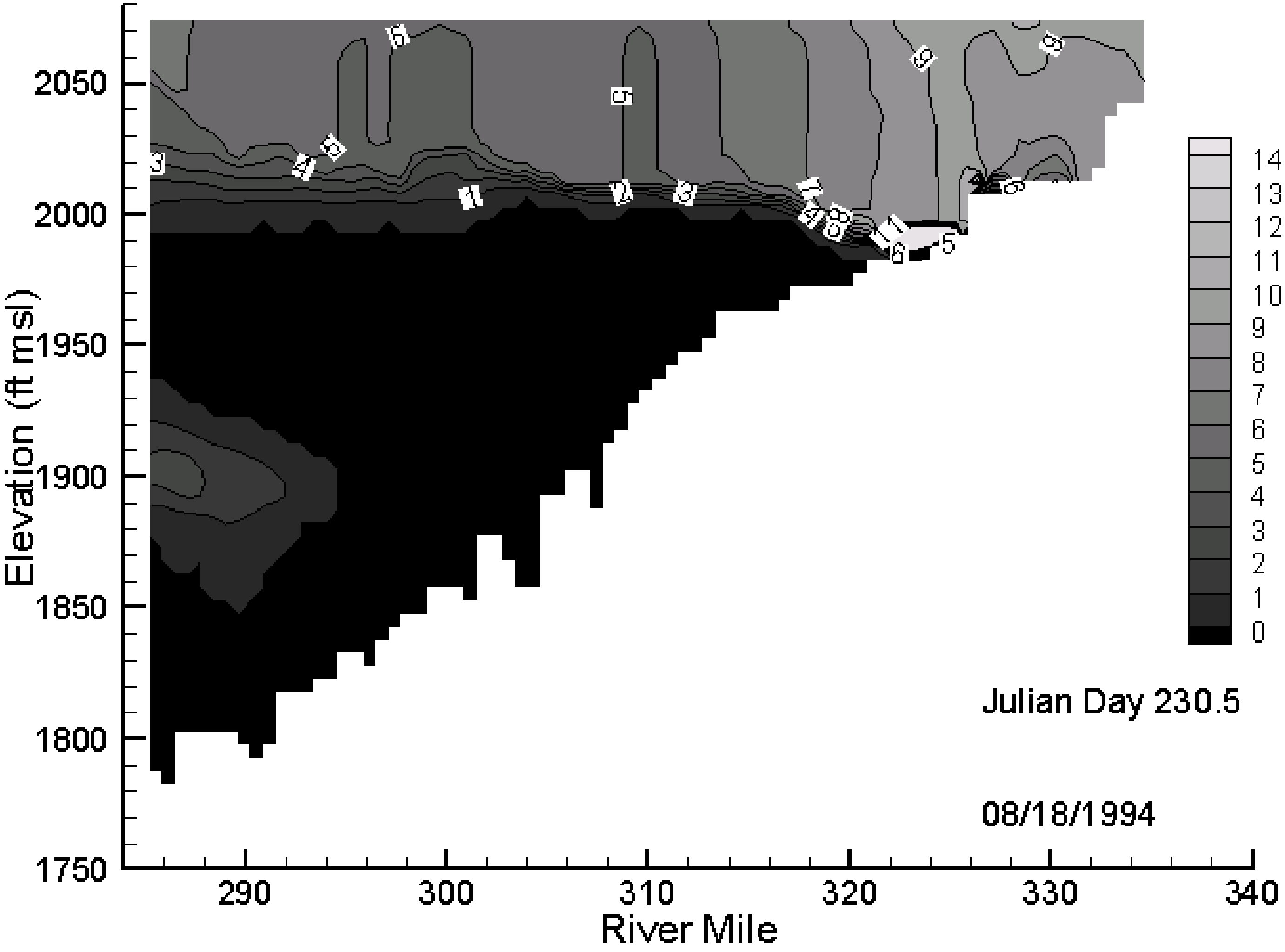


Figure 76. Simulated 1994 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

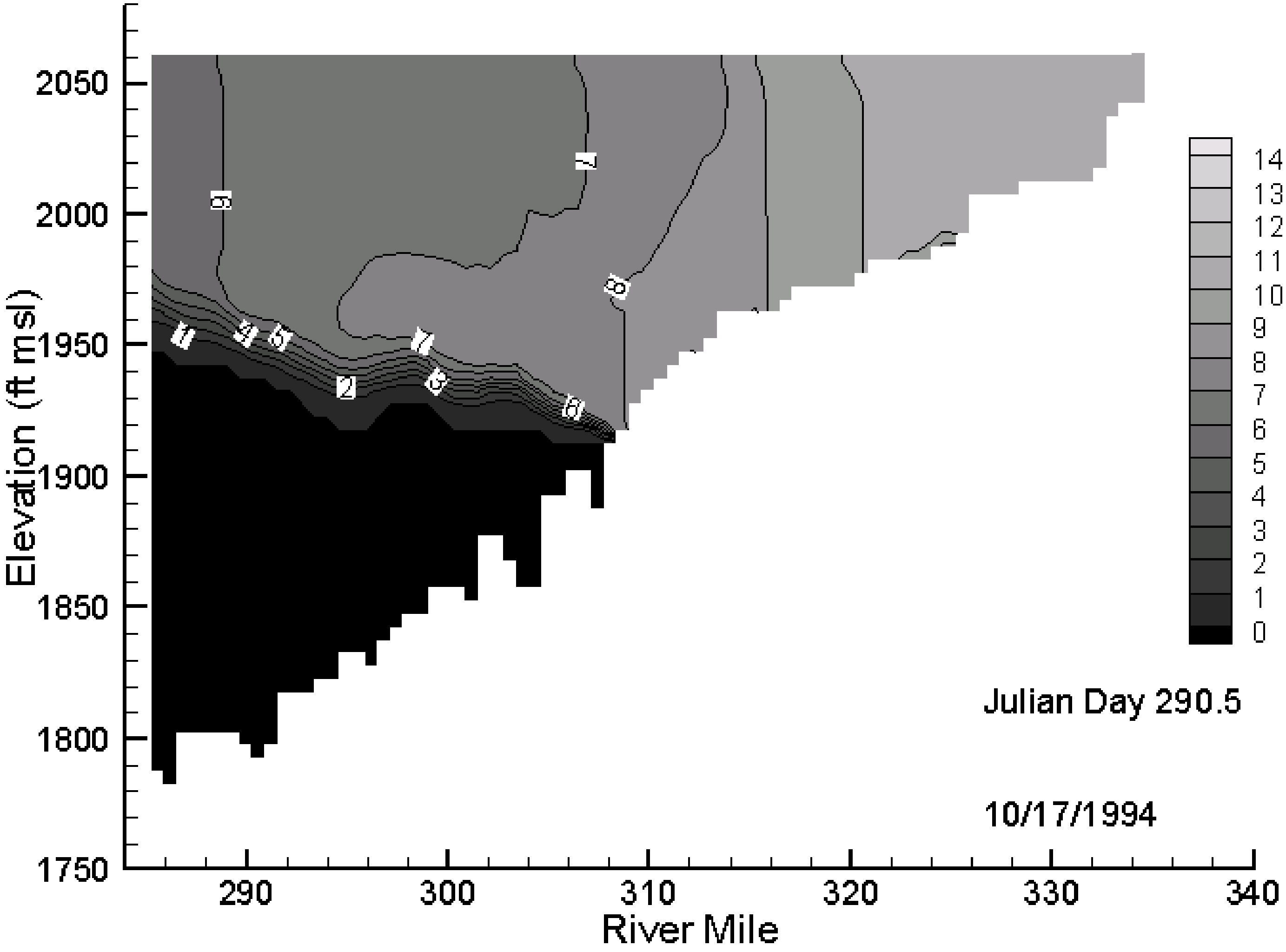


Figure 77. Simulated 1994 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

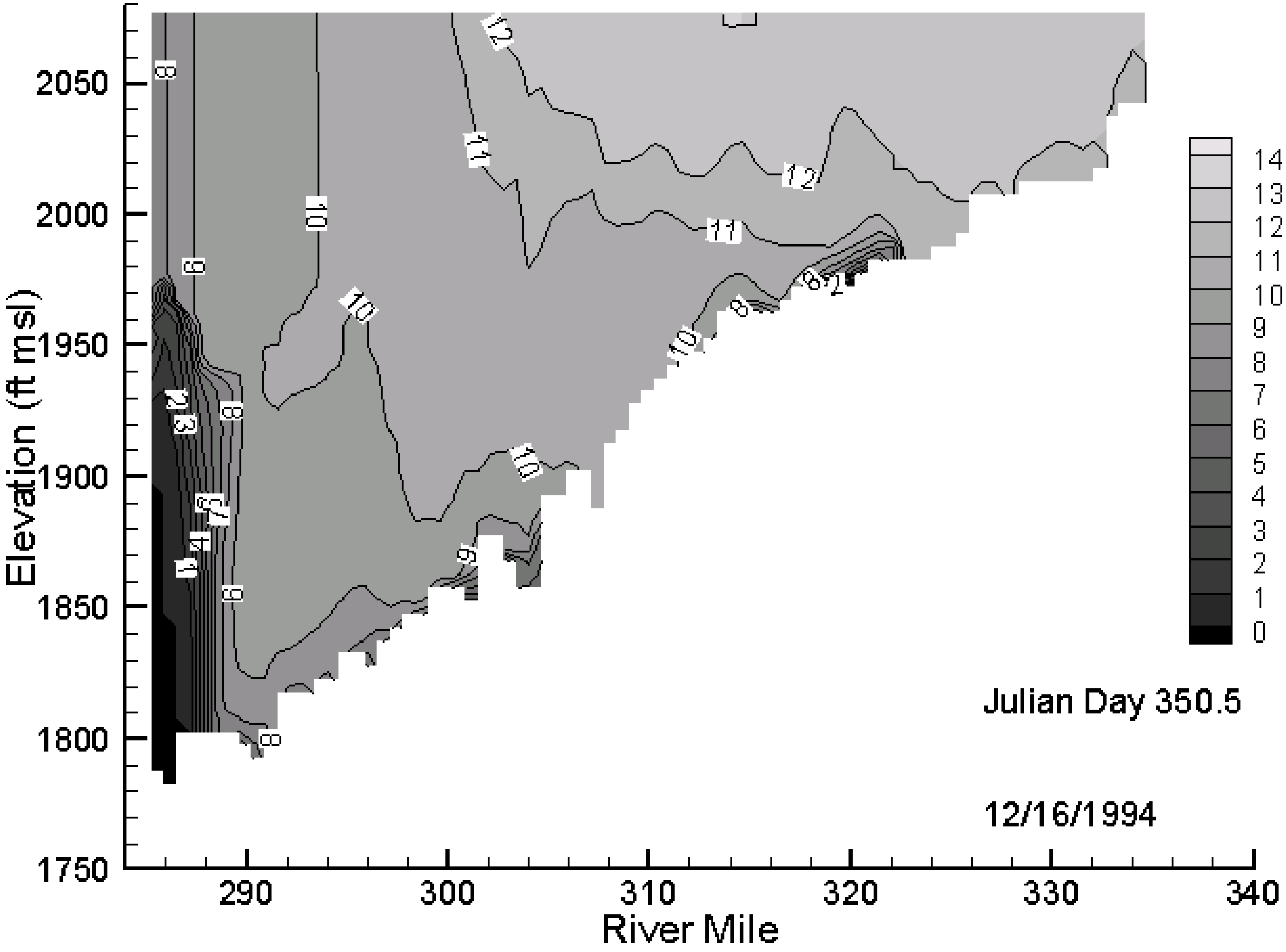


Figure 78. Simulated 1994 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

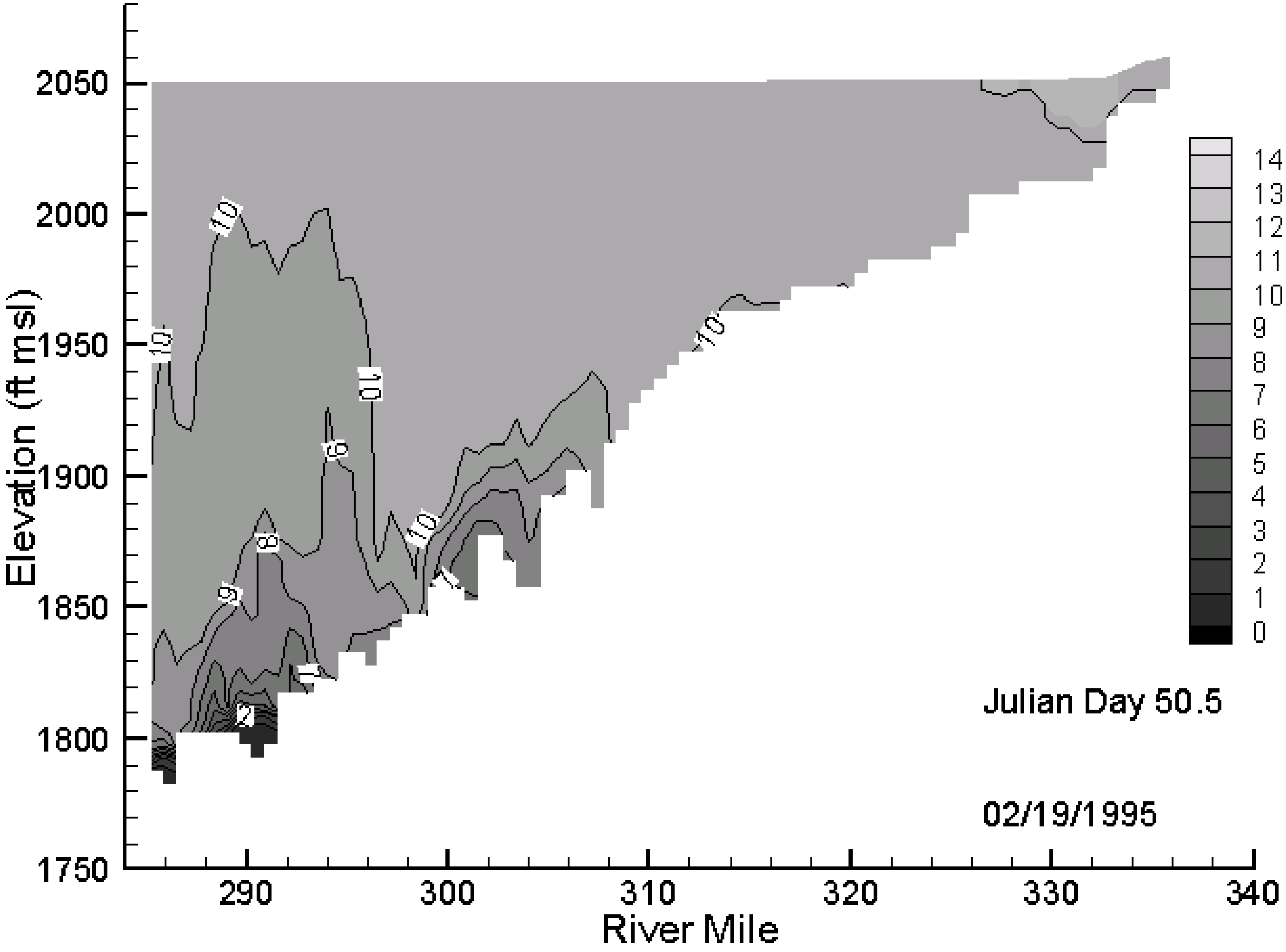


Figure 79. Simulated 1995 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

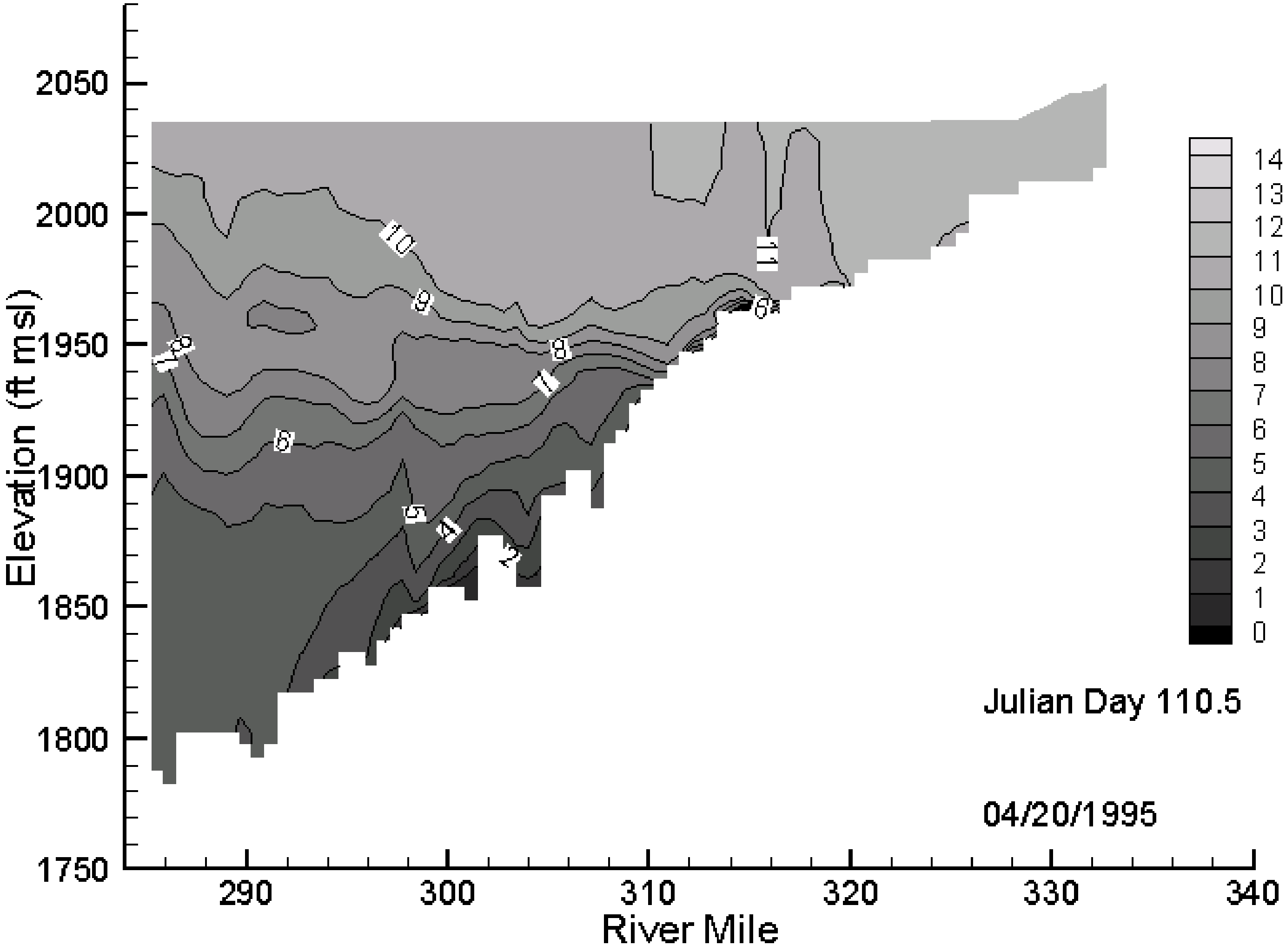


Figure 80. Simulated 1995 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

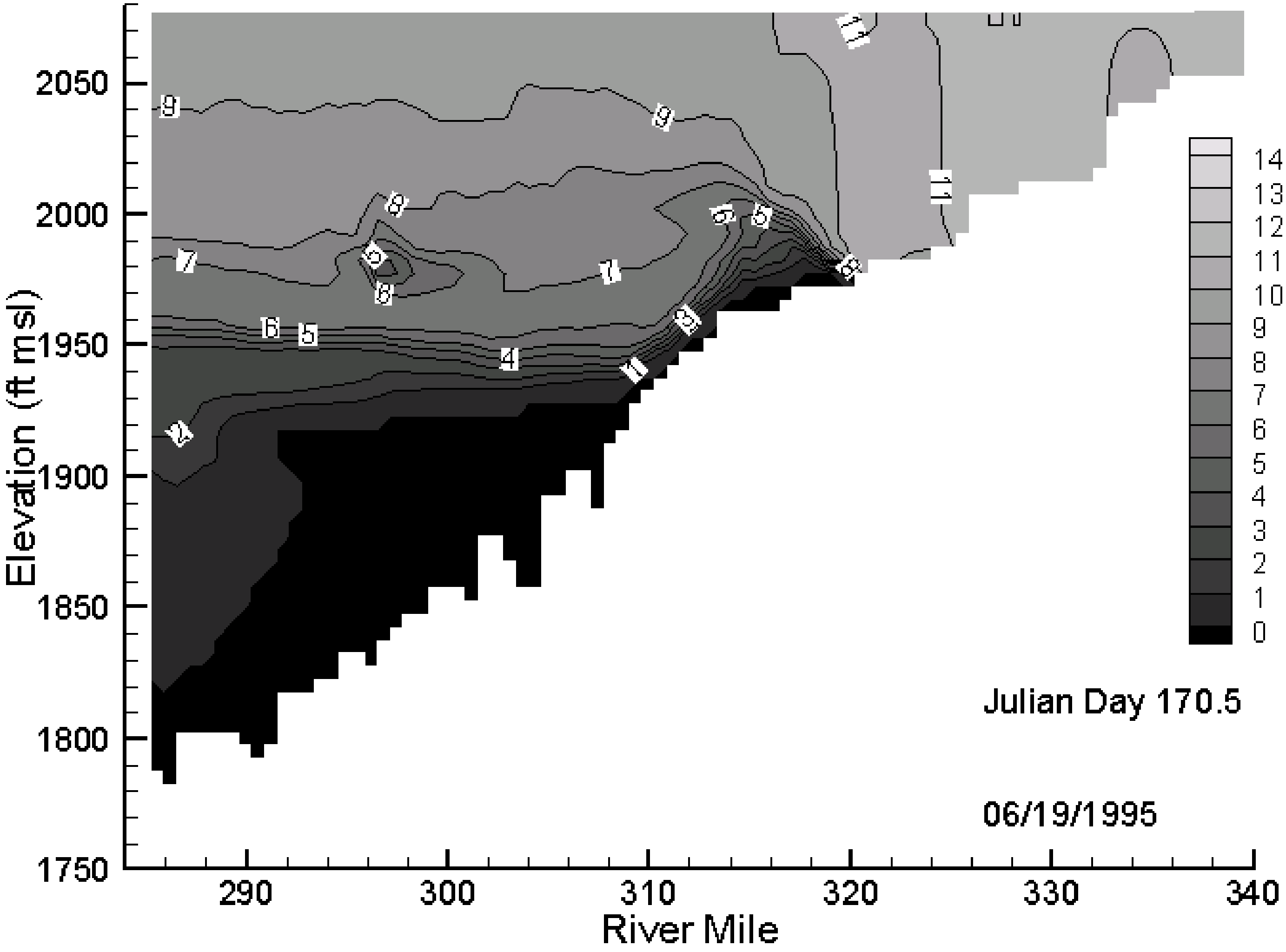


Figure 81. Simulated 1995 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

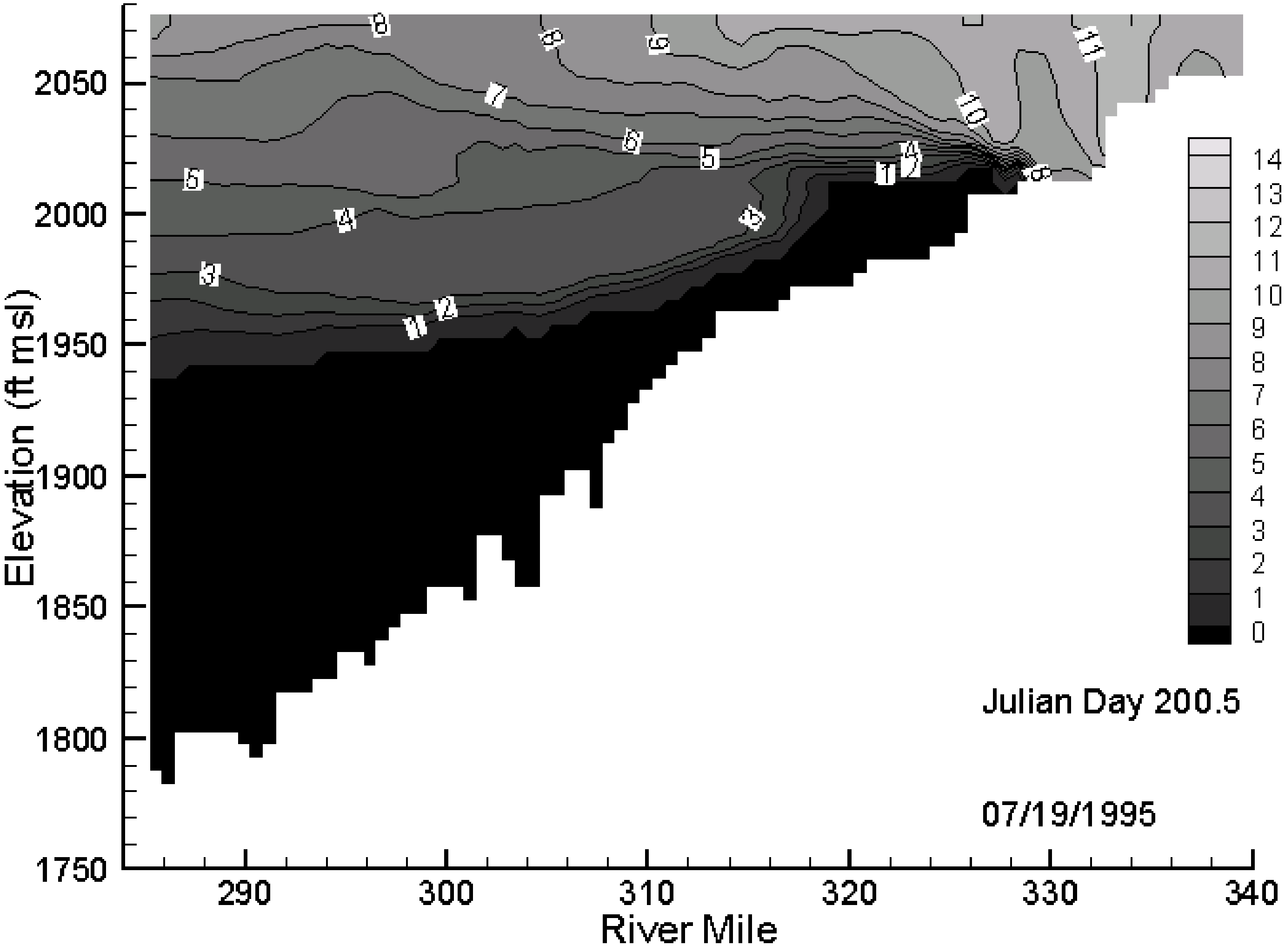


Figure 82. Simulated 1995 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

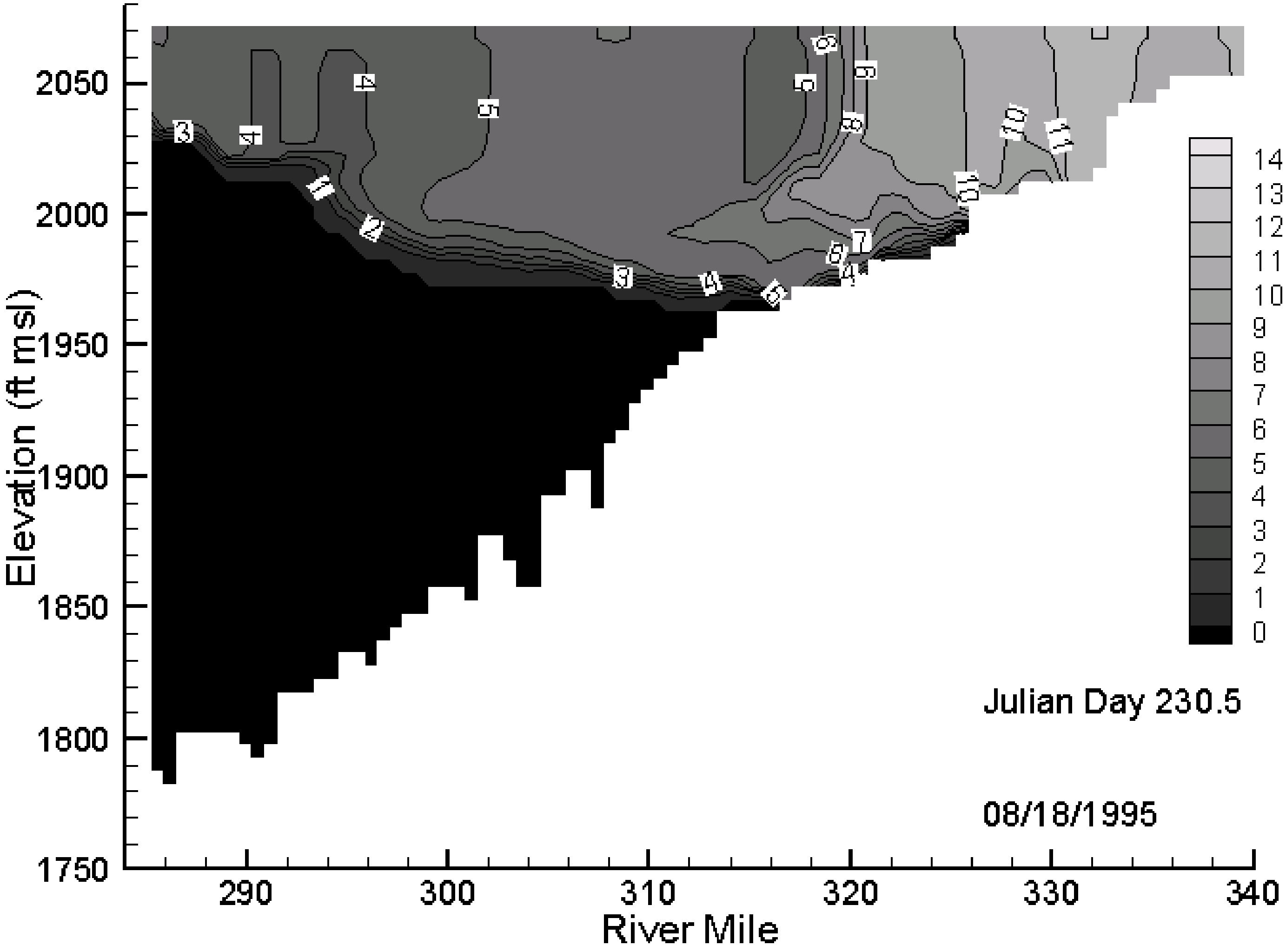


Figure 83. Simulated 1995 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

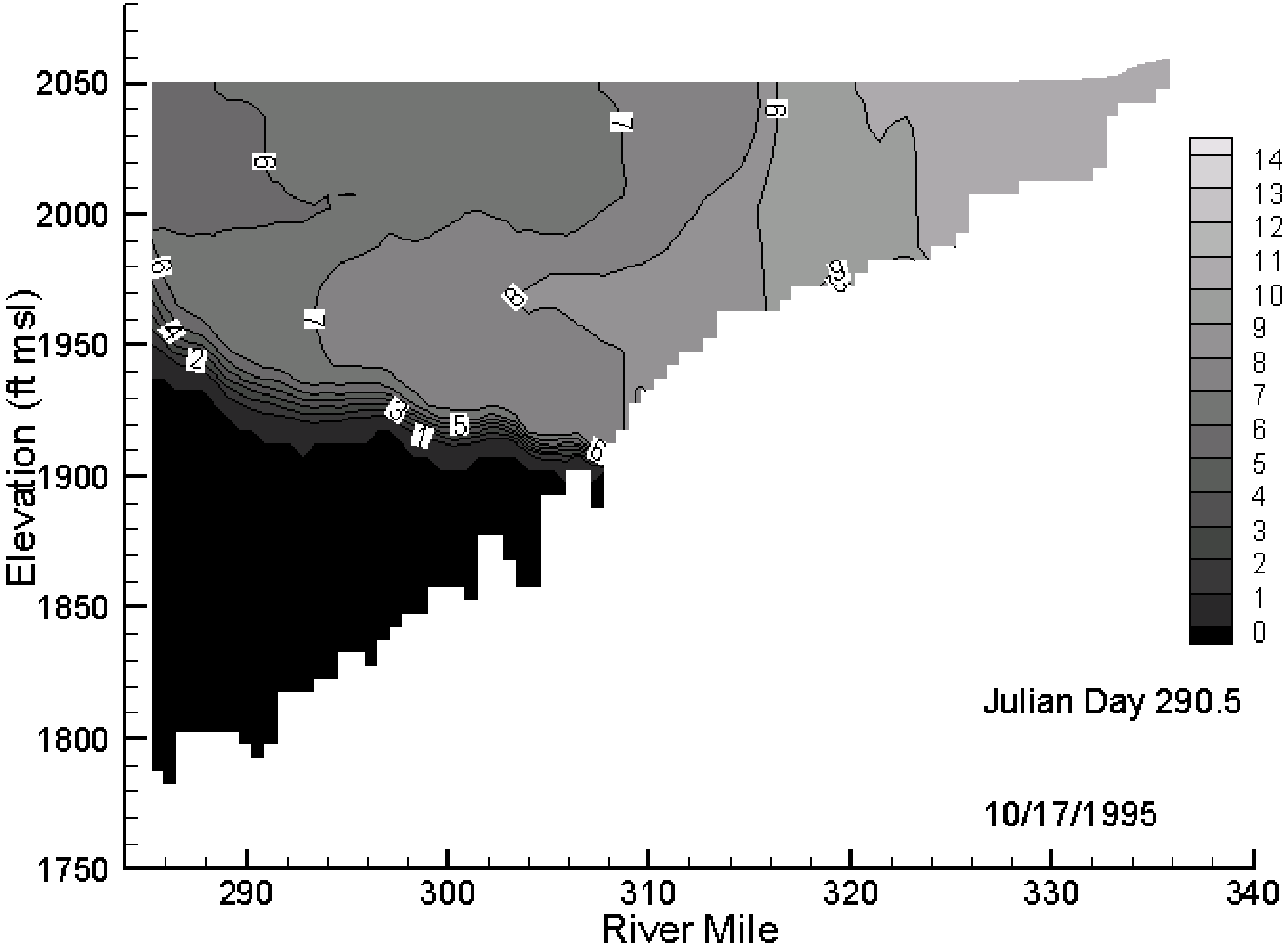


Figure 84. Simulated 1995 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

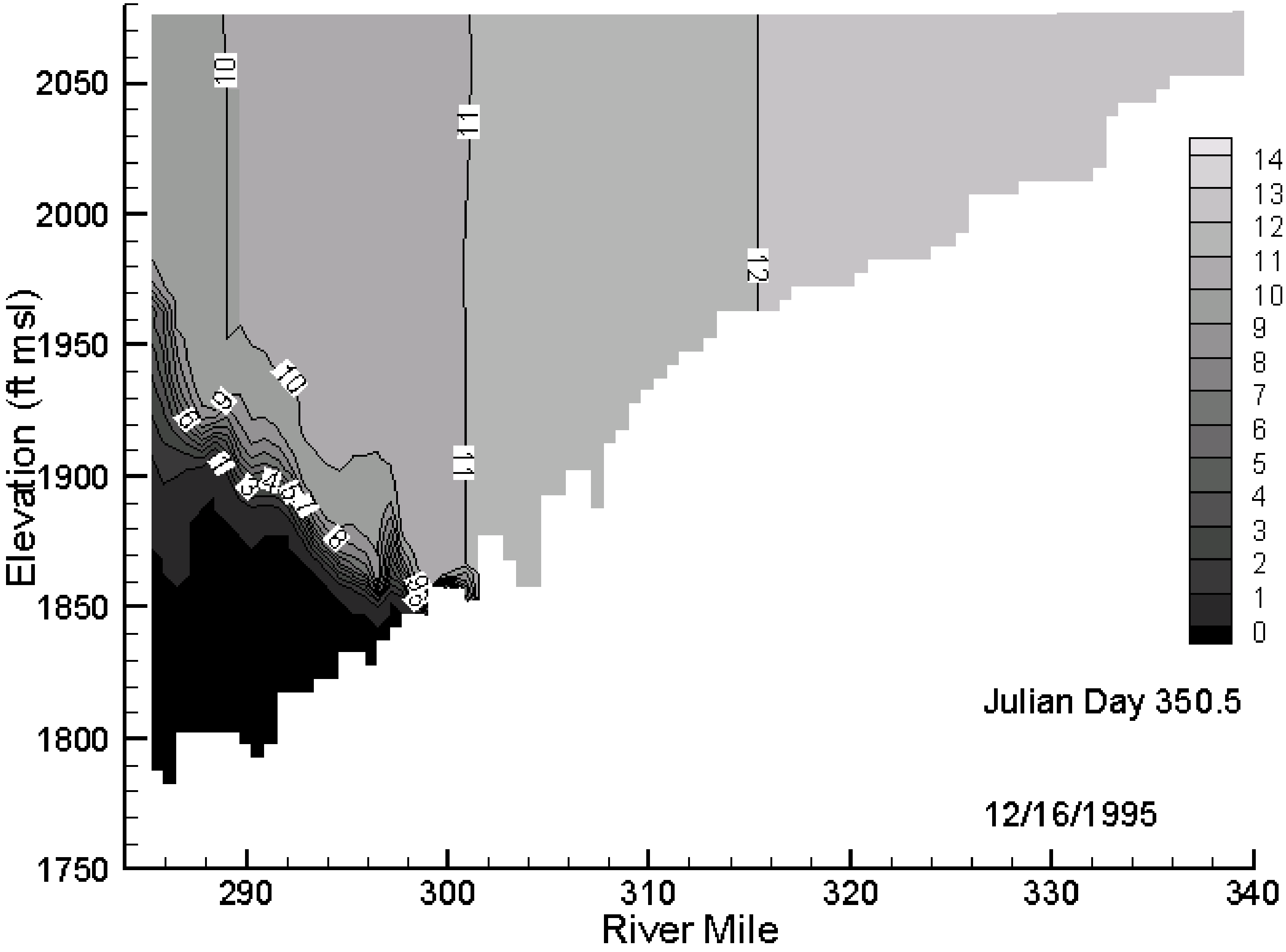


Figure 85. Simulated 1995 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

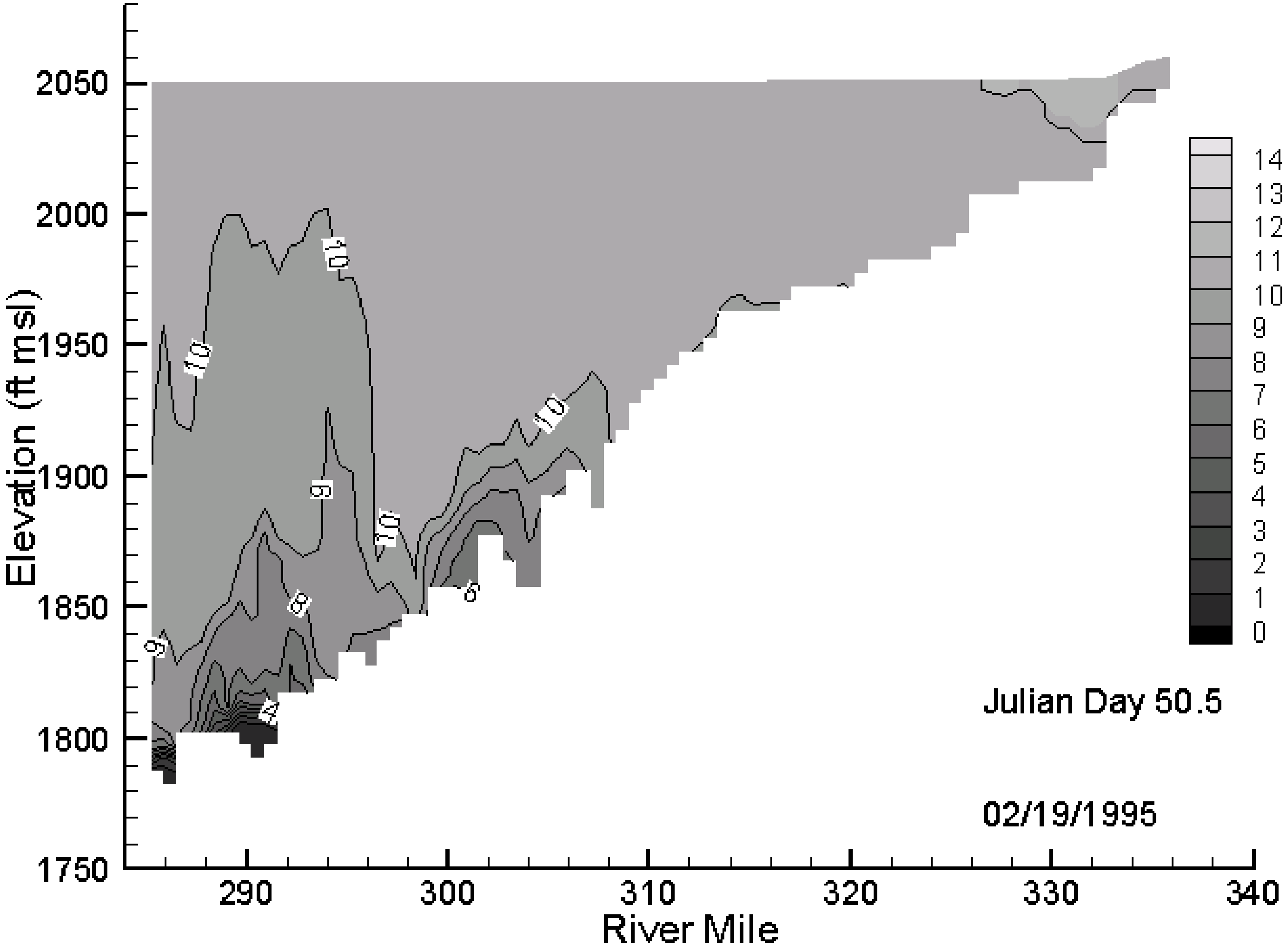


Figure 86. Simulated 1995 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

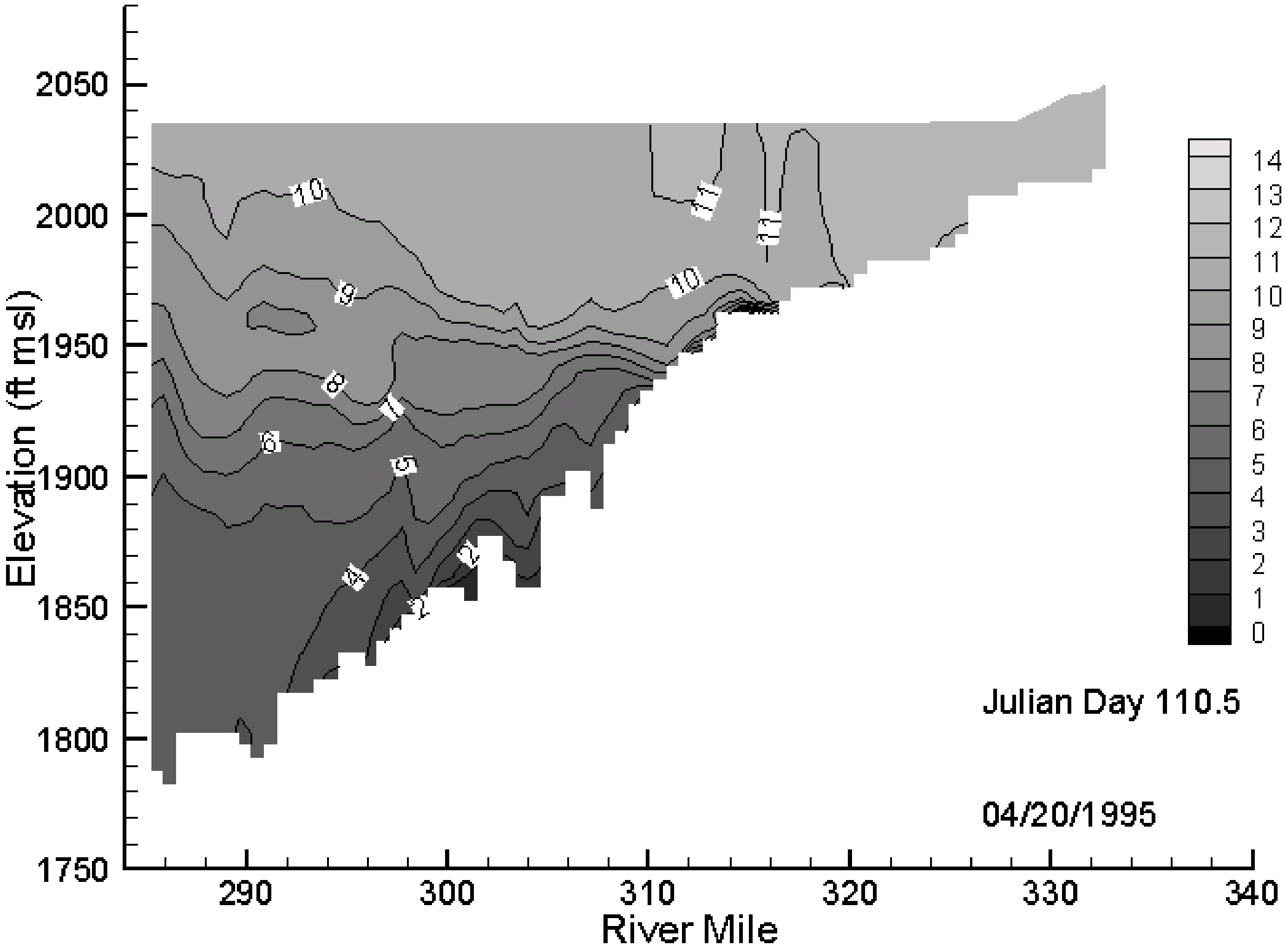


Figure 87. Simulated 1995 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

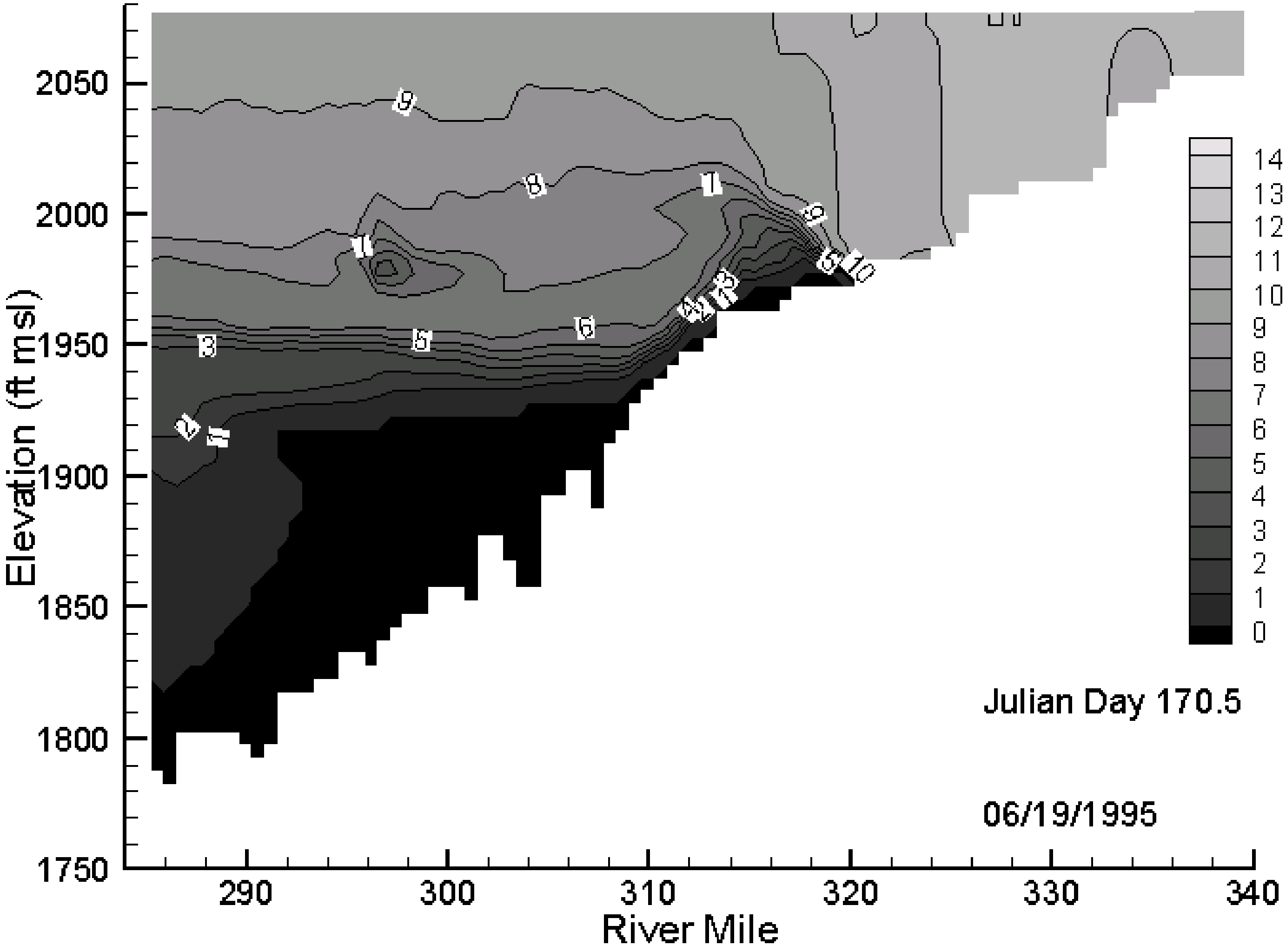


Figure 88. Simulated 1995 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

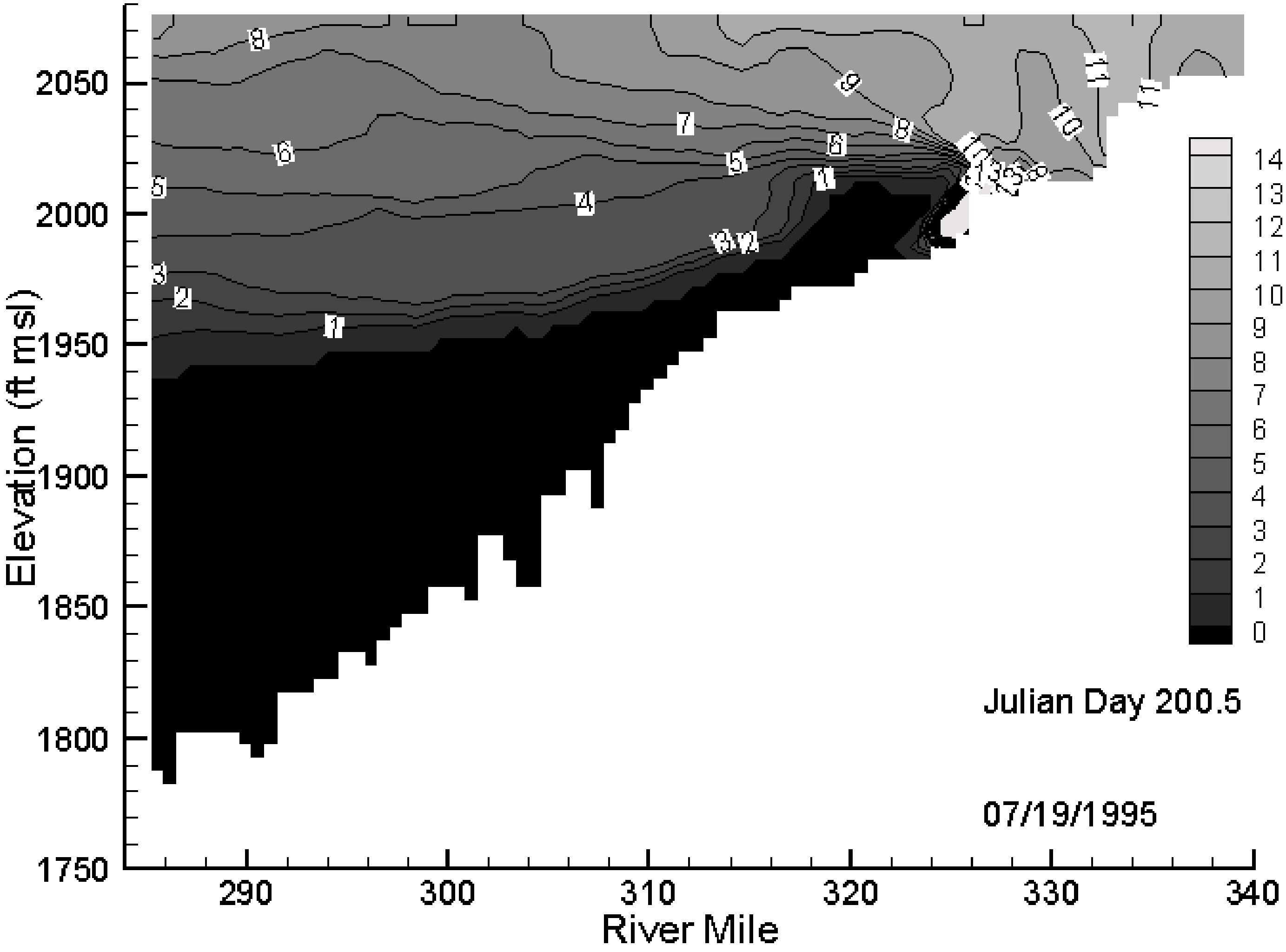


Figure 89. Simulated 1995 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

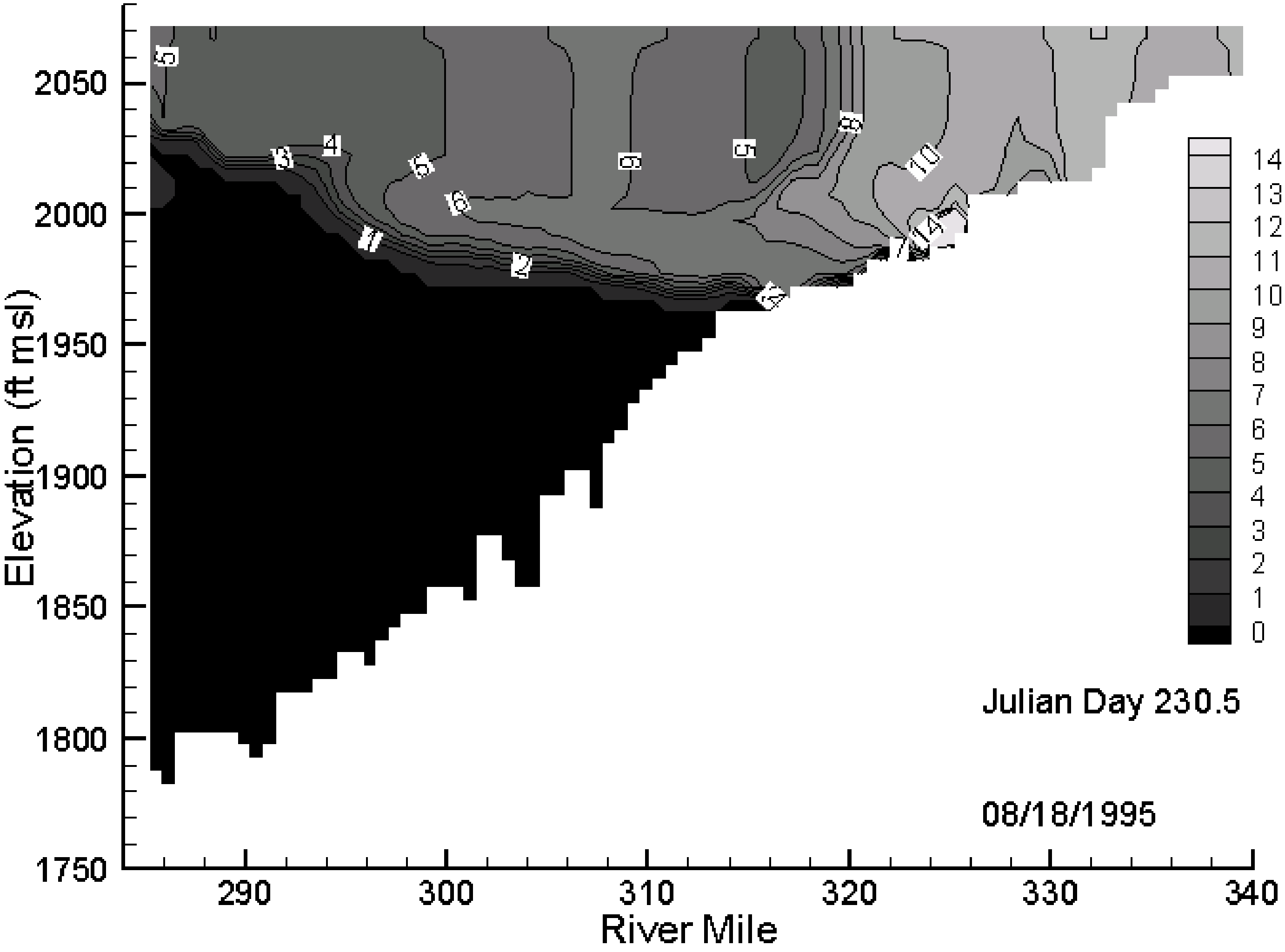


Figure 90. Simulated 1995 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at proposed the location.

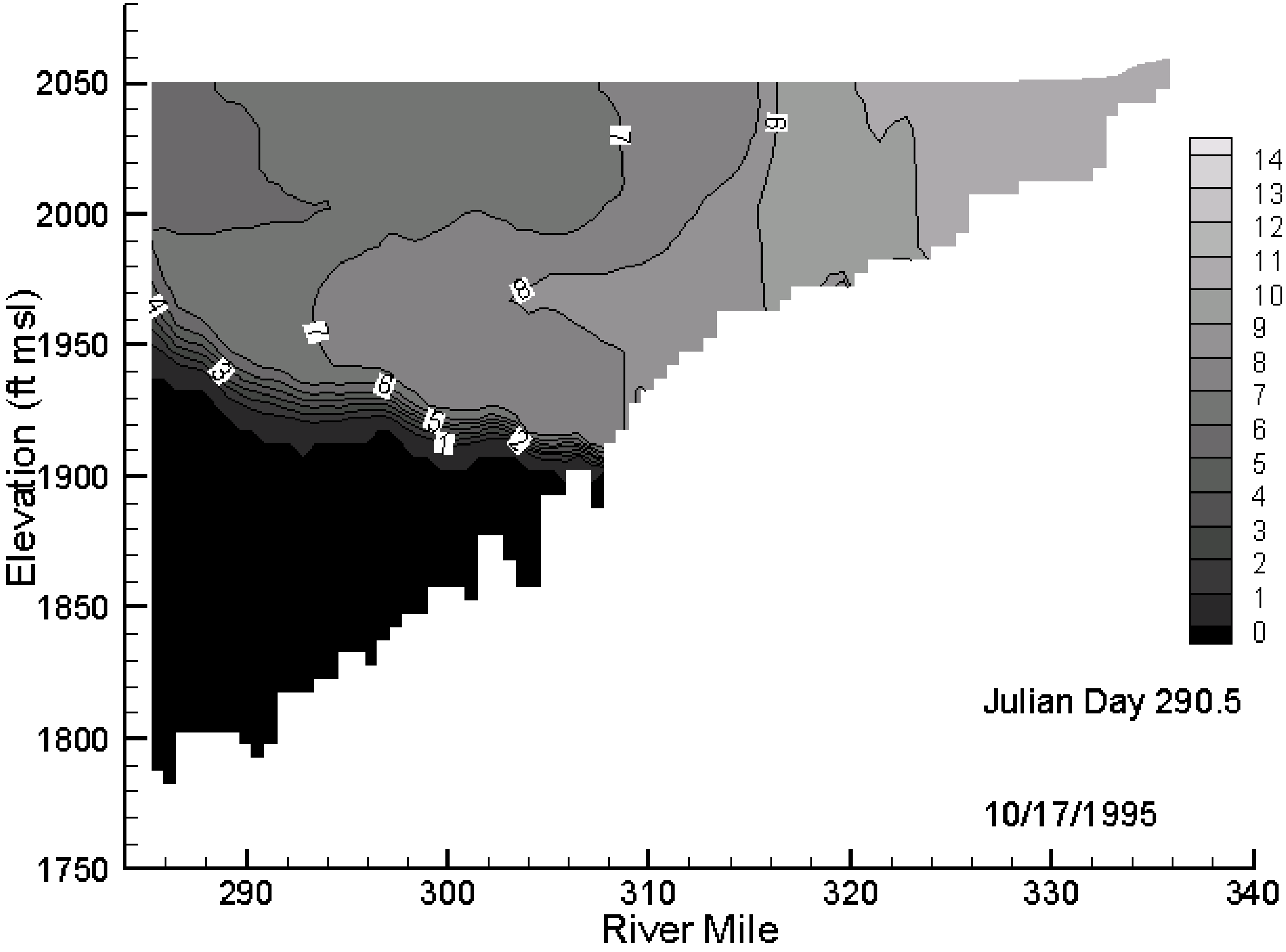


Figure 91. Simulated 1995 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

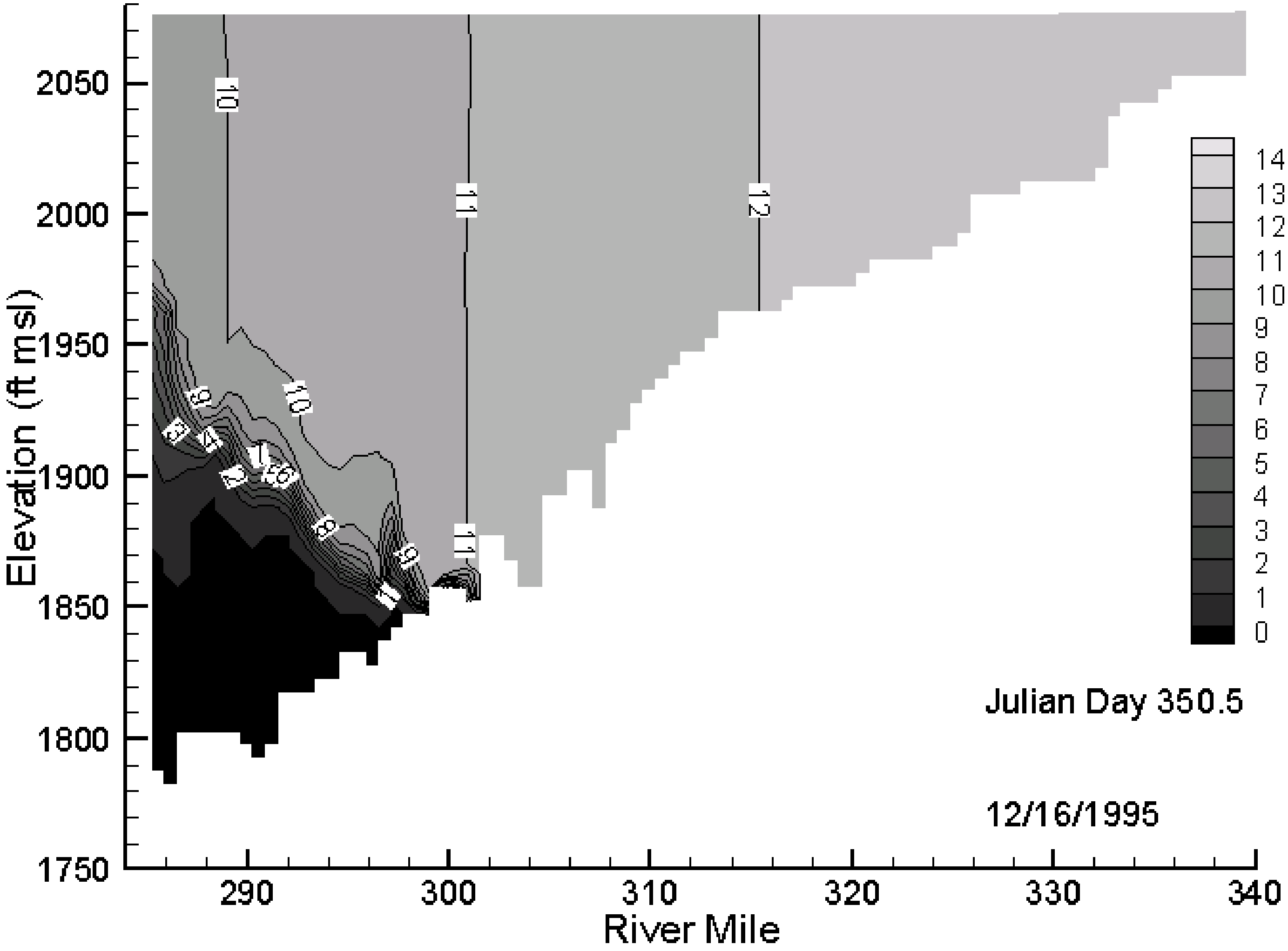


Figure 92. Simulated 1995 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

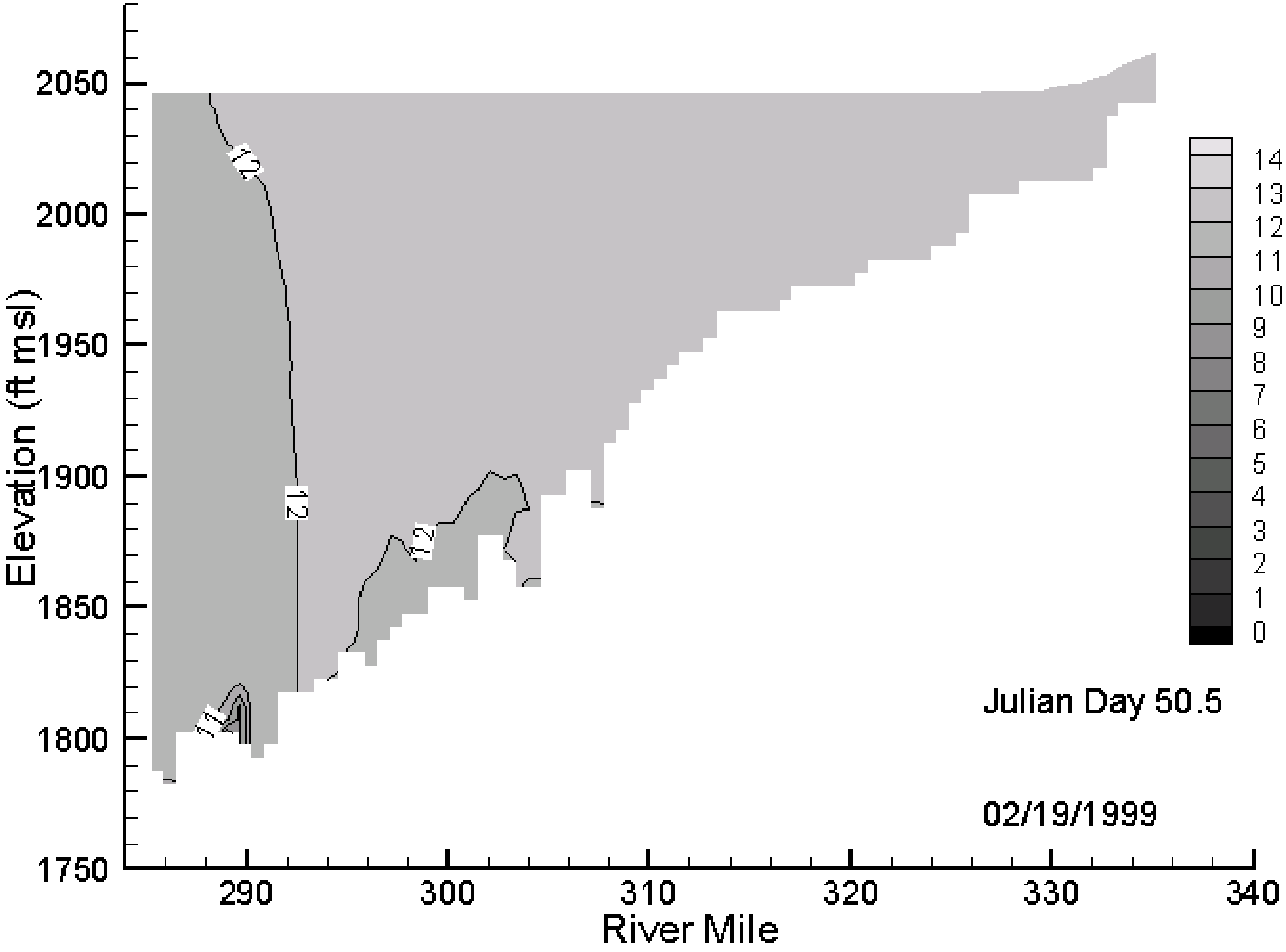


Figure 93. Simulated 1999 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

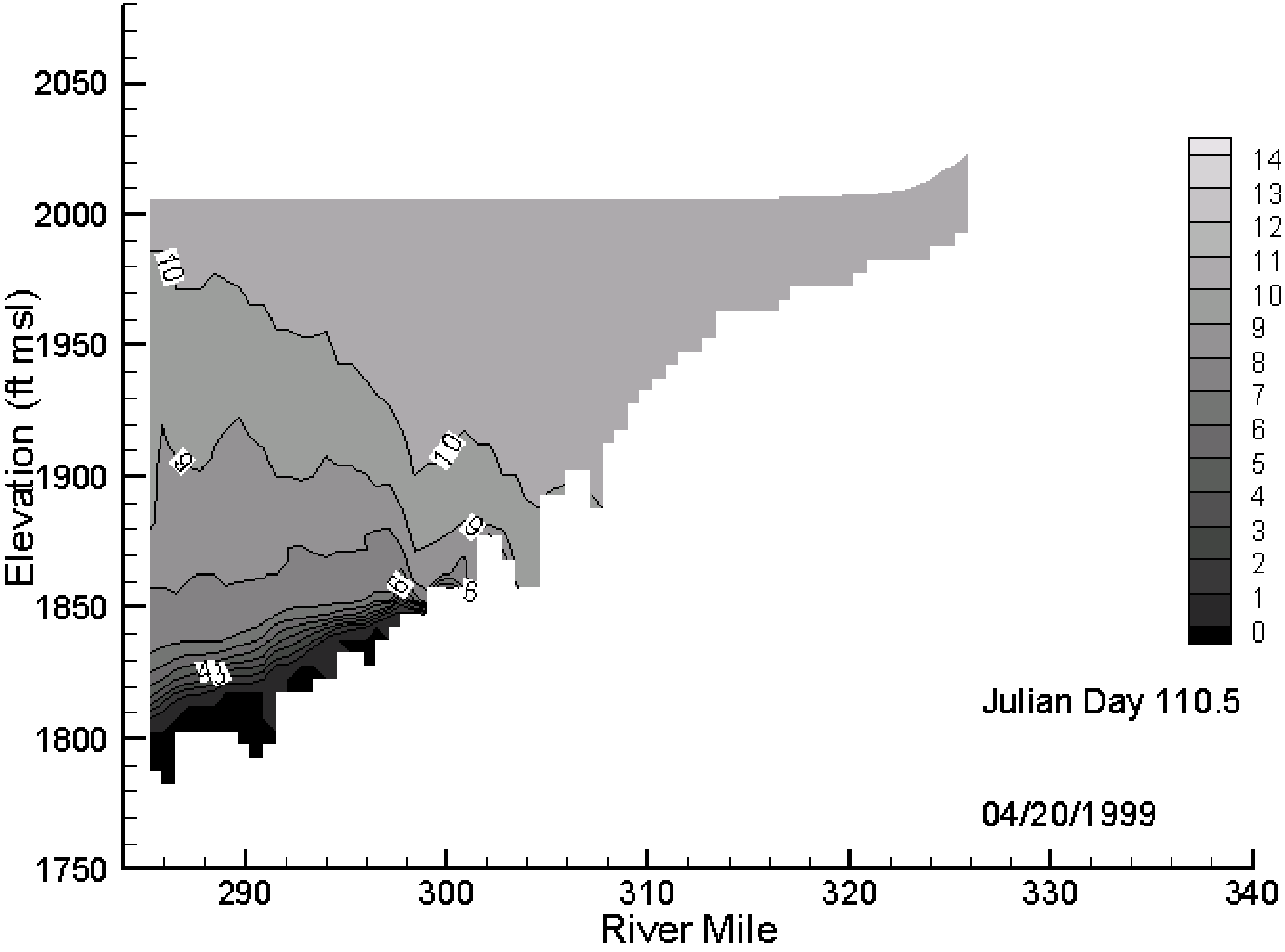


Figure 94. Simulated 1999 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

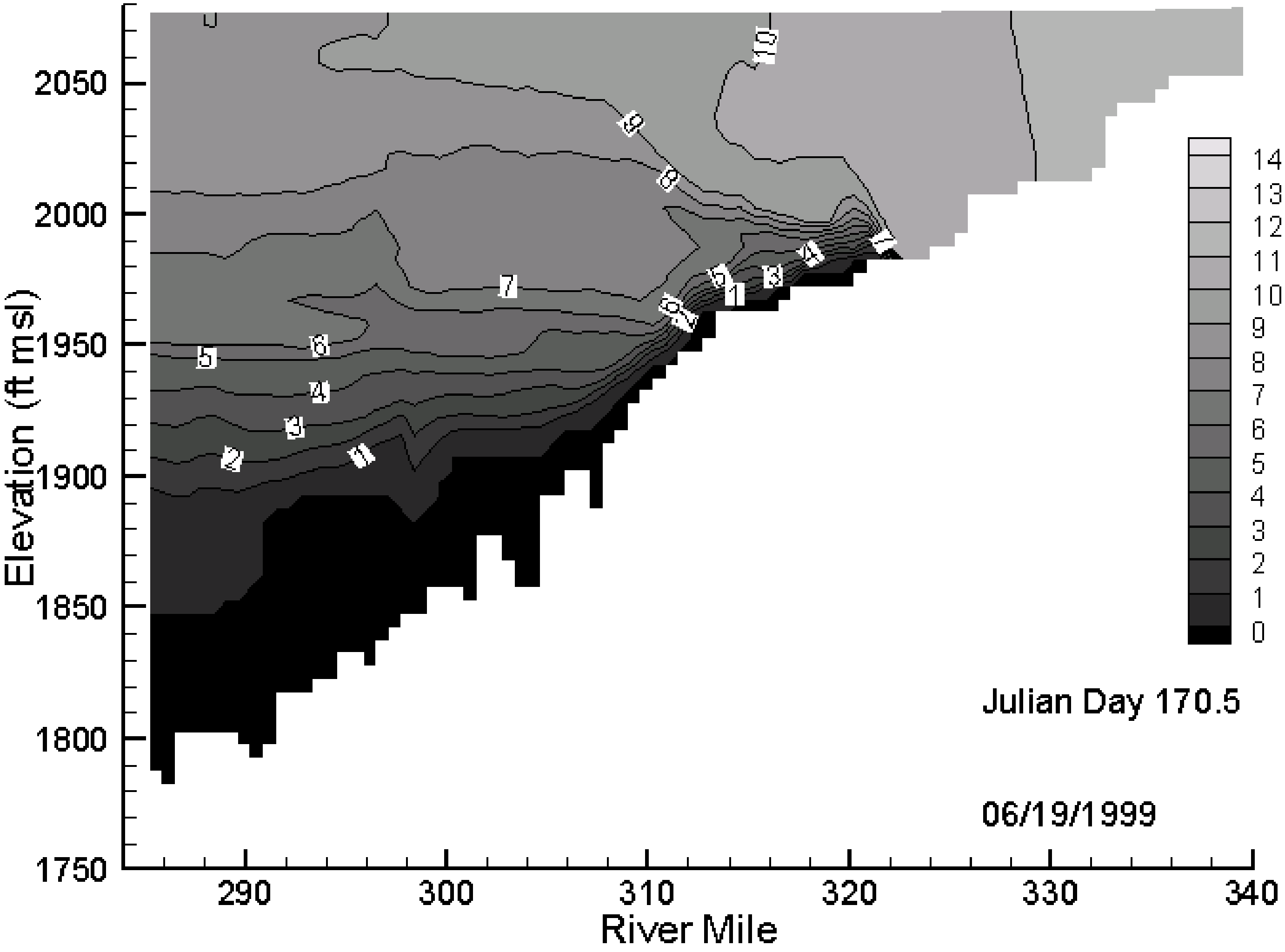


Figure 95. Simulated 1999 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

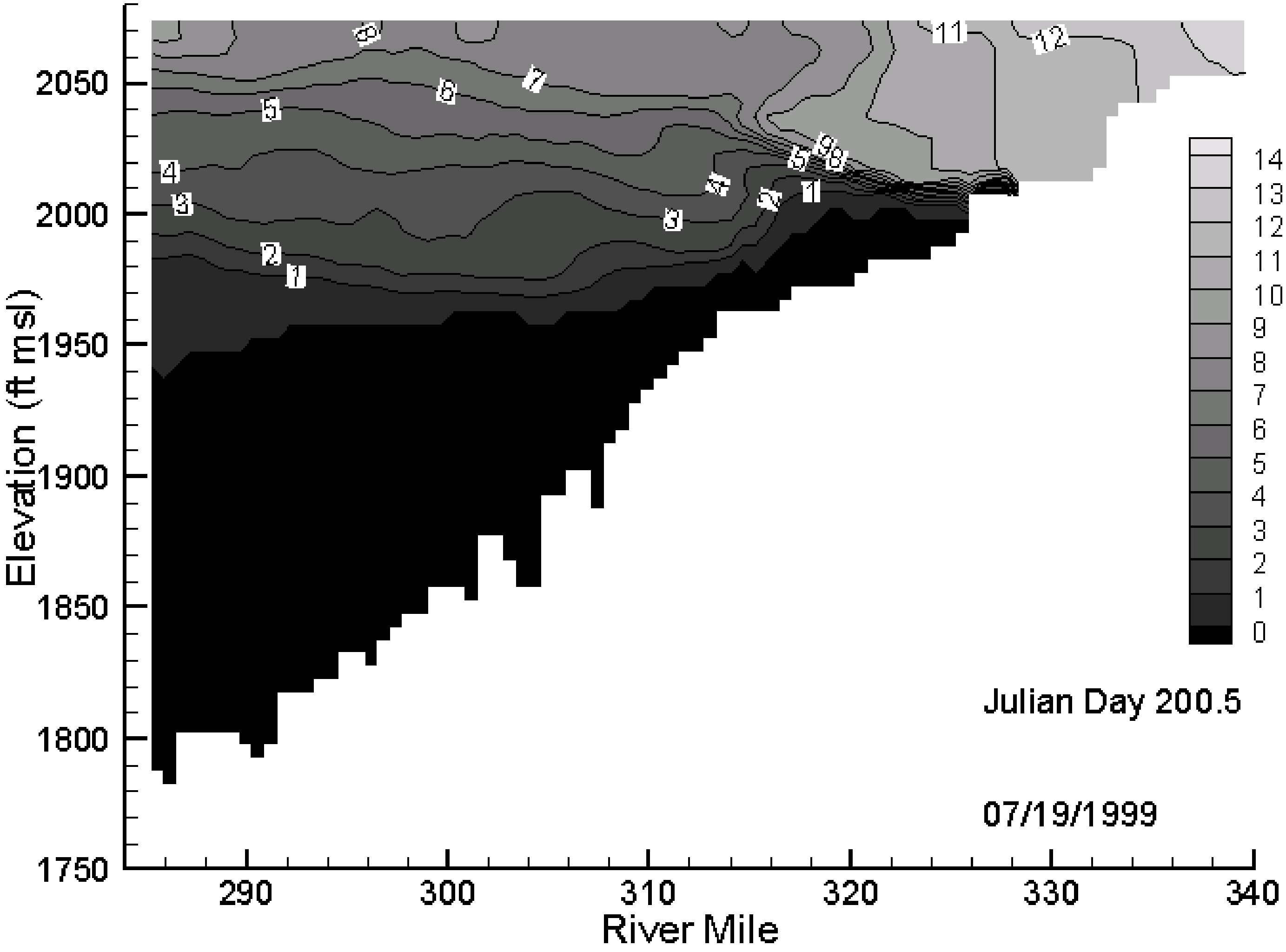


Figure 96. Simulated 1999 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

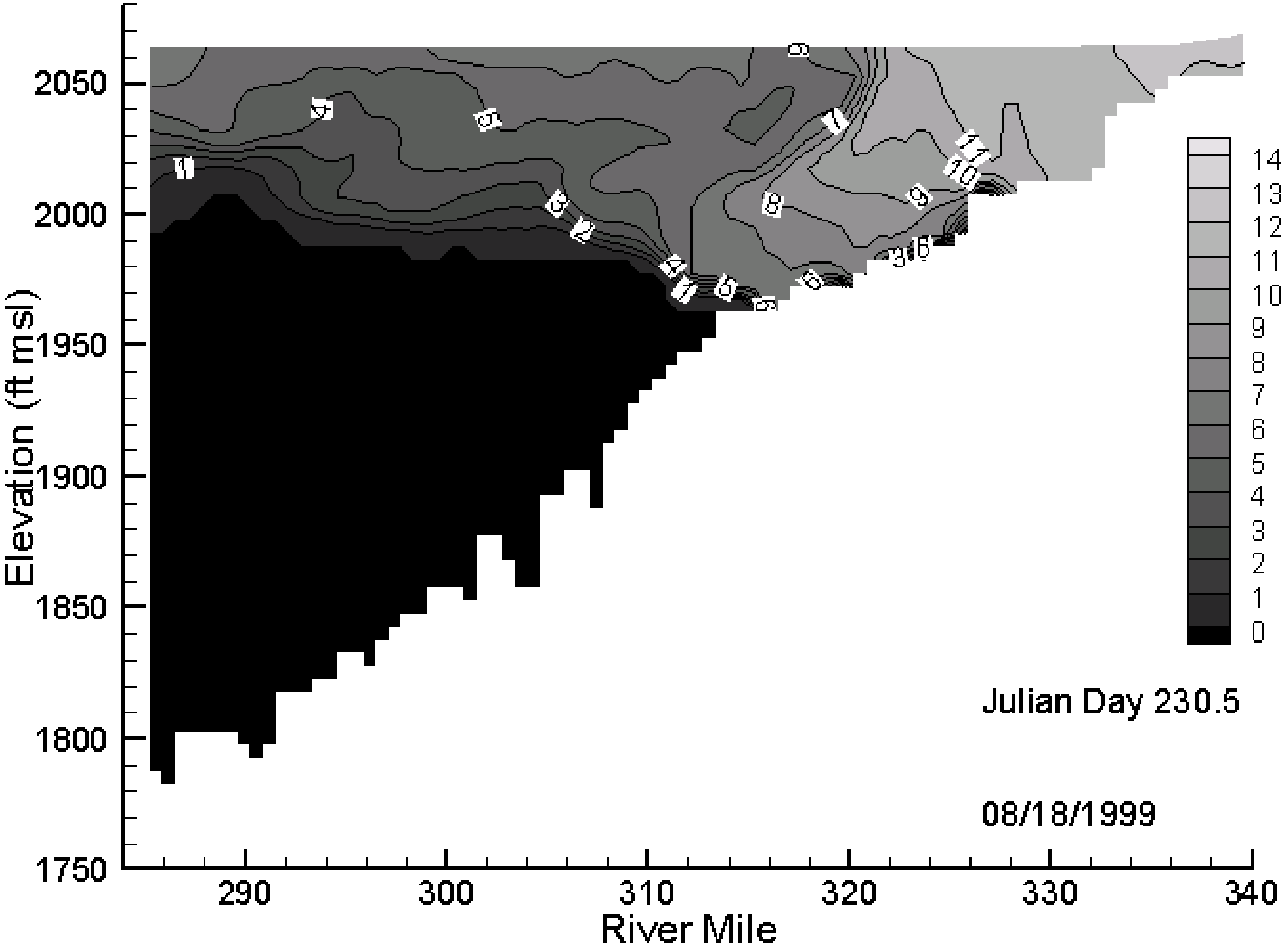


Figure 97. Simulated 1999 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

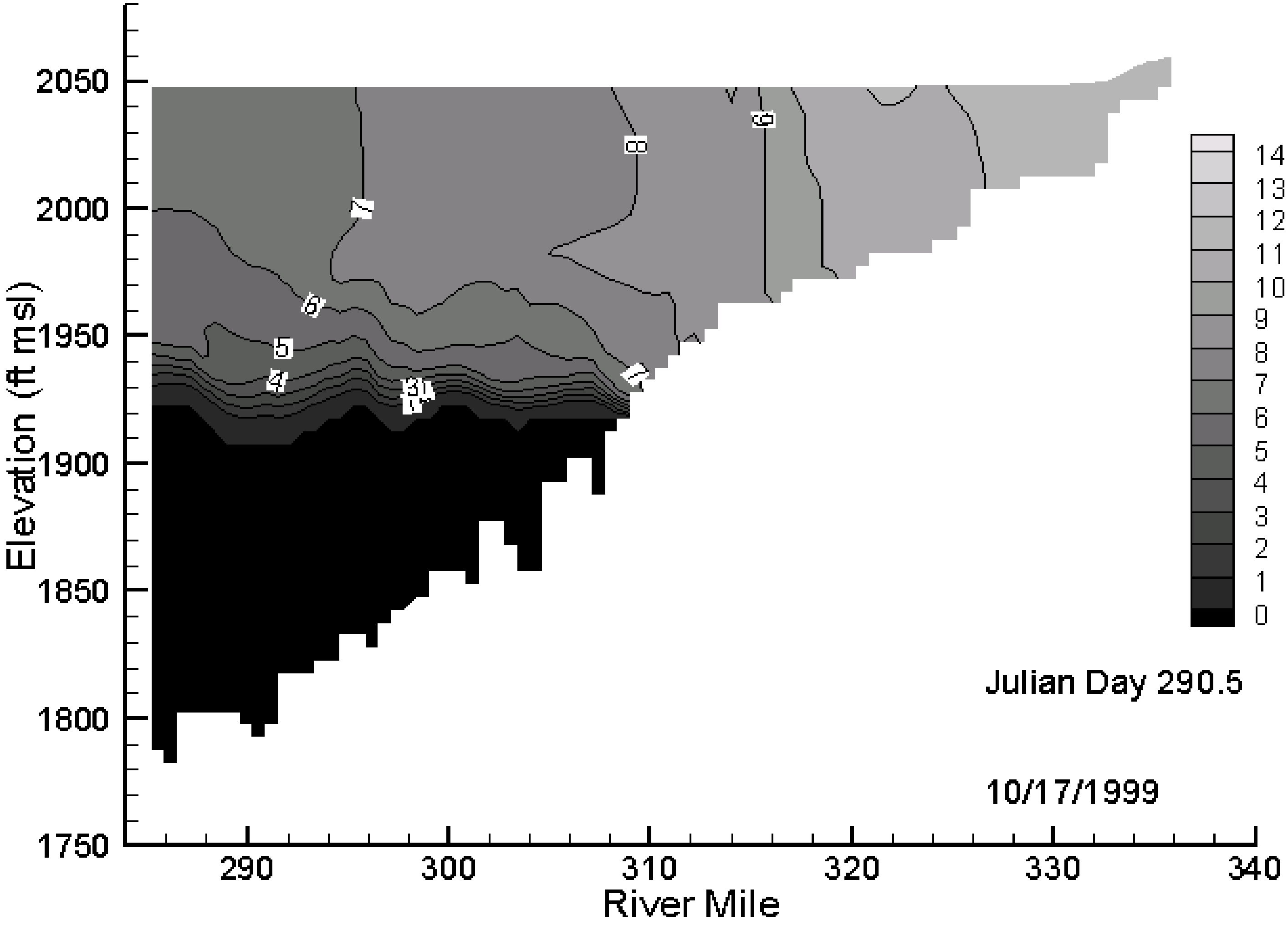


Figure 98. Simulated 1999 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

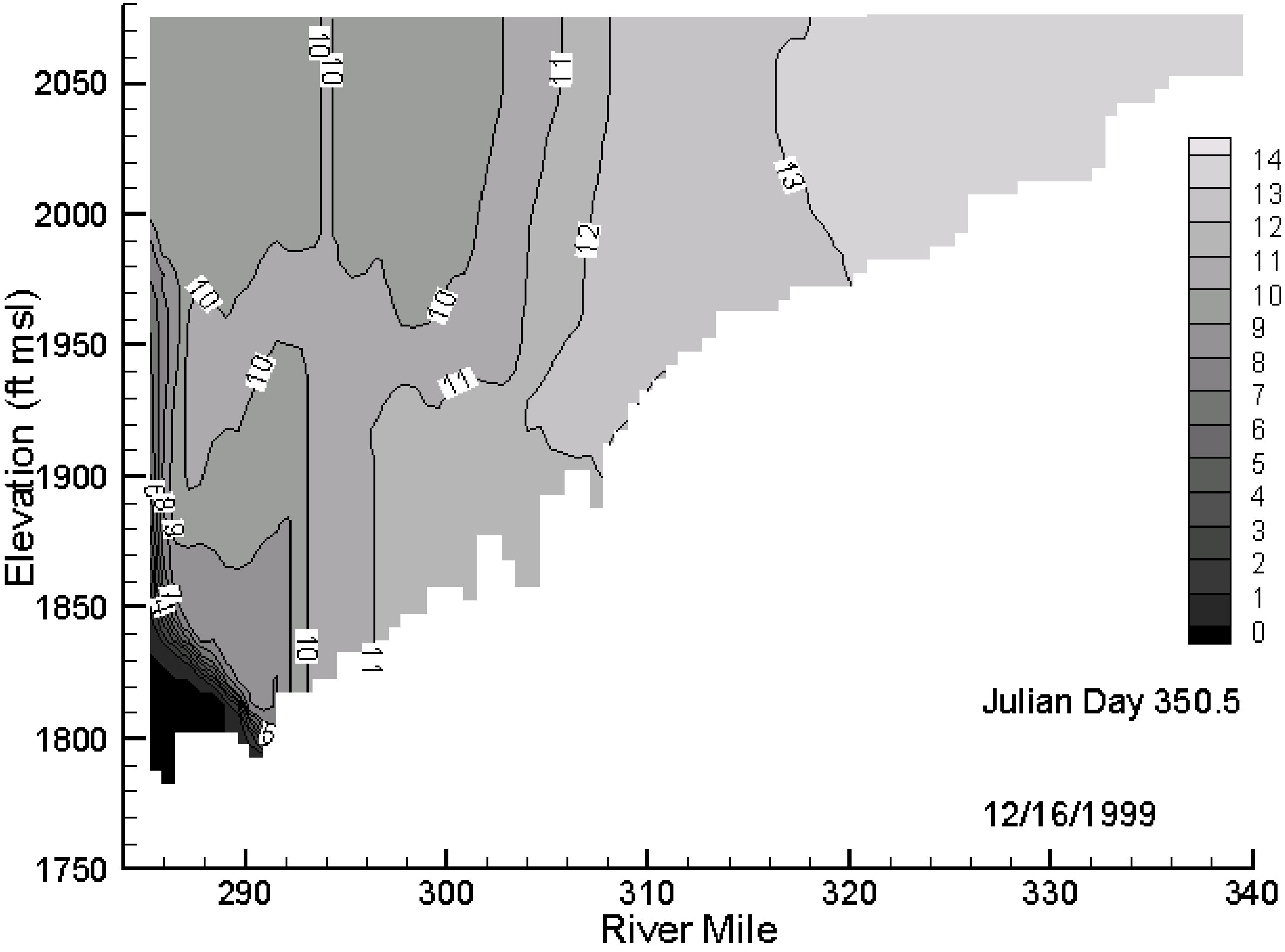


Figure 99. Simulated 1999 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

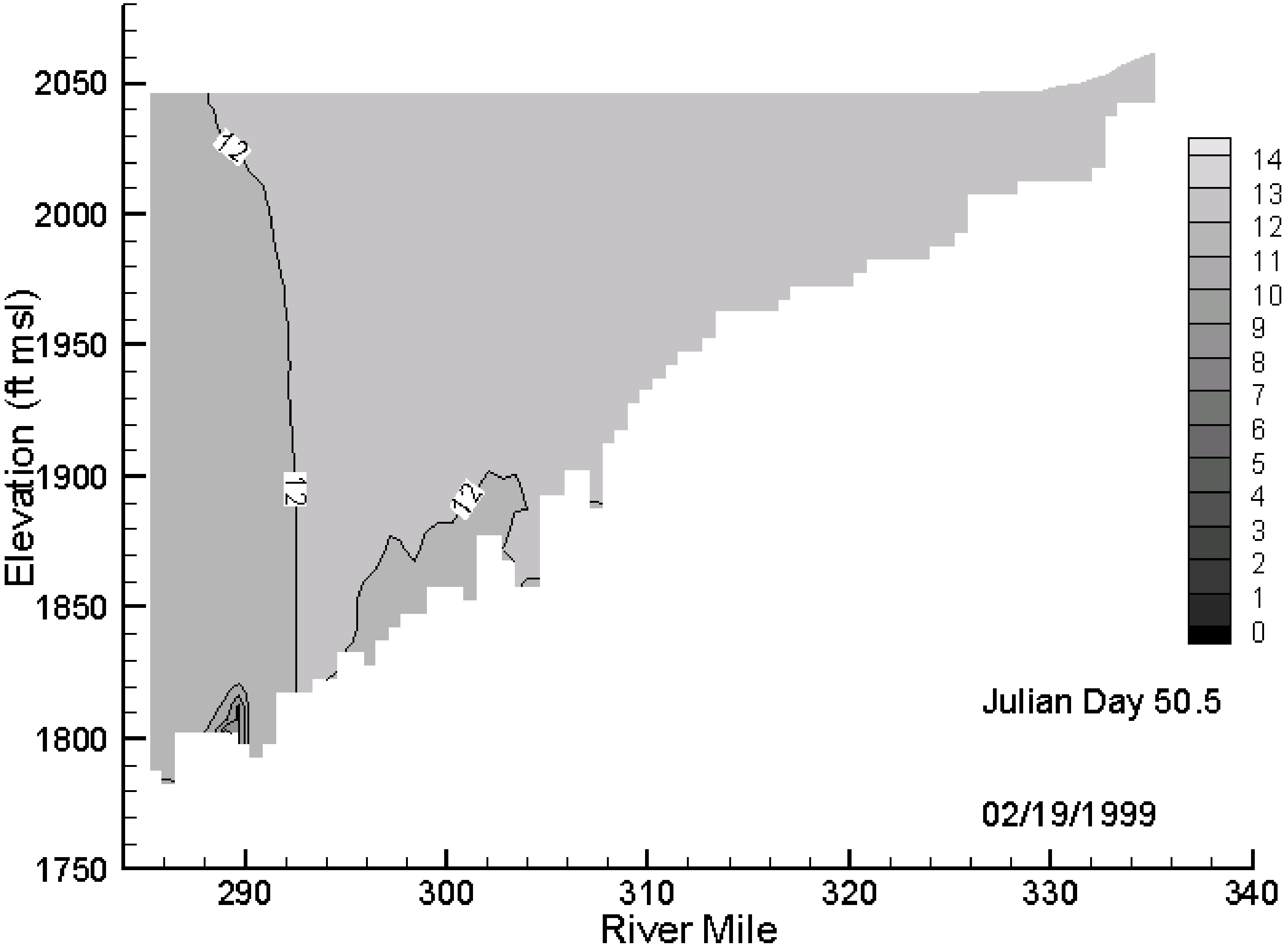


Figure 100. Simulated 1999 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

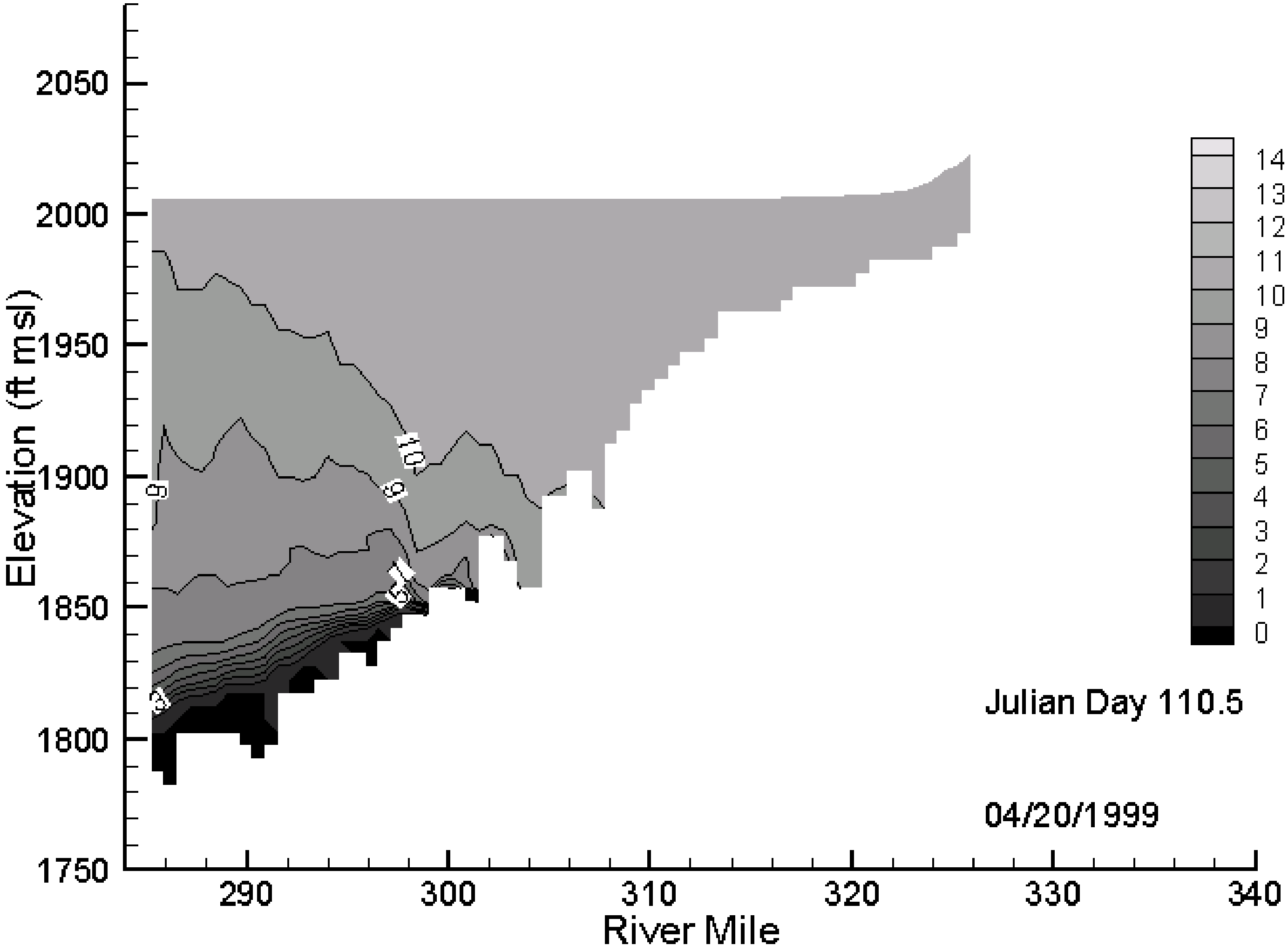


Figure 101. Simulated 1999 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

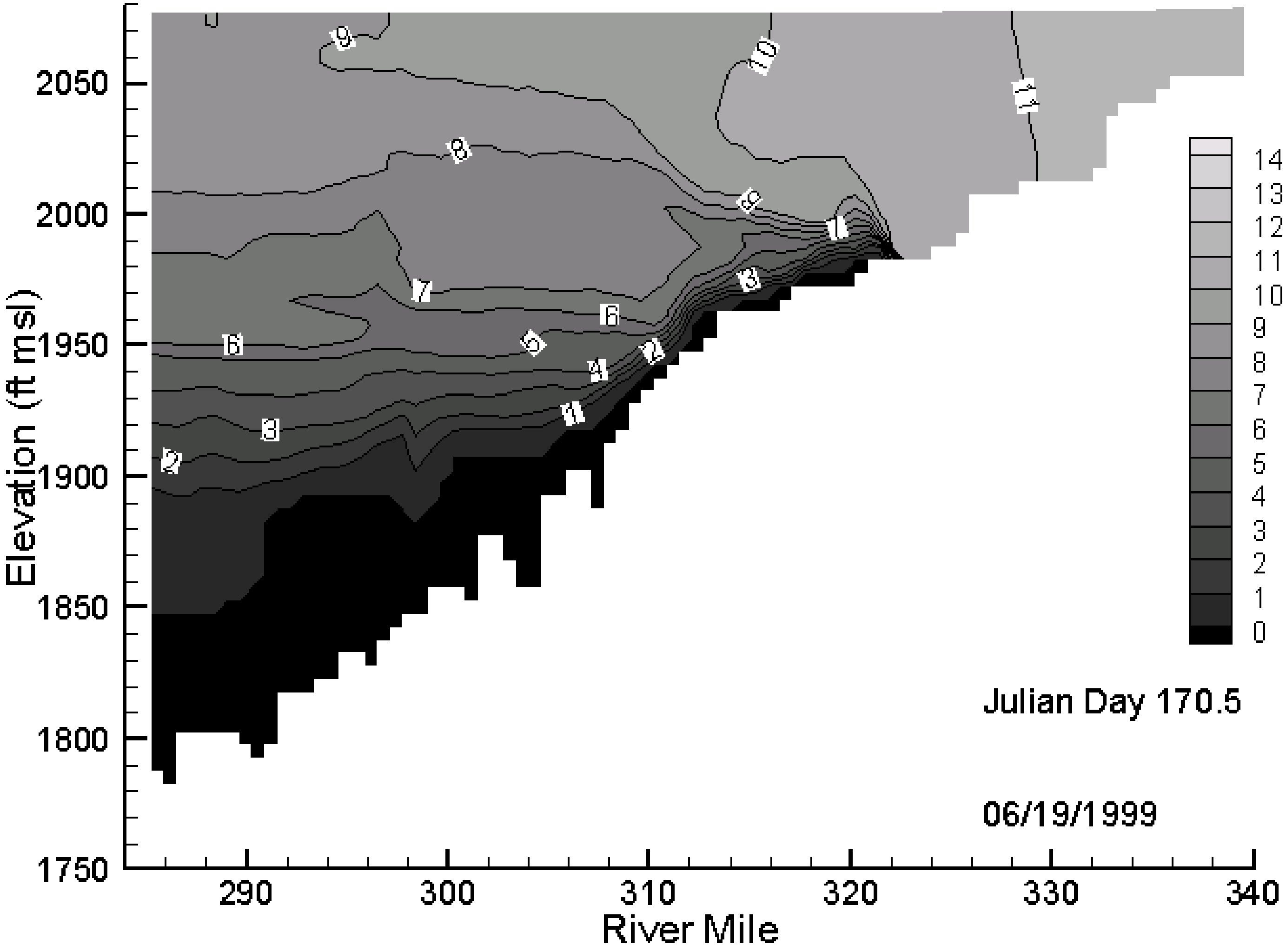


Figure 102. Simulated 1999 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

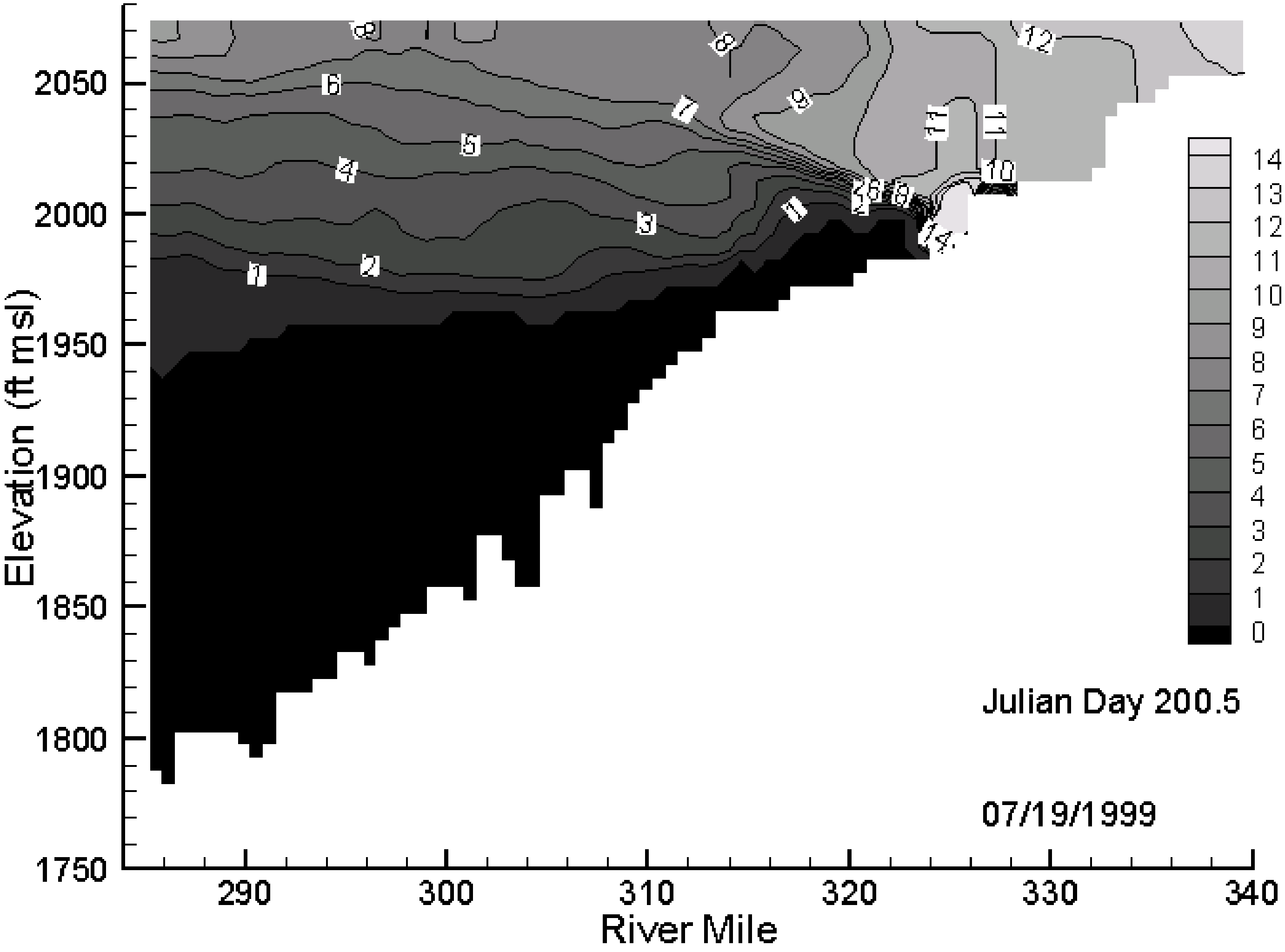


Figure 103. Simulated 1999 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

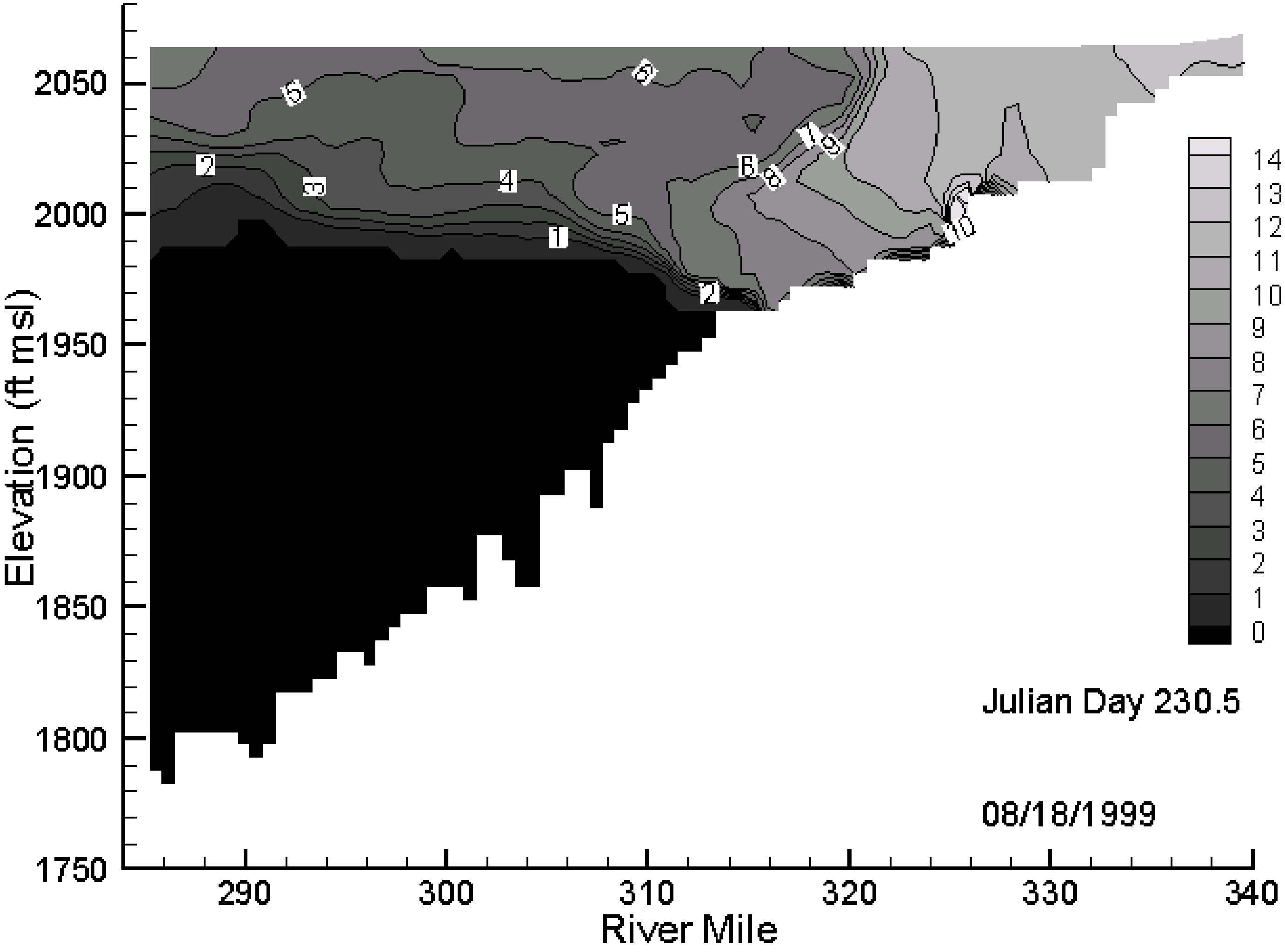


Figure 104. Simulated 1999 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

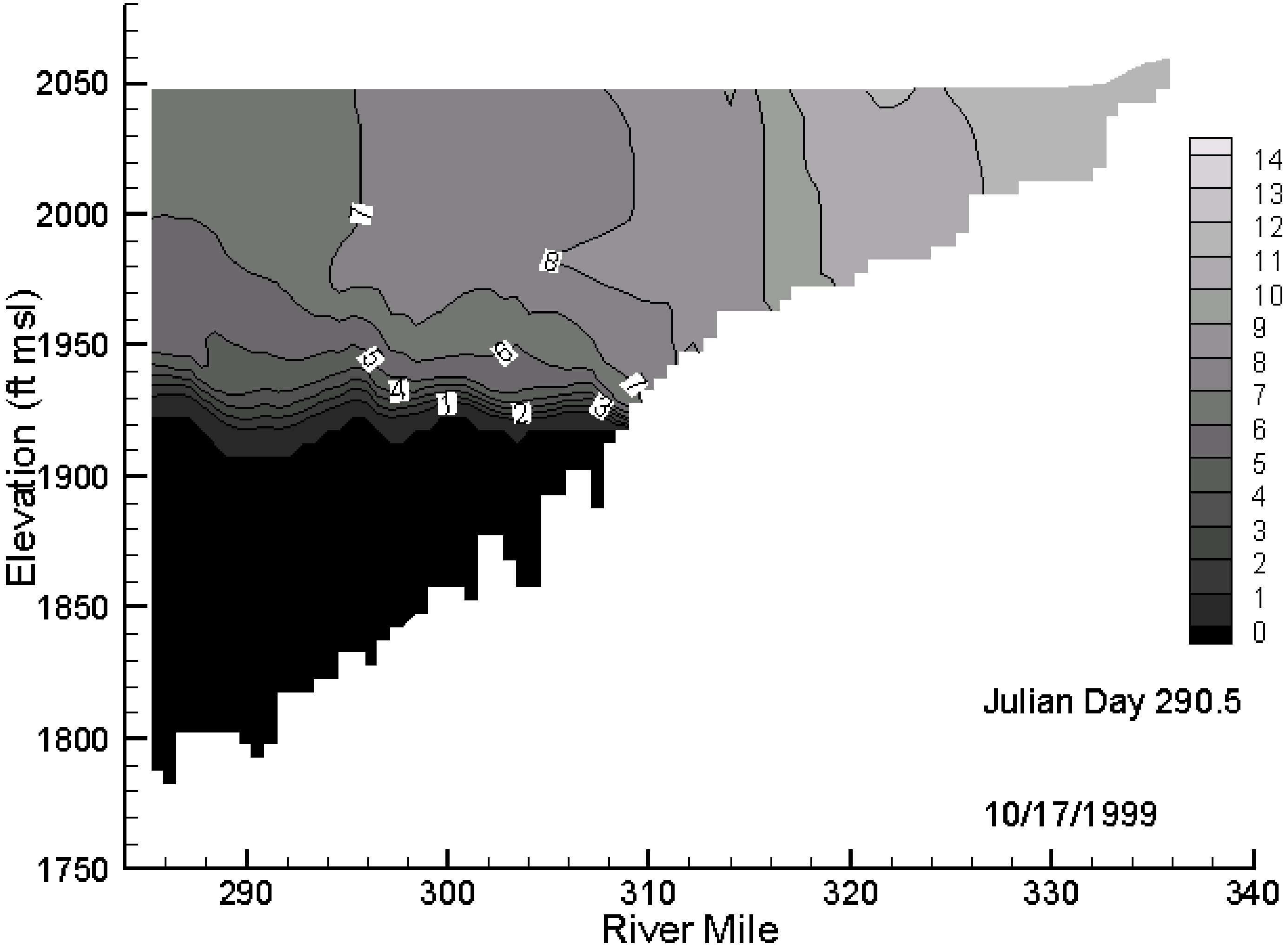


Figure 105. Simulated 1999 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

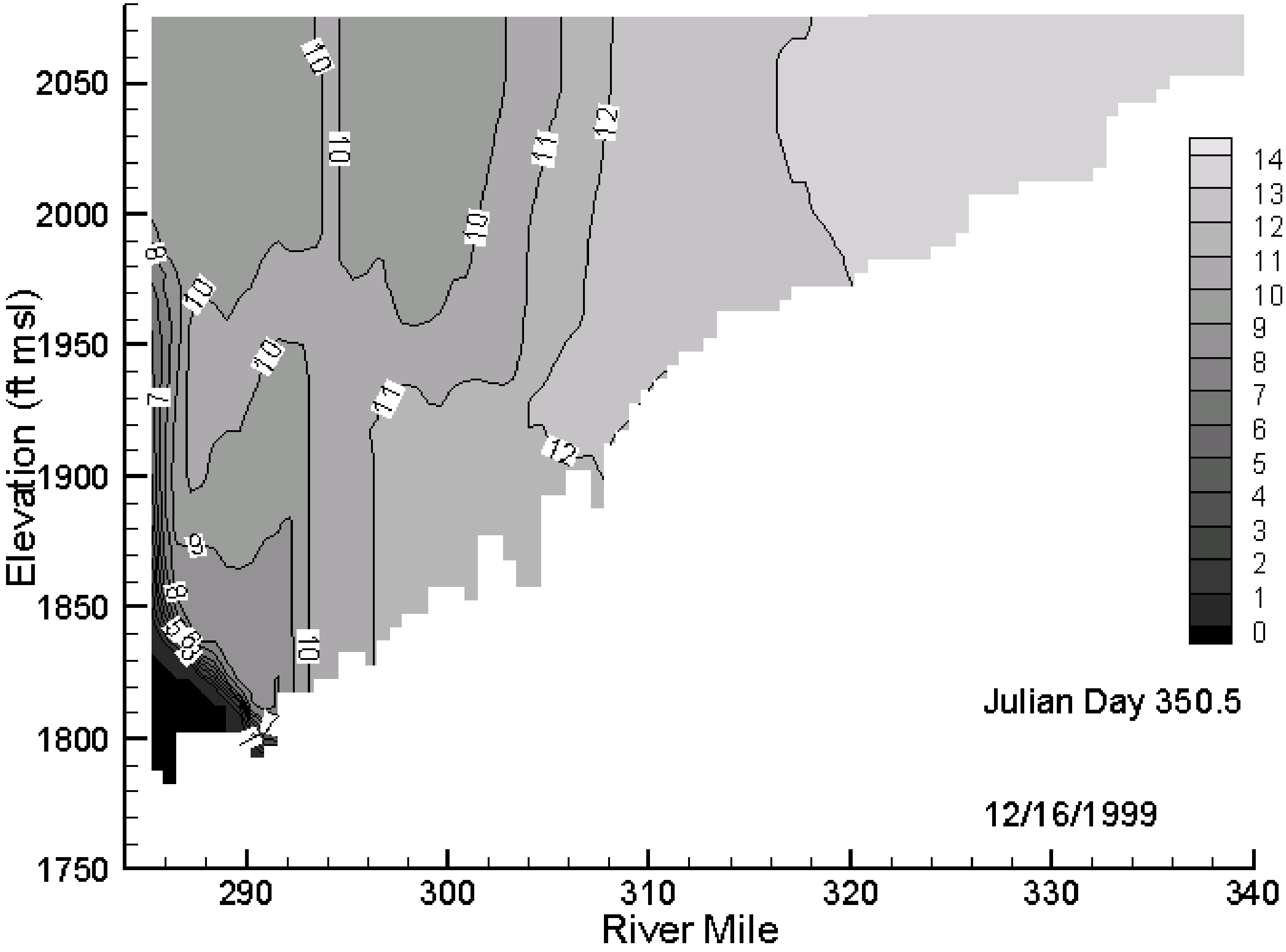


Figure 106. Simulated 1999 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

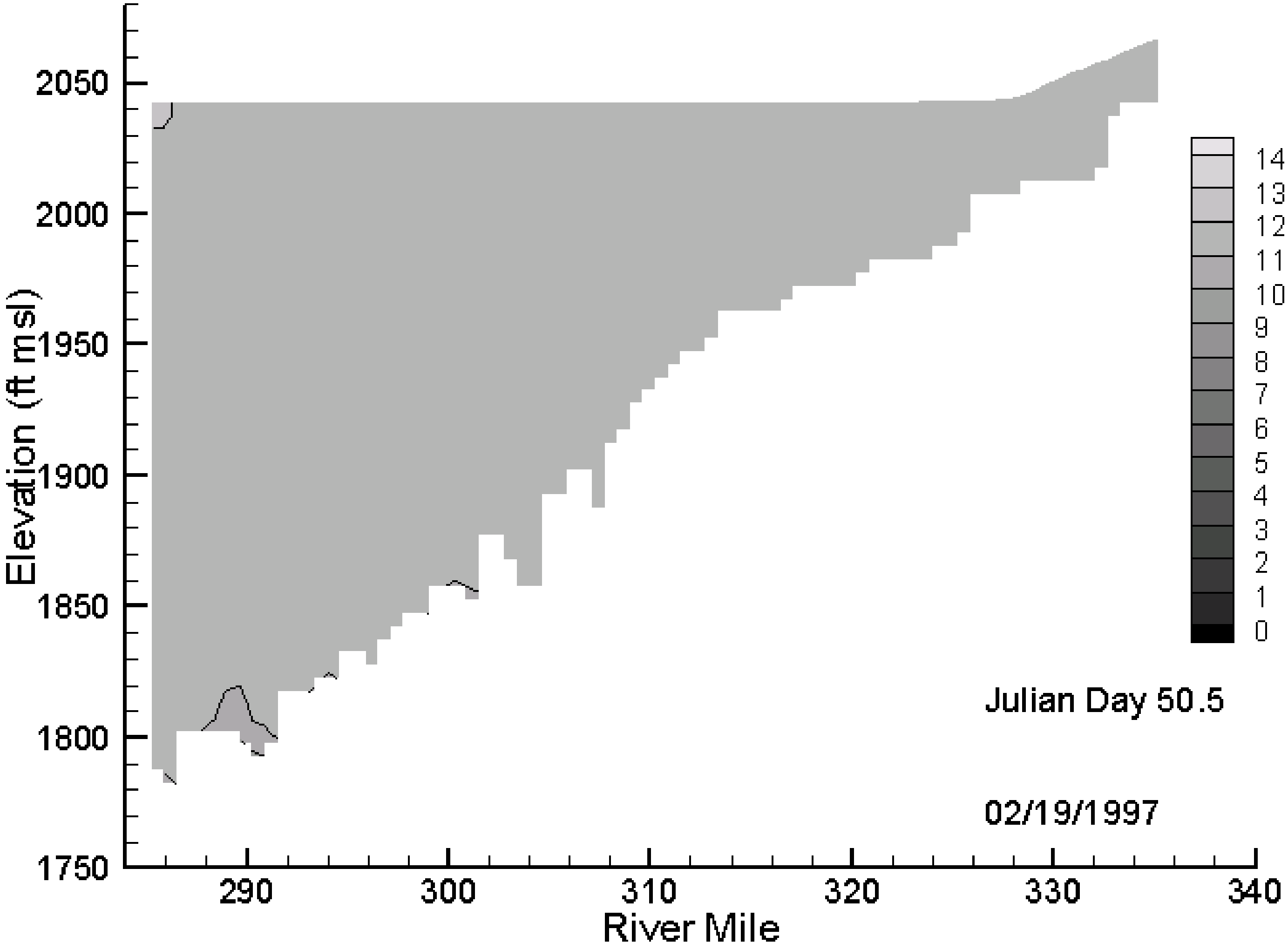


Figure 107. Simulated 1997 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

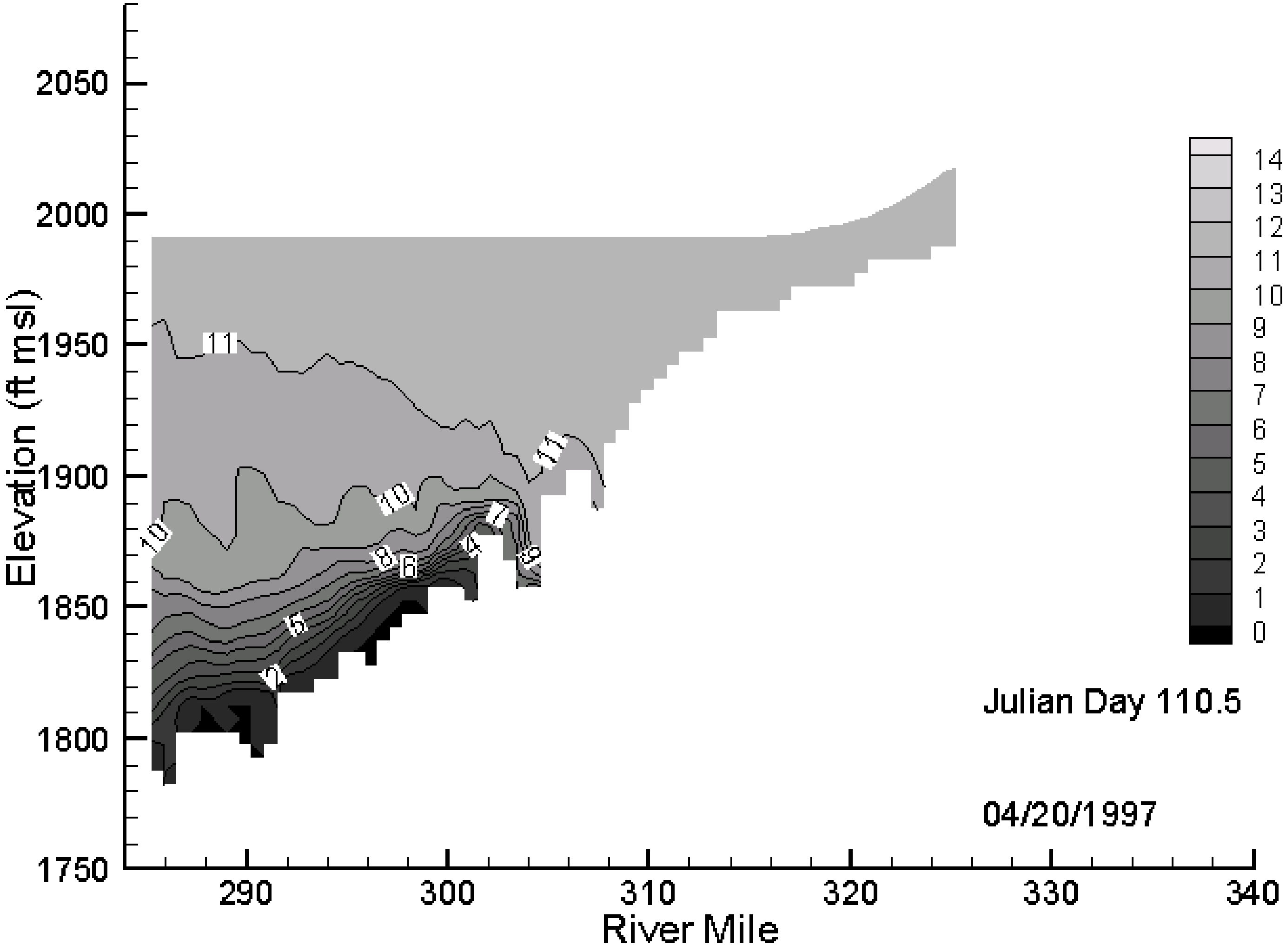


Figure 108. Simulated 1997 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

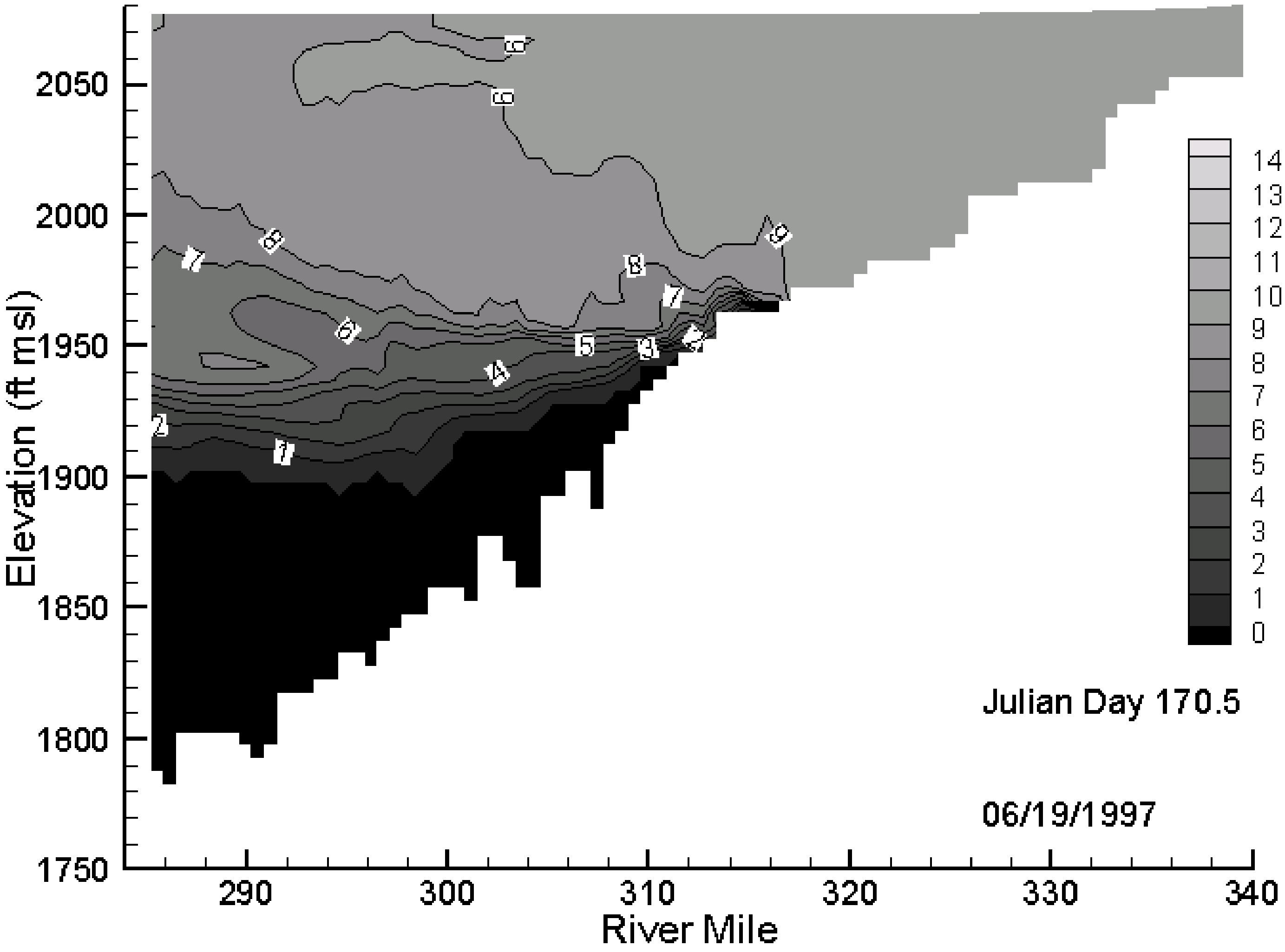


Figure 109. Simulated 1997 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

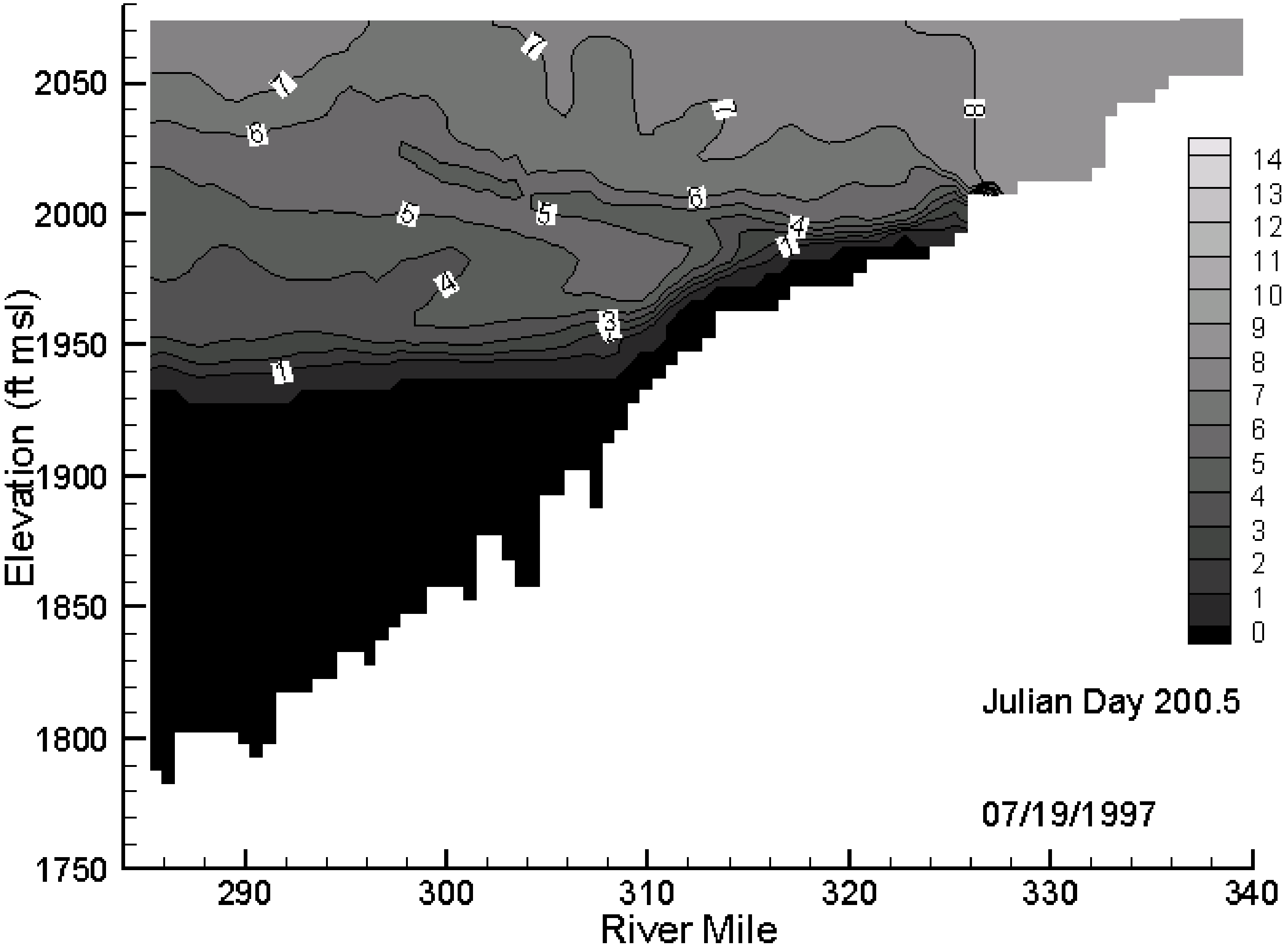


Figure 110. Simulated 1997 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

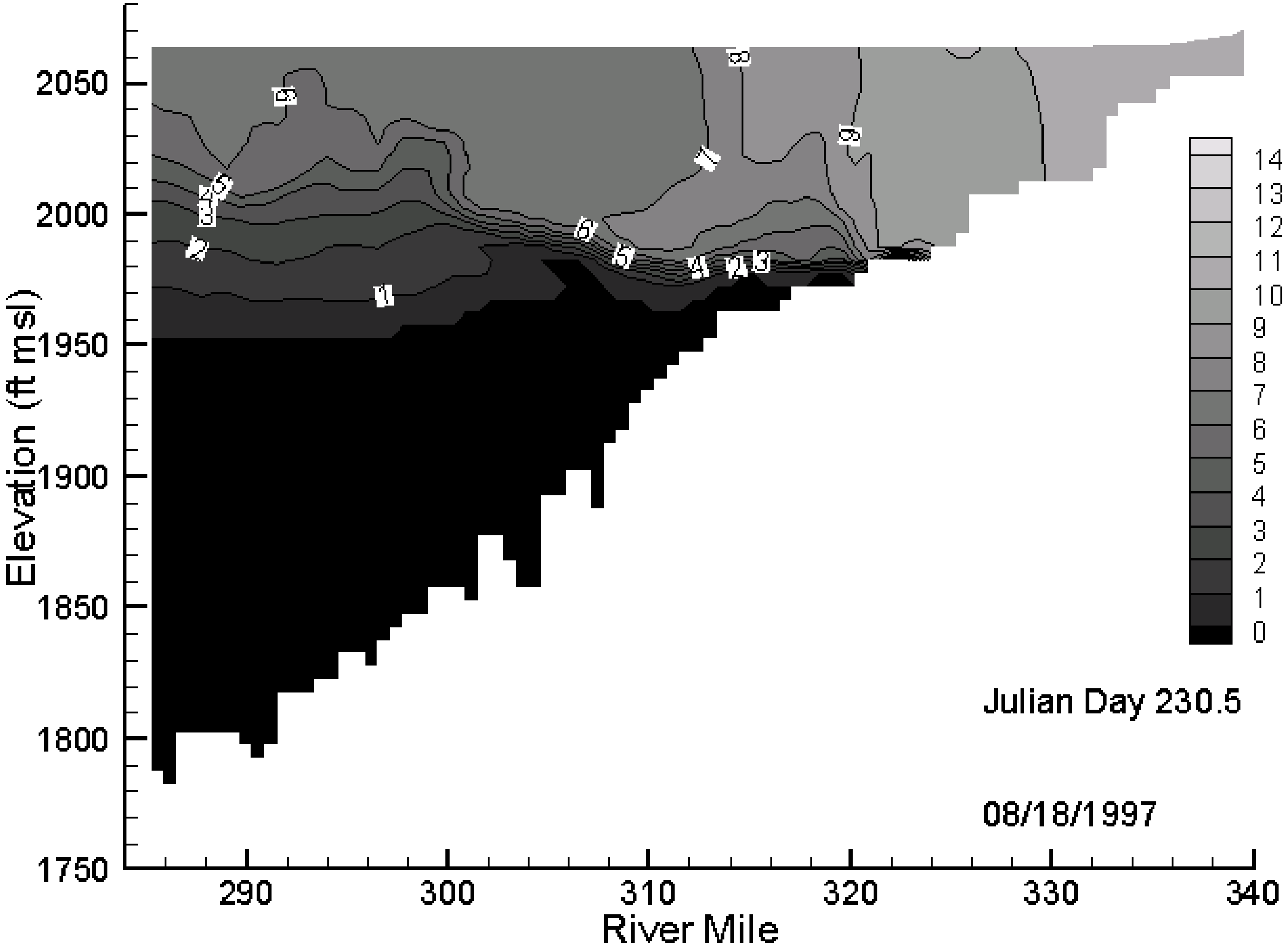


Figure 111. Simulated 1997 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

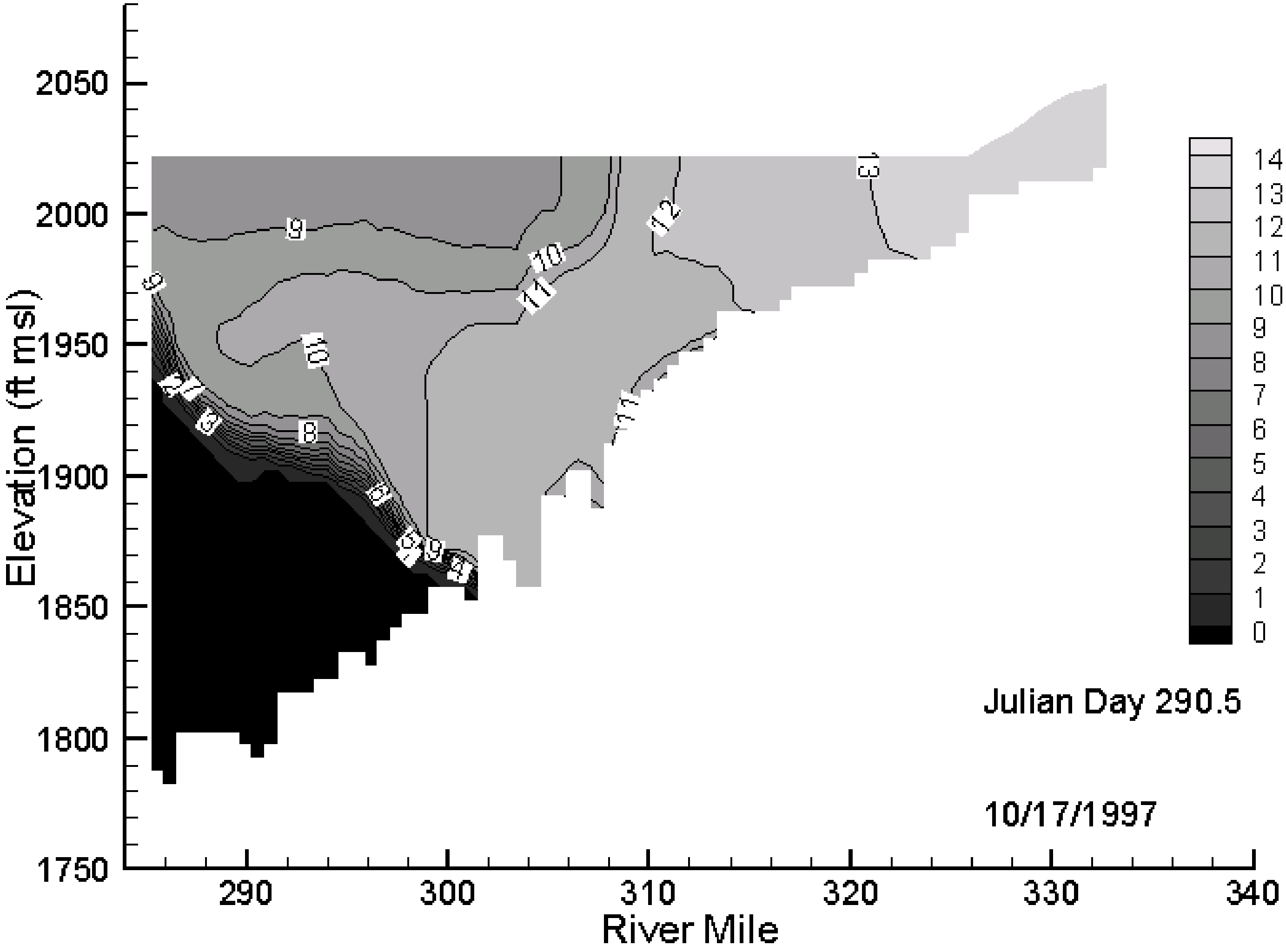


Figure 112. Simulated 1997 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

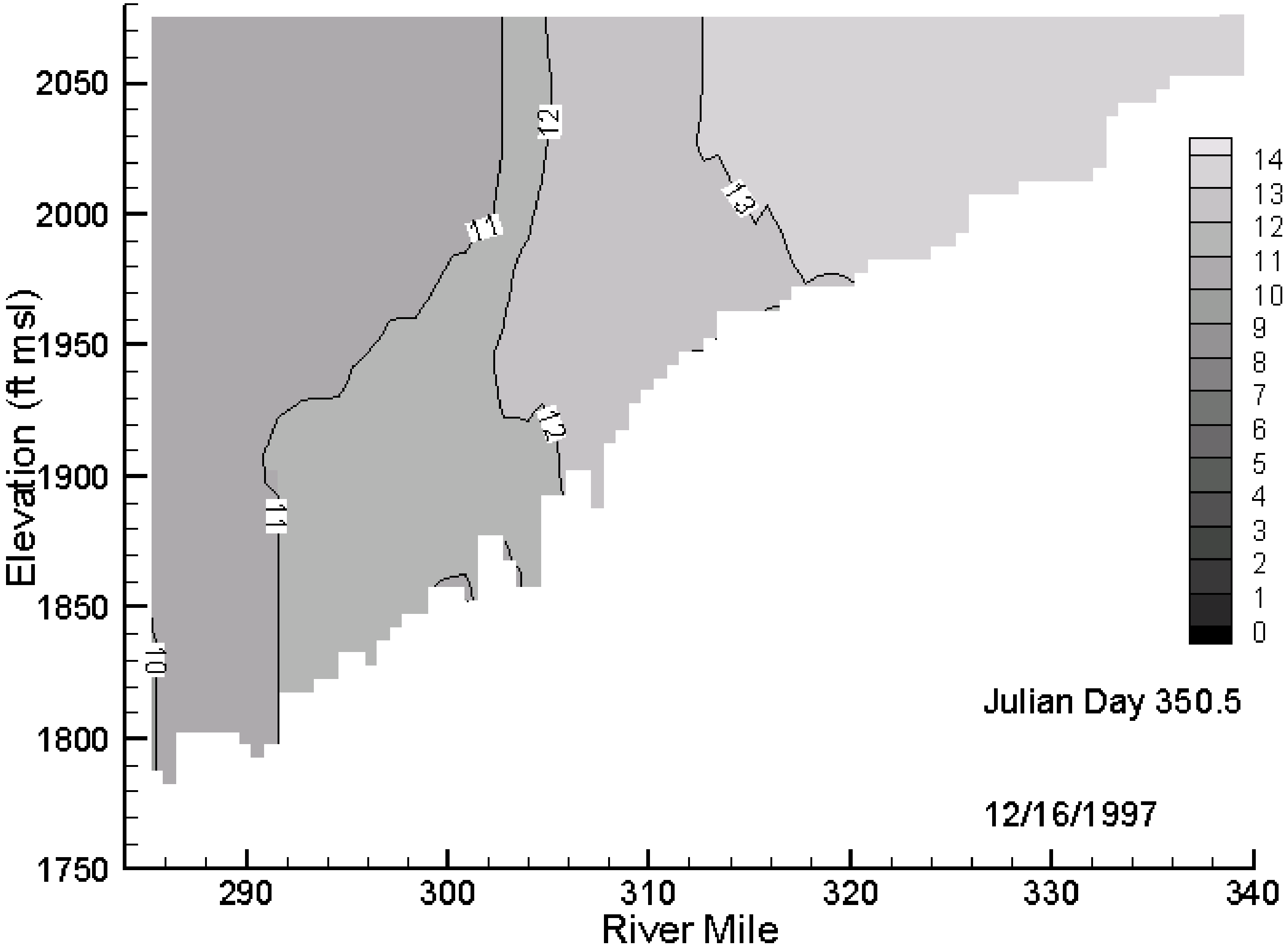


Figure 113. Simulated 1997 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations.

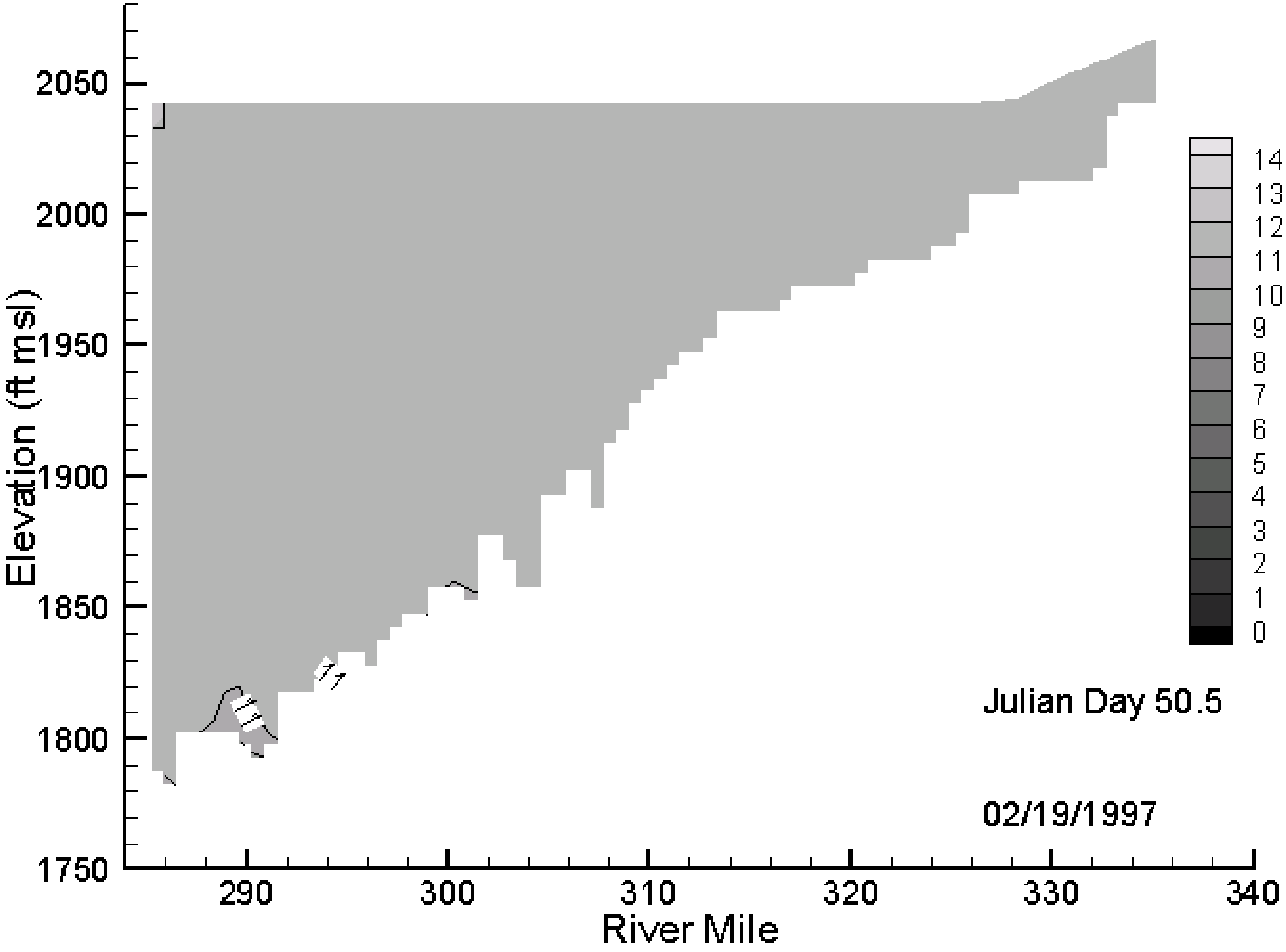


Figure 114. Simulated 1997 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

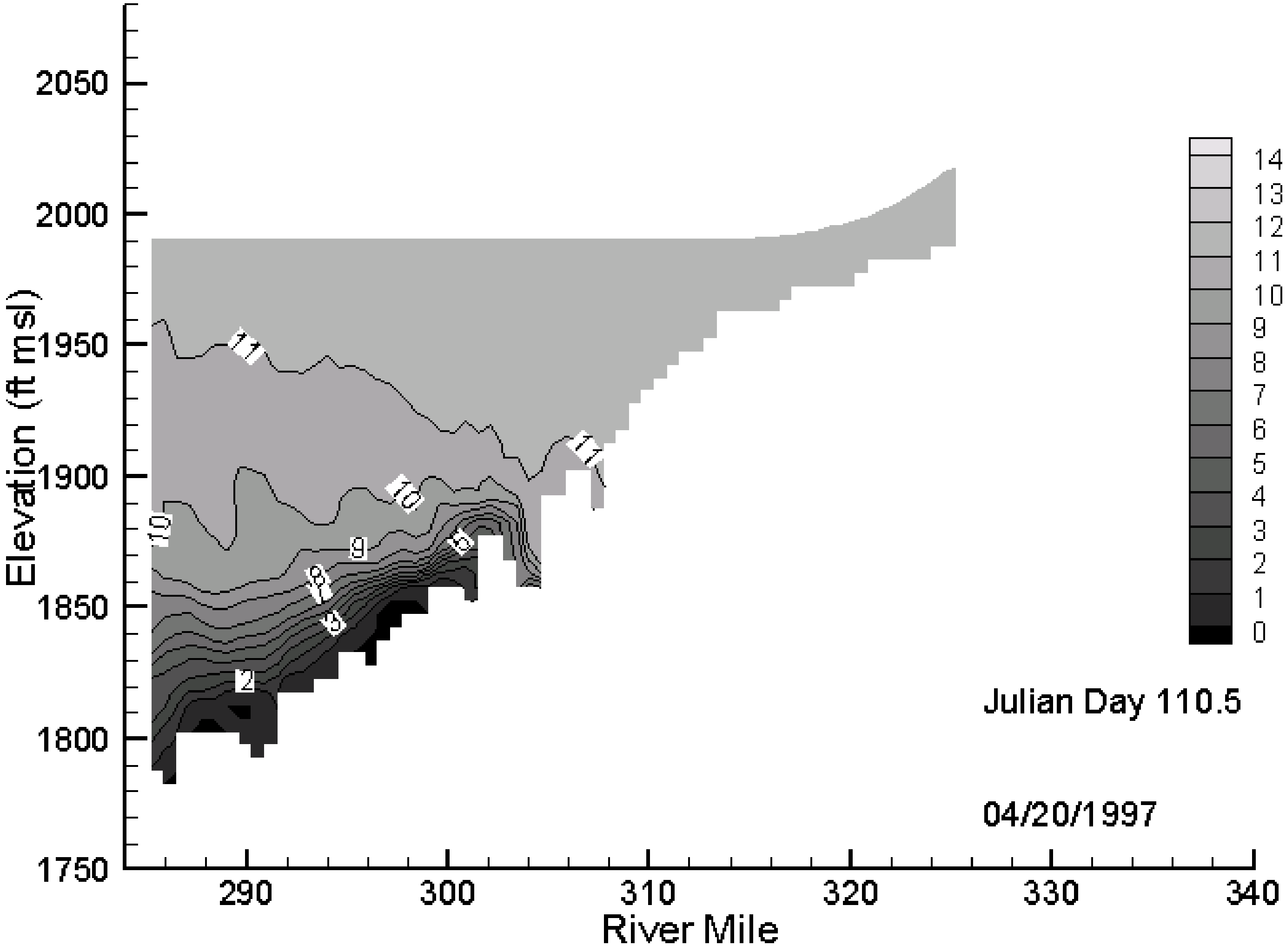


Figure 115. Simulated 1997 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

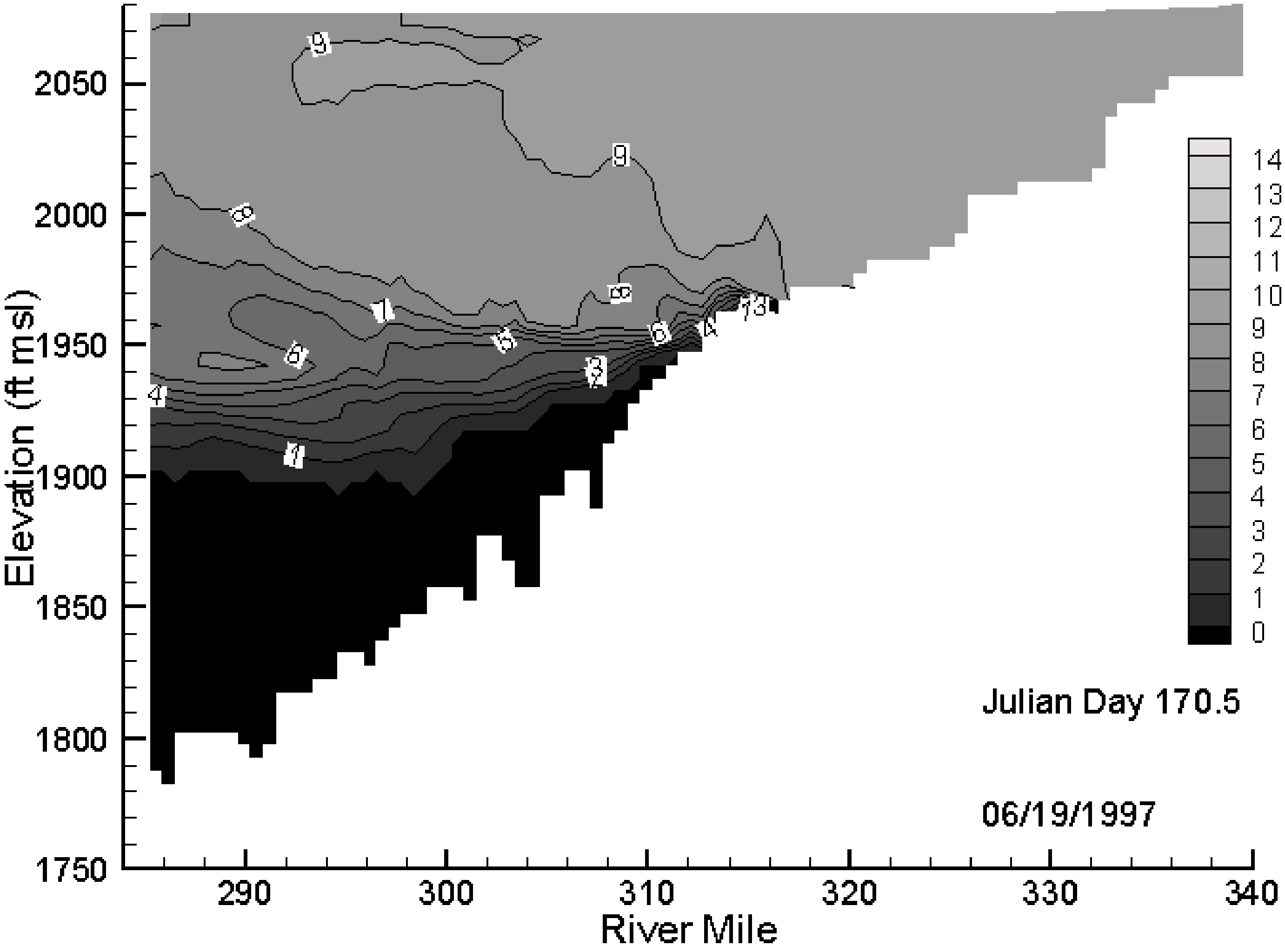


Figure 116. Simulated 1997 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

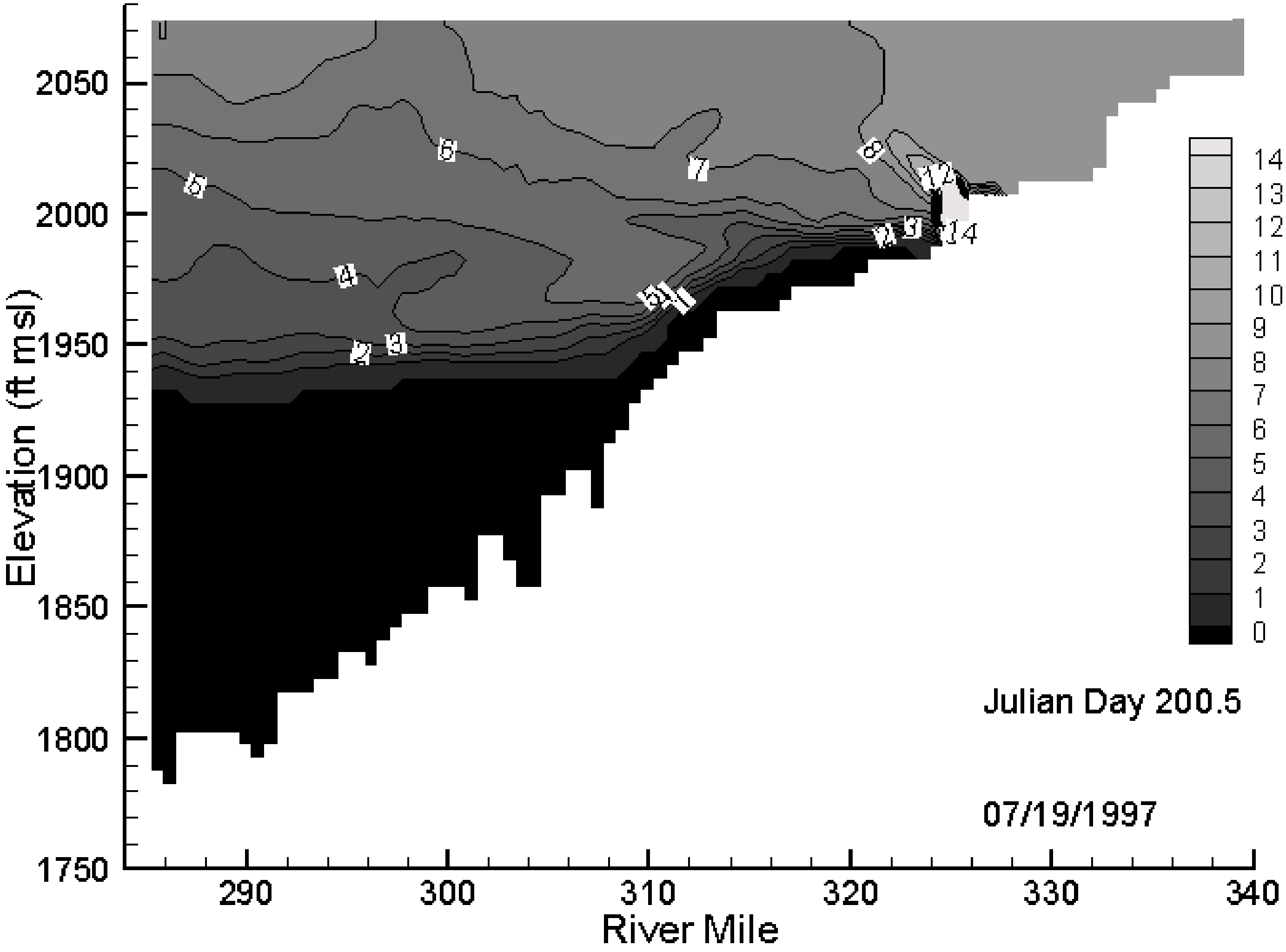


Figure 117. Simulated 1997 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

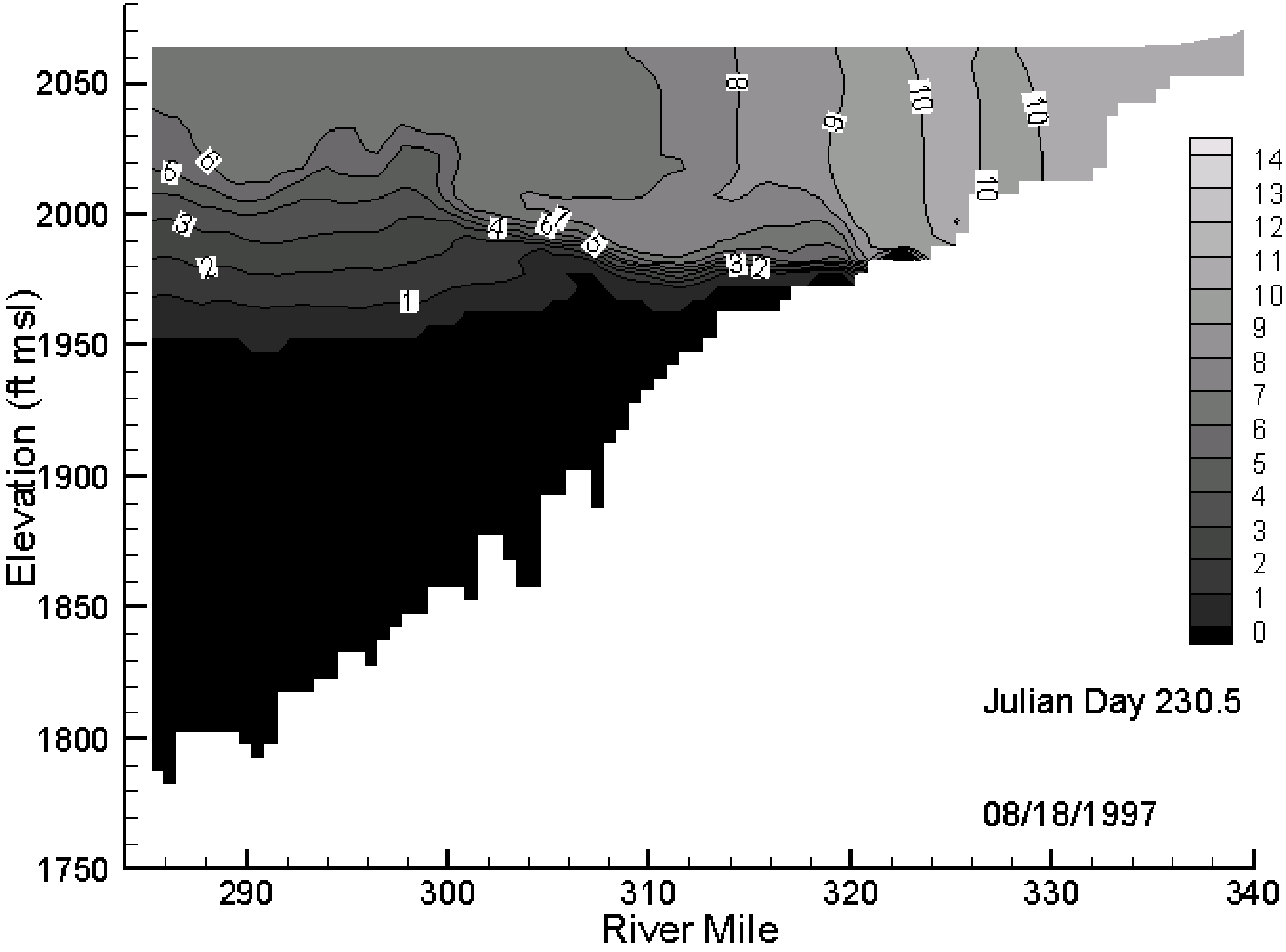


Figure 118. Simulated 1997 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

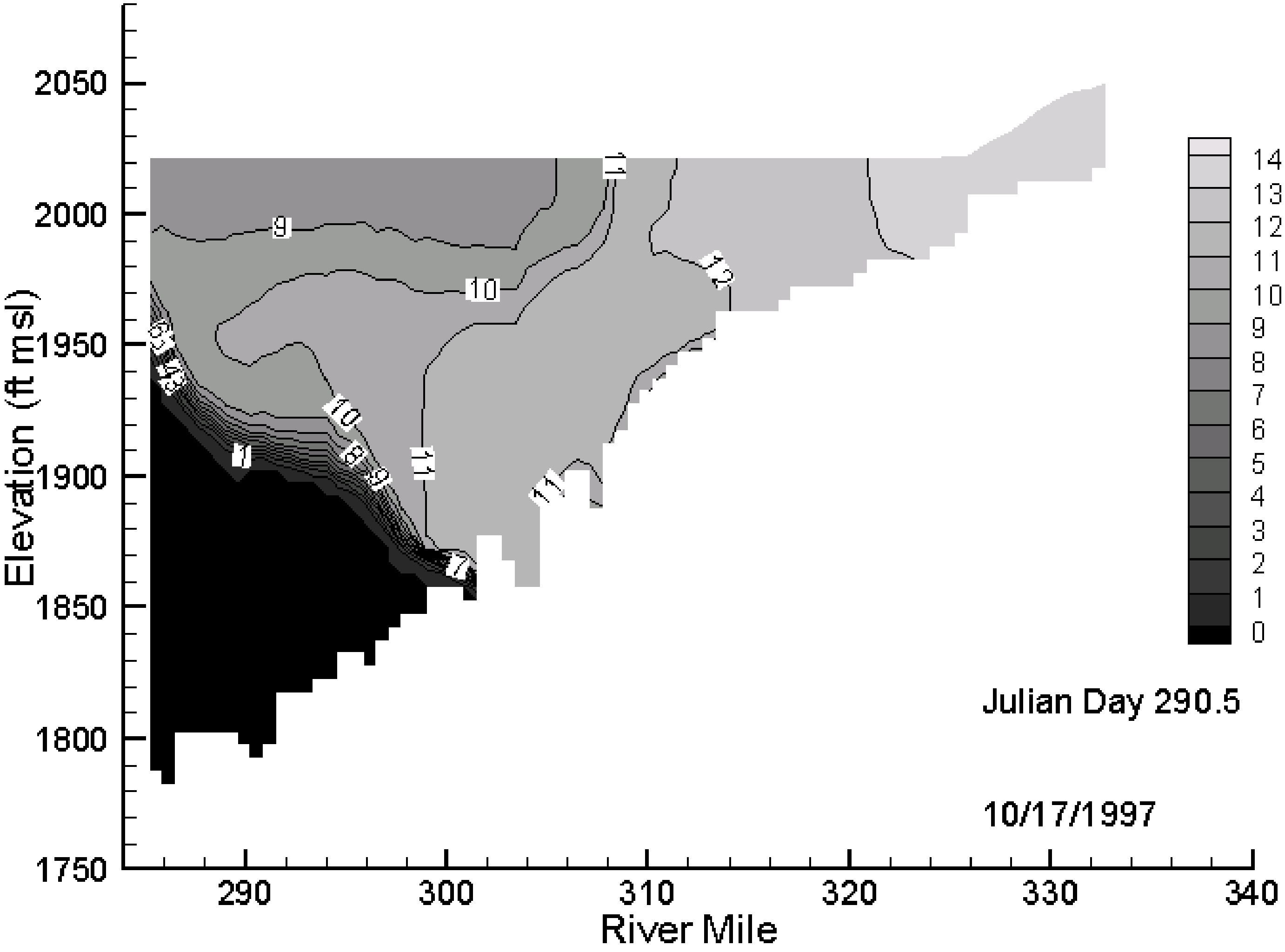


Figure 119. Simulated 1997 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

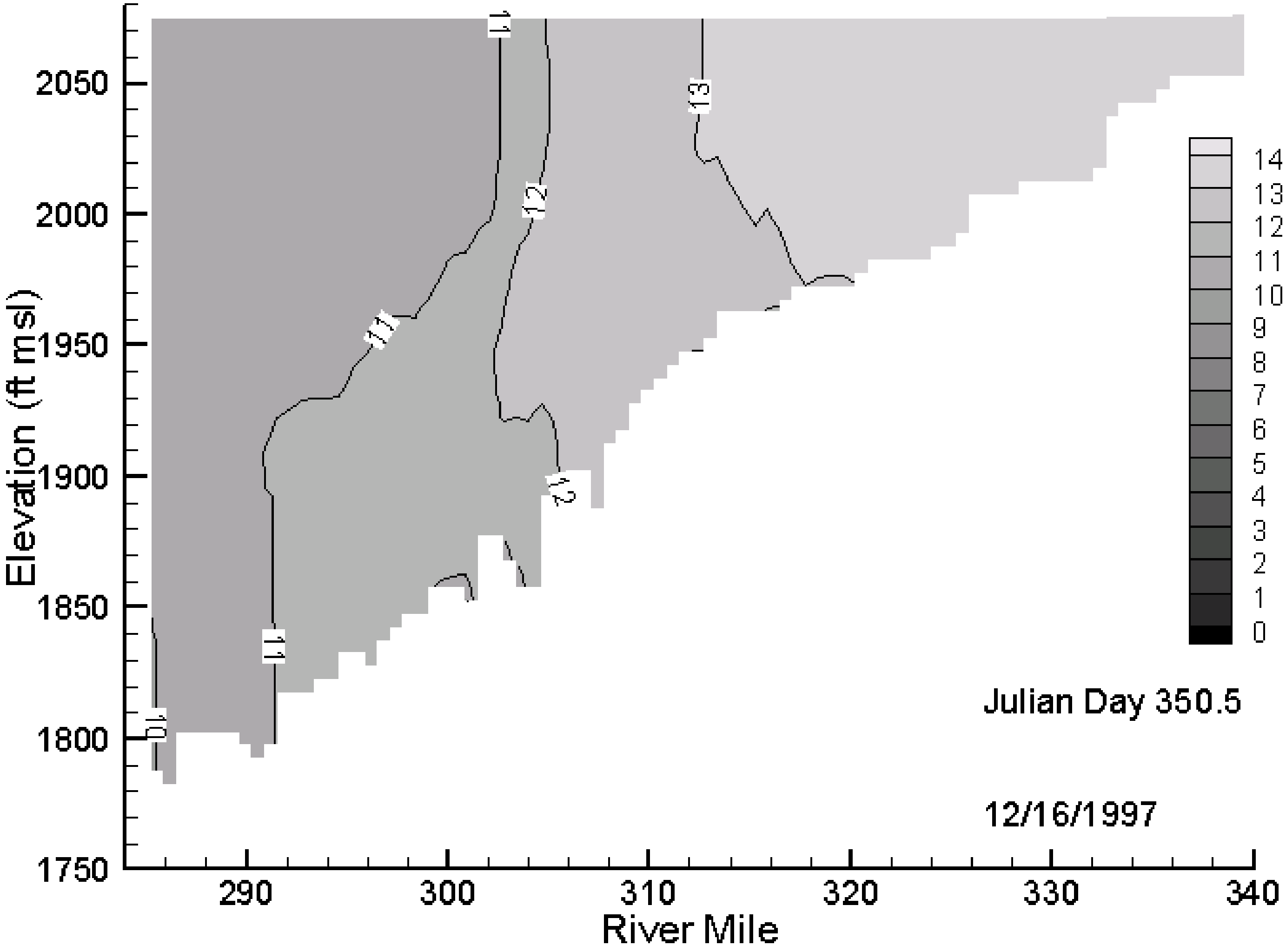


Figure 120. Simulated 1997 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location.

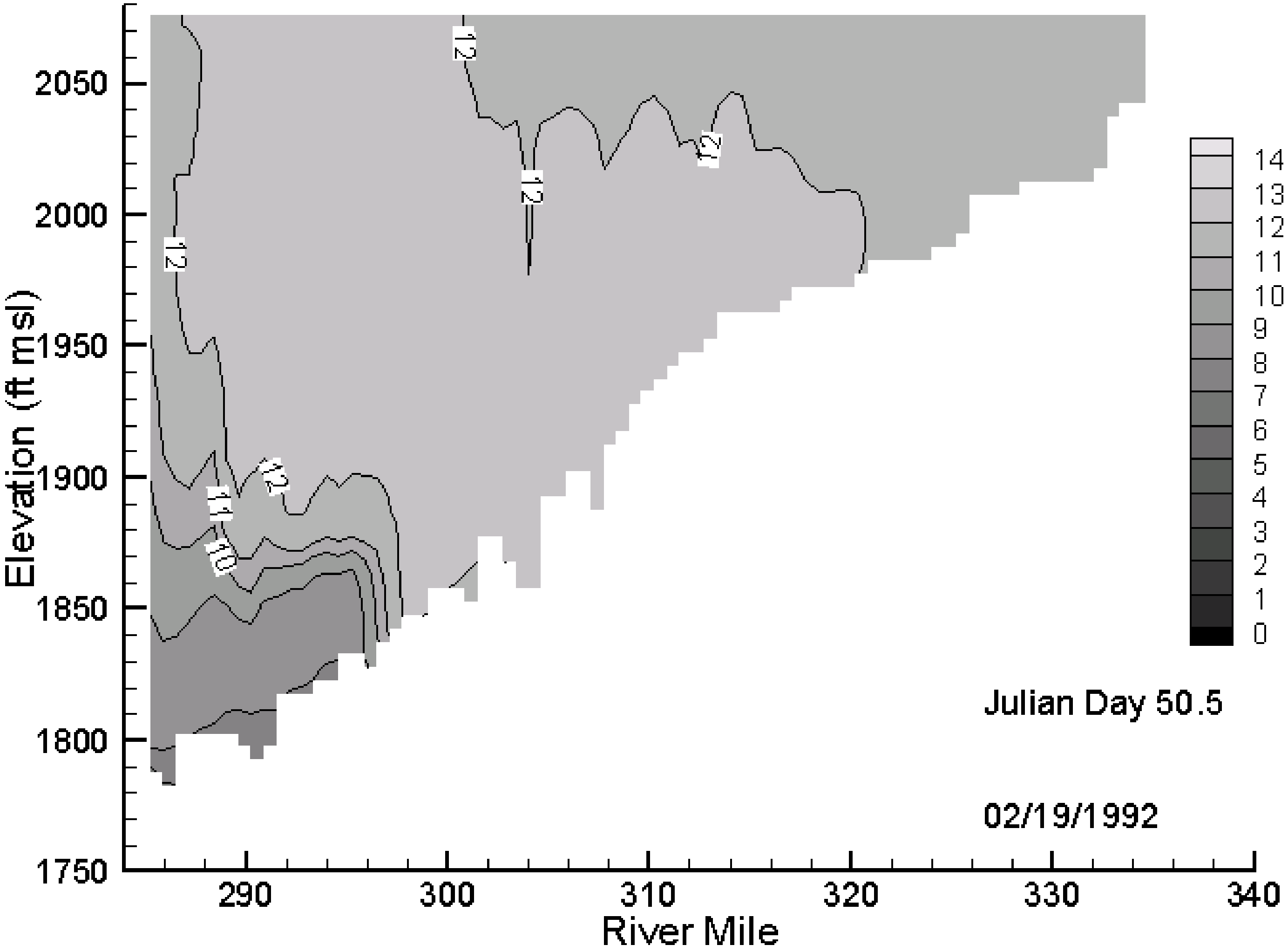


Figure 121. Simulated 1992 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

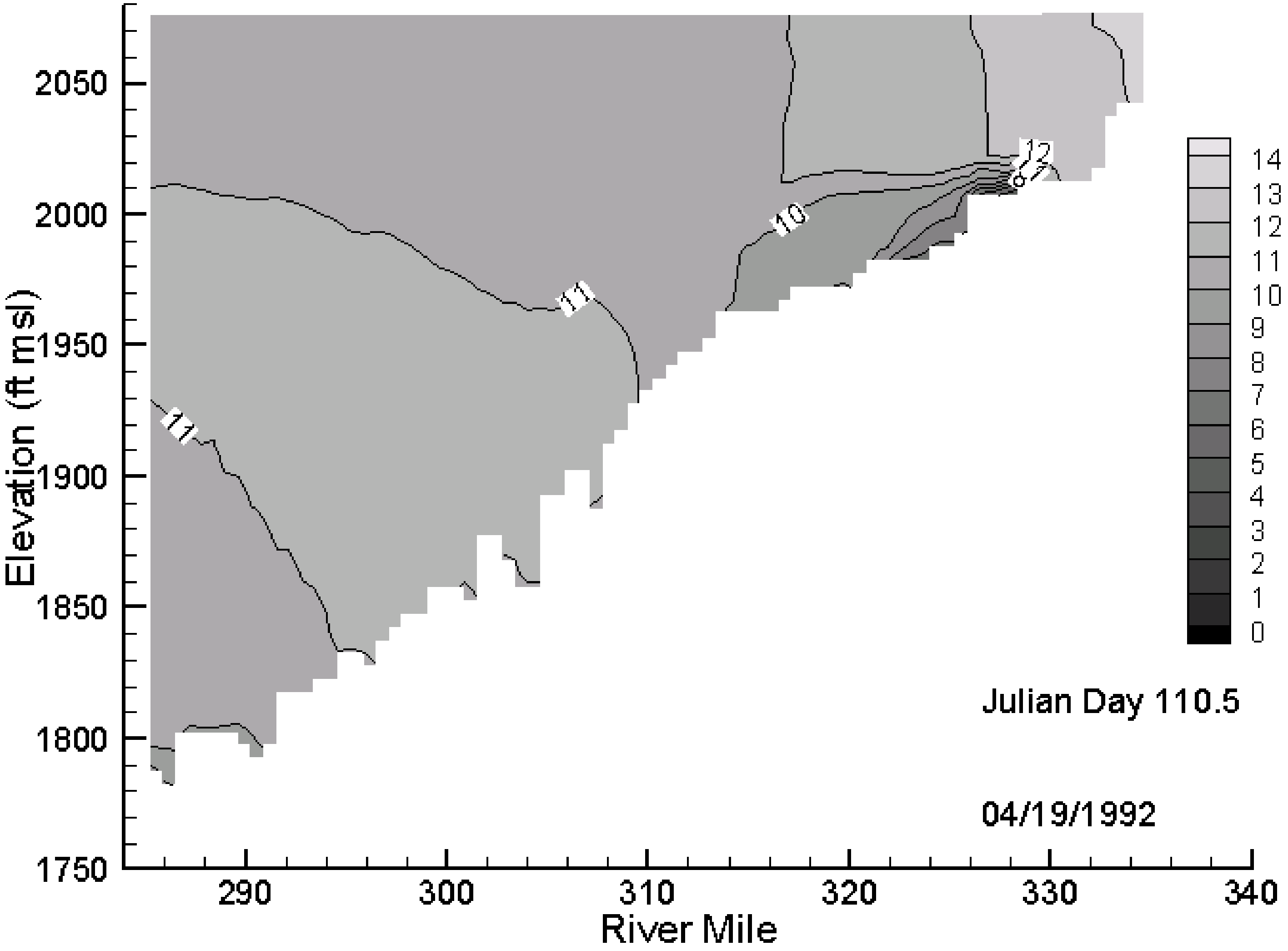


Figure 122. Simulated 1992 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

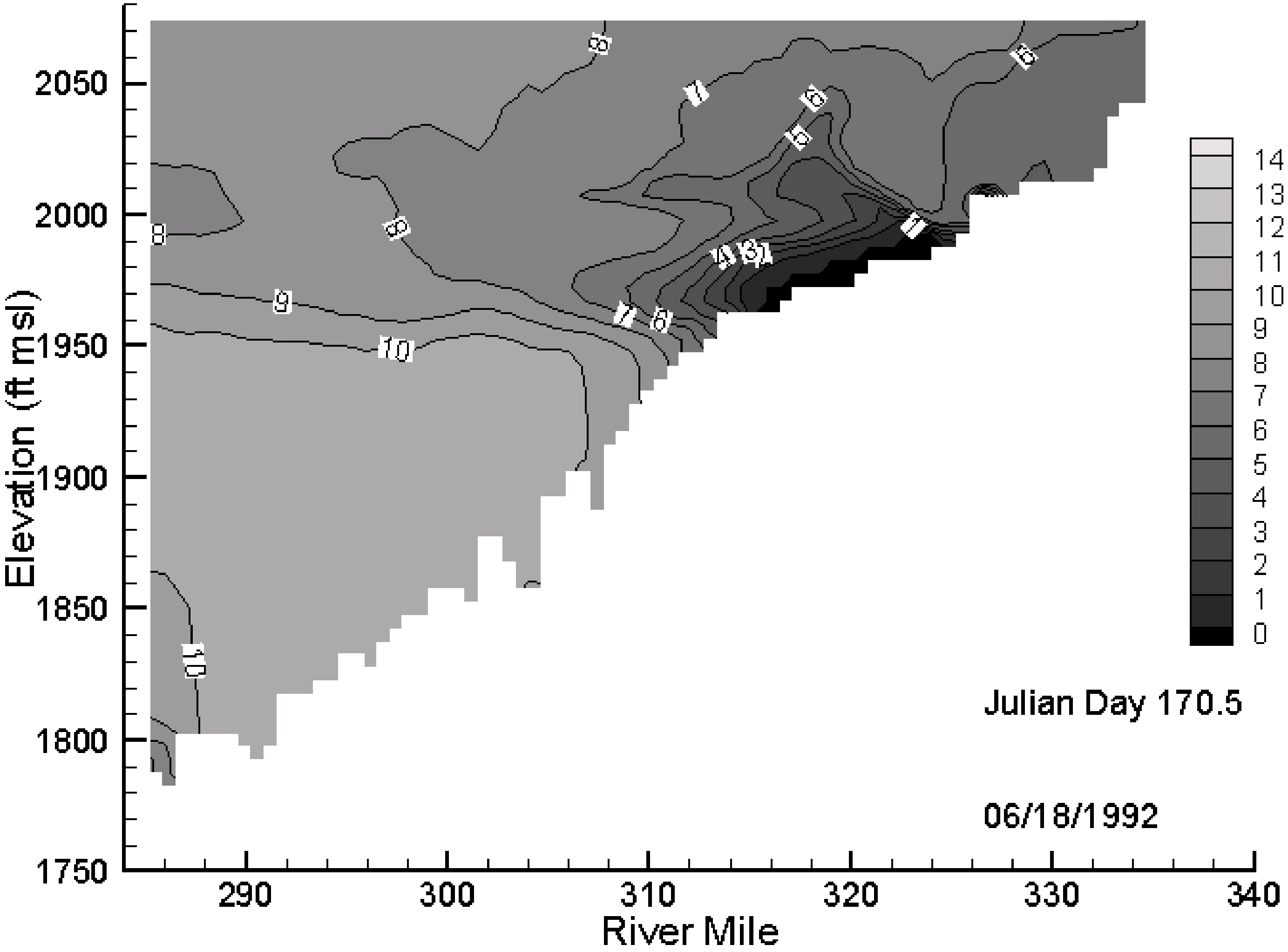


Figure 123. Simulated 1992 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

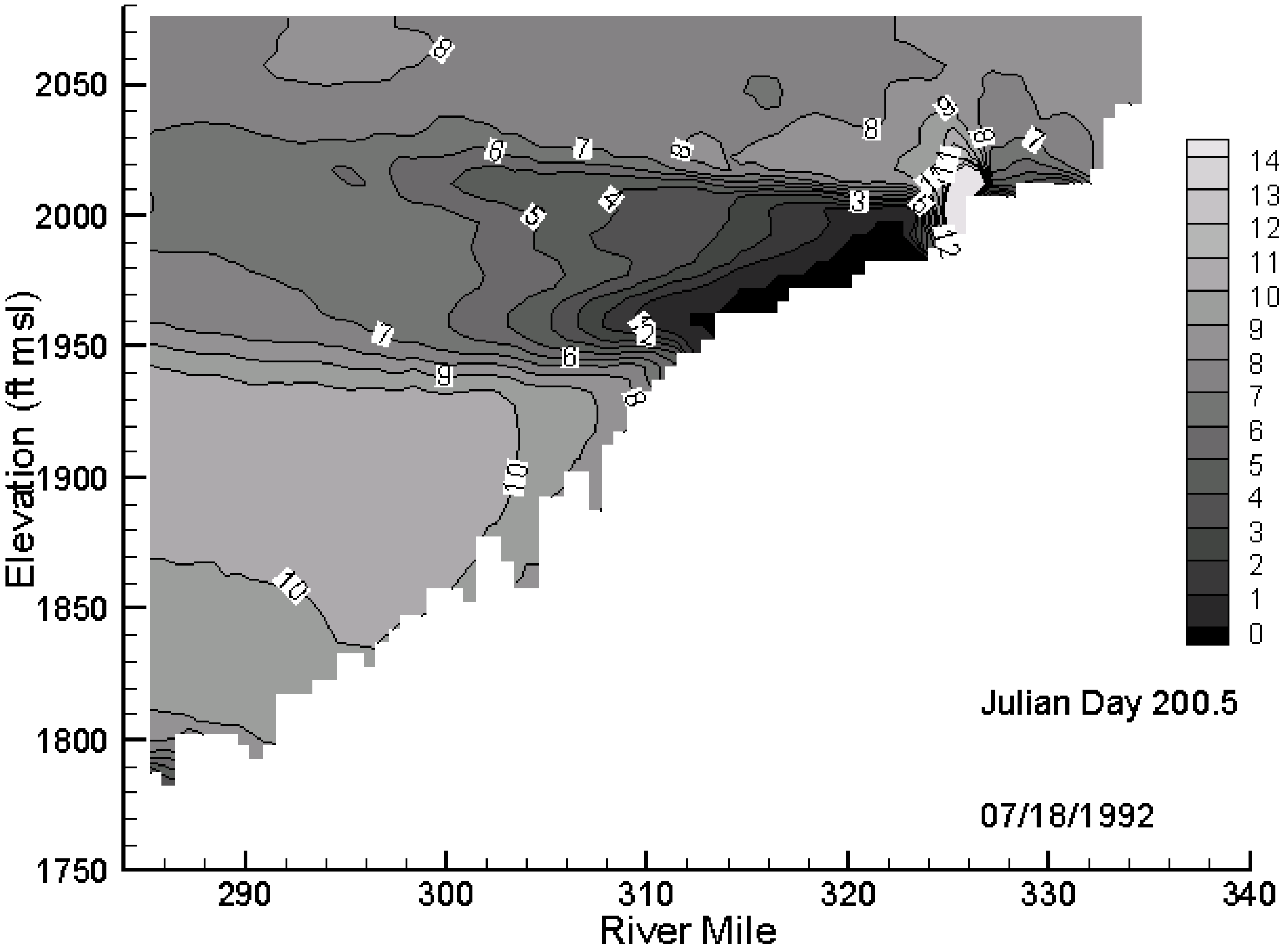


Figure 124. Simulated 1992 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

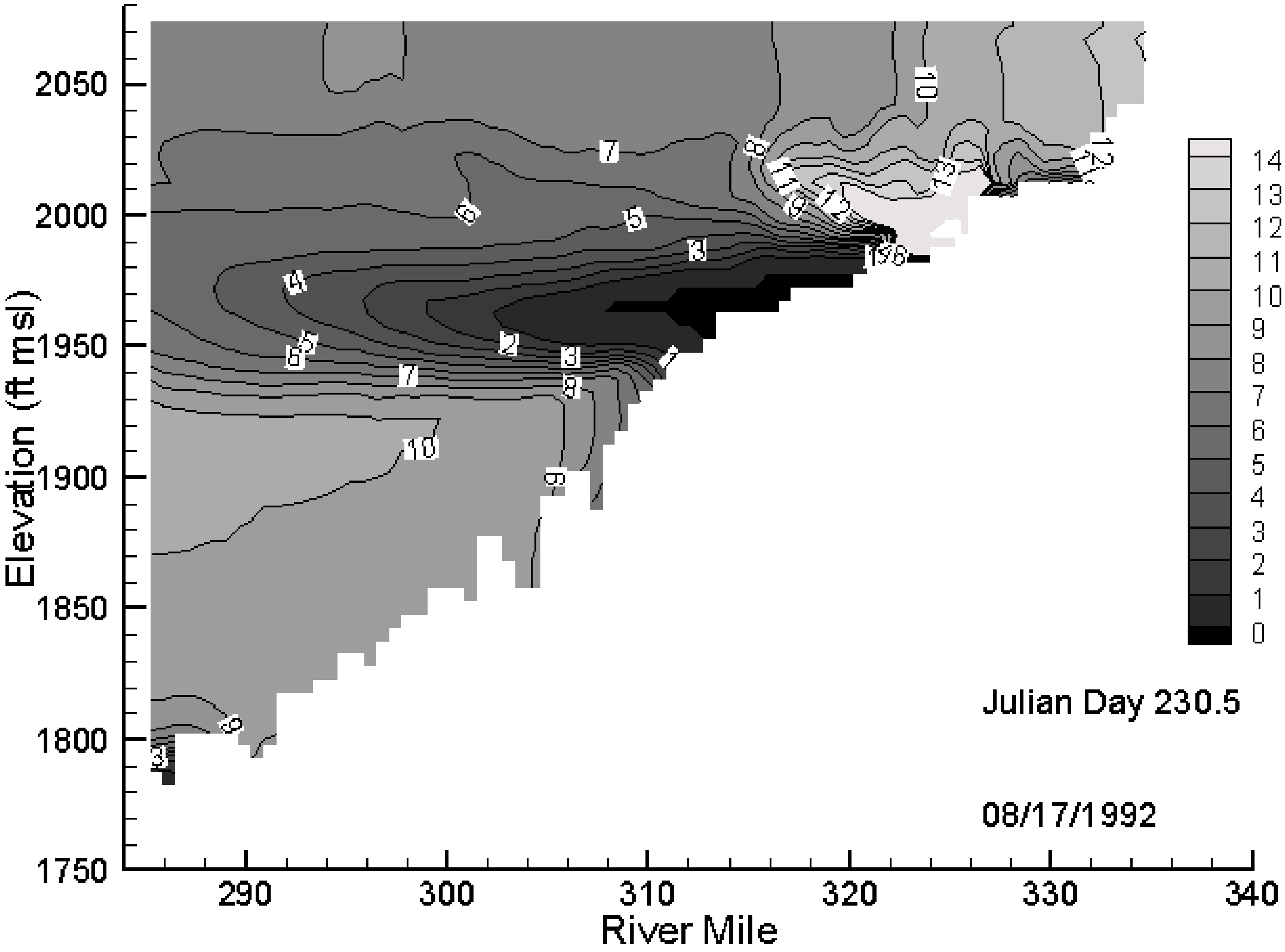


Figure 125. Simulated 1992 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125- tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

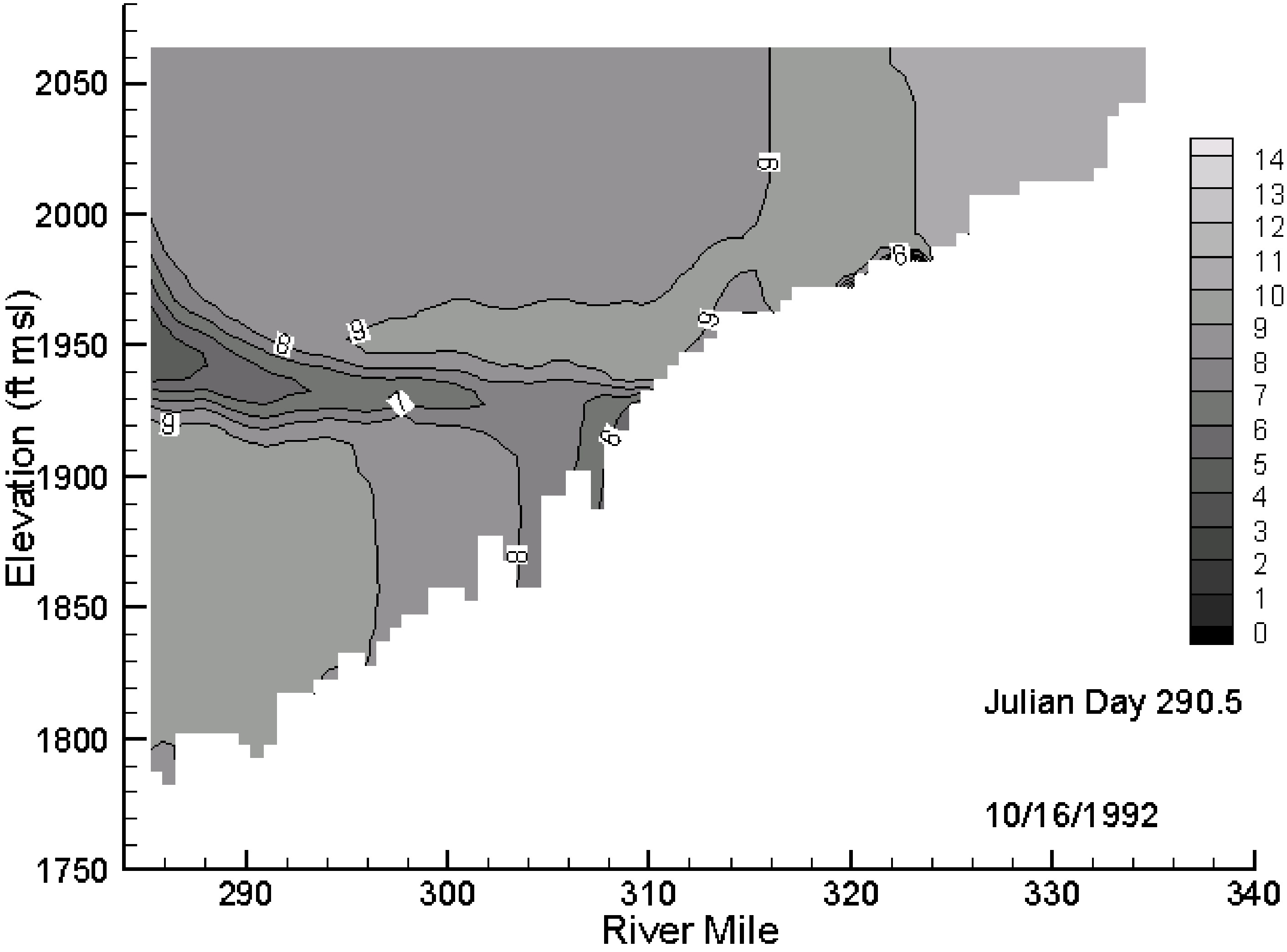


Figure 126. Simulated 1992 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

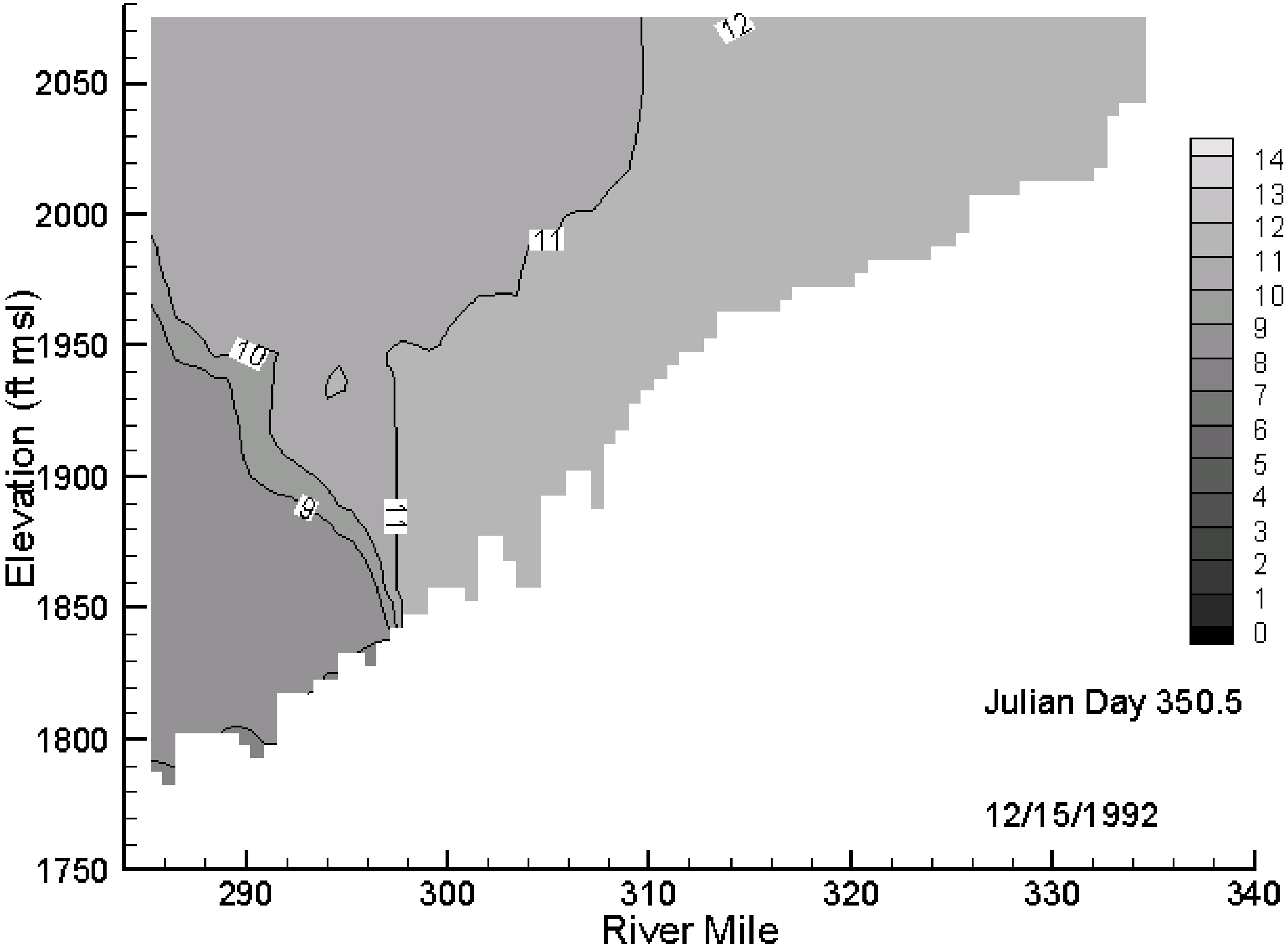


Figure 127. Simulated 1992 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

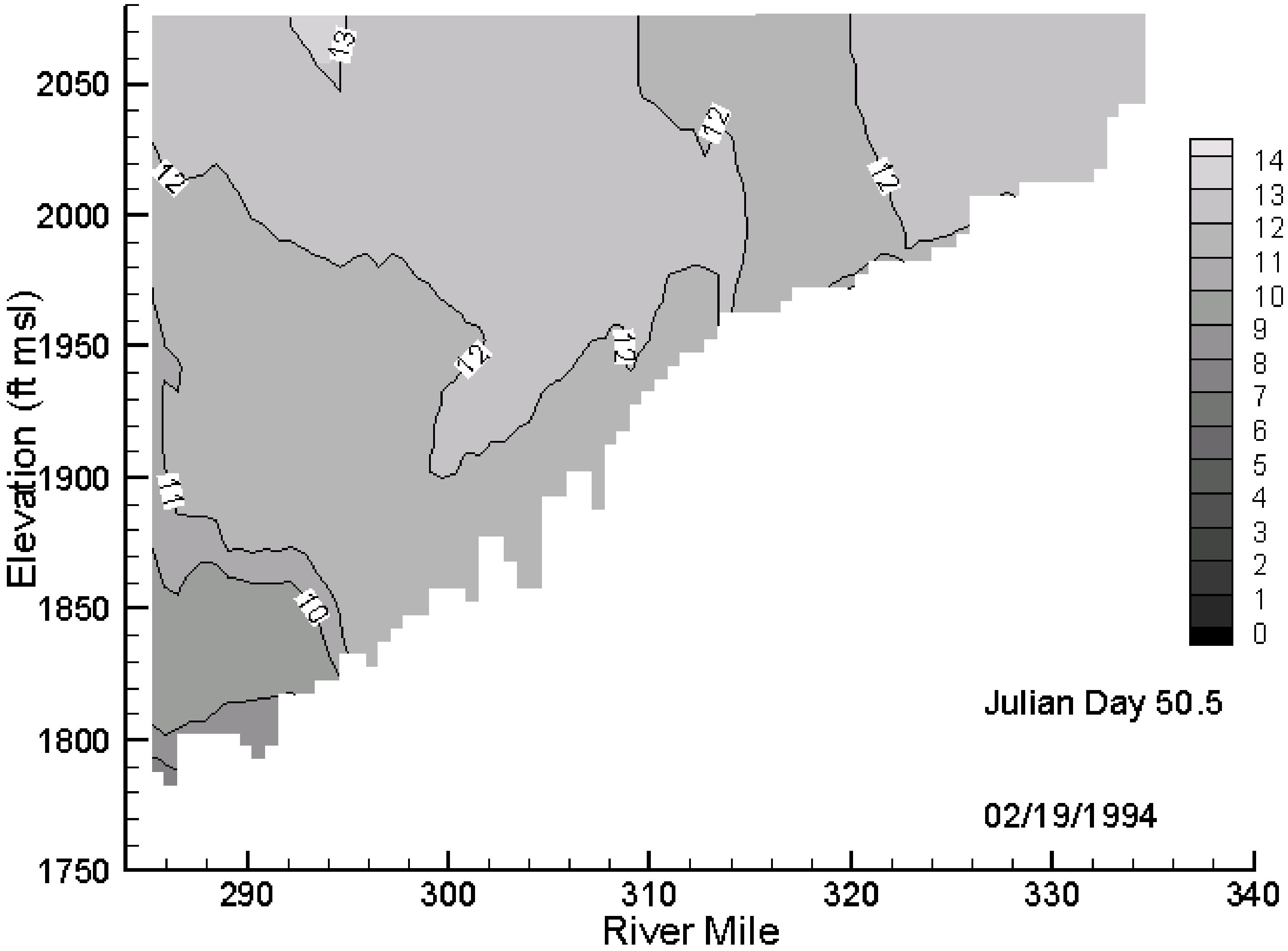


Figure 128. Simulated 1994 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

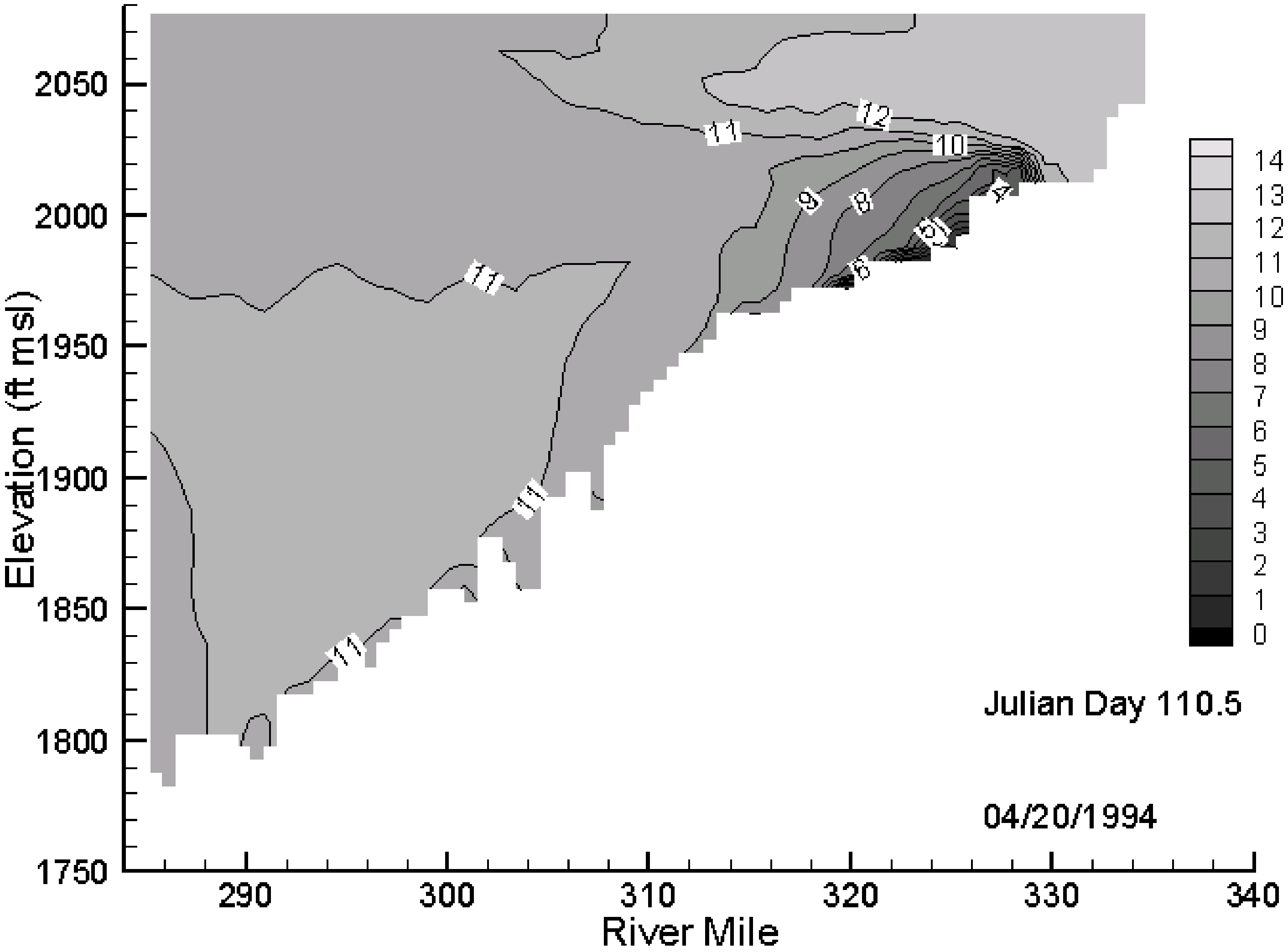


Figure 129. Simulated 1994 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

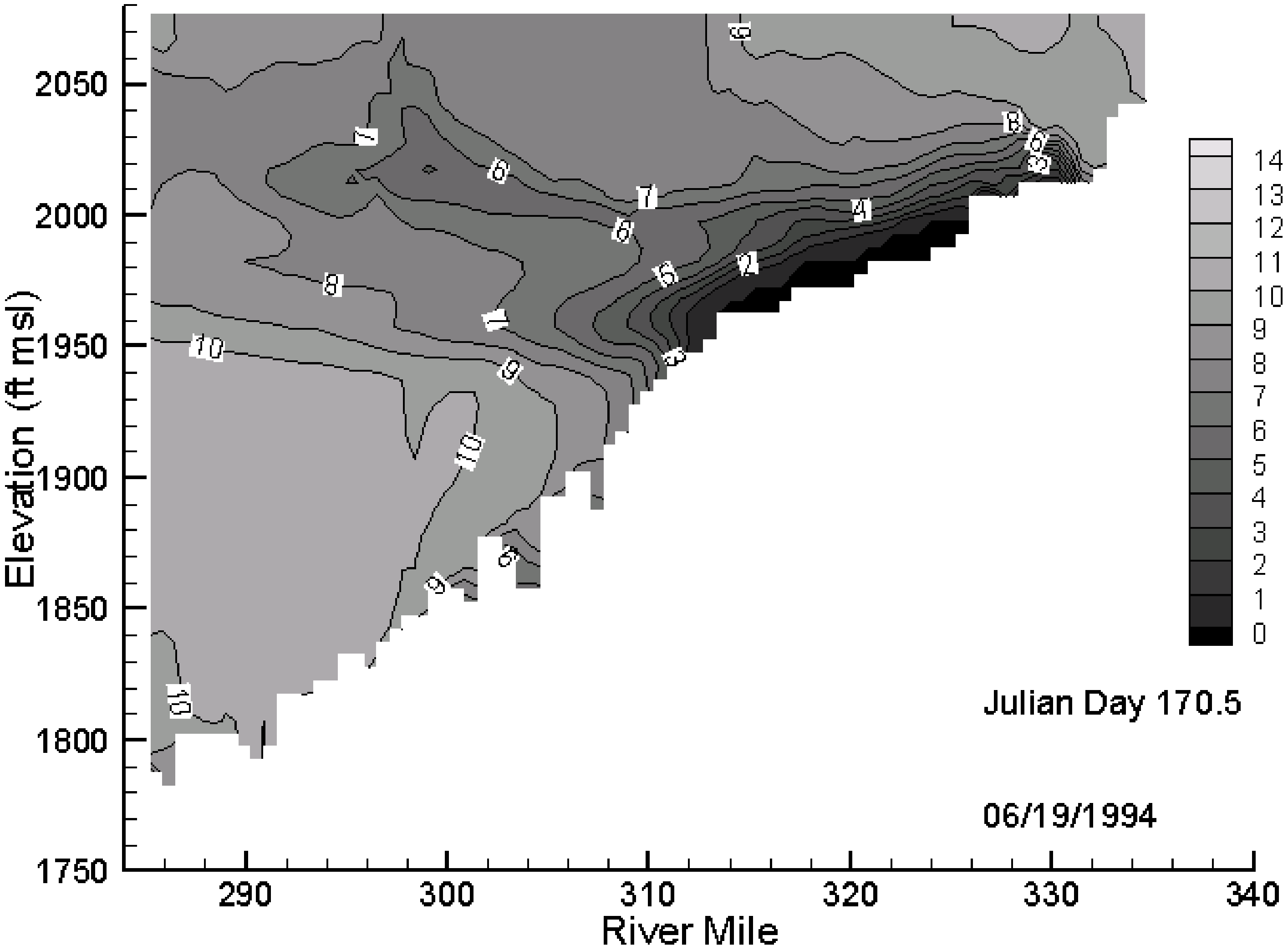


Figure 130. Simulated 1994 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

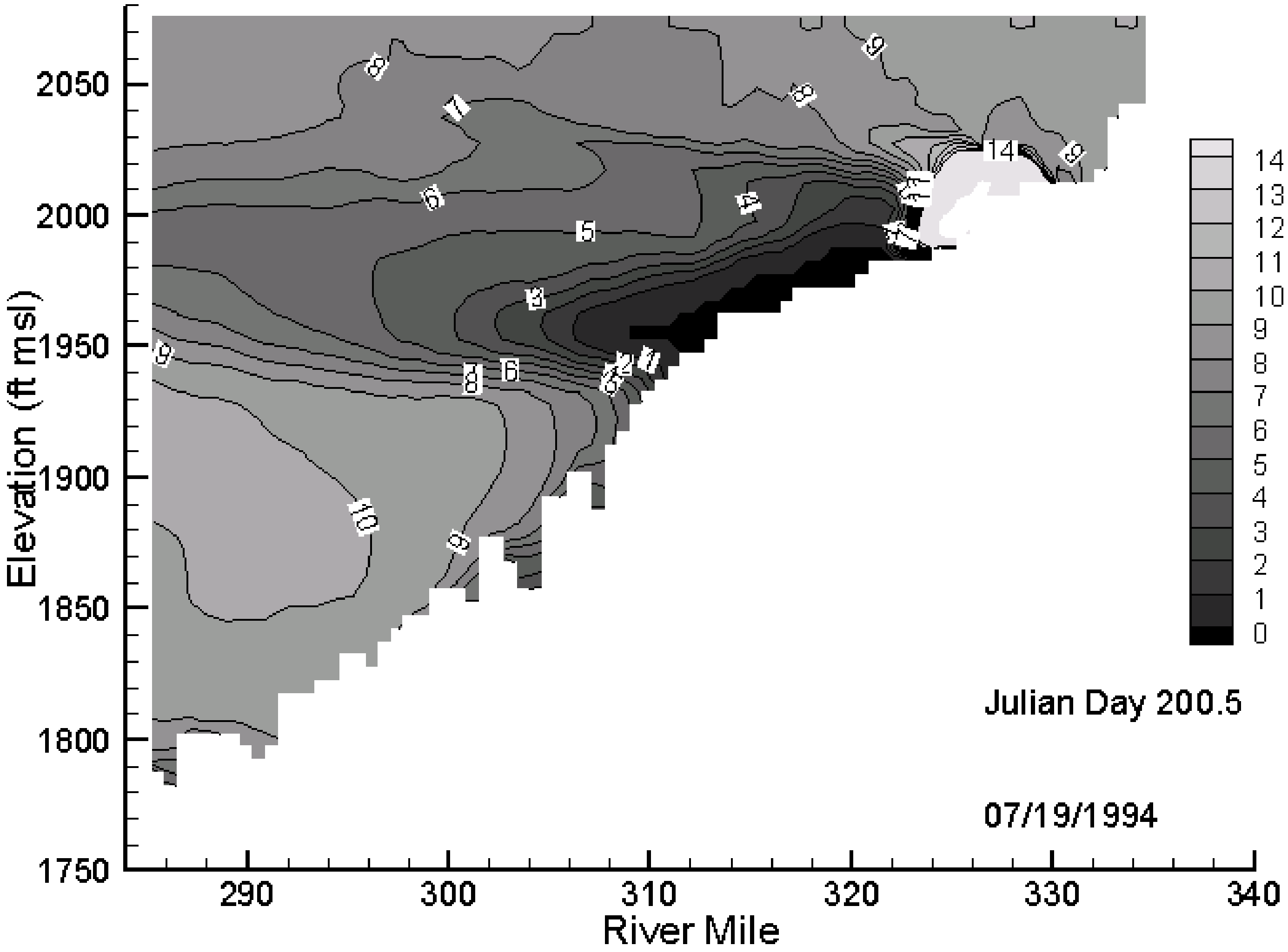


Figure 131. Simulated 1994 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

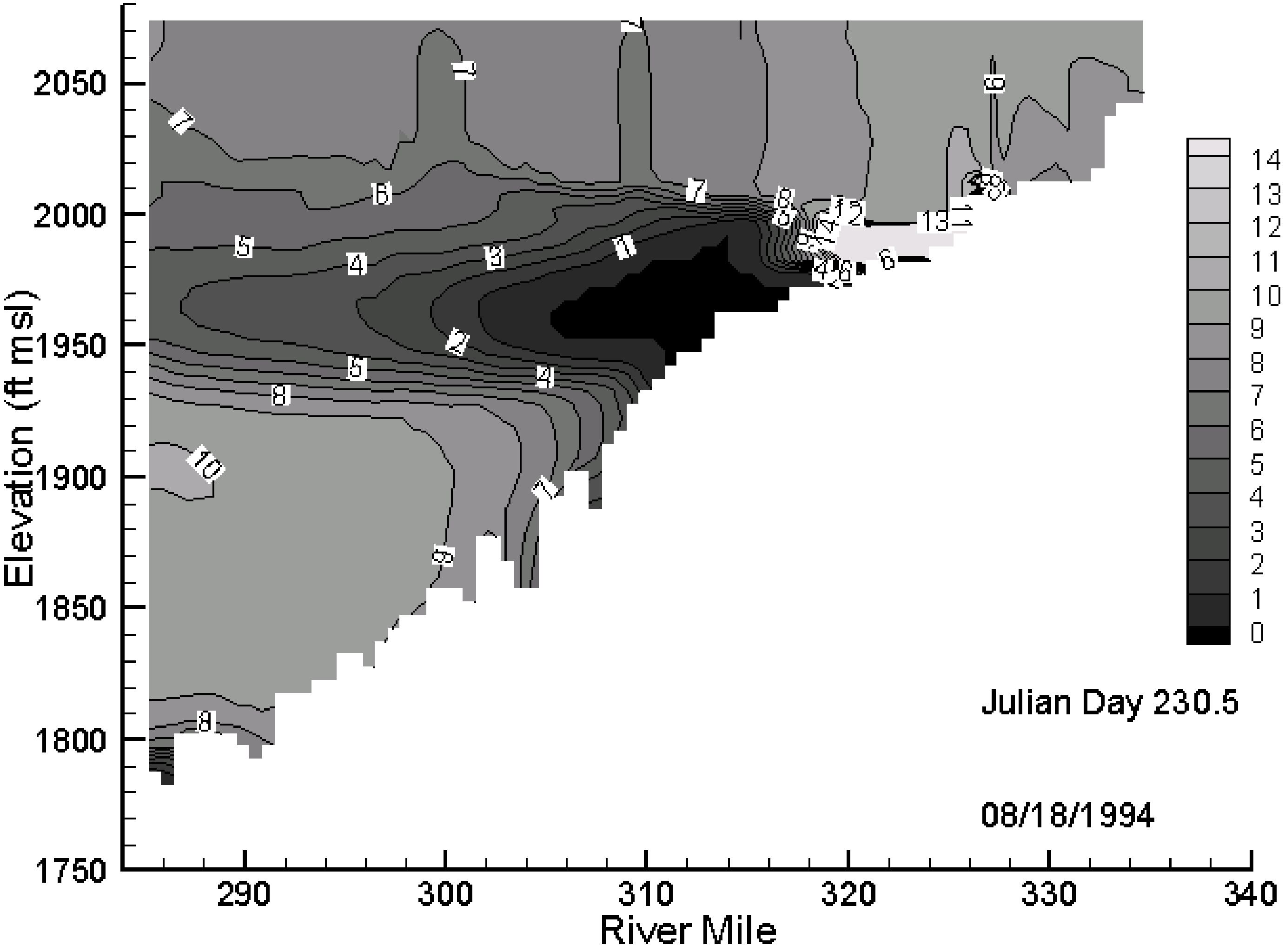


Figure 132. Simulated 1994 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

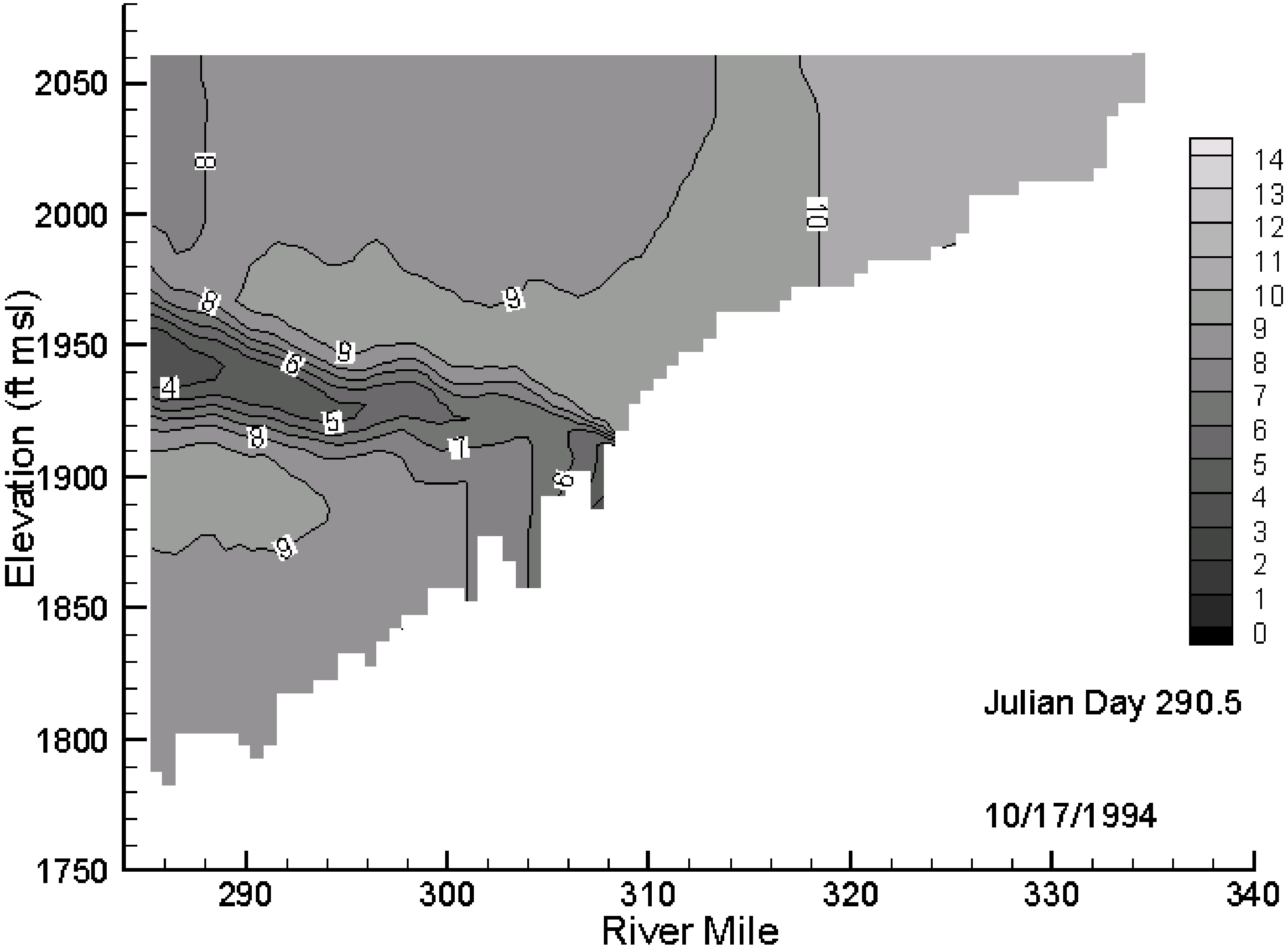


Figure 133. Simulated 1994 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

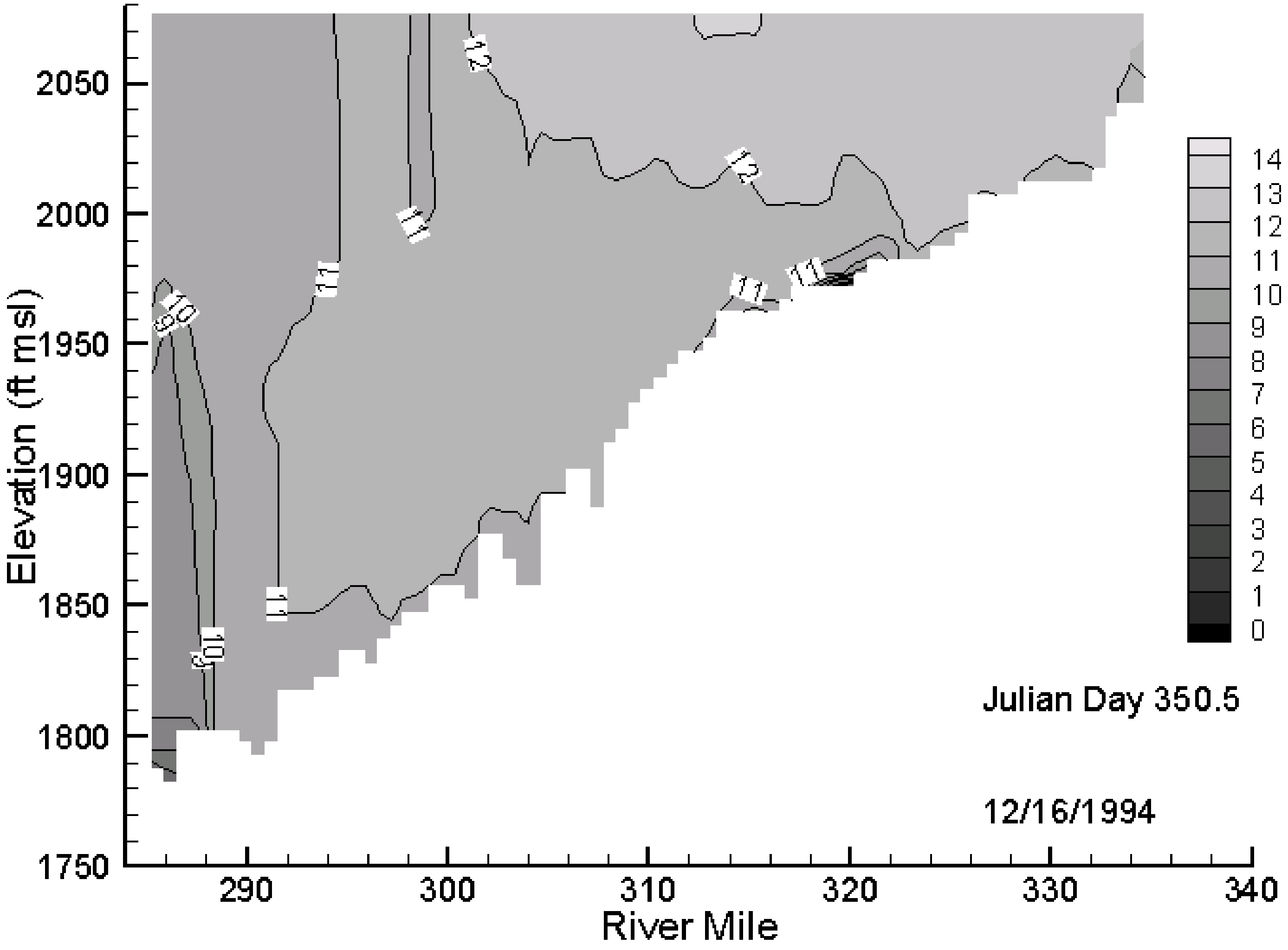


Figure 134. Simulated 1994 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

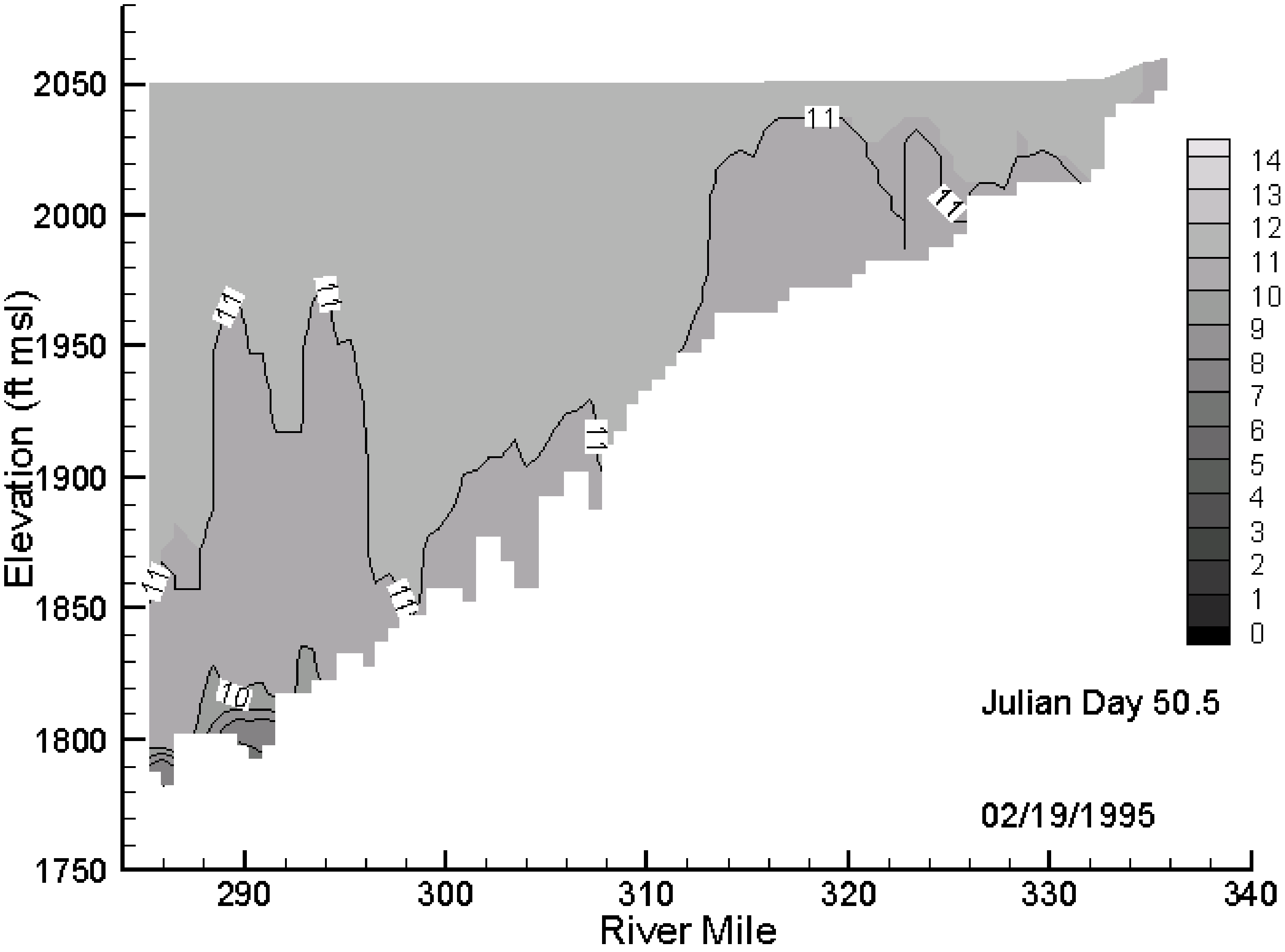


Figure 135. Simulated 1995 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

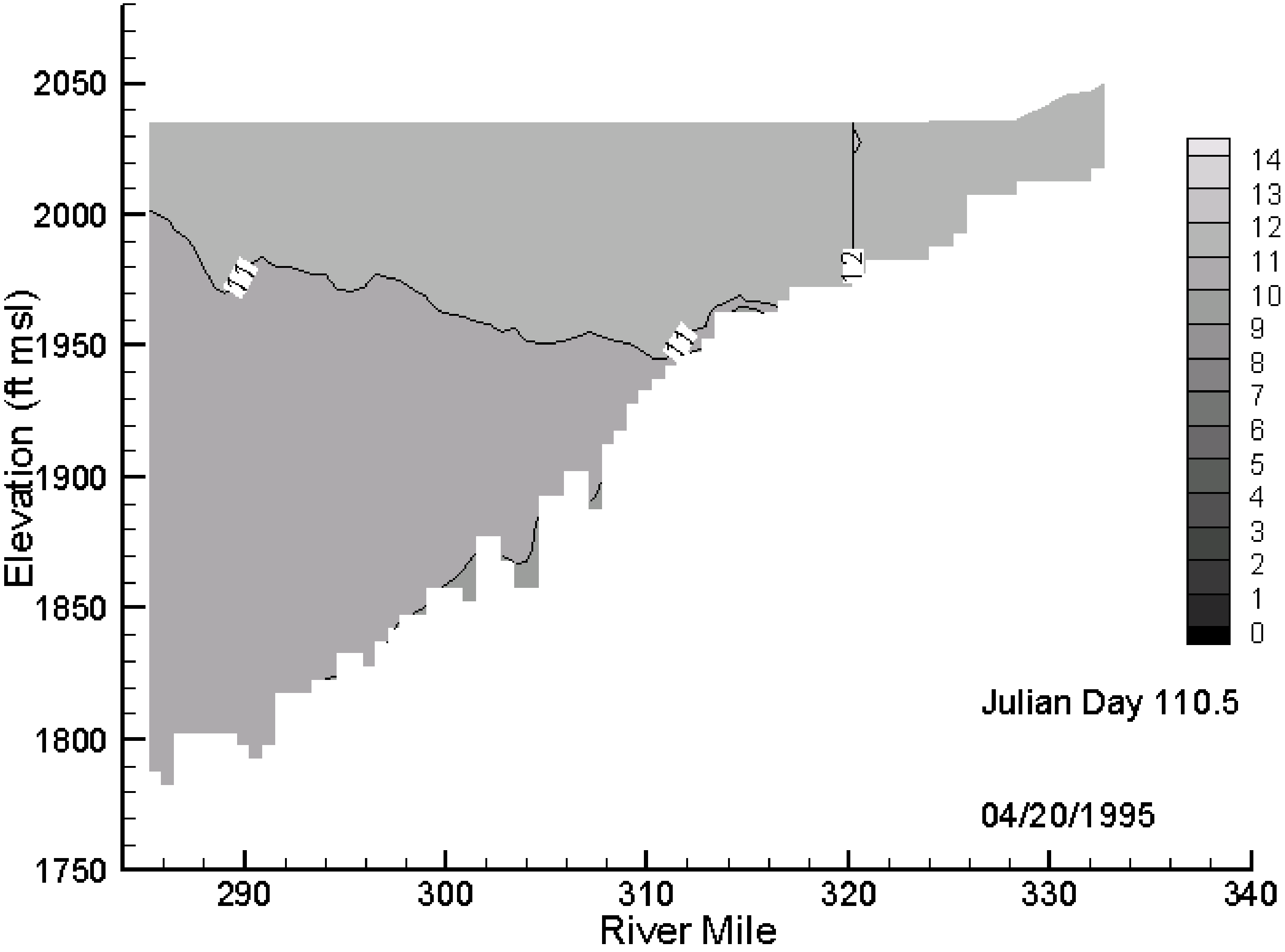


Figure 136. Simulated 1995 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

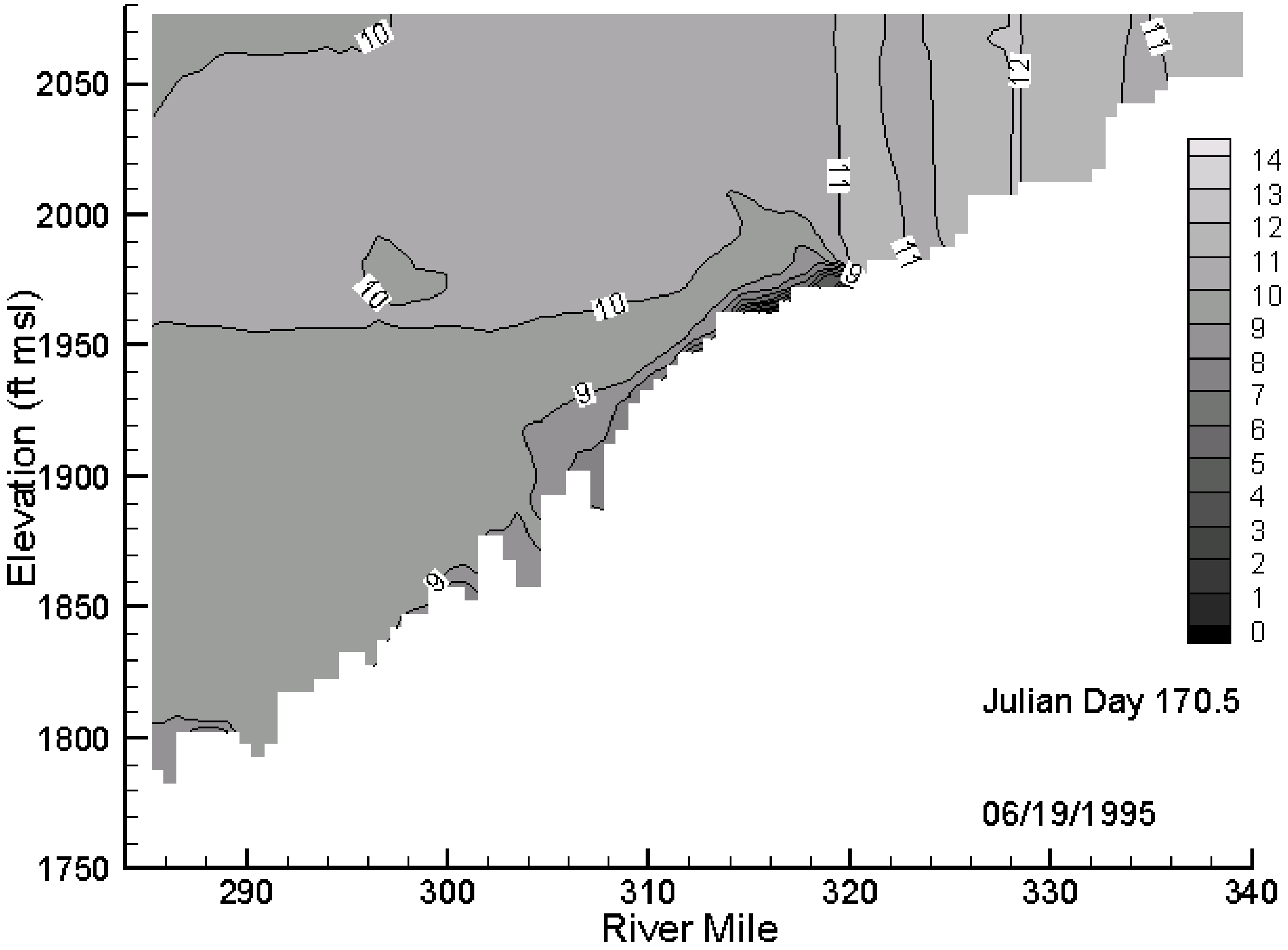


Figure 137. Simulated 1995 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

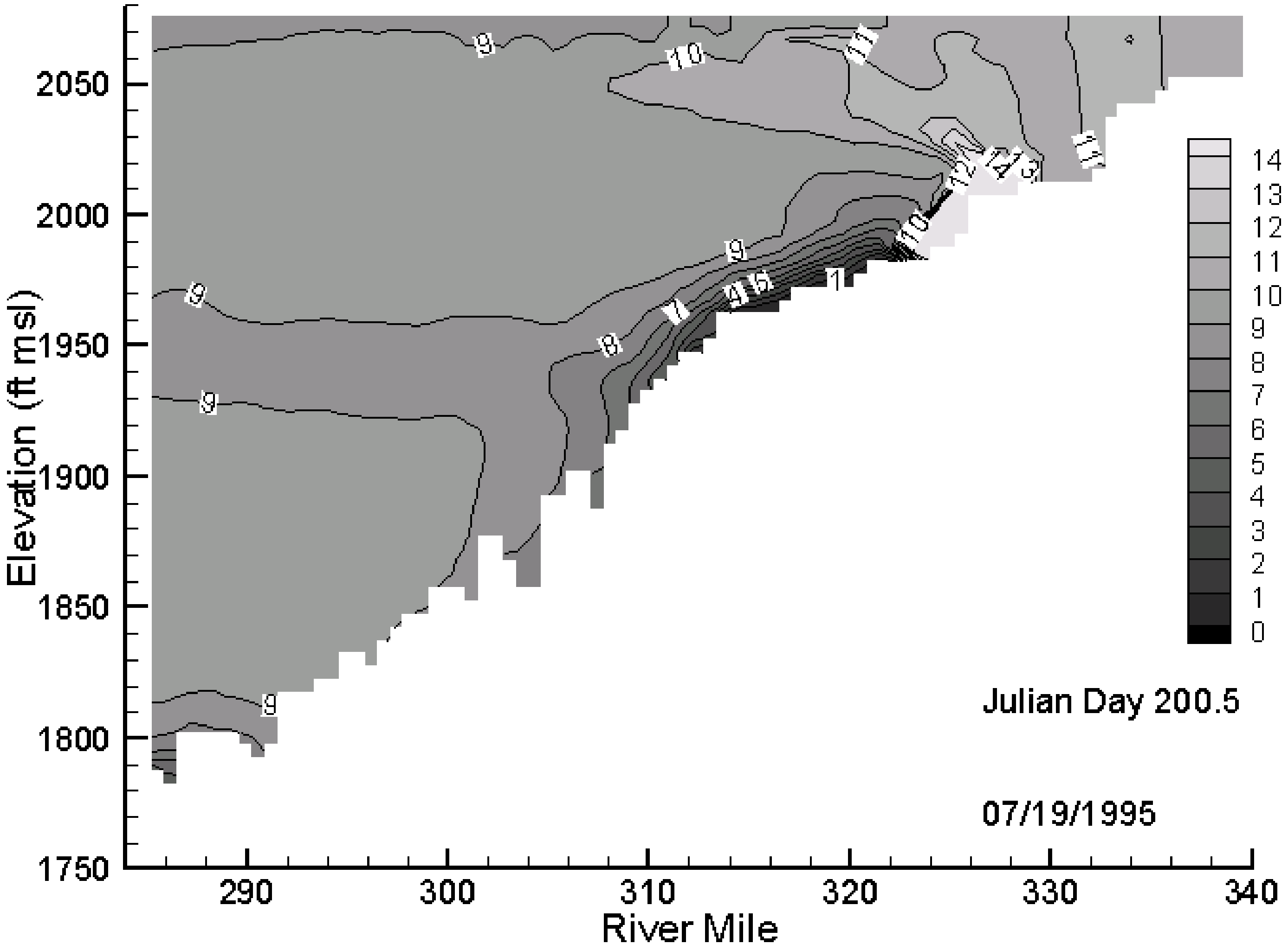


Figure 138. Simulated 1995 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

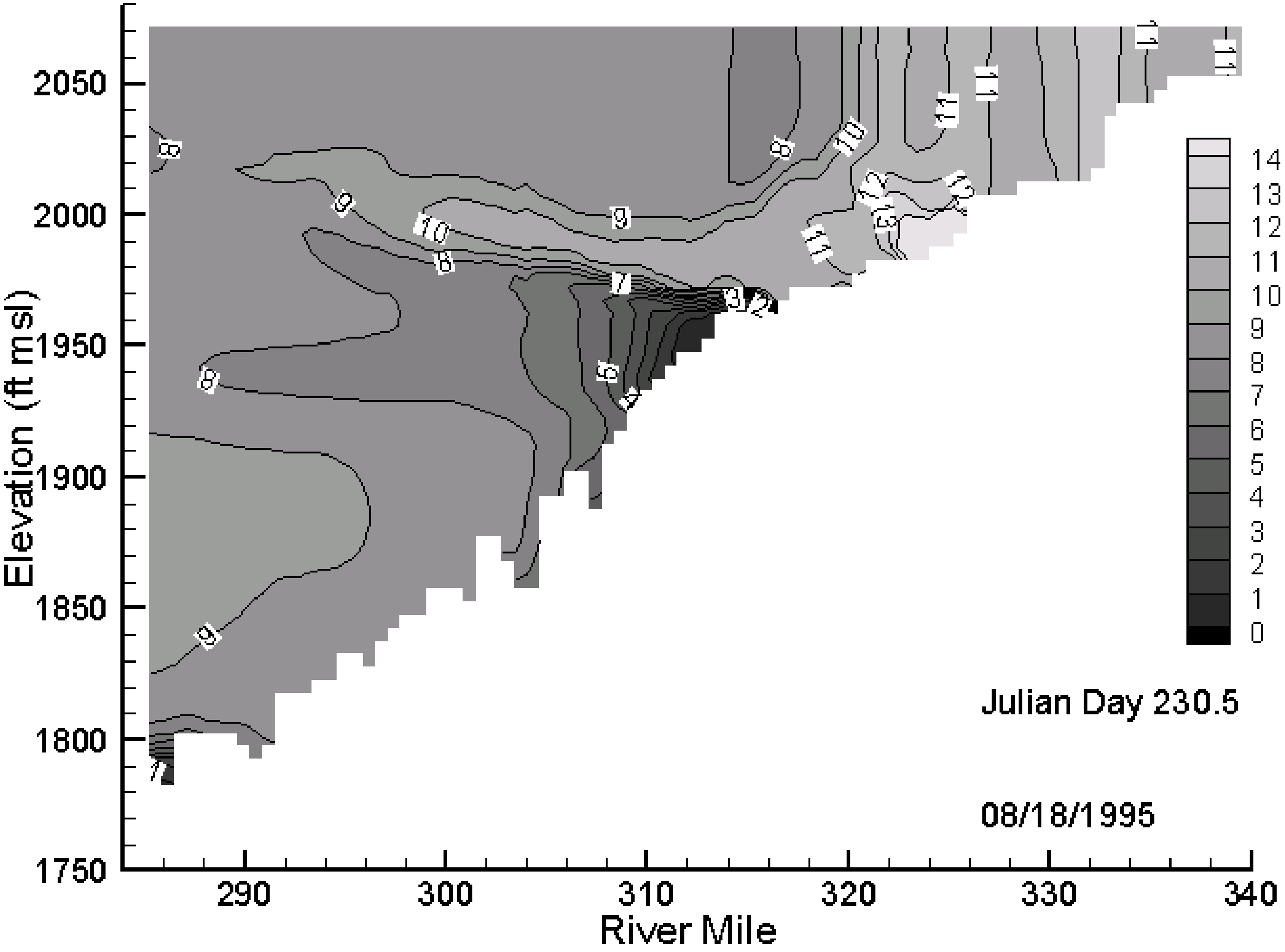


Figure 139. Simulated 1995 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

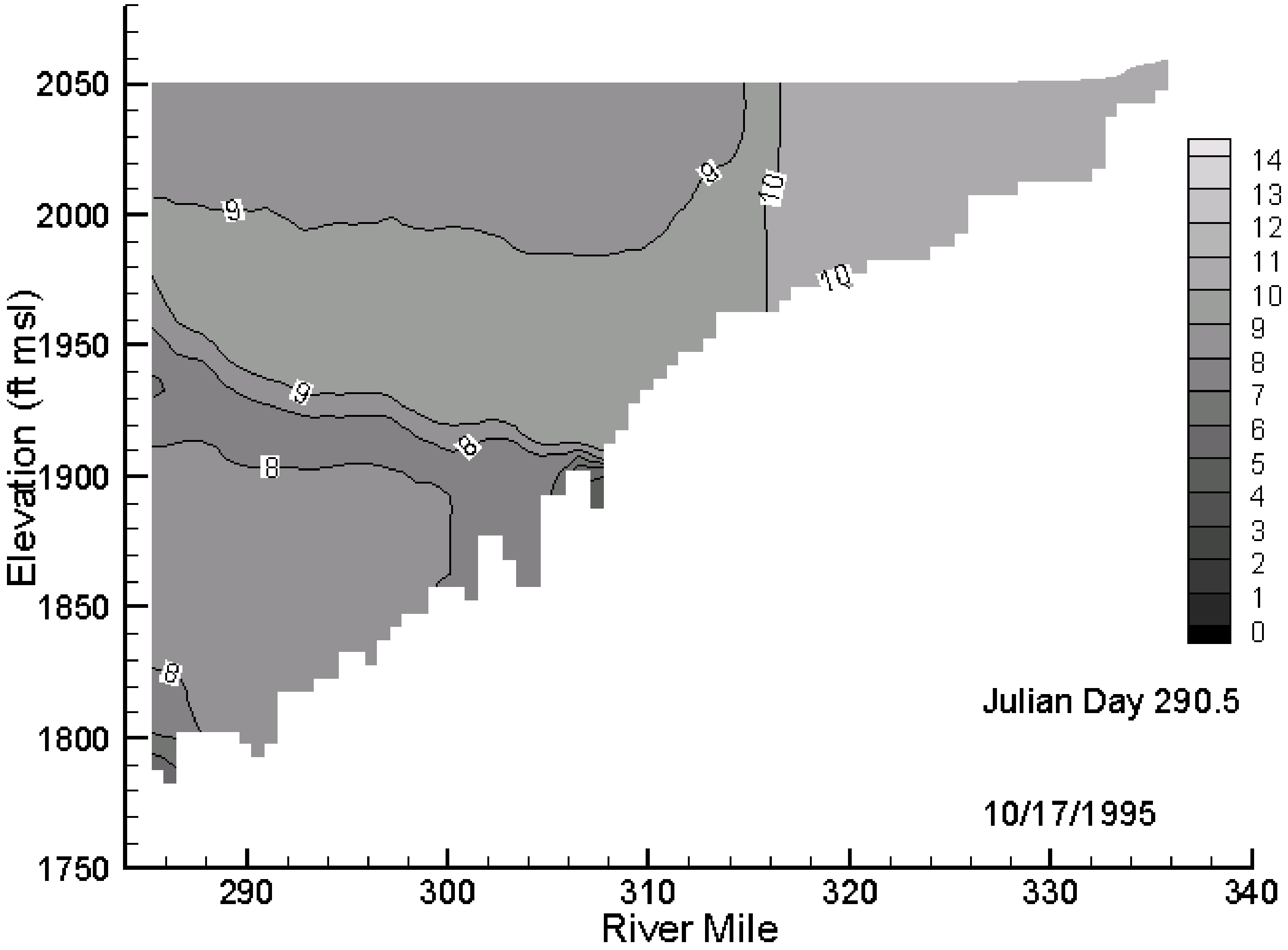


Figure 140. Simulated 1995 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

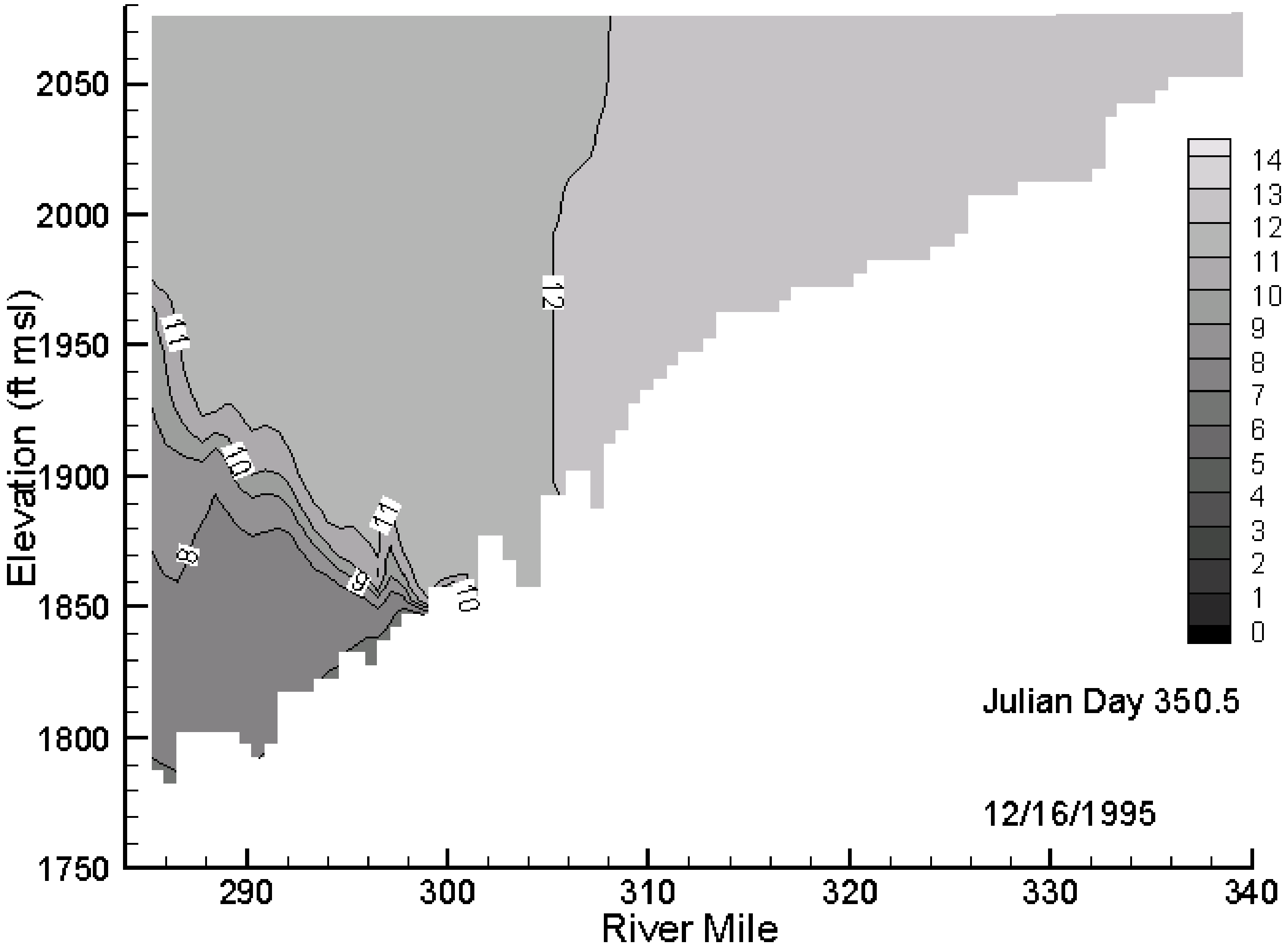


Figure 141. Simulated 1995 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

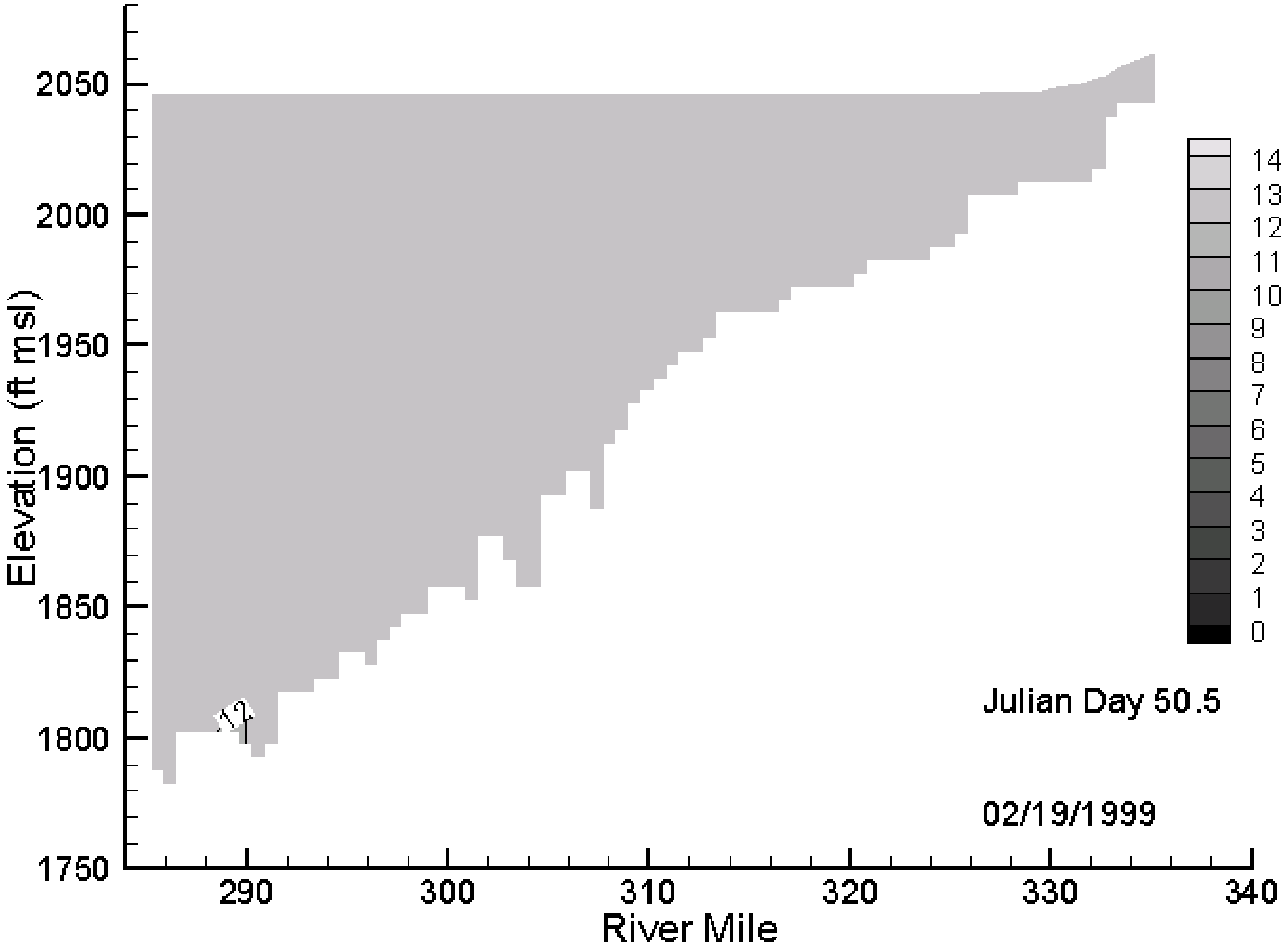


Figure 142. Simulated 1999 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

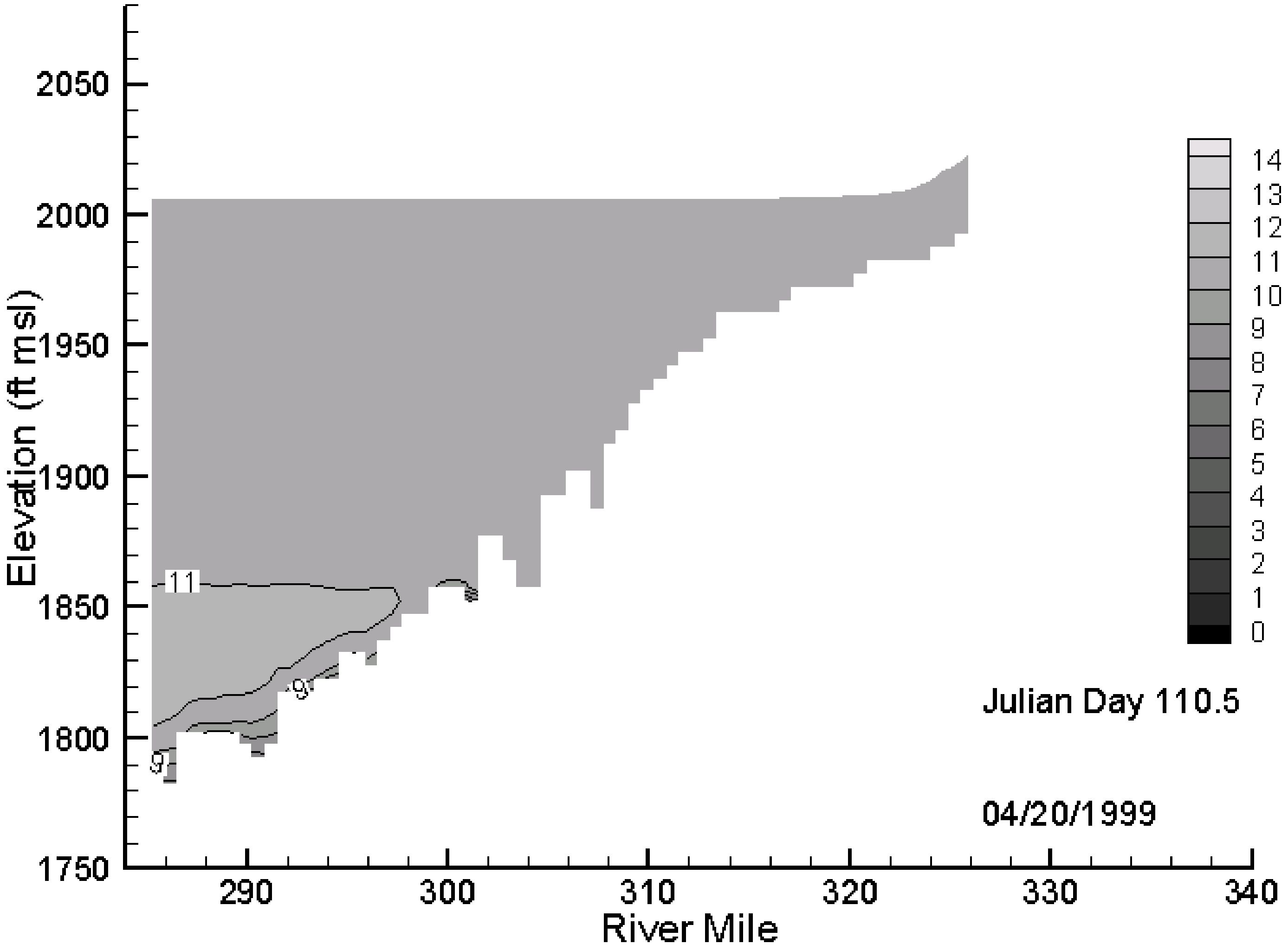


Figure 143. Simulated 1999 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

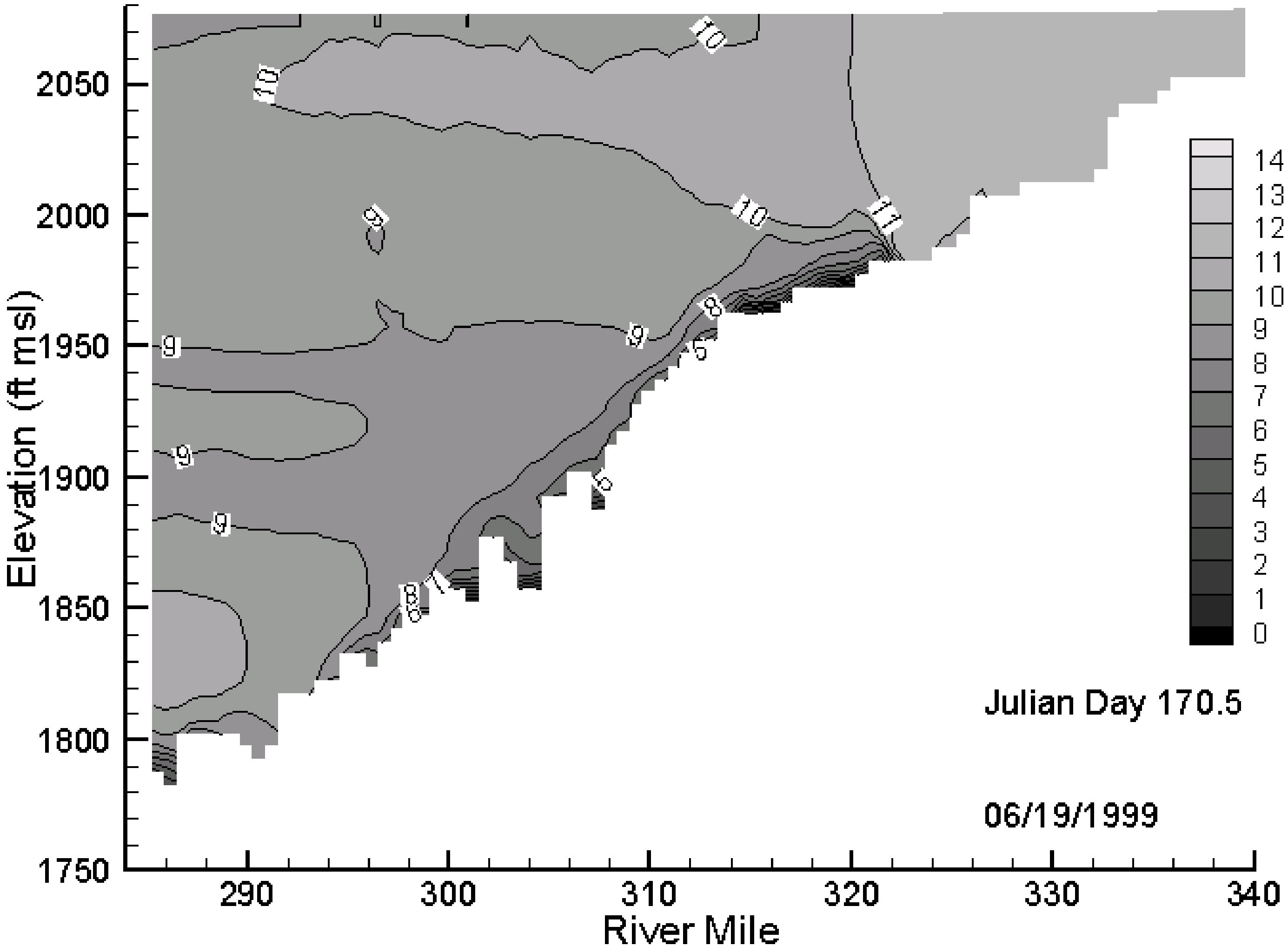


Figure 144. Simulated 1999 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

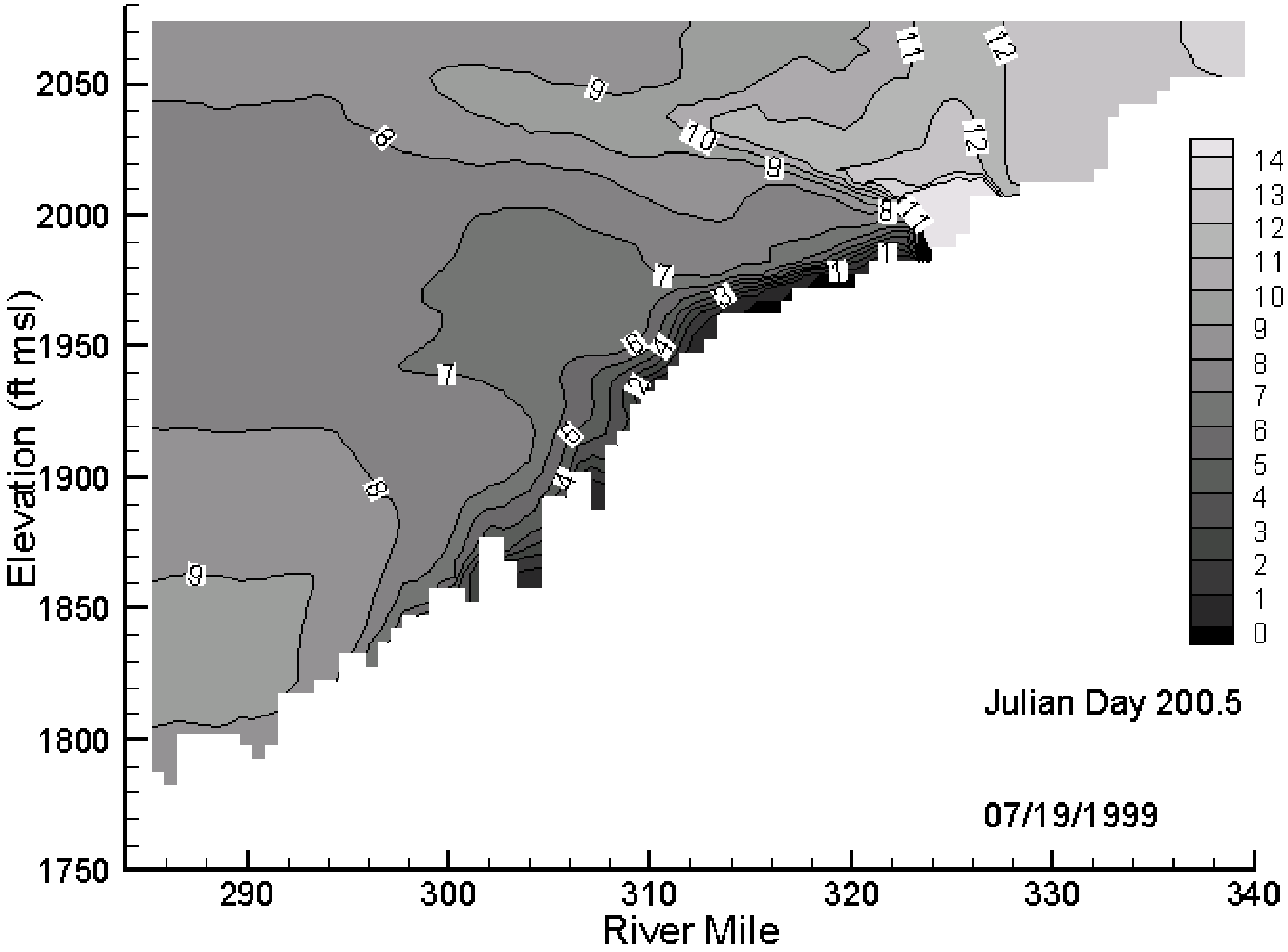


Figure 145. Simulated 1999 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

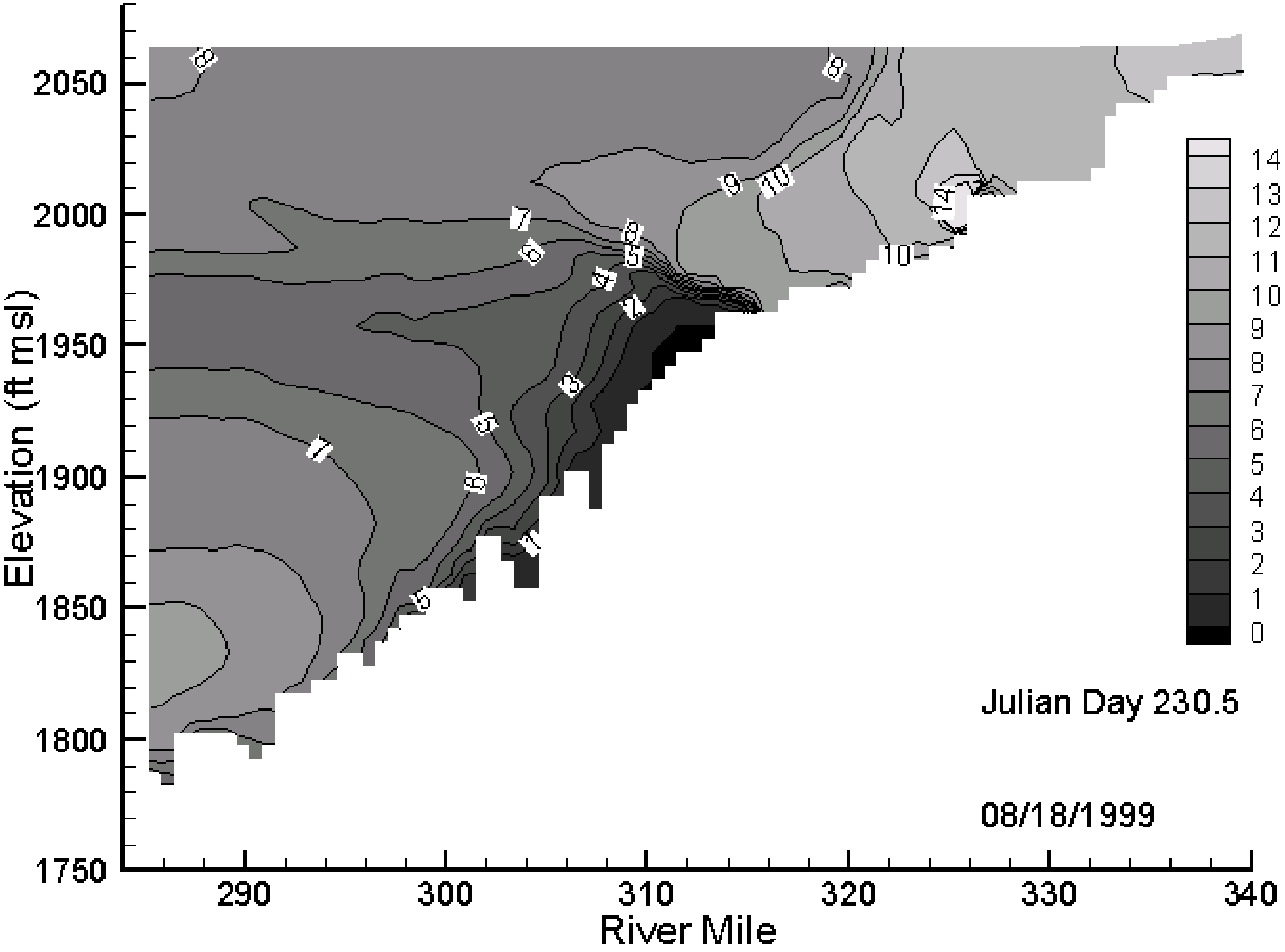


Figure 146. Simulated 1999 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

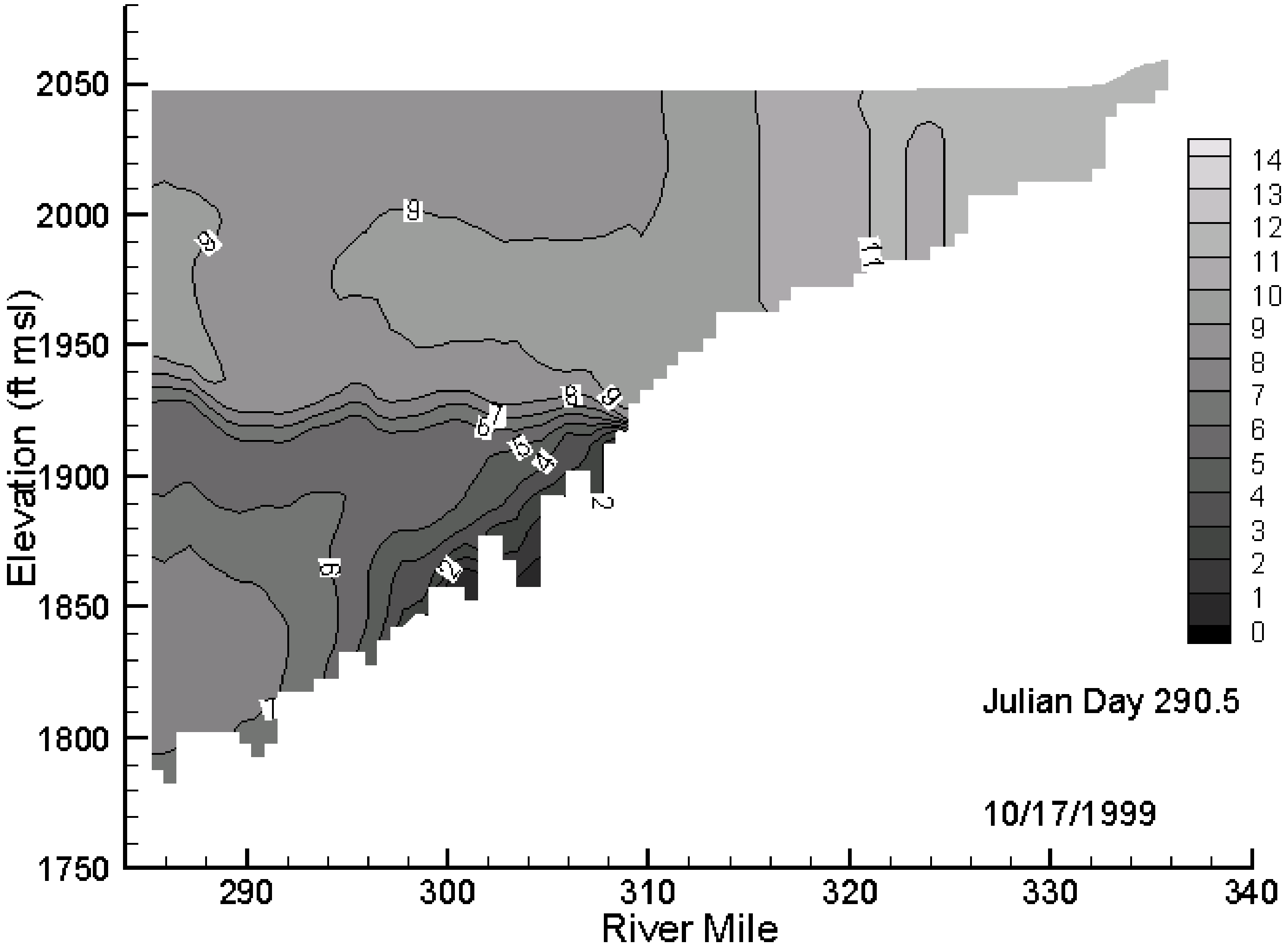


Figure 147. Simulated 1999 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

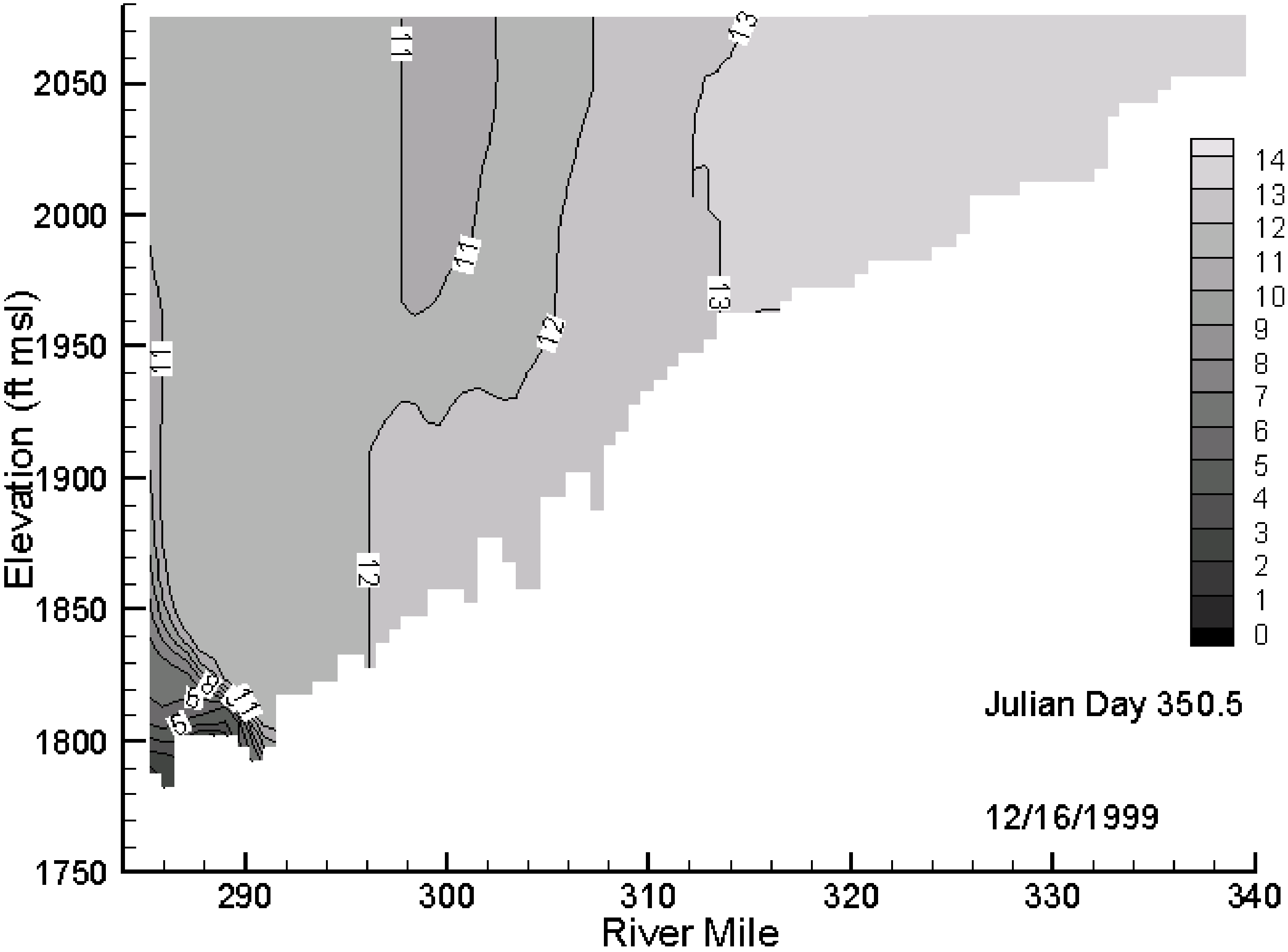


Figure 148. Simulated 1999 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

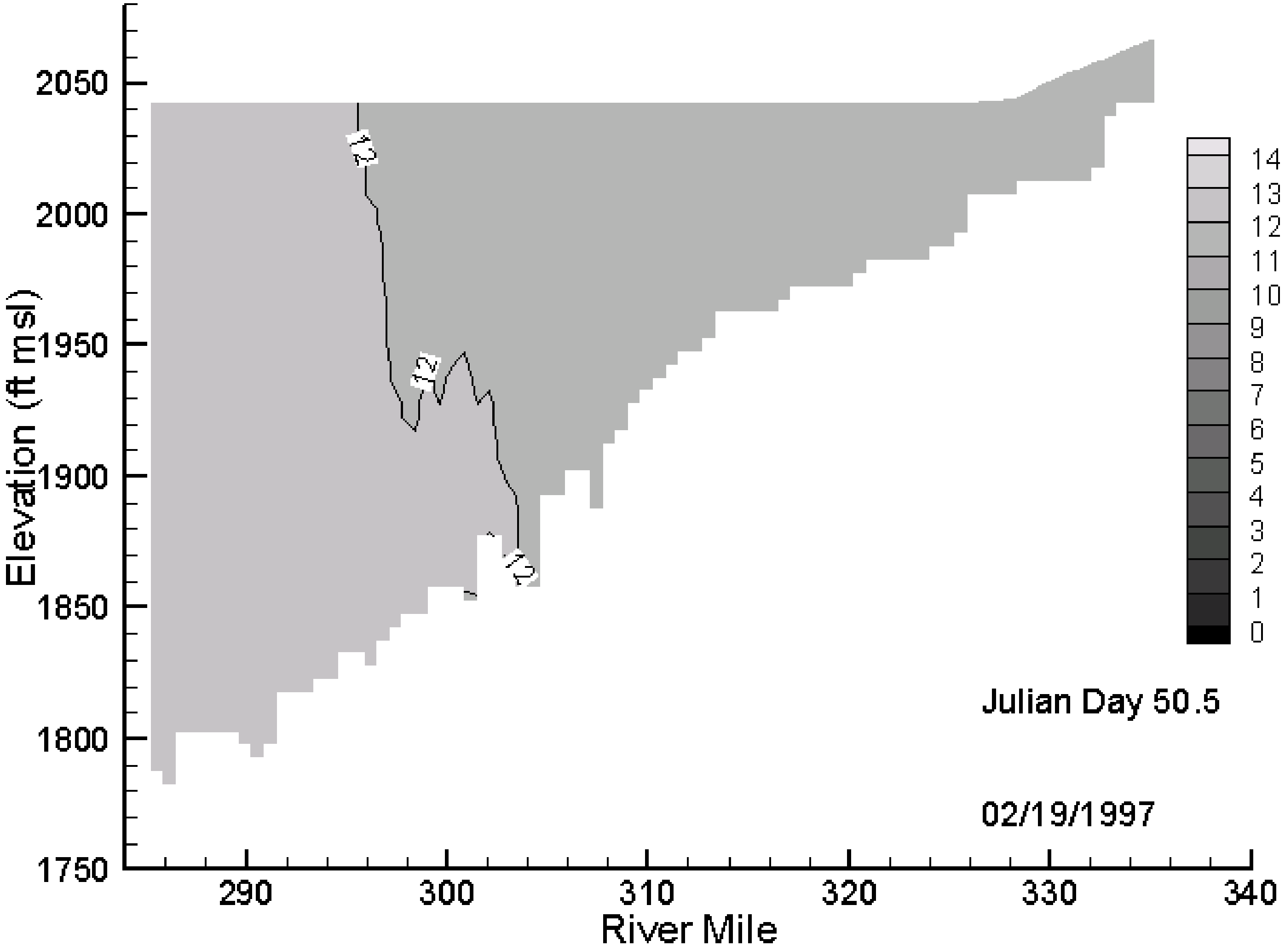


Figure 149. Simulated 1997 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

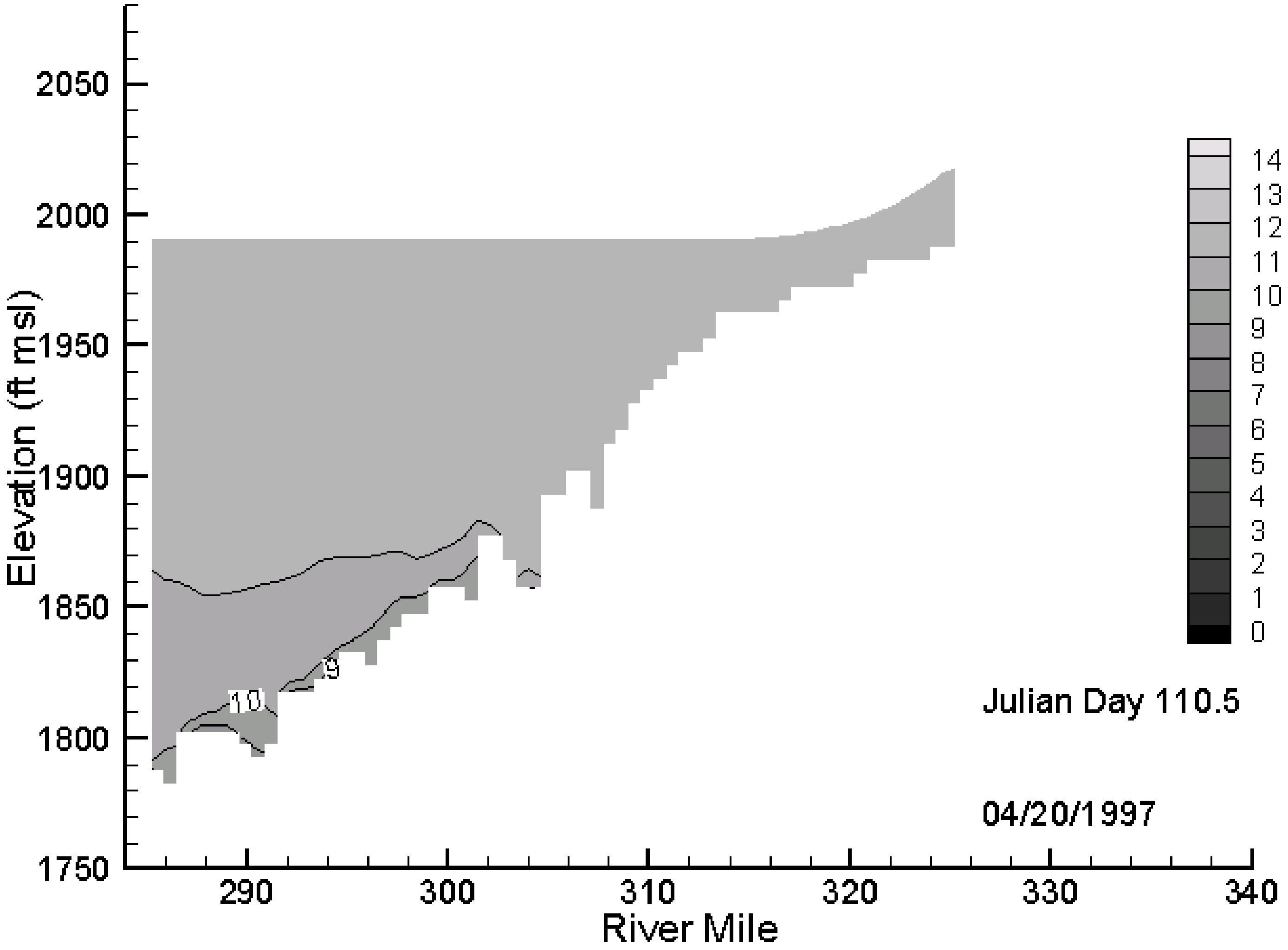


Figure 150. Simulated 1997 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

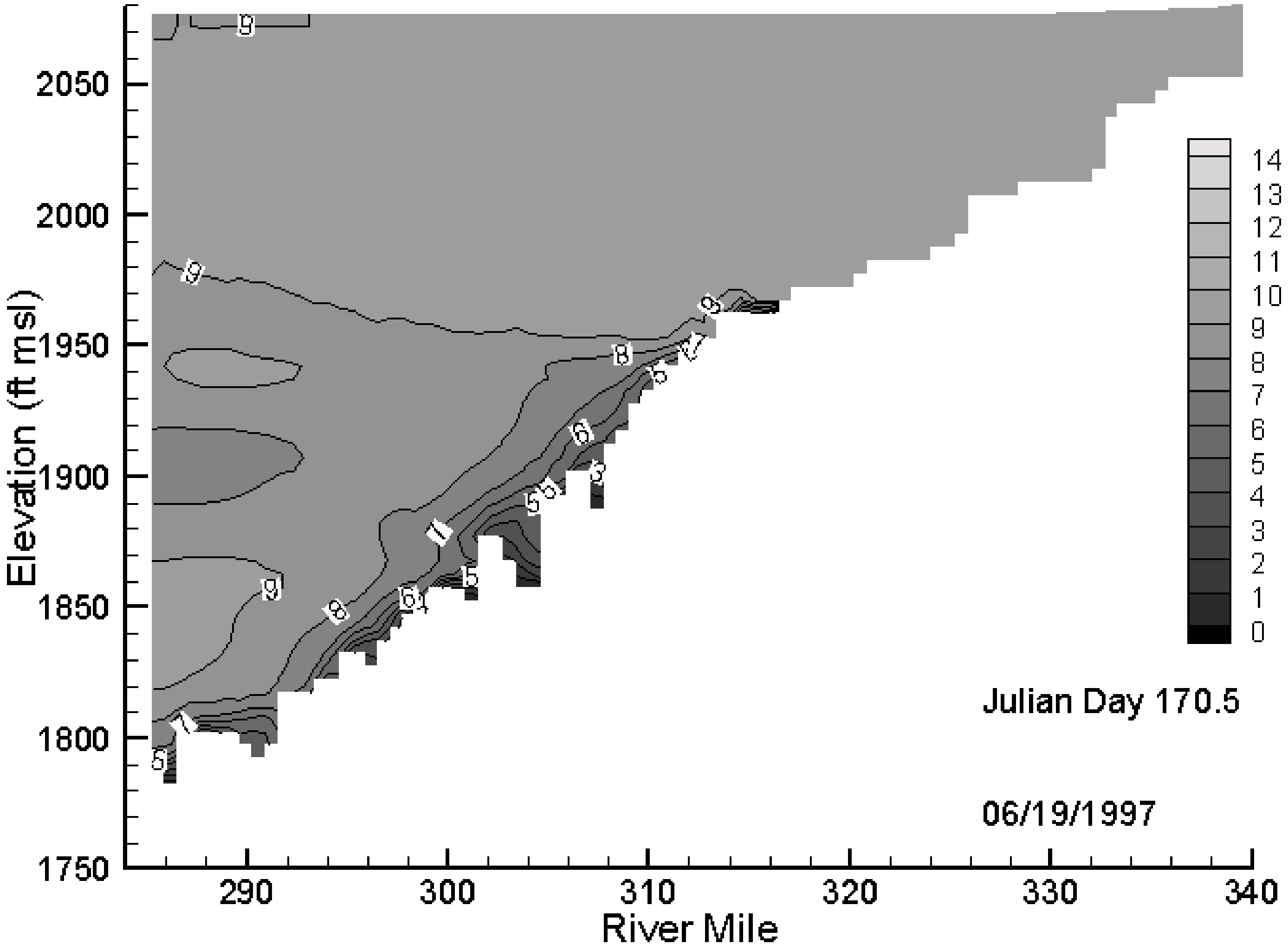


Figure 151. Simulated 1997 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

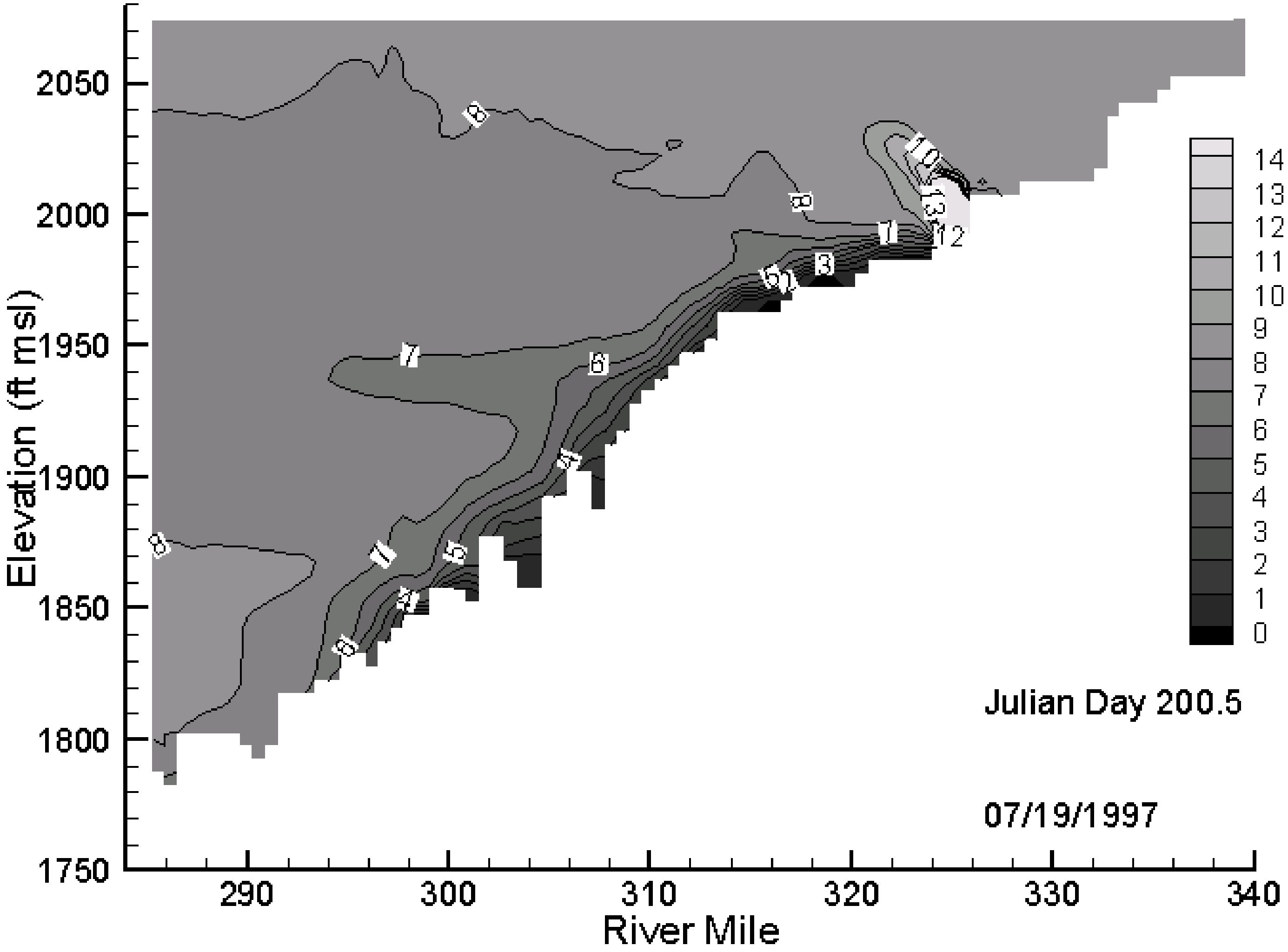


Figure 152. Simulated 1997 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

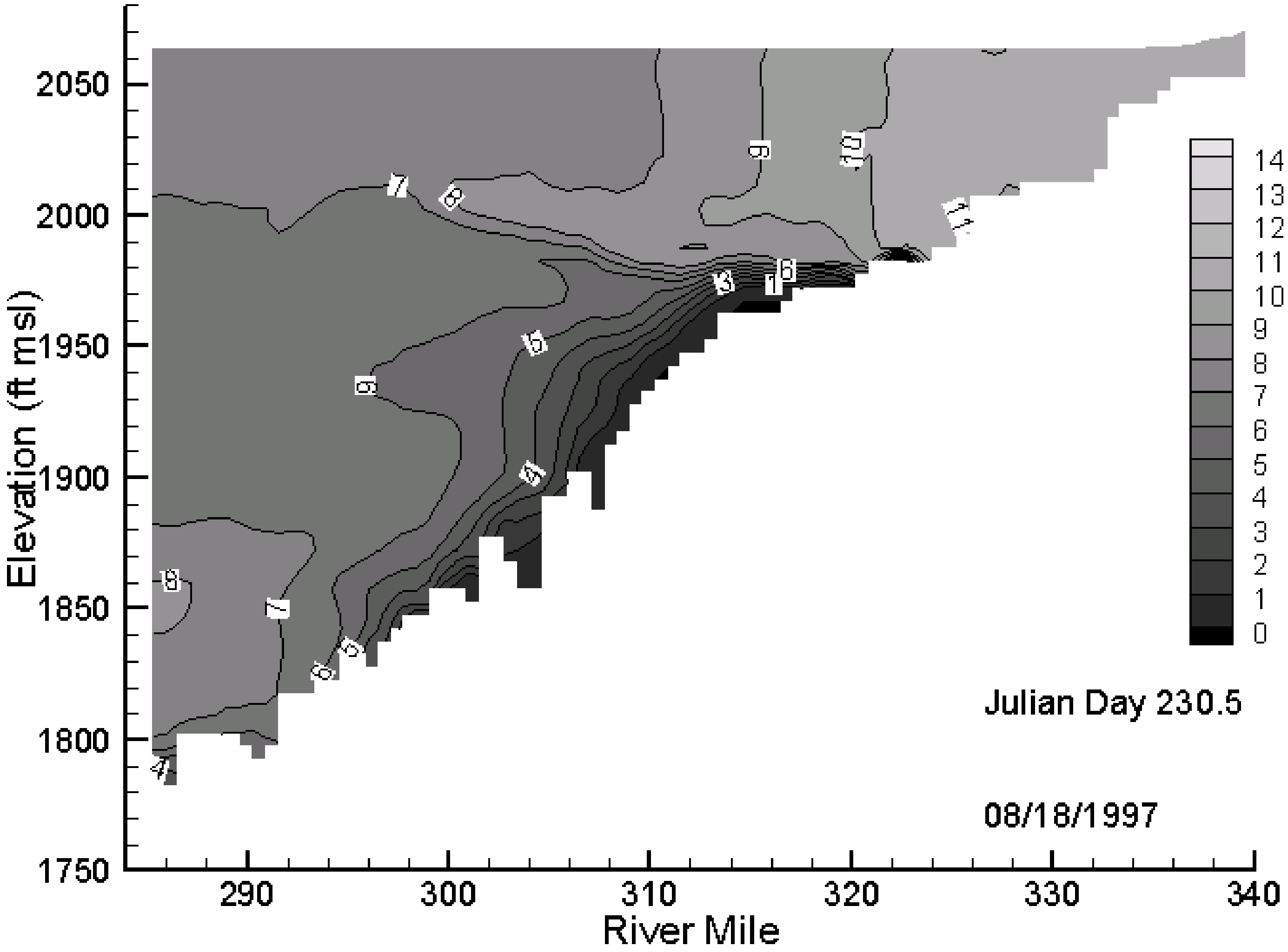


Figure 153. Simulated 1997 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

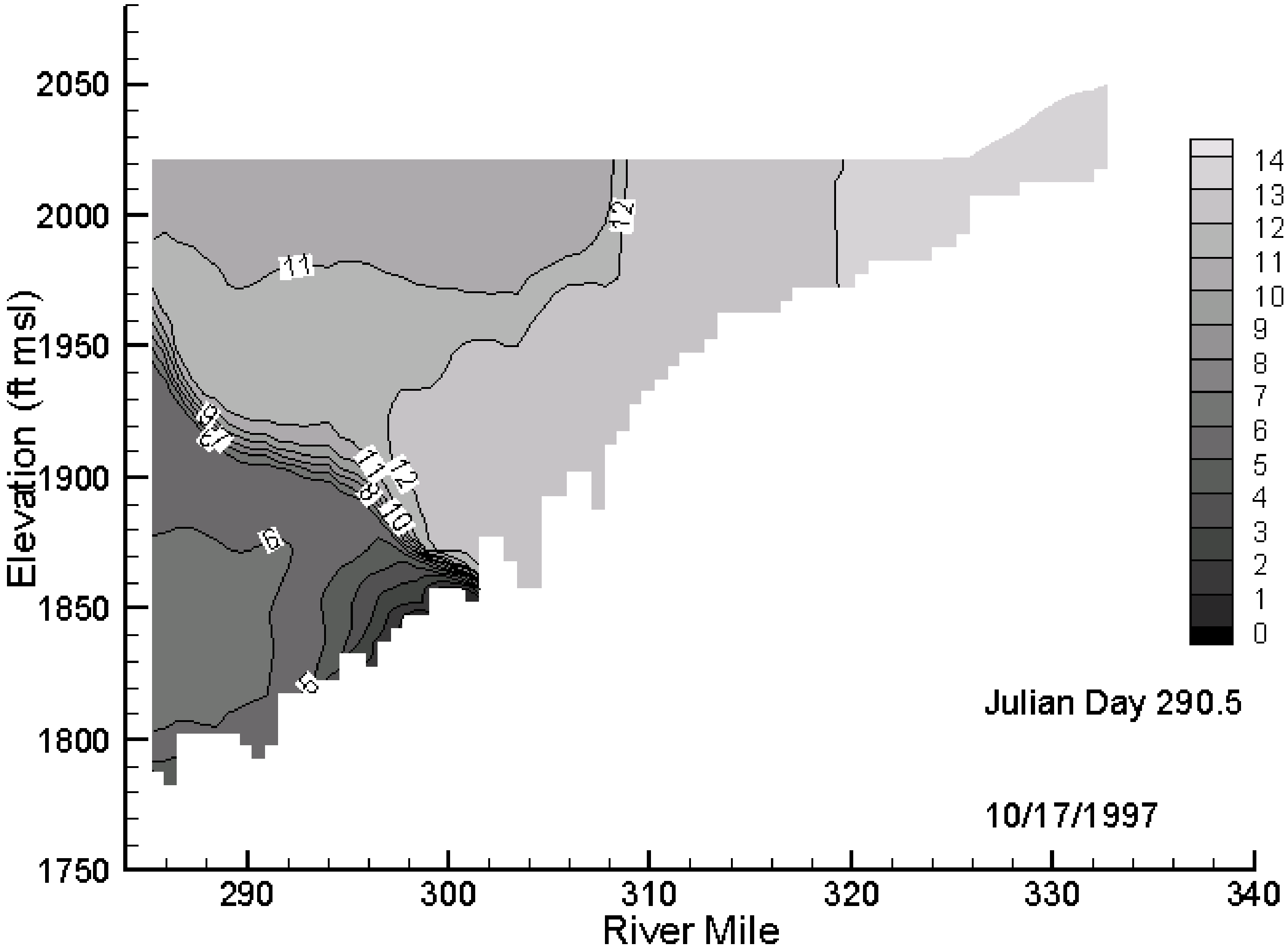


Figure 154. Simulated 1997 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

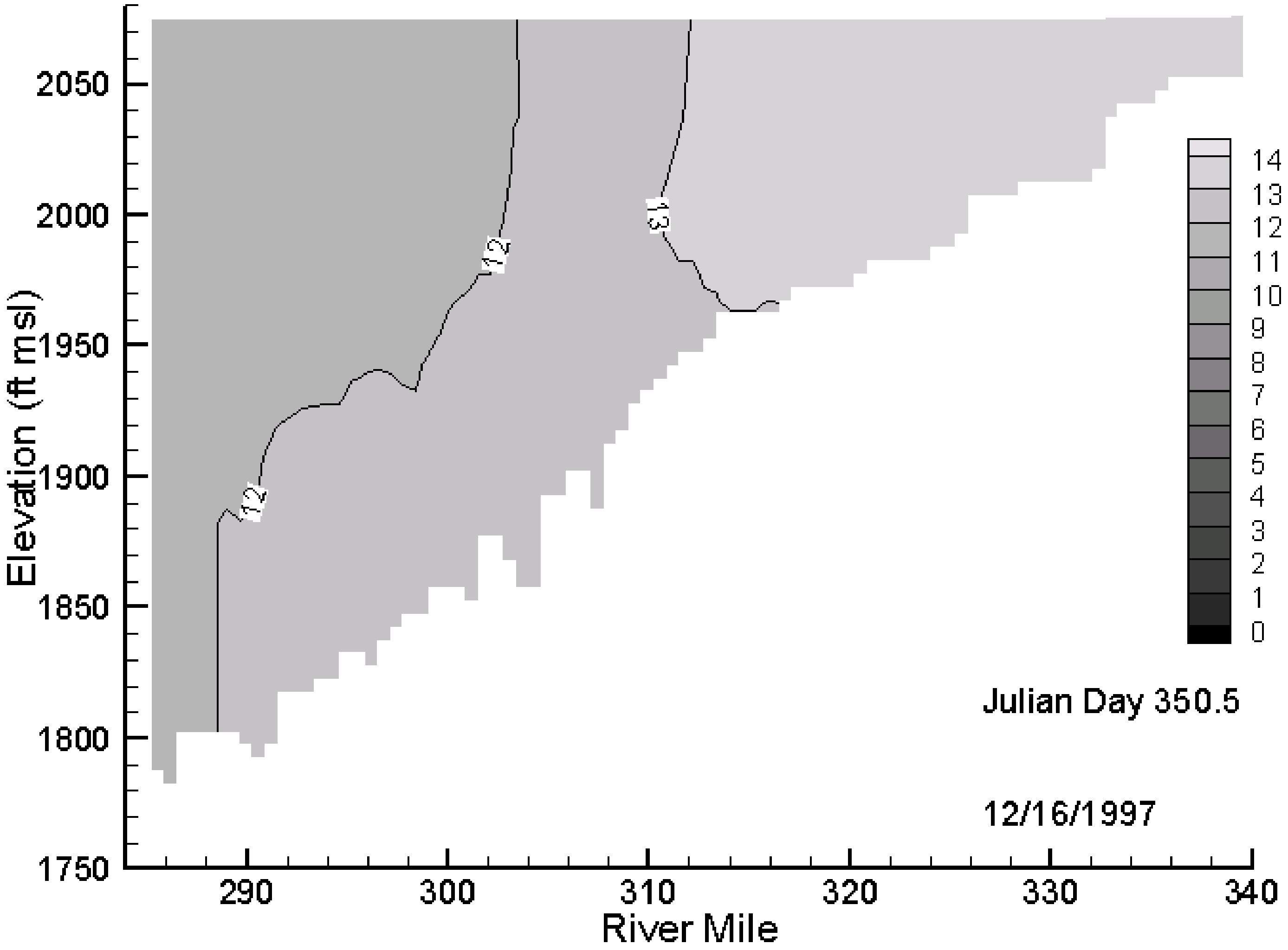


Figure 155. Simulated 1997 DO (mg/L) isopleth for Brownlee Reservoir under proposed operations with 1125-tons/yr aeration at the proposed location and inflow improvements from upstream TMDLs.

Appendix A. Supporting information for turbine aeration assumptions.

1. Introduction

All of the modeling needed for the AIRs assumes a benefit to discharge DO as the result of implementing certain measures. This appendix develops the assumptions used to represent this addition in the modeling. Information from four sources is used in this appendix. Data collected during the 2000 testing by Mobley Engineering (Attachment 1), Mobley Engineering Additional Information Requests, WQ-1, “Dissolved Oxygen Augmentation Using Forced Air” (Attachment 2), results from additional testing in 2004, and unpublished IPC turbine operational data.

2. Turbine Aeration

In August 2000, Mobley Engineering, Inc., in cooperation with Idaho Power Company, conducted tests on Brownlee unit 4 to determine the effectiveness of hub baffles installed on the runner to induce airflow from the vacuum breaker line. Premodification or “baseline” tests on unit 4 were conducted on August 14 and 15. The turbine was dewatered, and baffles were added over each thrust relief openings on the hub. On August 18 and 19, postmodification tests were conducted. The conclusions of this report indicated that the turbine was well suited for inducing airflow and that the baffles increased airflow for wicket gate openings greater than 50%.

During September 2004, Idaho Power’s Power Production Department conducted additional tests on Brownlee unit 4 to determine the effect of baffles on efficiency and airflow at various wicket gate settings. The first set of tests was conducted with baffles installed, and a second test was conducted without the baffles. Testing in 2004 showed negligible differences in efficiency with or without baffles (Figure 1). Addition of the baffles also appeared to have very little effect on airflow (Figure 2). Closer examination of the turbine drawings revealed that vacuum breaker air does not exit where the baffles were installed. Instead, the vacuum breaker air enters the head cover and exits from the runner cone. Therefore, installation of baffles cannot induce additional airflow into the turbine given the configuration of units 1 through 4 at Brownlee.

However, results of the 2000 Mobley Engineering and 2004 IPC testing indicate that, under normal operations (without any modifications), significant amounts of air can be aspirated by units 1 through 4. This aspirated air is mixed with the water and can increase discharge DO. To model Brownlee discharge DO concentrations as accurately as possible, the effects of aspiration should be included in Brownlee discharge DO concentrations. This section reanalyzes the results of the 2000 Mobley Engineering testing, (Attachment 1) and outlines the approach taken to include these effects.

2.1. Summary of 2000 Mobley Engineering's Tests (Attachment 1)

Airflow measurements throughout the testing showed that, when the air valve was open, air was aspirated into the turbine for most wicket gate settings. The authors noted that changes in airflow were largely driven by tailwater elevations, which were not constant during the pre- and postmodification tests. Increased airflow at wicket gate openings above 50%, determined by the authors to be a cause of baffles, was likely a result of changing tailwater elevations.

Tailrace DO with the air valve open, rather than with the air valve closed, during the 15- to 20-min operation tests was used to calculate DO uptake in milligrams per liter. Airflow was related to turbine flow to calculate the percentage of the water volume represented by the induced air (% air by volume). The mass of DO added (DO uptake) is related to the mass of oxygen available in the induced air to calculate oxygenation efficiency.

The report (Attachment 1) indicates that the amount of air introduced is highly dependent on the percentage of wicket gate opening (even when the air valve is forced open) and tailwater elevation. However, once the air is introduced, the oxygenation efficiency is not dependent on wicket gate openings (Figure 21 in Attachment 1) and was relatively low (15–25%). With these efficiencies, the relationship between % air by volume and DO uptake indicated that, for every 1% air by volume, about 0.6 mg/L DO uptake occurs. The relationship between airflow (and therefore % air by volume) and wicket gate opening appears to be reliable and predictable when factoring in tailwater elevation.

2.2. Estimating Effects on DO

Since the baffle modifications have been determined (2004 testing) not to have an effect of air aspiration, data collected in 2000 were revaluated by combining the pre- and postmodification datasets. Wicket gate opening related to % air by volume in the combined dataset for a range of tailwater elevations (Figure 3) mirrors the reported relationship (Figure 15 in Attachment 1) between wicket gate opening and airflow. DO uptake was calculated using the same method previously described and is related to % air by volume (Figure 4).

A large set of IPC unpublished operational data on a 15-min basis from a selected time frame (September 2002–July 2004) is summarized to provide ranges of wicket gate opening and tailwater elevations (Table 1). Units 1 through 4 were operated 80% of the time in a range from 37% to 62% wicket gate opening. Units were operated 50% of the time in a range from 44% to 56% wicket gate opening. Brownlee tailwater elevations during times when the units were operating ranged from 1802 to 1806 feet mean sea level (ft msl). Using the regression equations from Figures 3 and 4, % air by volume and estimated DO uptake were calculated for the wicket gate openings representing 50% and 80% of the summarized operations (Table 2).

For units 1 through 4, Table 2 shows that, for 80% of operations, the potential effect at low tailwater of air aspiration would range from 1.0 to 1.1 mg/L. When operating at higher tailwater elevations, the benefits would be lower at around 0.7 mg/L. Summarized tailwater elevations (Table 1) show that 90% of the time, turbines are operated with a tailwater elevation above 1802 ft msl. This finding corresponds with the medium and high tailwater results of the 2000 testing. Therefore, an estimated benefit of 0.5 mg/L DO increase in the discharge of units 1 through 4 would be a conservative assumption on the effects of turbine aspiration under normal operations (without any modifications).

The combined capacity for units 1 through 4 is approximately two-thirds of the total capacity at Brownlee. Therefore, due to normal air aspiration of units 1 through 4, 0.33 mg/L DO is added to modeled Brownlee discharge DO year round when DO is below saturation and above 6 mg/L. When the addition of this amount would increase DO above saturation, then only the amount needed to reach saturation is added to modeled discharge DO. The resulting discharge DO at Brownlee is then linked to the Oxbow model and run through the rest of the complex.

Table 1. Summarized wicket gate openings and tail water elevations for Brownlee turbines 1−4 from September 2002 to July 2004.

	Unit 1	Unit 2	Unit 3	Unit 4
Wicket gate opening				
10th percentile	38.1%	36.7%	37.2%	38.1%
25th percentile	45.7%	44.0%	45.6%	45.8%
50th percentile	50.9%	50.0%	52.1%	51.6%
75th percentile	56.0%	54.8%	56.2%	56.5%
90th percentile	61.2%	59.2%	62.1%	61.0%
Tail water elevations				
10th percentile	1802.4	1802.5	1802.2	1802.6
25th percentile	1803.0	1803.2	1803.0	1803.3
50th percentile	1804.0	1804.2	1804.1	1804.3
75th percentile	1804.9	1805.1	1804.4	1805.1
90th percentile	1805.9	1806.1	1806.1	1806.1

Table 2. Summarized wicket gate openings and tail water elevations for Brownlee turbines 1-4 from September 2002 to July 2004.

Operations	**Wicket gate openings**	**Low tail water (1800-1801.9 ft msl)**		**Medium tail water (1802-1803.9 ft msl)**		**High tail water (1804-1805.1 ft msl)**	
		Percent air by volume	**DO uptake mg/L**	**Percent air by volume**	**DO uptake mg/L**	**Percent air by volume**	**DO uptake mg/L**
50% of operations	44.0–56.5%	1.4–1.6	1.0–1.1	1.0–1.1	0.7–0.8	0.9–1.0	0.7
80% of operations	36.7–62.1%	1.3–1.6	0.9–1.1	0.8–1.1	0.6–0.8	0.8–1.0	0.6–0.8

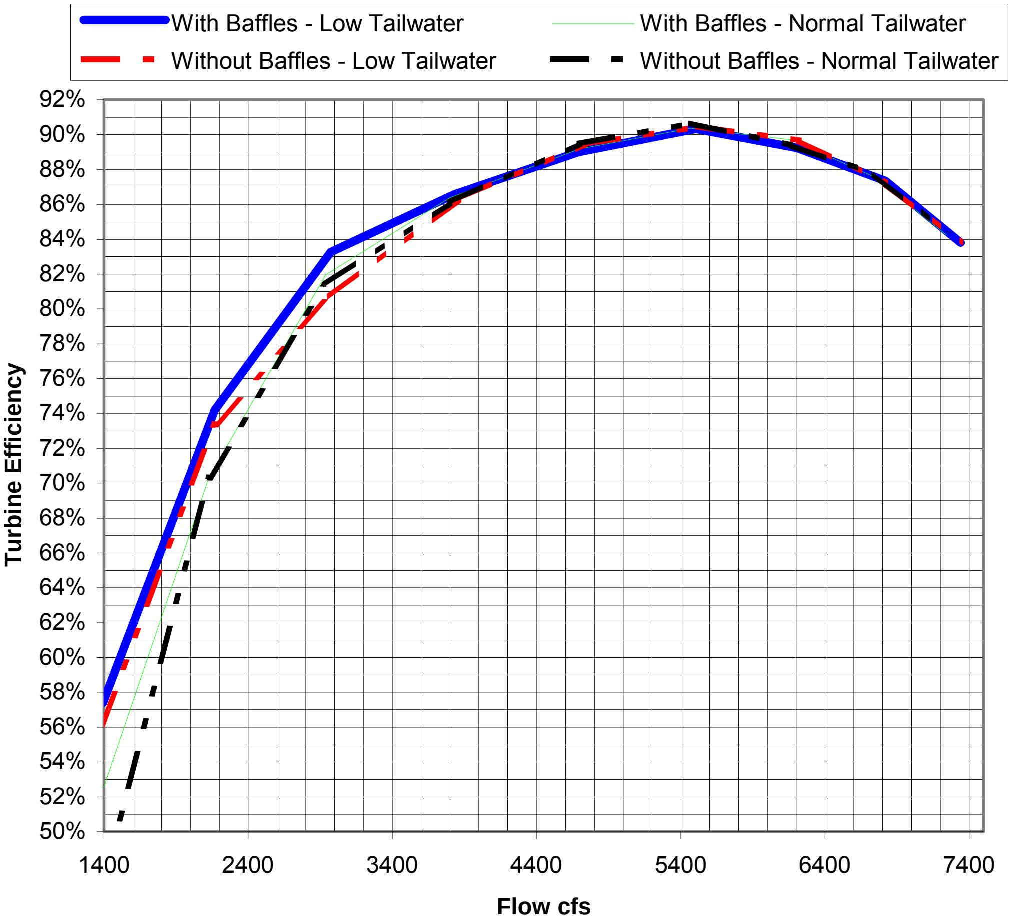


Figure 1. Unit 4 efficiency comparison from testing in 2004 with and without baffles.

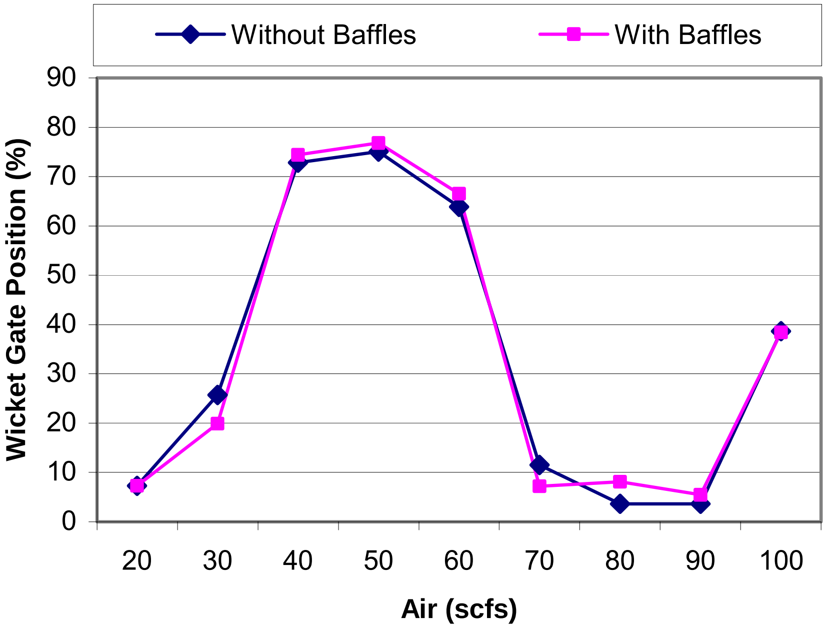
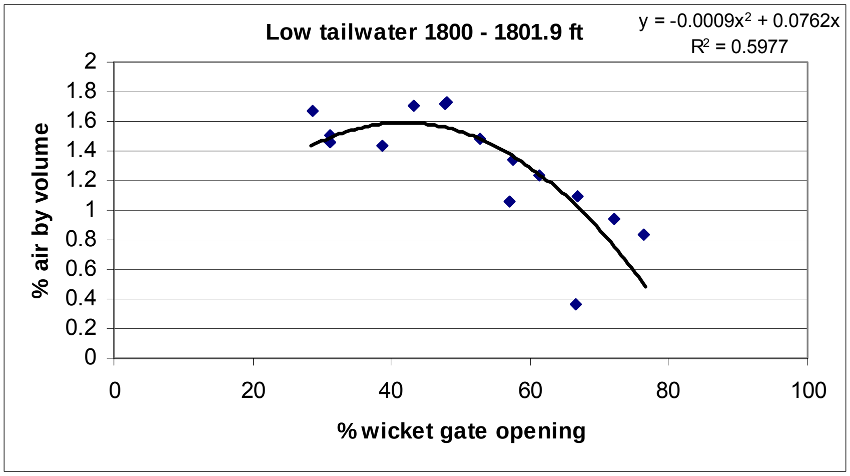
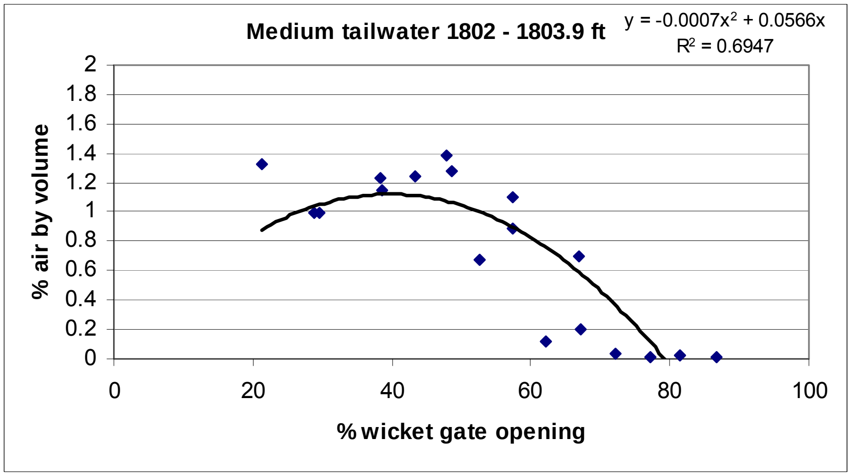


Figure 2. Unit 4 airflow comparison from 2004 testing with and without baffles.





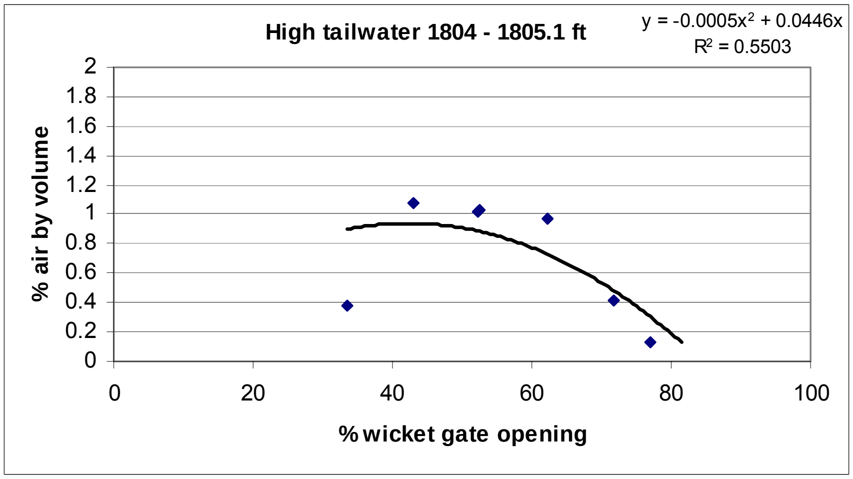


Figure 3. Relationships between % wicket gate opening and % air by volume for combined (pre- and post-modification) 2000 turbine venting tests under three tailwater elevation ranges.

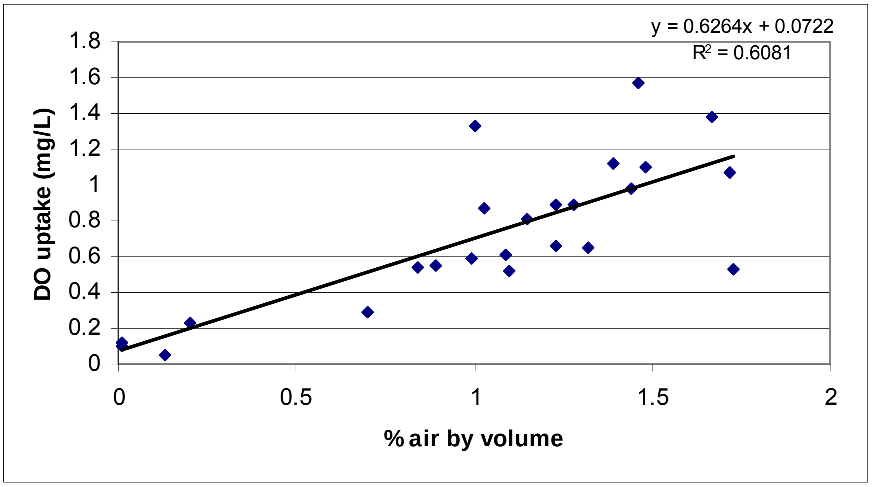
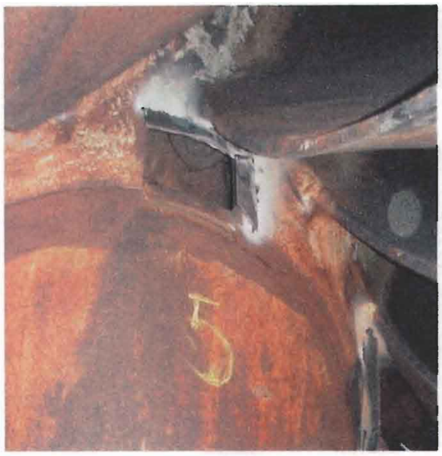
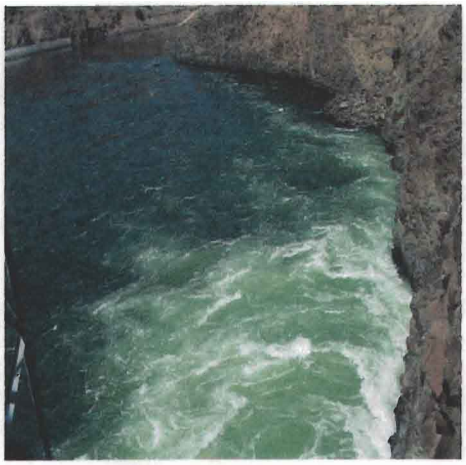


Figure 4. Relationship between % air by volume and DO uptake (mg/L) for combined pre- and post-modification 2000 turbine venting tests.

BROWNLEE TURBINE VENTING TESTS





Prepared by

Mobley Engineering, Inc.
E. Dean Harshbarger

RESERVOIR ENVIRONMENTAL MANAGEMENT, INC.
Richard J. Ruane

PRINCIPIA RESEARCH CORPORATION
Charles W. Almquist

In Cooperation with
Idaho Power Company

December 2000

TABLE OF CONTENTS

LIST OF FIGURES

BROWNLEE TURBINE VENTING TESTS

Introduction

The power generating facility at Brownlee Dam is composed of five hydroturbine-generator units. Units 1-4 are geometrically similar to one another with Francis turbines positioned such that under most discharge conditions, the centerline of the runners is above the elevation of the tailwater. This configuration suggests that turbine venting may be a viable option for increasing the dissolved oxygen (DO) concentration in the turbine discharge. Unit 5 has a runner elevation that is below normal tailwater elevation and it is unlikely that turbine venting for aeration is a workable option.

To evaluate the potential for turbine venting and the effect of adding hub baffles on the amount of air induced into the turbine discharge, tests were conducted on Unit 4 at Brownlee on August 14-19, 2000. Screening tests to measure and compare the amount of air currently induced into Units 1-3 were also conducted. This report describes the tests and presents the results obtained.

Test Description

The tests were conducted jointly by Mobley Engineering, Inc. and Idaho Power employees. Pre-modification or "baseline" tests on Unit 4 were run on August 14 and 15. The turbine was then dewatered and baffles were added over the thrust relief openings on the hub. A sketch of the baffles installed is shown in Figure 1. A photograph of two of the six baffles is shown in Figure 2.

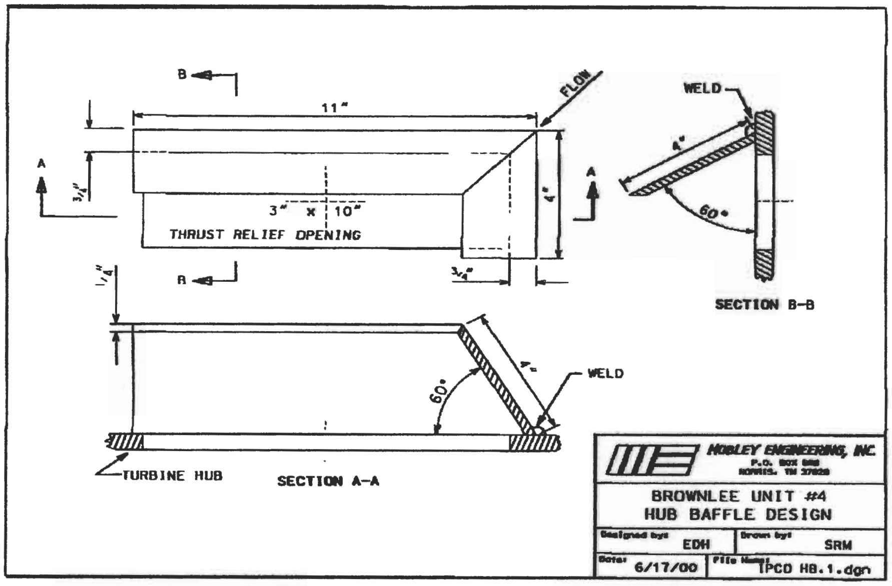


Figure 1; Sketch of Brownlee Unit 4 Hub Baffle

Figure 2: Hub Baffles 3 and 4

On August 18 and 19, post-modification tests were conducted on Unit 4. Screening tests to measure induced air flow on Units 1,2 and 3 were conducted on August 15, 16, and 17 while the baffles were being installed on Unit 4. The purpose of these tests was to assess any differences in air admission capacity, which may exist between the units.

Instrumentation and Procedures

The instrumentation used for these tests was installed and monitored by Idaho Power personnel. Measurements made for the Unit 4 tests are summarized in the following table. Additional information on some of the measurements follows the table. In addition, a DO and temperature profile were taken at the upstream end of the intake channel prior to the start of the tests on August 14.

With the exception of the DO and temperature readings, all of the information was accumulated on a data collection computer located in the control room. The data acquisition system was a National Instruments, SCXI-based system, controlled using NI's Labview data acquisition and control software. The output of the Validyne pressure transducer used on the bell mouth intake was ±10V. The output of the Keller absolute pressure cell on the draft tube was 4-20 mA converted to 1 – 5V by a 250 ohm dropping resistor. Generator power, amps, and MW were output by the Yokogawa power meter as a direct reading via a serial link. All other instruments operated on 4-20 mA current loops, which were converted to 0 – 10V signals by optical isolation and signal conditioning modules. Further information on the scaling factors, calibration constants, and calculation parameters used for these tests is found in the appendices.

The DO and temperature readings were recorded in separate files, integral to the probes used to collect the data.

Brownlee Unit 4 Turbine Venting Test Measurements

Parameter	Measurement Method	Instrument
Headwater	Submersible pressure cell	Keller GP cell
Tailwater	Submersible pressure cell	Keller GP cell
Turbine flow 1	Winter-Kennedy flowmeter	Rosemount ΔP cell
Turbine flow 2	Acoustic flowmeter	Accusonic Time-flight
Wicket gate position	Piston stroke	LVDT
Power output	Digital meter	Yokogawa 3351
Generator Amps	Digital meter	Yokogawa 3351
Generator MVARs	Digital meter	Yokogawa 3351
Turbine inlet pressure	Net head ring	Keller AP cell
Draft tube pressure	Pressure tap at mandoor	Keller AP cell
Headcover pressure	Pressure tap at mandoor	Keller AP cell
Air flow	Bellmouth Inlet	Validyne ΔP Cell
Shaft orbits	Prox probes	Bently-Nevada System
DO/temp in tailrace	DO Probe	Hydrolab Datasonde
DO/temp in draft tube	DO Probe	Hydrolab Datasonde
DO/temp in scroll case	DO Probe	Hydrolab Datasonde

Measurements made during the screening tests on Units 1, 2, and 3 included headwater and tailwater elevations, turbine discharge, wicket gate position, and air flow. Air flow was measured from the data acquisition system.

During the pre-modification tests, turbine discharge was determined from the Winter-Kennedy flowmeter. During the post-modifications tests, readings from a newly installed acoustic flowmeter were used. During the post-modification test, the Winter-Kennedy flowmeter was not functioning properly, and the ASL flowmeter occasionally gave erratic results. Thus, it is difficult to determine the effect of the hub baffles themselves on turbine efficiency. However, the effect of air admission on turbine efficiency can be deduced.

Headcover pressure was obtained using a pressure cell attached to a tap in the headcover. This pressure cell was not installed on Unit 4 until after the pre-modification tests were completed.

Air flow was determined by measuring the pressure differential across a bellmouth entrance device attached to the intake of the vacuum breaker pipe located on an outside wall near the generator. A photograph of the bellmouth is shown in Figure 3.

DO, TDG (total dissolved gas), and temperature measurements were made using Hydrolab® multiprobe water quality monitors. In the tailrace, several probes were used to obtain representative data as the turbine discharges changed. One probe was located on the left bank, looking downstream, about 2,000 feet downstream from the taildeck. A second probe was located near the right bank about 400 feet downstream from the taildeck. The location of this probe is indicated in the photograph in Figure 4. A third probe was operated from a boat, which for each test run, was maneuvered into an area which appeared to be representative of the discharge from Unit 4. A photograph of the boat in position for data collection for one of the test runs is shown in Figure 5. A review of the collected data and observations made of flow patterns in the tailrace indicated that the measurements made from the boat were the most reliable and it is these measurements which were used to calculate DO uptake and oxygenation efficiency.

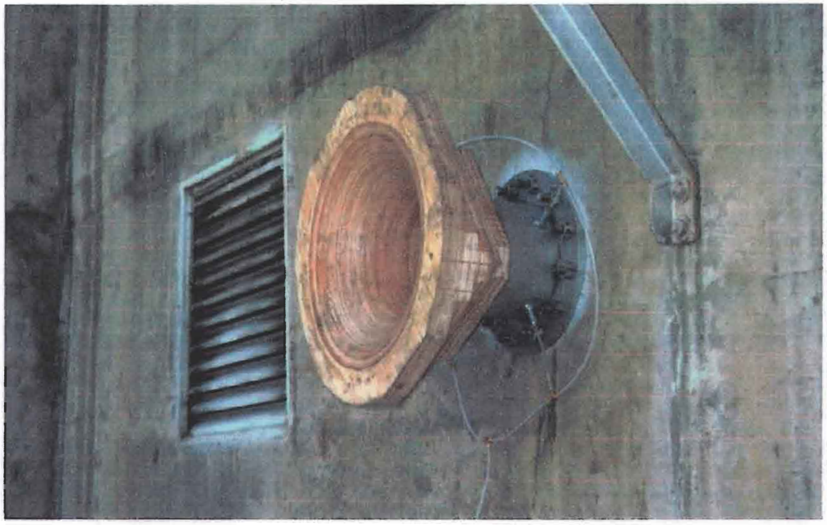


Figure 3: Bellmouth Installed on Unit 4

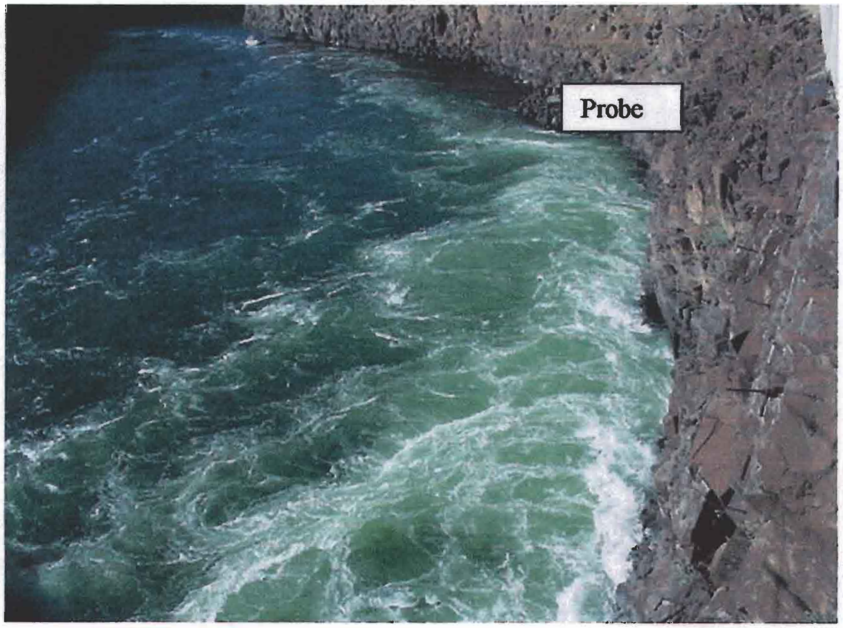


Figure 4: Probe Location in Unit 4 Tailrace

During the pre-modification tests, DO in the scrollcase was monitored using a probe in a sample line connected to a tap in the scrollcase access door. A photograph of this probe is shown in Figure 6. During the post-modification tests, a second probe was used to monitor a sample obtained from one of the Winter-Kennedy taps at the downstream end of the penstock.

Figure 5: DO and Temperature Monitoring Boat

Figure 6: Scrollcase DO Probe

The instrumentation was installed and checked before testing was initiated. Calibrations, especially on the DO probes and the bellmouth differential pressure cell, were done before each set of tests and when conditions prompted recalibration.

The test procedure was to establish a desired wicket gate position and wait for conditions to stabilize before recording data. The variable which usually determined test condition stability was tailrace DO as measured from the boat. Each test run usually took about 10 to 15 minutes for conditions to stabilize and data to be recorded.

Results

Summary tables of the data that was collected are provided in the Appendices. The values shown in the tables are the averages of the recorded data for the test runs. A review of the DO and water temperature data indicated that the data collected from the boat in the tailrace was the most reliable; therefore, these data were used to calculate oxygenation efficiencies and DO uptake.

Forebay Profiles

Graphic representations of the temperature, DO, TDG, and TDN (total dissolved nitrogen) profiles are presented in Figures 7, 8, 9, and 10 respectively. The data in Figure 7 indicate that the temperature at the turbine intake level ranged from about 13 to 20 degrees Centigrade. The data in Figure 8 indicates that the DO at the turbine intake level was on the order of 0.2 mg/L. The data in Figures 9 and 10 indicate that TDG and TDN were higher at lower depths and were about 102 and 128 percent, respectively, at the level of the turbine intakes. No further traverses were taken, so it is unknown if this profile changed significantly during the tests.

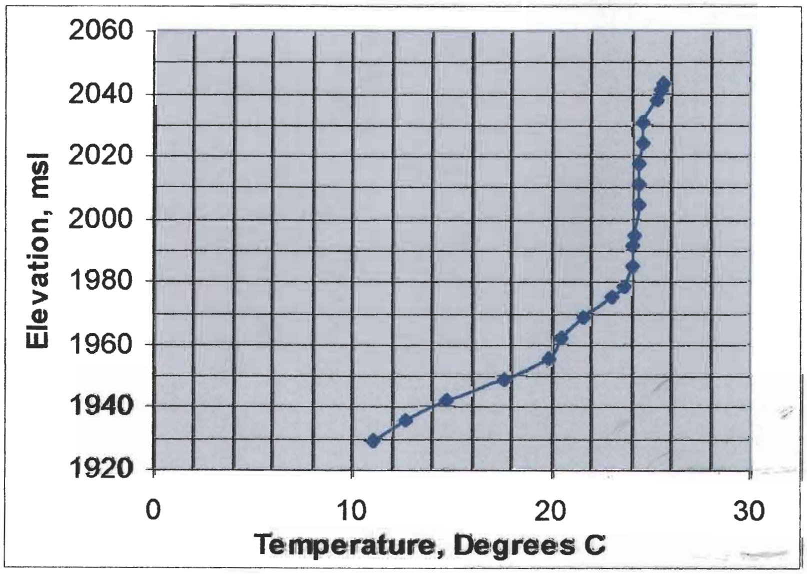


Figure 7: Forebay Temperature Profile, August 14, 2000

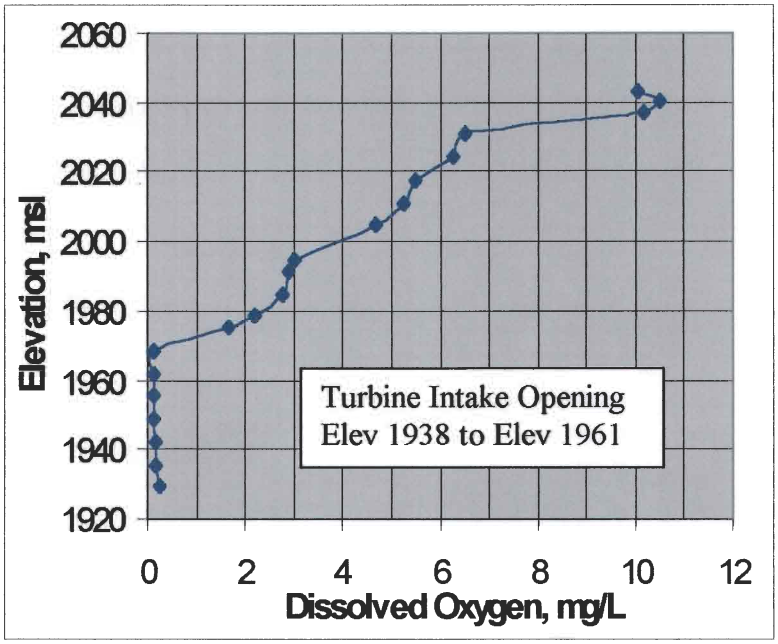


Figure 8: Forebay DO Profile, August 14, 2000

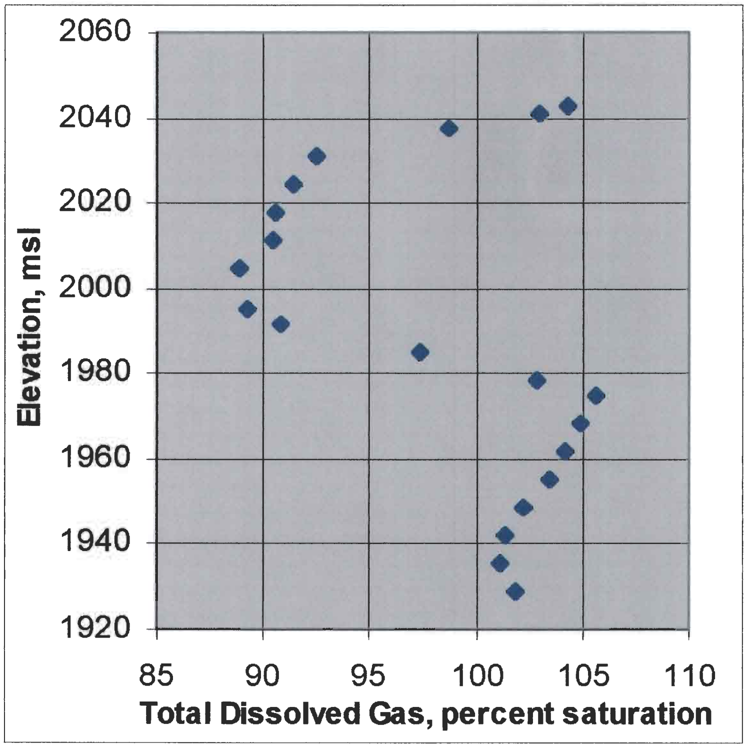


Figure 9: Forebay Total Dissolved Gas Profile

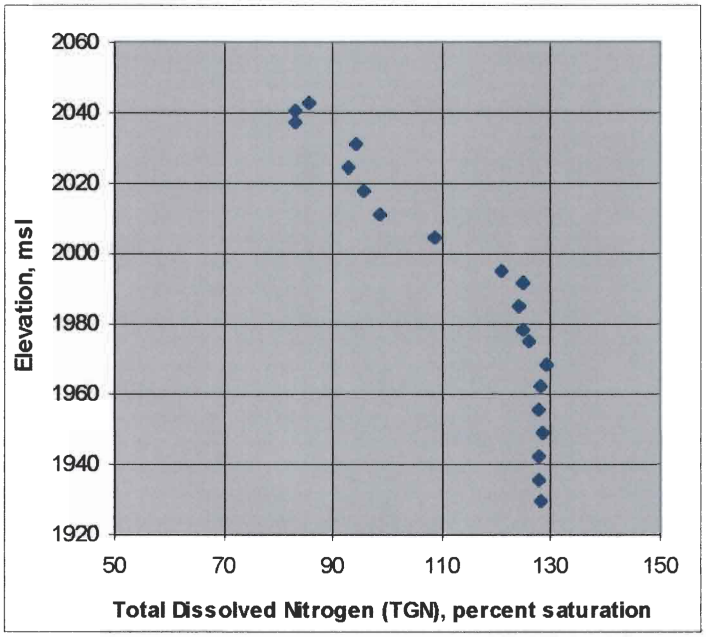


Figure 10: Forebay Total Dissolved Nitrogen Profile

Evaluation of Unit 4 Water Quality Monitoring Locations

DO data are needed to provide the baseline DO conditions from which DO increases can be determined to evaluate the effectiveness of aeration using the current vacuum breaker system and the system after hub baffles were added. To determine baseline DO conditions without any air induction to the turbines, three locations were evaluated: at a tap in the scrollcase door, at a monitor placed on the stream bank about 500 feet downstream, and from a boat that moved around in the tailwater to measure the most representative mass of water in the turbine discharges. Figure 11 shows the results of measuring DO at the tailrace locations when air was not being introduced, as well as at the scrollcase door with and without air being induced.

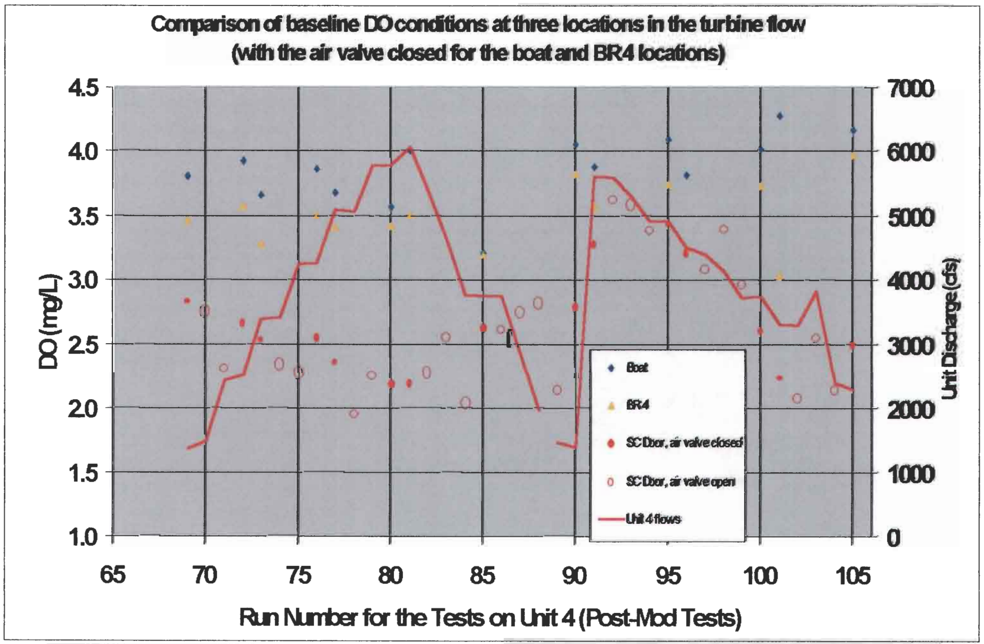


Figure 11: DO at Three Locations in the Discharge of Unit 4

There are significant and systematic differences in the results, and the data from the boat are considered to be the most accurate. The scrollcase data are problematic since there was widespread difference in DO patterns and concentrations for similar flow conditions in Unit 4. The boat data were more representative of the total discharge because much of the data were collected in the main part of the flow from Unit 4, as well as downstream from the location of the stream bank monitor, BR4, to allow for more mixing and aeration due to longer contact time for air bubbles in the water. The stream bank monitor would probably be more representative if it were moved further downstream from its current location. Figure 12 shows that temperature at the scrollcase location was sometimes significantly lower and systematically different than the measurements collected from the boat or at BR4. The results from the boat are the most representative because water measured by the monitor in the boat is mixed more than water in the scrollcase, i.e., water in the penstock and scrollcase is not as mixed as the water after it travels through the turbine wheel, draft tube, and tailrace where high turbulent swirling action occurs.

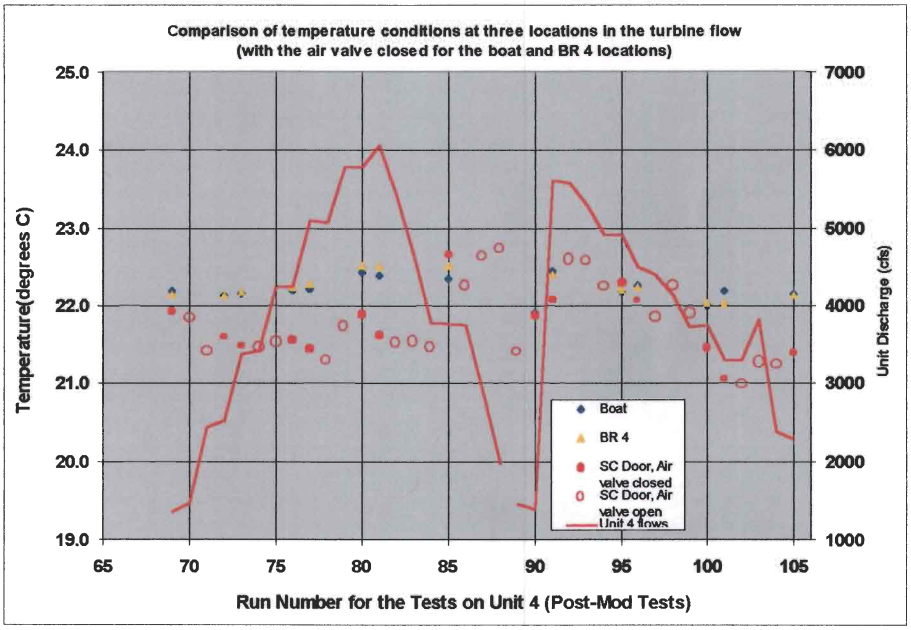


Figure 12: Temperature at Three Locations in Unit 4 Discharge

Effects of the Reservoir Withdrawal Zone

As discussed in the two reports on water quality in the releases from Brownlee (Ruane, 1999, and Ruane et al., 2000), the vertical withdrawal zone for water drawn from Brownlee Reservoir is complex compared to other hydropower reservoirs. Based on data collected during the field tests, Unit 5 discharges had the warmest temperatures and, generally, the highest DO when it was generating along with at least one other unit. The temperature of the water released from the other units varied within a more narrow range, but the pattern of variation of temperature between Units 1-4 was inconclusive and requires further analyses that take into account the variation in flows between all the units on a small time step (e.g., one- to five-minute operational data for all the units.)

Figures 13 and 14 show that DO and temperature was higher in the discharges from Unit5 than in Unit 4 for the first 22 test runs when Unit 5 was operating. Whenever Unit 5 operated during the tests, the turbine discharges were always warmer than the discharge from Unit 4; but the difference in DO was not usually as much during the remainder of the test runs.

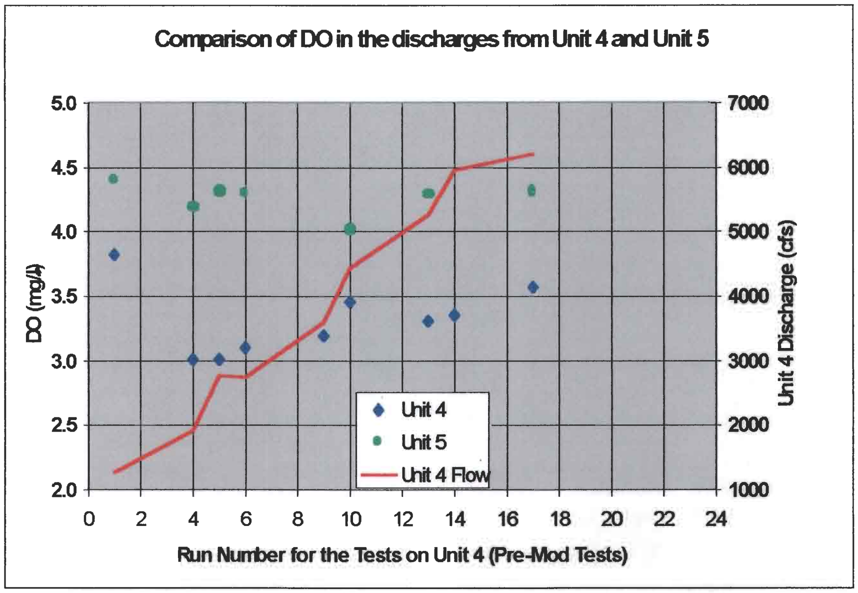


Figure 13: Comparison of DO in the Discharges of Units 4 & 5

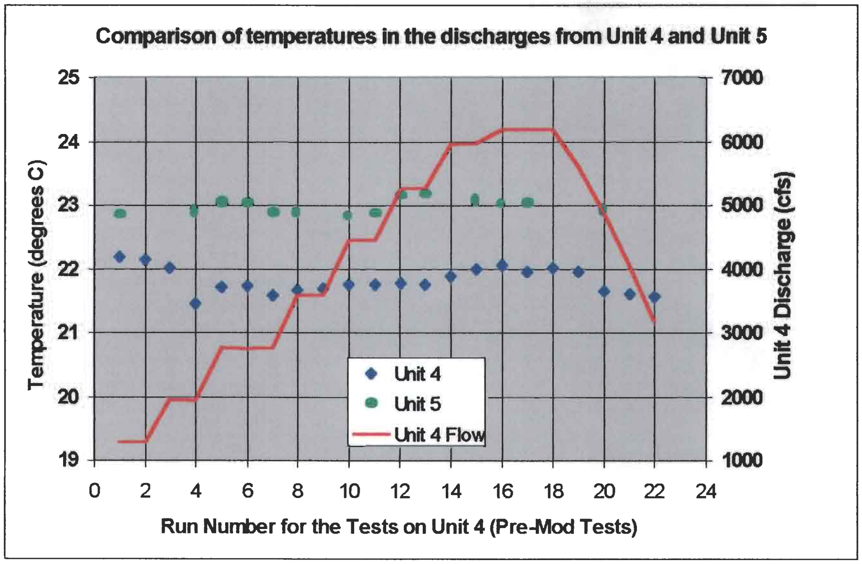


Figure 14: Comparison of Temperatures in the Discharges of Units 4 & 5

Another indication of the variability of the withdrawal is the variability of DO and temperature at the scrollcase door location, as shown in Figures 11and 12. For the same flow patterns in Unit 4, on two different days, the temperatures (and therefore the withdrawal zone for water drawn from the reservoir) were significantly different.

Due to this complex variation in the withdrawal zone that is mainly affected hour-to-hour by the operational patterns for the project, as well as day-to-day by the characteristics of the density stratification in the lake, DO uptake can only be measured using data collected with and without air induction for set operating conditions over a fairly short period of time (e.g., over a period of about 15-20 minutes, as was done in this field study). However, there were a few runs during these field tests where operating changes in the other units during testing on Unit 4 affected the baseline temperature and, therefore, probably the DO during set gate openings thereby affecting the DO uptake calculations. It can be concluded that the withdrawal zone is complex and highly variable as indicated by temperature changes in the releases over the course of the field tests.

Induced Air Flow

Induced air flows before and after modifications to the turbine (i.e., the addition of the hub baffles) are shown in Figure 15 as a function of wicket gate opening.

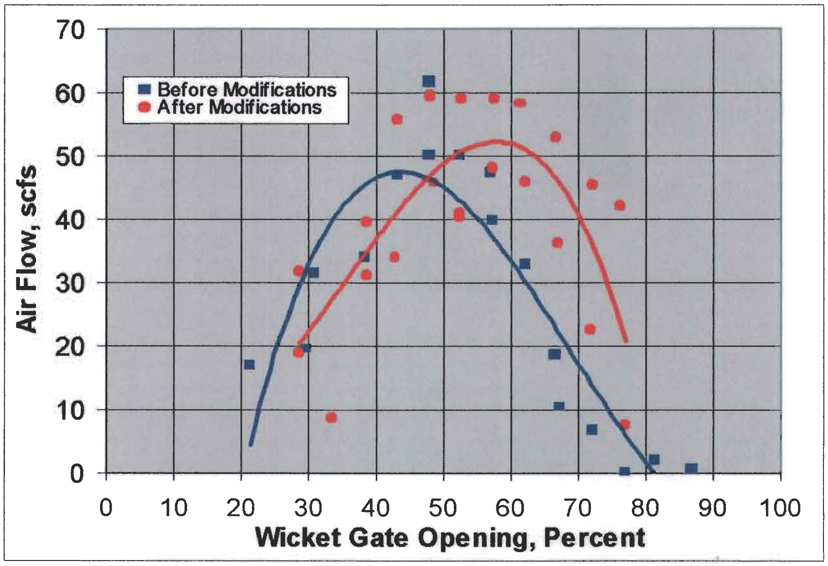


Figure 15: Unit 4 Induced Air Flow

These data indicate that the addition of baffles decreased air flow for wicket gate openings below about 45 percent, and increased air flow for gate openings above 45 percent. However, the variations in tailwater elevations during the tests make it difficult to separate the effect of the baffles from the effect of tailwater elevation.

Figure 16 compares air flow as a function of wicket gate opening for tests conducted with a low (1800-1801.6) tailwater elevation range and for a high (1803-1805) tailwater elevation range. The post-mod data indicate that increasing the tailwater some 3 to 4 feet decreased air flow by about 15 scfs for gate openings of about 65 percent or lower and decreased it even more for wicket gate openings greater than 65 percent. The pre-mod data is not conclusive because the tailwater elevation varied significantly from test to test and very little data were collected at low tailwater elevations. Comparing pre-mod and post-mod data to discern the effect of the modifications is difficult because very few tests were run with the same gate opening andsame tailwater elevation. The data do indicate however, that for both tailwater ranges compared, the baffles increased air flow significantly for gate openings greater than about 50 percent.

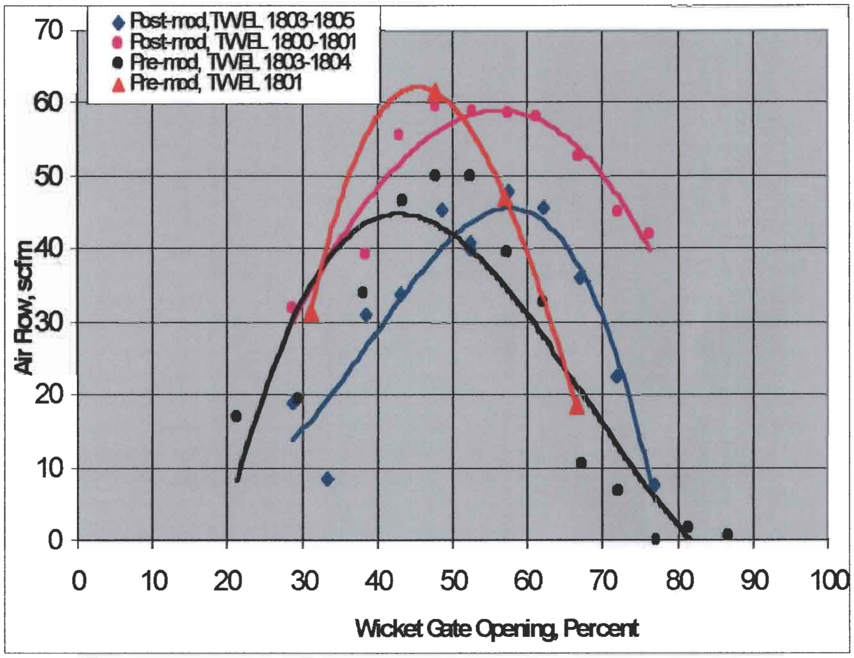


Figure 16: Effect of Tailwater Elevation on Air Flow

The air flows measured during the screening tests on Units 1, 2, and 3 are shown in Figure 17 as a function of wicket gate opening. Data from the pre-modification tests on Unit 4 are shown for comparison. These data indicate that air flow was approximately the same for all four units, and that the shape of the curves with respect to wicket gate openings was very similar. This suggests that any modifications made would likely perform similarly on each unit. Some of the scatter in the data is due to differences in tailwater elevations.

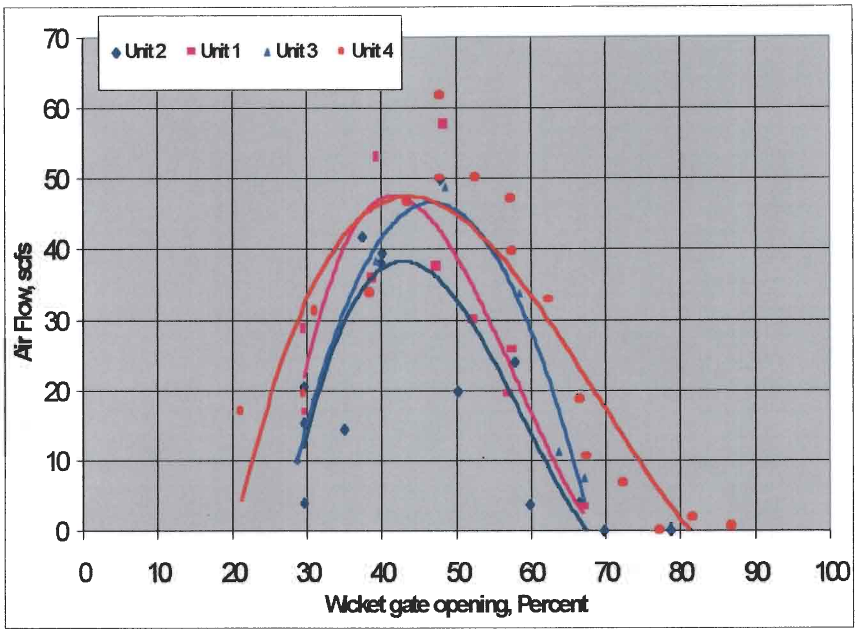


Figure 17: Brownlee Units 1, 2, 3, & 4 Air flow

DO in the Releases During Field Tests

The field data collected during runs when the air valve was closed to provide baseline DO and temperature conditions are presented in Figures 18 and 19. The baseline DO and temperature conditions changed day to day, primarily due to different operating conditions for the other units while the tests were conducted on Unit 4. The scatter in the DO data around the trend lines was due primarily to changing operations of the other units during the tests. The scatter in the DO data was much less on the day of post-mod testing when the tailwater was low, and during these tests only Unit 1 was operated along with Unit 4 until the last two runs. It should be noted that the effect of variable baseline conditions can be minimized by determining the DO uptake for individual test runs by using data collected with and without air induction for set operating conditions over a fairly short period of time (e.g., about 15-20 minutes).

The baseline DO levels were about 2 to 3 mg/L higher than the lowest DO values observed in data from previous years (Myers, 1997, and Ruane et al., 2000). The DO uptake values for this study will be somewhat lower than if the baseline DO conditions had been lower (i.e., DO uptake values would be higher if the baseline DO conditions were at the lower levels observed in the past). The effect of these higher baseline DO conditions on DO uptake can be determined using a first-order draft tube DO uptake model that accounts for variable baseline DO conditions. However, the baseline DO conditions during the study were close to what might occur if an aeration system in the reservoir was used to add DO.

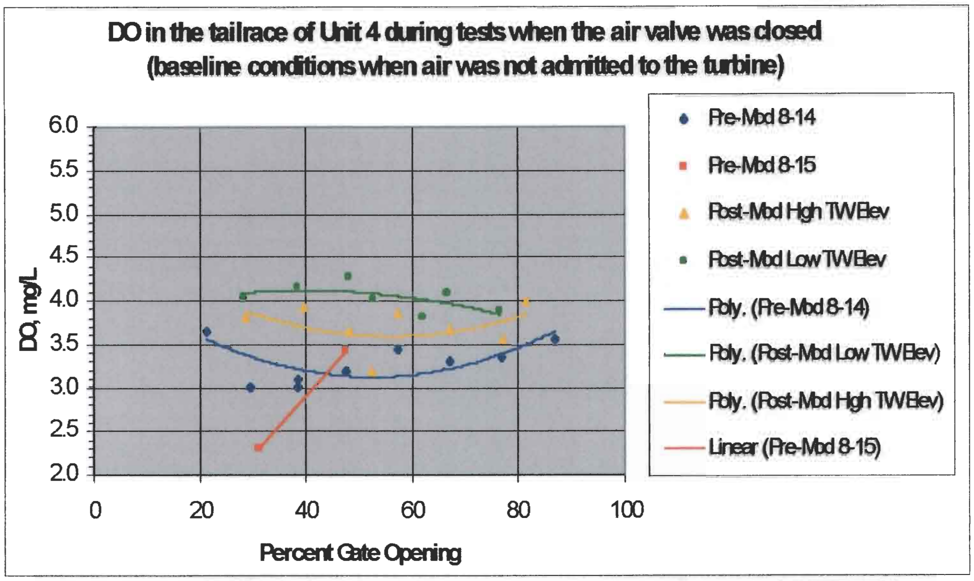


Figure 18: DO in Unit 4 Discharge Without Air Induction

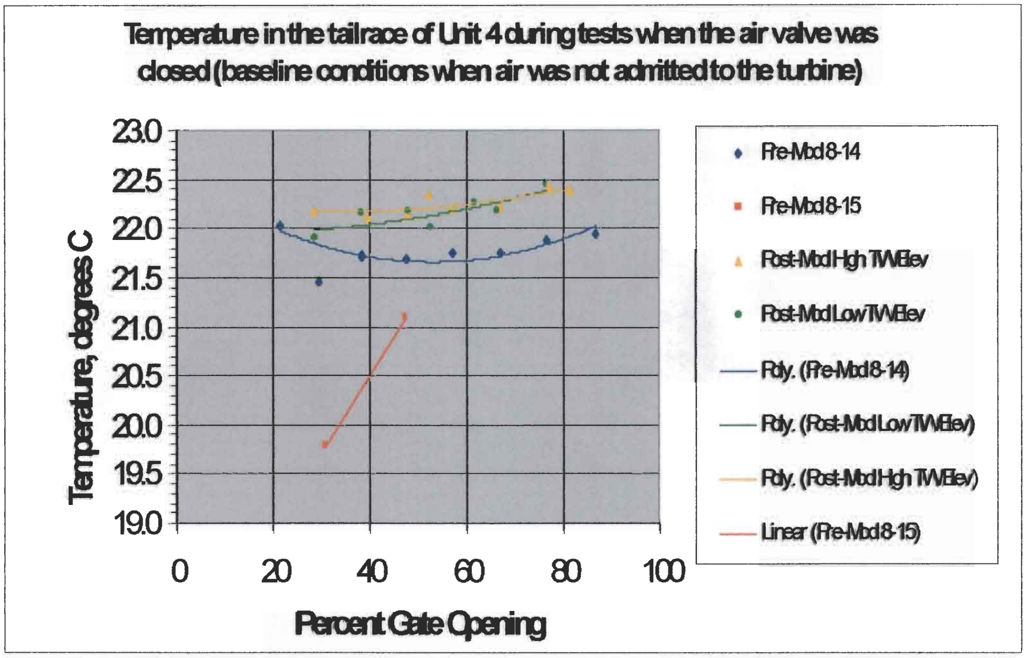


Figure 19: Temperature in Unit 4 Discharge Without Air Induction

There was a general correlation between temperature and DO where lower temperatures corresponded with lower DO values; but, this relationship was not apparent for the two days of testing after the hub baffles were added to Unit 4.

The DO levels when the air valves were opened are presented in Figure 20. The highest DO levels occurred at lower gate openings and when the tailwater was low.

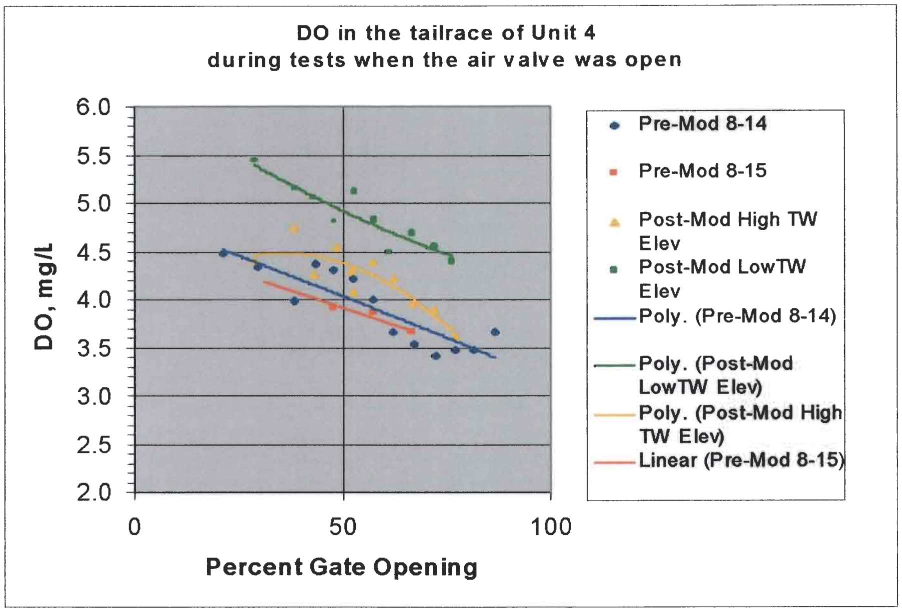


Figure 20: DO in Unit 4 Discharge With Air Induction

Oxygenation Efficiency

Oxygenation efficiency, E_0 is defined as the mass of oxygen available in the induced air divided by the mass of oxygen dissolved in the turbine discharges. To obtain the amount of oxygen dissolved, the DO measured with and without air flow and the water flowrate determined from the Winter-Kennedy tap measurements was used. Oxygenation efficiency as a function of wicket gate opening is shown in Figure 21. These data indicate the efficiency was roughly 25 percent over the range of wicket gate openings tested, and decreased slightly as wicket gate opening increased. Data for the three highest efficiencies measured were taken during tests when Unit 2 operation was initiated during mid-test. This may have affected the tailrace DO and thus the efficiencies calculated. It should be noted that E_0 would be higher if baseline DO levels were lower, as discussed previously.

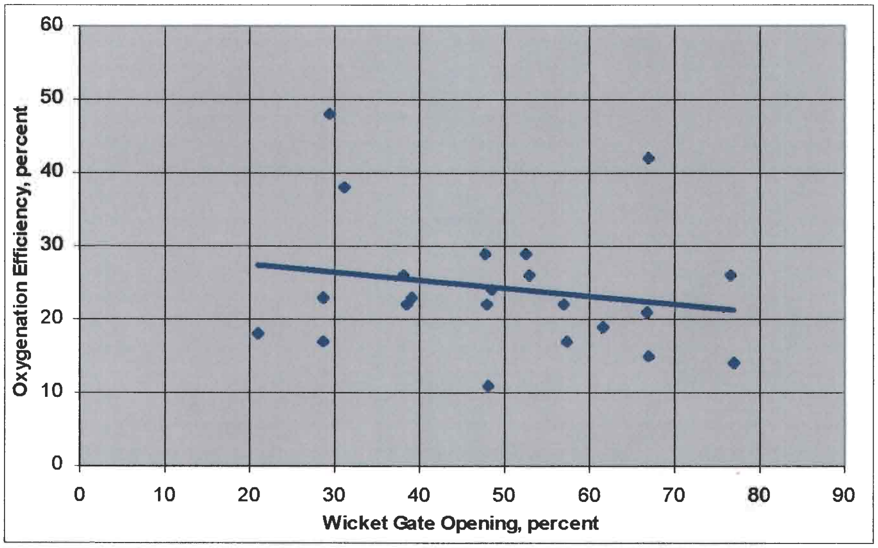


Figure 21: Unit 4 Oxygenation Efficiency

Dissolved Oxygen Uptake

Dissolved oxygen increase in the turbine discharge as a function of percent air by volume in the discharge is shown on Figure 22. There was considerable scatter in the data because of the difficulty of obtaining accurate tailrace DO readings, which were not affected by discharges from the other units. However, the curve fit through the data points is useful in indicating the DO uptake that could be expected for given air/water flow conditions. The data indicate that about 0.6 mg/L of uptake could be expected for every 1 percent air by volume. If the background DO were about 1 mg/L instead of 3-4 mg/L, it is estimated that the uptake would be about 0.7 to 0.8 mg/L for every one percent air by volume.

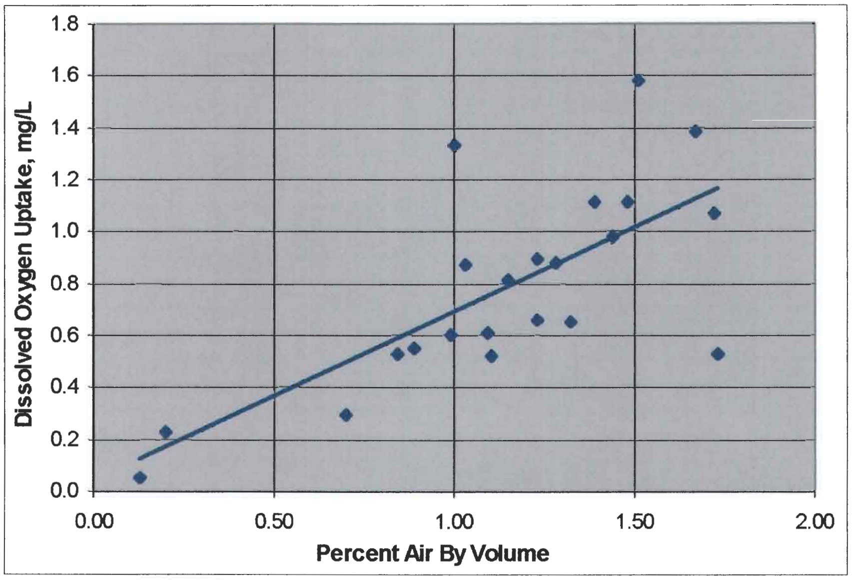


Figure 22: DO Uptake Related to Percent Air By Volume

Dissolved oxygen uptake, before and after modifications, is shown in Figure 23 as a function of wicket gate opening. There is significant scatter in the data, but in general, it appears that more DO uptake can be obtained if the units are operated at wicket gate openings below 50 percent, and that the effect of the modifications was to increase the DO uptake at higher wicket gate openings. The DO uptake obtained for the incoming conditions during the tests was on the order of 0.5 to 0.7 mg/L, when wicket gate opening was greater than 50 percent and the tailwater elevation was low.

Headcover Pressures

Headcover pressure was not measured during the pre-mod tests, so the effect of the modifications could not be determined. Figure 24 shows post-mod headcover pressures as a function of wicket gate opening measured both with and without the vacuum breaker valve open. During the tests, the water quality monitor in the tailrace indicated a pressure of about 710 mm of Hg. This translates to an atmospheric pressure of about 13.7 psia. The data in Figure 24 therefore indicate that before modifications, the pressure under the headcover was below atmospheric for wicket gate openings less than about 60 percnet,

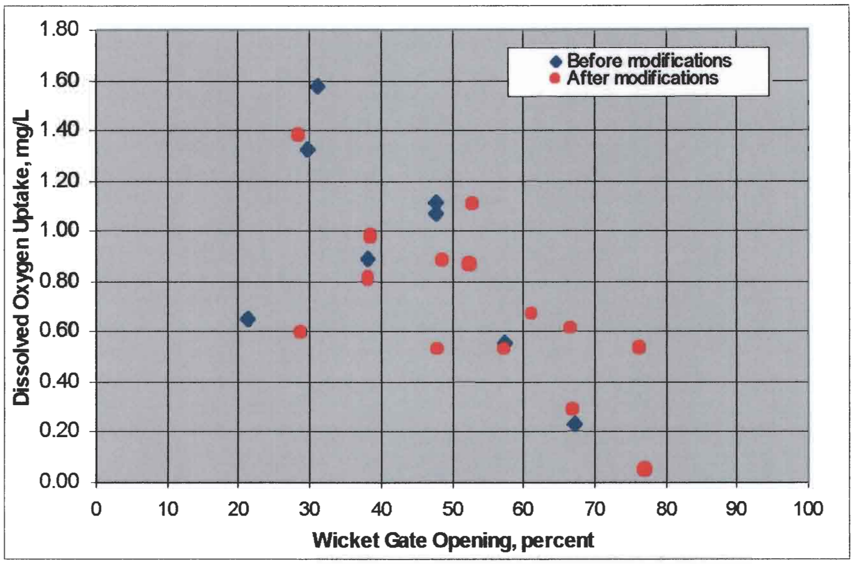


Figure 23: Unit 4 Dissolved Oxygen Uptake

but was at or above atmospheric pressure for higher wicket gate openings. The data also indicate that after the modifications, the pressure under the headcover is below atmospheric for all gate openings. These negative pressures suggest that additional air could be induced if the vacuum breaker piping were modified or additional openings were available in the headcover.

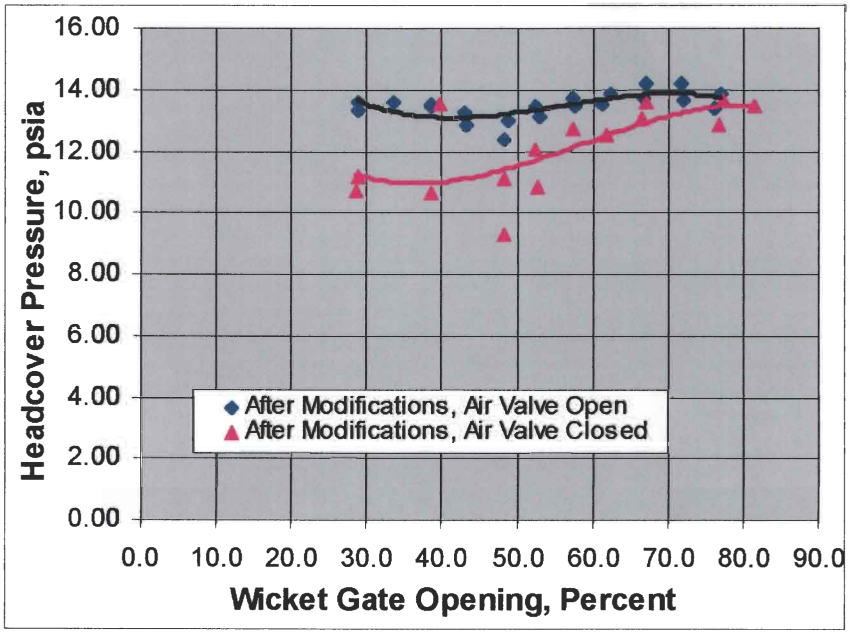


Figure 24: Unit 4 Headcover Pressure

Generation Efficiency

Because water flow rates obtained during the post-mod tests were not accurate, generation efficiencies for the post-mod tests could not be calculated with enough accuracy and confidence to make them useful. Therefore, the effect of the baffles on unit generation efficiency could not be determined. The effect of the air flow on generation efficiency, however, can be ascertained by comparing generation efficiency with and without air induction during the pre-mod tests. The data in Figure 25 indicates that the inducted air may have slightly increased efficiency at gate openings below about 30 percent, but had almost no effect on generation efficiency at higher wicket gate openings.

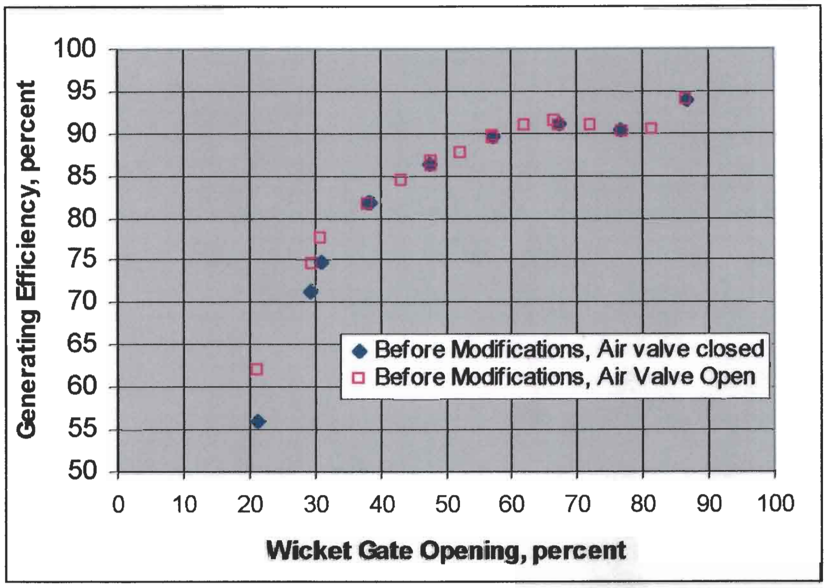


Figure 25: Effect of Air on Generation Efficiency

Total Dissolved Gases

When air is used to aerate releases from hydropower projects, TDG in the tailrace needs to be evaluated to avoid supersaturation levels that can impact fisheries. Total dissolved gases include mainly nitrogen, oxygen, carbon dioxide, and argon, but under anoxic conditions TDG can also include methane and sulfide. The EPA criteria for TDG are 110 percent, but adjustments can be made to this level to account for hydrostatic compensation when water depths are greater than about 1 meter.

For the purpose of this report, it will be assumed that the criteria is 110 percent. Also, the measurements for this study were taken using a saturometer-based instrument that measures TDG. The only dissolved gas measured directly was oxygen, so the remainder of the total dissolved gases were calculated by difference. Since nitrogen comprises such a high percentage of the remaining dissolved gas in natural waters and nitrogen and oxygen make up about 99 percent of the gases in air that is induced by turbine venting, the difference between TDG and DO will be referred to as TDN. Hence, the following relationship is used to estimate the association between TDG, DO, and TDN.

$$\%TDG = 0.21\ \%DO + 0.79\ \%TDN,$$

where %TDG, %DO, and %TDN represent the percent saturation values for the three dissolved gases. However, at hydropower projects other gases, like methane, can be included in the calculated values for TDN.

Baseline TDG and TDN levels are presented in Figures 26 and 27 for the range of field test conditions. The highest baseline levels of TDG and TDN were measured during the runs when the tailwater was low, which also was when the total plant flow was generally lower than for other runs during the study. Since the TDG and TDN were highest when total plant flow was low, as well as when Unit 4 gate opening was low, this suggests that the withdrawal zone was an important factor in contributing the higher levels of TDG and TDN. It would be expected that the withdrawal zone would be lower in the reservoir when total project flows are relatively low.

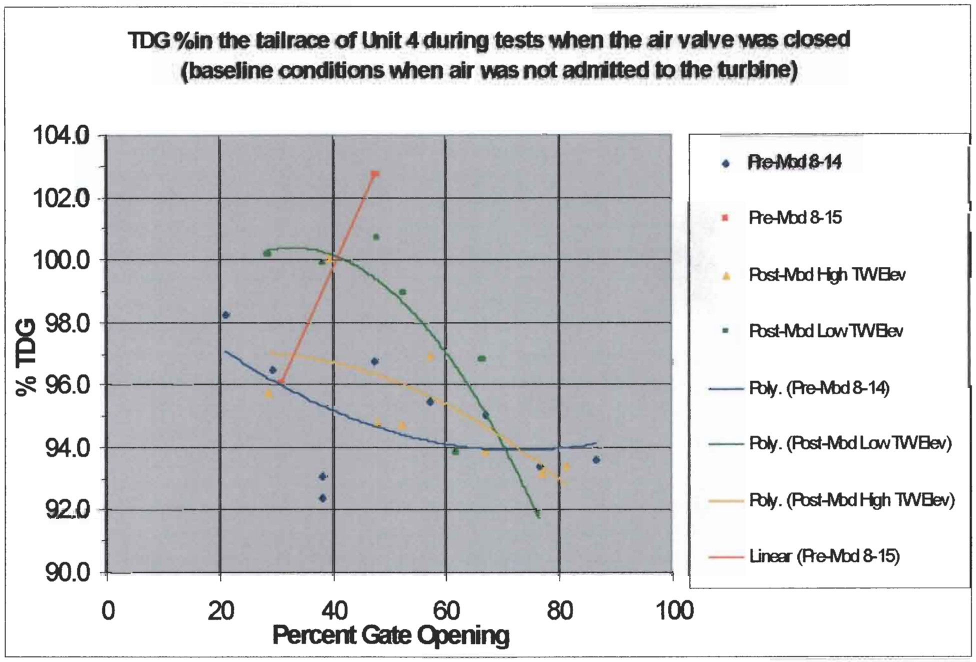


Figure 26: TDG in Unit 4 Discharge Without Air Induction

In general, TDN levels are relatively low or are in the low range of values experienced at other hydropower projects (Ruane, 2000); however, since anoxic products like methane and nitrogen gas (from denitrification) occur later in the low DO period, the TDN values might have increased in September or early October after more time had allowed additional anoxic products to form. IPC monitoring of the tailrace in the year 2000 should provide data to determine if background TDN levels increase as time progresses during the low DO period.

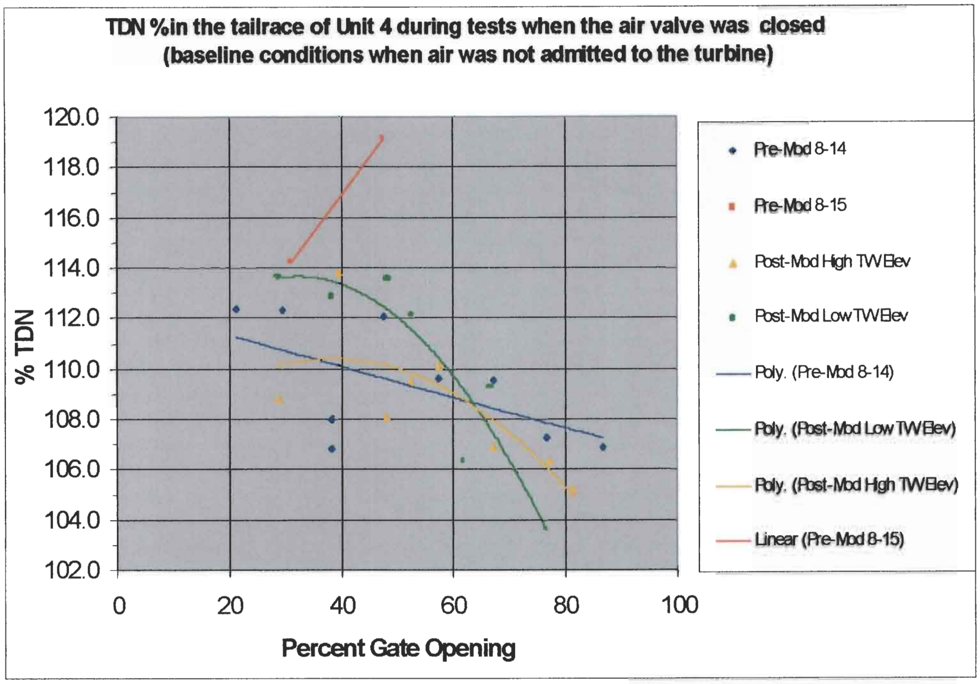


Figure 27: TDN in Unit 4 Discharge Without Air Induction

TDG and TDN levels during aeration tests are presented in Figures 28 and 29. The TDG was generally less than about 105 percent and therefore is less than the EPA criteria; however, if additional air were used to increase DO, the TDG would be higher. Considering that aeration using air from turbine venting or through the use of forced air will likely be an attractive alternative at Brownlee, it is recommended that IPC assess the potential limitations of using air for aeration due to TDG constraints.

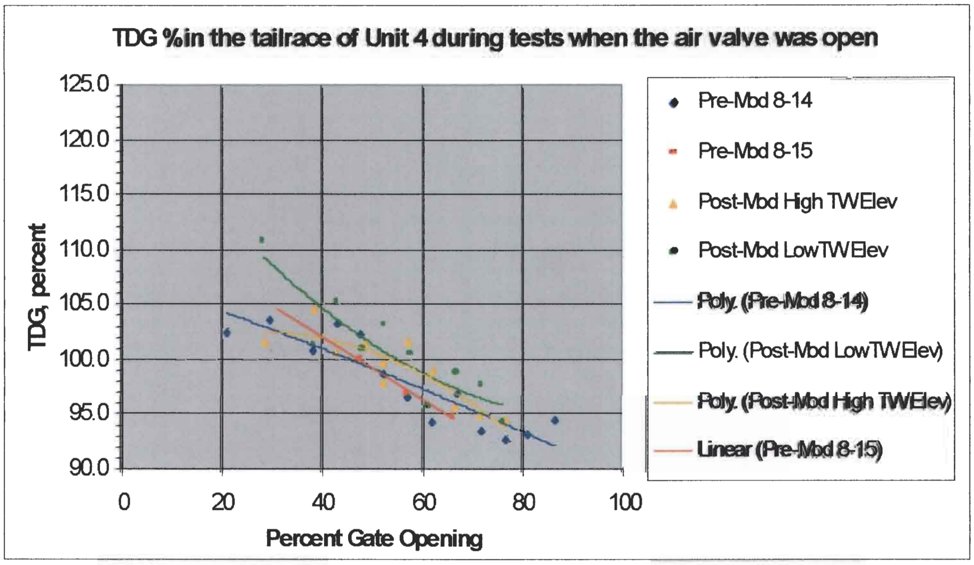


Figure 28: TDG in Unit 4 Discharge With Air Induction

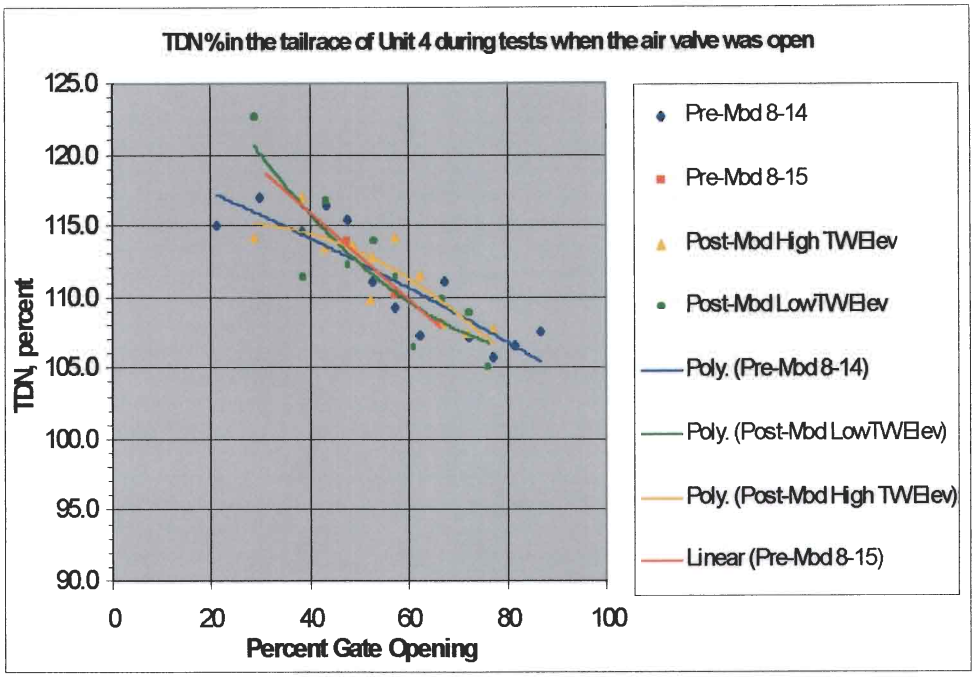


Figure 29: TDN in Unit 4 Discharge With Air Induction

Conclusions and Recommendations

Tests results indicate that significant amounts of air can be induced into the turbine discharges of Units 1-4 simply by keeping the vacuum breaker valves open. The tests also show that the addition of baffles, can increase the air flow for some wicket gate openings and will expand the gate opening range over which air is induced.

The headcover pressures measured after the addition of the 4-inch baffles indicate that larger baffles or increased air passages might also increase air flow. It is therefore recommended that an additional supply of air to the headcover be investigated. This additional supply can be made available either by reducing flow losses by shortening the vacuum breaker piping or by adding an additional opening through the headcover.

Since the baffles apparently served to improve the DO in the tailrace without significant effects on turbine performance, it is also recommended that baffles be added to Units 1-3 to increase air flow. These baffles should be similar in shape to those installed on Unit 4, but 6 inches high rather than 4 inches.

The data indicate an oxygenation efficiency of only about 20-25 percent. This means that only about 5 percent of the air (25 percent of the oxygen) shows up as increased DO in the tailrace. Based on the measured DO increases, the oxygenation efficiency obtained, the effect of the 4-inch baffles, and the headcover pressures measured after baffle installation, it is estimated that the maximum DO uptake obtainable from turbine venting would be on the order of 1 to 1.5 mg/L. This uptake may increase when the incoming DO is lower than that present during the tests. A draft tube computer model for Units 1-4

?

and for Unit 5 would be helpful to determine E_0 for DO levels that have occurred historically, as well as to compare results of tests when baseline DO conditions are different. This model would also be useful for evaluating forced air aeration systems if turbine venting aeration turns out to be insufficient. Additionally, such a model could be used to address TDG and TDN conditions.

If enough air were induced to increase the DO in the turbine discharge to target levels of 4 or 6 mg/L, the TDG may exceed desirable levels. To better understand the DO/temperature/TDG/TDN conditions and relationships in the tailrace, the following analyses are recommended:

- Analyze the data collected from the tailrace monitors during the year 2000, during the low DO period of September and October, to determine baseline conditions for TDN.
- Analyze TDG taking into account hydrostatic compensation in the tailwater to determine how much air can be added to increase DO without causing an impact to downstream fisheries.

It is recommended that data collection in the tailrace continue and, that to obtain more representative data, that the monitoring probes used during the tests be moved further downstream.

Since the amount of air induced into the turbines depends greatly upon the elevation of the tailwater at Brownlee, an analysis should be made of the frequency of occurrence of various tailwater levels during the low DO season and the relationship of tailwater elevations to operations at Brownlee and Oxbow Dams.

References

Myers, RE (1997), "Pollutant Transport and Processing in the Hells Canyon Complex—Progress Report 1997," Idaho Power Company Environmental Affairs.

Ruane, RJ (1999), "Feasibility Assessment of water quality management systems for Brownlee reservoir," report prepared for IPC, Oct. 1999

Ruane, RJ, MH Mobley, GE Hauser, ED Harshbarger, and DF McGinnis (2000), "Preliminary Assessment Of Water Quality Management Alternatives For Brownlee Reservoir," report prepared for IPC, Nov. 2000

Ruane, RJ (2000), personal communication

BROWNLEE TURBINE VENTING TESTS

APPENDICES

APPENDIX A

Summary Results for Turbine Venting Tests on Brownlee Unit 4, August 14-19, 2000

Pre-Modification Tests

Run No.	Gate Opng. (%)	Hw El. (msl)	TW Elev. (msl)	Unit 4 Flow (cfs)	Power Out (Mw)	Air Valve Position	Air Flow (Scfm)	Percent air by volume	Net Unit Efficiency	DO (mg/L)	Temp. (Deg. C)	TDG (% sat.)	DO Uptake (mg/L)	HC Press. ("H2O)
0	22.5	2044.00	1802.70	na	na	closed	na	na	na	3.45	22.11	680.33		na
1a	22.5	2044.00	1802.70	na	na	closed	na	na	na	3.67	22.03	696.50		na
1b	21.42	2044.00	1802.70	1279	14.5	closed	0	0	56	3.83	22.19	691.00	0.65	na
2	21.3	2043.99	1802.41	1284	16.1	open	16.9	1.32	62	4.48	22.14	726.00		na
3	29.65	2043.99	1802.57	1949	29.4	open	19.5	1	74.7	4.34	22.01	734.50	1.33	na
4	29.47	2043.99	1802.78	1921	27.7	closed	0	0	71.5	3.01	21.46	684.00		na
5	38.42	2043.97	1802.82	2757	45.5	closed	0	0	82	3.01	21.7	660.00		na
6	38.33	2043.97	1802.83	2750	45.4	closed	0	0	81.9	3.1	21.74	655.00		na
7	38.28	2043.98	1802.69	2757	45.4	open	33.9	1.23	81.7	3.99	21.58	714.40	0.89	na
8	47.8	2043.99	1802.69	3581	62.1	open	49.9	1.39	86.2	4.31	21.66	725.25	1.11	na
9	47.63	2043.98	1802.80	3585	62.3	closed	0	0	86.3	3.19	21.7	686.00		na
10	57.3	2043.98	1802.88	4438	80	closed	0	0	89.8	3.45	21.75	677.00		na
11	57.39	2043.97	1803.01	4444	79.8	open	39.6	0.89	89.4	4	21.75	684.88	0.55	na
12	67.25	2043.97	1803.53	5265	95.6	open	10.3	0.2	91	3.54	21.77	686.40	0.23	na
13	67.17	2043.95	1803.61	5264	95.7	closed	0	0	91.1	3.31	21.75	673.88		na
14	76.73	2043.94	1803.61	5943	106.8	closed	0.4	0.01	90.4	3.36	21.88	662.20		na
15	77.13	2043.94	1803.57	5964	106.9	open	0	0	90.2	3.48	21.98	656.14	0.12	na
16	86.68	2043.92	1803.58	6187	114.9	open	0.7	0.01	94	3.66	22.05	669.50	0.09	na
17	86.8	2043.93	1803.61	6187	114.8	closed	1.2	0.02	94	3.56	21.95	663.80		na
18	81.43	2043.94	1803.66	6187	111.1	open	1.8	0.03	90.5	3.47	22.02	660.00		na
19	72.16	2043.96	1803.63	5608	101.6	open	6.7	0.12	90.9	3.42	21.94	663.00		na
20	62.18	2043.98	1803.42	4868	88.5	open	32.6	0.67	90.9	3.66	21.65	668.00		na
21	52.53	2043.99	1802.96	4024	70.9	open	50	1.24	87.7	4.22	21.61	699.00		na
22	43.37	2043.99	1802.87	3181	54	open	46.6	1.46	84.3	4.37	21.55	732.00		na
23	31.17	2044.10	1801.33	2045	31.1	closed	0	0	74.9	2.3	19.79	689.58	1.58	na
24a	31.14	2044.11	1801.35	2079	32.7	open	31.3	1.51	77.5	3.87	20.16	727.00		na
24b	31.14	2044.12	1801.35	2079	32.7	open	31.3	1.51	77.5	4.42	20.49	782.92		na
25	47.81	2044.12	1800.62	3581	63.2	open	61.7	1.72	86.8	4.49	21.12	772.43	1.07	na
26	47.66	2044.11	1801.11	3602	63.1	closed	0	0	86.3	3.42	21.11	737.29		na
27	66.51	2044.11	1801.44	5219	96	open	18.6	0.36	91.3	3.58	21.61	690.67		na
28	57.12	2044.11	1801.33	4434	80.4	open	47.1	1.06	89.7	4.02	21.58	709.18		na

APPENDIX B

Summary Results for Turbine Venting Tests on Brownlee Unit 4, August 14-19, 2000

Post-Modification Tests

Run No.	Gate Opng. (%)	Hw El. (msl)	TW Elev. (msl)	Unit 4 Flow (cfs)	Power Out (Mw)	Air Valve Position	Air Flow (Scfm)	Percent air by volume	Net Unit Efficiency	DO (mg/L)	Temp. (Deg. C)	TDG (% sat.)	DO Uptake (mg/L)	HC Press. (psia)
68	0.16	2044.006	1802.136	na	0	na	0	na	na	na	na	na		13.7
69	28.70	2044.002	1803.0	1354	27.1	closed	1.6	0.08	70.7	3.81	22.1	722.8095		11.2
70	28.70	2044.004	1803.105	1471	28.7	open	19.0	0.99	74.2	4.40	22.2	738.4737	0.60	13.3
71	38.52	2044.006	1803.099	2431	45.1	open	31.1	1.15	83.0	4.73	22.1	698.5882	0.81	13.5
72	39.68	2044.007	1803.104	2518	47.4	closed	0.9	0.03	83.8	3.92	22.2	671.7895		11.1
73	48.08	2044.009	1803.28	3374	63.0	closed	0.1	0.00	87.6	3.65	22.1	715.8261		10.2
74	48.65	2044.008	1803.282	3419	63.6	open	45.4	1.28	89.3	4.54	22.2	723.2105	0.88	13.0
75	57.42	2043.992	1803.28	4241	79.7	open	47.9	1.10	91.3	4.38	22.2	684.5789	0.52	13.7
76	57.34	2043.972	1803.436	4262	79.9	closed	0.0	0.00	90.3	3.86	22.2	675.52		12.7
77	67.13	2043.944	1803.485	5089	95.6	closed	0.0	0.00	92.8	3.67	22.2	677.92		13.6
78	66.95	2043.904	1803.453	5061	94.8	open	36.1	0.70	91.5	3.96	22.2	677.8095	0.29	14.2
79	76.99	2043.895	1804.123	5776	106.2	open	7.6	0.13	93.1	3.62	22.4	656.1429	0.05	13.8
80	77.13	2043.902	1804.121	5779	106.5	closed	0.0	0.00	95.4	3.57	22.4	660.4211		13.6
81	81.48	2043.888	1804.229	6063	110.4	closed	0.0	0.00	90.6	4.00	22.2	679.4211		13.4
82	71.83	2043.892	1804.244	5401	100.3	open	22.5	0.41	91.7	3.89	22.1	700.9412		14.2
83	62.27	2043.89	1804.237	4636	87.0	open	45.8	0.97	92.2	4.22	22.1	707.7368		13.8
84	52.50	2043.838	1804.618	3775	70.1	open	40.9	1.03	88.4	4.07	22.3	656.9048	0.87	13.4
85	52.36	2043.832	1804.955	3757	69.6	closed	0.0	0.00	87.4	3.20	22.3	700.9333		12.0
86	52.35	2043.83	1805.032	3748	69.7	open	40.2	1.02	88.7	4.29	22.4	718.1538		13.5
87	43.06	2043.815	1805.028	2885	53.4	open	34.0	1.08	84.7	4.27	28.7	732.9524		13.2
88	33.47	2043.786	1804.905	1961	36.1	open	8.6	0.38	79.3	4.04	21.9	793.25		13.6
89	28.67	2043.988	1800.737	1471	29.2	open	31.8	1.67	75.0	5.43	21.9	704.619	1.38	13.6
90	28.47	2043.995	1800.951	1364	27.2	closed	0.0	0.00	70.4	4.05	22.2	670.4783		10.7
91	76.63	2044.003	1801.512	5752	108.1	closed	0.0	0.00	98.1	3.87	22.3	697.4615		12.8
92	76.27	2044.004	1801.276	5742	107.7	open	41.9	0.84	107.9	4.41	22.2	705.0667	0.53	13.3
93	72.07	2044.005	1801.135	5440	102.4	open	45.1	0.94	106.7	4.56	22.2	704.2308		13.7
94	66.79	2044.007	1801.206	5025	95.3	open	52.8	1.09	97.4	4.69	22.3	684.3846	0.61	13.7
95	66.52	2044.008	1801.197	5009	95.7	closed	0.6	0.01	97.2	4.08	22.3	663.3333		13.0
96	61.87	2044.007	1801.393	4590	88.0	closed	0.4	0.01	91.9	3.81	22.3	707.7059		12.5
97	61.25	2044.003	1801.474	4514	86.5	open	58.0	1.23	90.7	4.47	22.2	726.7368	0.66	13.5
98	57.62	2043.999	1801.094	4249	81.0	open	58.8	1.34	91.1	4.83	22.1	733.2308		13.5
99	52.82	2043.989	1800.757	3814	72.3	open	58.9	1.48	89.1	5.12	22.3	704.6154	1.11	13.1
100	52.74	2043.989	1800.831	3848	72.6	closed	1.2	0.03	97.1	4.02	22.3	732.2381		10.8
101	48.07	2043.98	1800.895	3395	64.0	closed	0.0	0.00	90.3	4.27	21.9	723.0286		9.3
102	48.05	2043.962	1800.829	3359	63.2	open	59.5	1.73	90.3	4.80	21.0	745	0.53	12.4
103	43.24	2043.992	1800.924	2897	54.4	open	55.7	1.71	82.2	5.04	21.1	709.7647		12.9
104	38.58	2043.999	1801.809	2447	45.4	open	39.4	1.44	82.1	5.14	22.2	709.1579	0.98	13.5
105	38.36	2044.004	1801.81	2403	45.4	closed	0.0	0.00	83.0	4.16	22.1	749		10.7

APPENDIX C

Water Quality Results for Pre-Modification Turbine Venting Tests on Brownlee Unit 4, August 14-15, 2000

Run Numb	% Gate	Air Valve	Unit 2	Unit 5	Time Range	DO, mg/L					Temperature, C deg					TDG		
						Boat	BR4	SC door	BR1	BR5	Boat	BR4	SC door	BR1	BR5	Boat	BR4	BR1
0	35	closed	off	off	15:38-43	3.558333	na	na	na	na	22.08667	na	na	na	na	680.3333	na	na
1a	22.5	closed	off	off	15:54-58	3.7325	3.52	2.05	4.78	4.35	22.0875	22.1	21.89	22.41	22.78	694	693	734
1b	22.5	closed	off	on	16:08-18	3.906	3.17	2.37	4.76	4.39	22.176	22.29	22.01	22.51	22.83	693.4	688	727
2	22.5	open	off	on	16:27-34	4.434	na	na	na	na	22.11	na	na	na	na	729.4	na	na
3	30	open	off	on	16:39-44	4.1025	na	na	na	na	21.9375	na	na	na	na	732.5	na	na
4	30	closed	on	on	16:53-55	3.01	3.01	2.07	4.55	4.19	21.46	21.64	21.22	22.11	22.91	684	711	725
5	40	closed	on	on	17:02-07	3.01	2.87	2.1	4.07	4.31	21.7	21.86	21.01	21.79	23.04	660	686	724
6	40	closed	on (open)	on	0.71875	3.1	2.71	1.61	3.53	4.29	21.74	21.79	20.39	21.67	23.02	655	674	711
7	40	open	off	on	17:22-26	4.042	3.64	2.05	3.86	4.12	21.588	21.7	20.81	21.85	22.88	717.8	689	703
8	50	open	off	on	17:33-41	4.185	3.8	1.38	4.11	4.18	21.67	21.82	20.29	21.85	22.87	721.875	716	703
9	50	closed	off	on	17:48-52	3.24	na	na	na	na	21.69	na	na	na	na	682.6	na	na
10	60	closed	off	on	17:59-18:05	3.508571	2.89	1.65	3.73	4.01	21.76286	21.87	20.19	21.75	22.8	676.2857	679	710
11	60	open	on	on	18:09-15	3.95625	3.9	1.74	3.79	4.11	21.76	21.94	20.78	21.78	22.85	686.75	678	700
12	70	open	on	on	18:25-31	3.494	3.46	1.95	3.99	4.43	21.754	21.95	21.36	21.54	23.12	686	680	704
13	70	closed	on	on	18:37-45	3.31	3.43	2.15	3.43	4.28	21.77	22.03	19.54	21.46	23.15	670.875	668	700
14	80	closed	on	on	18:48-52	3.348	na	na	na	na	21.868	na	na	na	na	660.8	na	na
15	80	open	on	on	18:55-19:01	3.52	3.33	2.42	3.35	4.2	22.01857	22.03	20.49	21.47	23.09	658.5714	662	691
16	90	open	on	on	19:06-12	3.635	3.56	1.96	3.28	4.07	22.03333	22.32	21.29	21.48	23.01	668	659	684
17	90	closed	on	on	19:14-19	3.542	3.62	1.68	3.32	4.31	21.932	22.22	20.78	21.59	23.02	663.2	659	678
18	85	open	on	on	19:27-30	3.47	na	na	na	na	22.02	na	na	na	na	660	na	na
19	75	open	on	on	19:36-40	3.42	na	na	na	na	21.94	na	na	na	na	663	na	na
20	65	open	off	on	19:44-50	3.66	3.74	1.94	3.21	4.27	21.65	22	20.41	21.46	22.93	668	655	668
21	55	open	off	on	19:56-20:01	4.22	na	na	na	na	21.61	na	na	na	na	699	na	na
22	45	open	off	on	20:06-12	4.37	na	na	na	na	21.55	na	na	na	na	732	na	na
23	30	closed	off	off	7:44-49	2.303333	2.158	0.39	4.35	3.14	19.8175	19.85	17.55	21.15	20.26	687.0833	745.3	743
24a	30	open	off	off	7:54-57	3.895	3.5625	0.68	4.23	3.76	20.16	20.26375	19.34	20.7	20.14	730.875	725.875	742
24b	30	open	on	off	8:04-16	4.4148	4.031304	0.85	4.61	3.43	20.4888	20.57391	19.8	20.41	20.32	783.96	751.0435	745
25	50	open	on	off	8:22-25	4.485714	4.048333	1.22	5.01	4.75	21.14714	21.11167	20.38	20.64	20	771.2857	761.1667	765
26	50	closed	on	off	8:31:30-34:30	3.324286	3.205714	1.24	4.92		21.11857	21.10286	20.15	20.89		732.1429	751.7143	786
27	70	open	on	off	8:47-51	3.581111	3.168889	na	na	na	21.62556	21.69333	na	na	na	690.2222	697.7778	na
28	60	open	on	off	8:58-9:04	4.112727	3.444167	na	na	na	21.53273	21.58167	na	na	na	710.5455	687	na

Note 1: These data have limited use for comparing results between locations because BR4, BR1, BR5, and SC usually had only one value for the time ranges (they are based on 10-minute data collected on the "5's" of the clock.) Boat data usually included 4 to 10 values taken over a 4-6 minute period.

Note 2: The yellow filled cells indicate those tests when the data from "Boat", BR4, and SC would be expected to be similar.

BR4: Data from the monitor on the streambank below Unit 4
BR1: Data from the monitor on the streambank below Unit 1
BR5: Data from the monitor in the discharge channel of Unit 5
SC door: Data from the monitor on the scroll case door

Note, test 4: Probable withdrawal zone change caused by U2, as indicated by decrease in temperature
Note, test 8: This test was run to evaluate effect of U2 on tr measurements--the tw measurements were not affected much, but SC and BR were
Note, test 24a: Temp increased during the test, so background DO probably increased too
Note, test 24b: Temp increased during the test after U2 came on, so background DO probably increased too; there might not be any powerhouse data for this time period
Note, test 26: The apparent best background DO was 3.0 but the temp was higher; so the best temp was used in order to get the best estimate for similar w/d which yielded a DO of 3.42

APPENDIX D

Water Quality Results for Post-Modification Turbine Venting Tests, Brownlee Unit 4, Aug. 18, 2000

Run Number	% Gate	TW Elev.	Air Valve	Unit 2	Unit 5	Time Range	DO Boat	Temp Boat	TDG Boat
68	0	2044.01	closed	3900	off	na	na	na	na
69	30	1802.34	closed	off	on	11:59-12:09	3.81	22.18	678.5
70	30	1802.50	open	off	on	12:15-24	4.40	22.15	719.7
71	40	1802.50	open	off	on	12:35-43	4.73	22.15	741.0
72	40	1802.50	closed	off	on	12:49-58	3.92	22.12	708.8
73	50	1802.69	closed	off	on	13:05-16	3.65	22.16	671.7
74	50	1802.69	open	off	on	13:23-32	4.54	22.12	719.0
75	60	1802.70	open	off	on	13:41-50	4.38	22.16	719.4
76	60	1802.83	closed	off	on	13:56-14:08	3.86	22.20	686.8
77	70	1802.88	closed	off	on	14:20-32	3.67	22.21	665.3
78	70	1802.86	open	off	on	14:37-47	3.96	22.16	677.8
79	80	1803.53	open	on	on	14:58-15:08	3.62	22.28	668.9
80	80	1803.53	closed	on	on	15:11-20	3.57	22.43	660.1
81	85	1803.59	closed	on	on	15:23-32	4.00	22.38	661.8
82	75	1803.64	open	on	on	15:37-45	3.89	22.24	672.2
83	65	1803.63	open	on	on	15:52-16:01	4.22	22.15	701.3
84	55	1803.94	open	on	on	16:06-16	4.07	22.00	705.5
85	55	1804.42	closed	on	on	16:20-27	3.20	22.35	671.1
86	55	1804.44	open	on	on	16:35-41	4.29	22.35	693.4
87	45	1804.44	open	on	on	16:45-55	4.27	22.39	713.4
88	35	1804.37	open	on	on	17:03-13	4.04	30.05	740.6
89	30	1800.03	open	off	off	8:15-25	5.43	21.92	793.3
90	30	1800.57	closed	on	off	8:29-40	4.05	21.90	717.0
91	80	1800.90	closed	off	off	8:55-9:01	3.87	22.44	657.4
92	80	1800.62	open	off	off	9:03-10	4.41	22.43	675.1
93	75	1800.53	open	off	off	9:13-19	4.56	22.33	699.2
94	70	1800.60	open	off	off	9:23-29	4.69	22.20	707.7
95	70	1800.63	closed	off	off	9:31-38	4.08	22.17	692.9
96	65	1800.82	closed	off	off	9:42-50	3.81	22.26	671.5
97	65	1800.78	open	off	off	9:52-10:01	4.47	22.25	684.6
98	60	1800.51	open	off	off	10:05-11	4.83	22.21	718.9
99	55	1800.15	open	off	off	10:15-21	5.12	22.16	738.2
100	55	1800.32	closed	off	off	10:23-33	4.02	22.00	708.2
101	50	1800.28	closed	off	off	10:39-56	4.27	22.18	720.8
102	50	1800.27	open	off	off	10:58-11:08	4.80	21.91	722.8
103	45	1800.3	open	off	off	11:11-19	5.04	21.85	752.6
104	40	1801.2	open	off	on	11:30-39	5.14	21.81	724.6
105	40	1801.2	closed	off	on	11:42-49	4.16	22.15	714.8

Note, test 88: Boat results washed out by Unit 2 operations
Note, test 68: Run to zero and check instrumentation

APPENDIX E

Forebay Temperature and dissolved Oxygen Profile Data, Brownlee Dam, August 14, 2000

Annotation at 081400 135647 : BR BOUY in forebay

Date MMDDYY	Time HHMMSS	Temp øC	DO mg/L	pH Units	ORP mV	Turb NTUs	SpCond mS/cm	TDG mmHg	BPSvr4 mmHg	Dep100 meters	IB%Svr4 %Left
8/14/00	135754	10.98	0.24	6.66	329	0	0.318	719	706.2	35	84.9
8/14/00	140023	12.65	0.17	6.67	318	0	0.306	714	705.6	33	84.7
8/14/00	140138	14.65	0.16	6.69	312	0	0.298	716	706	31	83.9
8/14/00	140246	17.58	0.14	6.69	307	0	0.3	722	706	29	83.7
8/14/00	140353	19.88	0.12	6.70	304	0	0.334	730	705.4	27	83.1
8/14/00	140446	20.49	0.11	6.70	302	0	0.345	735	705.7	25	83.3
8/14/00	140553	21.58	0.12	6.71	300	0	0.383	740	705.5	23	82.2
8/14/00	140706	23.06	1.68	6.71	295	0	0.416	745	705.2	21	81
8/14/00	140917	23.68	2.20	6.71	293	0	0.427	725	705.1	20	80.5
8/14/00	141021	24.03	2.76	6.71	292	0	0.433	687	705.3	18	81.1
8/14/00	141110	24.07	2.87	6.71	291	0	0.434	640	705.1	16	80
8/14/00	141242	24.16	3.00	6.71	289	0	0.434	629	705	15	80.8
8/14/00	141352	24.32	4.68	6.71	283	0	0.434	626	704.6	12	81.2
8/14/00	141554	24.34	5.26	6.71	280	0.1	0.434	638	705.1	10	80.3
8/14/00	141640	24.35	5.49	6.71	279	0	0.433	639	705.1	8	79.5
8/14/00	141726	24.52	6.25	6.71	278	0.7	0.432	645	705.2	6	79.4
8/14/00	141820	24.57	6.49	6.72	278	1.7	0.432	652	704.8	4	80.7
8/14/00	142002	25.27	10.15	6.74	270	4	0.428	696	704.8	2	79.3
8/14/00	142145	25.51	10.49	6.74	268	0	0.428	725	703.9	1	78.2
8/14/00	142237	25.62	10.06	6.73	269	54.2	0.428	735	704.6	0.3	78.3

Calculated Values

% TDG	% TDN	
	assumes DO sat=	
101.8125	128.126	128.0791
101.1905	127.5576	127.5243
101.4164	127.8749	127.8436
102.2663	129.0132	128.9858
103.4874	130.6214	130.598
104.1519	131.4938	131.4723
104.8901	132.3971	132.3736
105.6438	128.4724	128.144
102.8223	123.2747	122.8447
97.40536	114.6665	114.127
90.76727	105.9198	105.3589
89.21986	103.5545	102.9682
88.84473	97.8258	96.91106
90.48362	98.08649	97.05838
90.62544	97.54673	96.47366
91.46341	96.23068	95.00907
92.50851	96.80303	95.53451
98.75142	93.25943	91.27553
102.9976	97.57103	95.52068
104.3145	100.5828	98.61646

BROWNLEE TURBINE VENTING TESTS

Introduction

The power generating facility at Brownlee Dam is composed of five hydroturbine-generator units. Units 1-4 are geometrically similar to one another with Francis turbines positioned such that under most discharge conditions, the centerline of the runners is above the elevation of the tailwater. This configuration suggests that turbine venting may be a viable option for increasing the dissolved oxygen (DO) concentration in the turbine discharge. Unit 5 has a runner elevation that is below normal tailwater elevation and it is unlikely that turbine venting for aeration is a workable option.

To evaluate the potential for turbine venting and the effect of adding hub baffles on the amount of air induced into the turbine discharge, tests were conducted on Unit 4 at Brownlee on August 14-19, 2000. Screening tests to measure and compare the amount of air currently induced into Units 1-3 were also conducted. This report describes the tests and presents the results obtained.

Test Description

The tests were conducted jointly by Mobley Engineering, Inc. and Idaho Power employees. Pre-modification or "baseline" tests on Unit 4 were run on August 14 and 15. The turbine was then dewatered and baffles were added over the thrust relief openings on the hub. A sketch of the baffles installed is shown in Figure 1. A photograph of two of the six baffles is shown in Figure 2.

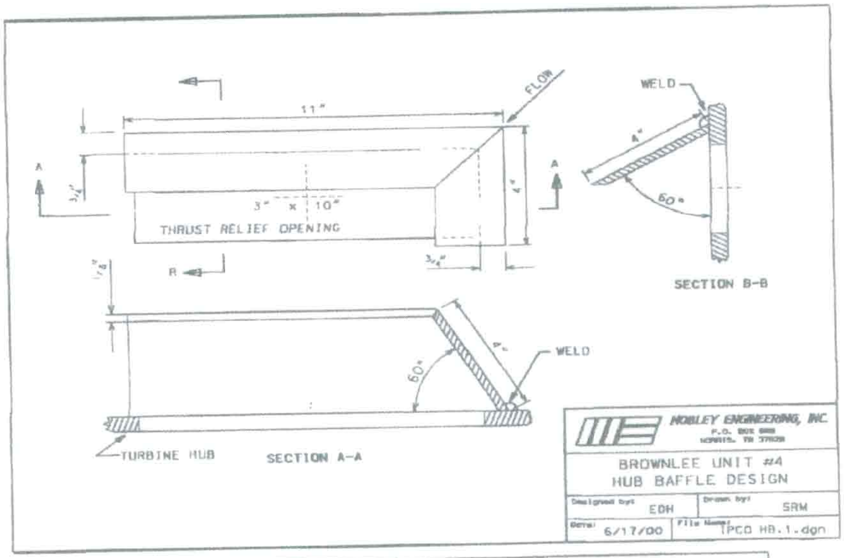


Figure 1; Sketch of Brownlee Unit 4 Hub Baffle

Hells Canyon Complex Final License Application
Additional Information Requests
WQ-1

Dissolved Oxygen Augmentation Using Forced Air

November 2004

Executive Summary

Mobley Engineering, Inc. has provided conceptual designs and cost estimates for forced air systems for the hydroturbine units at Brownlee Dam. Results from previous turbine venting tests and a calibrated bubble plume model were used to evaluate air flow requirements to obtain 1 mg/L and 2 mg/L uptakes as well as total dissolved gas levels. For all units, a 2 mg/L DO increase is likely to reach and may slightly exceed desirable total dissolved gas levels.

For Unit 5 an air supply building would be required on the exterior top deck level. Air supply piping would be routed down a stairway to the pump room and connected to existing compressed air water depression piping. Pressure requirements for Unit 5 were evaluated using a pipe flow program and a conceptual piping design. Two blowers each rated at 6,500 scfm and 900 to 1,000 HP would be operated to supply approximately 1 mg/L of DO uptake each as needed. Estimated capital costs are $1M to $1.5M for a one unit or two unit installation respectively. Operating costs are calculated separately.

For Units 1 – 4, the blowers could be installed on the draft tube level. Air supply piping would be routed to the existing vacuum breaker piping. Two blowers each rated at 6,500 scfm and 800 to 900 HP would be operated to supply approximately 1 mg/L of DO uptake each as needed. Estimated capital costs are $0.75 M to $1.2M for a one unit or two unit installation respectively. Operating costs are calculated separately.

Introduction

Forced air aeration utilizes compressors or blowers to force air into the draft tube, either through passages in the turbine or through the draft tube wall. Oxygen from this air is then dissolved into the water to increase the DO in the turbine discharges. The blowers are operated when the turbines are running. This alternative is similar to turbine venting, placing air in the draft tube for aeration and is generally applied only if turbine venting was unsuccessful at meeting desired dissolved oxygen uptake levels. Oxygen transfer is obtained in the turbulent flow of the draft tube and as the bubble rises to the surface in the tailrace. Long, deep draft tubes increase oxygen transfer efficiency by providing high hydrostatic pressure driving force and bubble-water contact time. Forced air systems include mechanical compressors or blowers, electric supply, air piping, and controls. Turbine efficiency is often reduced in proportion to the amount of air in the draft tube. Like turbine venting, water flow patterns in the turbine are changed with the introduction of air. Cavitation is typically reduced with the introduction of air but cavitation damage patterns may be changed. Mechanical equipment like a large air blower requires a significant amount of maintenance. Electric power requirements are large and may not be available without installation of additional station service capacity at the powerhouse.

Previous Experience:
Idaho Power currently utilizes forced air at American Falls Dam.

Forced air is also currently being used at two TVA projects, Tims Ford and Nottely. Both TVA projects are unmanned hydro stations. There are two forced air blowers at Tims Ford, a 350 HP 4,400-scfm Unit and a 200 HP, 3,400-scfm Unit. Both of these blowers force air into a distribution ring around the draft tube of the single 45MW Unit discharging about 4,800 cfs. Operation of the blowers is initiated with a single blower, then both as DO conditions decline. DO uptake is limited by TDG measured in the tailrace. As TDG approaches dangerous limits the operation of the penstock oxygen system is initiated to provide the desired uptake – generally operating with at least one blower. Installation of the Tims Ford system cost approximately $800,000 in 1993 (Harshbarger et. al. 1995)

Application of Forced Air to Brownlee Unit 5

Description

Unit 5 is a 265 MW unit with a turbine flow of about 12,000 cfs at normal operating conditions and peak efficiency. Forcing air into the draft tube of Unit 5 appears to be a viable option for increasing the dissolved oxygen in the turbine discharge. The centerline of the unit is situated 6-feet below the usual tailwater elevation, thus turbine venting is not feasible due to passageway pressures that are greater than atmospheric pressure.

If air were to be introduced through the vacuum breaker ports, the static pressure to be overcome should be on the order of 7 feet of water or about 3 psi. If air were to be introduced into the draft tube at the level of the discharge ring chamber, the static pressure to be overcome should be on the order of 6.5 psi. The draft tube pressure gage typically indicates 9 to 10 psi at peak efficiency with a maximum of 12 psi. These relatively low pressures suggest that a low pressure-high volume air blower(s) would be suitable to supply air for aeration at either location.

The size of the piping available and the area of the intricate passages beneath the head cover may limit the amount of air that can be introduced through the existing vacuum breaker system. The discharge ring chamber however appears to provide an area for air injection that is easily accessible and which could accommodate enough ports around the periphery of the draft tube to obtain good air distribution which increases DO uptake efficiency. It appears quite possible that existing depression air piping already present in the discharge ring chamber, may be modified to accommodate an additional air supply from a new blower or blowers.

An examination of available drawings and a tour of the Brownlee hydro facility disclosed an area on the top deck level of the plant which should be adequate and conveniently located for the installation of blowers to supply aeration air to Unit 5. Piping from this blower(s) could be routed into an existing building and down stairwells through four intermediate floors to the draft tube floor level. From there it could be connected to the existing depression air piping for introduction into the draft tube through the discharge ring chamber. A schematic sketch showing such an air supply system is shown as Figure 1.

Air Supply Requirements

The amount of injected air needed to raise the DO depends upon the efficiency of oxygen uptake as the flow passes through the draft tube. To determine the air requirements, a bubble plume model was used to track oxygen transfer from bubbles in the draft tube and tailrace.

Discrete-Bubble Model

A discrete-bubble model (DBM) that predicts the rate of oxygen transfer in diffused-bubble systems was applied to a draft-tube system and tailrace to simulate the effects of turbine aeration for the units at Brownlee. Key inputs are the water flow rate through the turbine, the air flow rate, and the initial bubble size. The model accounts for changes in the volume of individual bubbles due to transfer of oxygen and nitrogen (and hence changing partial pressure), variation in hydrostatic pressure, and changes in temperature. The bubble-rise velocity and mass-transfer coefficient, both known functions of the bubble diameter, are continually adjusted.

Calibration of the DBM for Predicting DO in Discharges from Brownlee Hydro

The model was set up for the draft tube geometries of Units 1- 4 and Unit 5, and then calibrated using test data collected in 2000 on Unit 4 to measure DO uptake through the unit over the full range of turbine operating conditions. Figures 2 shows how the model for Unit 4 at Brownlee matched the data collected during the testing in 2000. Predictions for TDG seemed high and were manually adjusted downward by 4% to better meet actual results yet still be safely conservative.

Since data were not available for Unit 5, information from a model calibration on a similar unit owned by SCE&G (Saluda Hydro Unit 5) was used for model settings for Unit 5 at Brownlee.

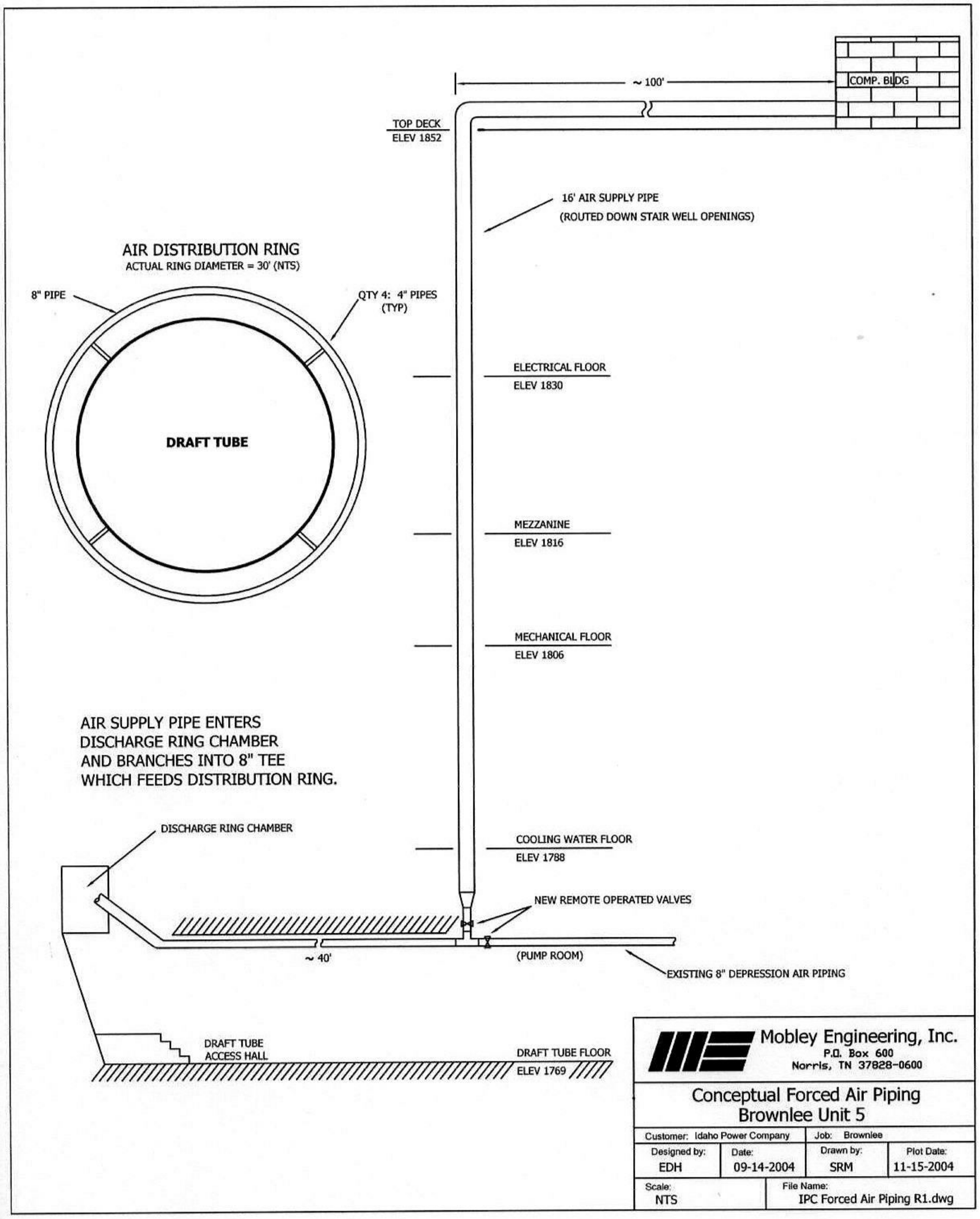
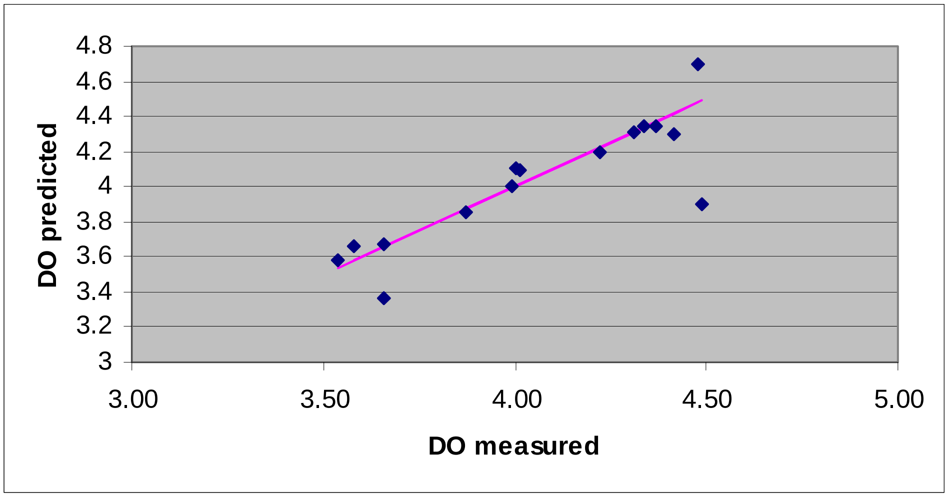
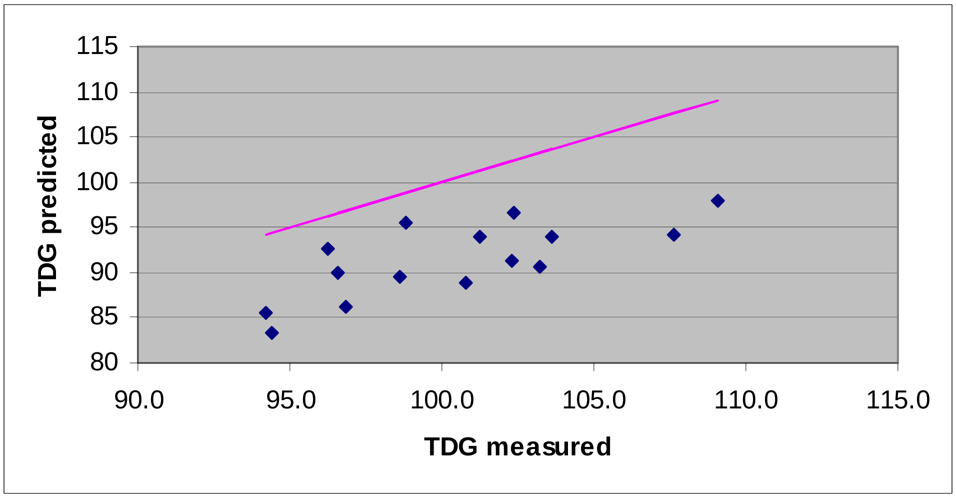


Figure 1: Conceptual Layout Drawing – Unit 5 Forced Air Piping





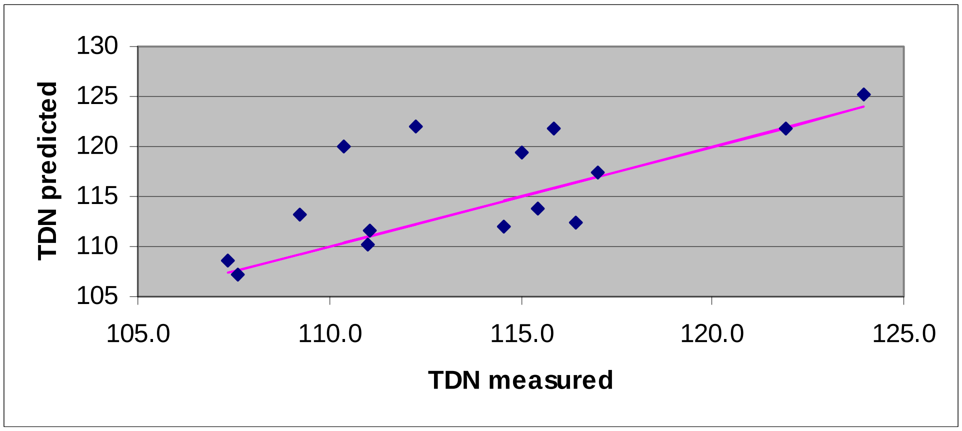


Figure 2: Example of Model Calibration Results for Brownlee Unit 4 Tests with Hub Baffles

The results of modeling the Unit 5 draft tube indicate that the oxygen transfer efficiency will be on the order of 40% decreasing with increasing air flow as shown in Figure 3.

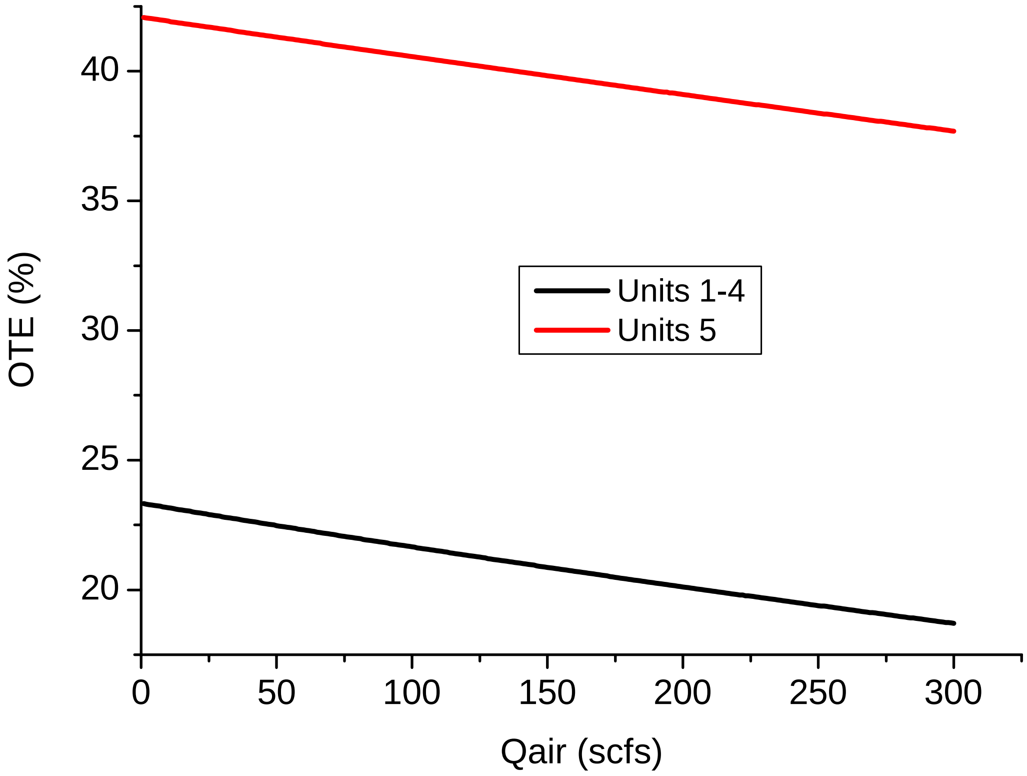
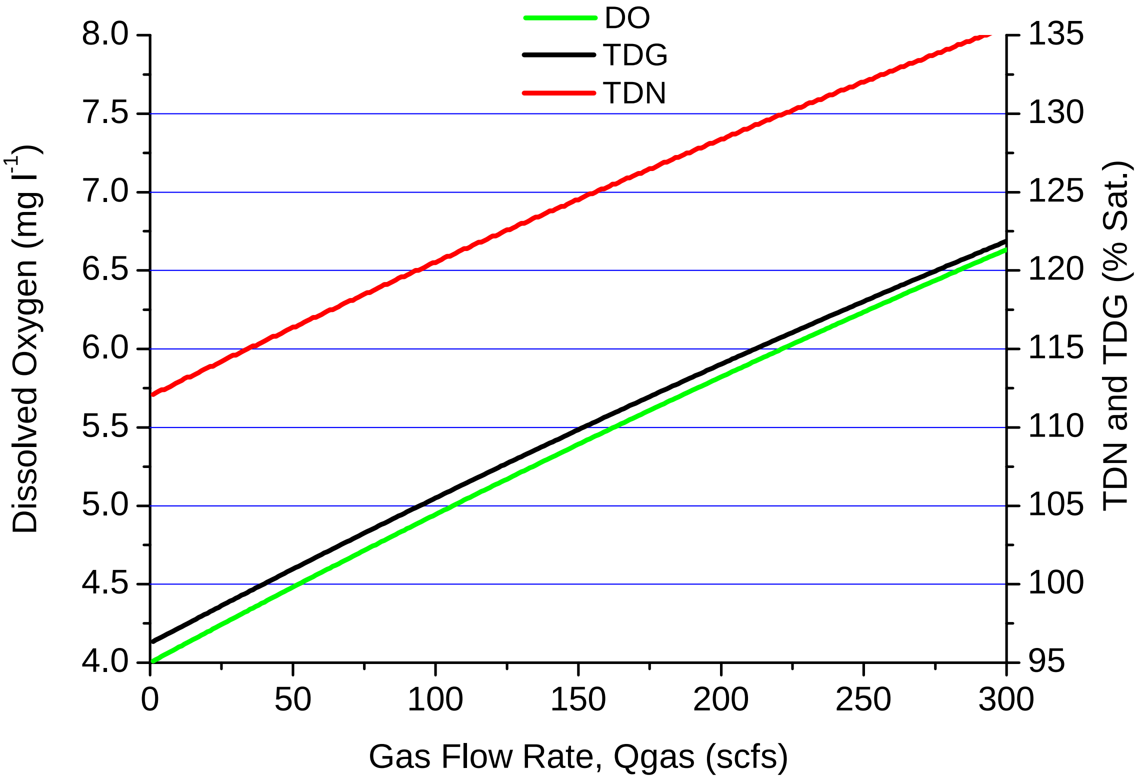


Figure 3: Predicted Oxygen Transfer Efficiency for Units 1-4 and Unit 5 Draft Tubes

The model predictions indicate that the tailrace DO of Unit 5 will be increased about 1 mg/L for every 107 cfs of air injected as shown in Figure 4.



For Unit 5 initial conditions:
Q = 12,000 cfs
Incoming DO content = 4.0 mg/L
Bubble radius = 1.3 mm
TDG = 96%
TDN = 110%
TWEL = 1802.6 ft
Water temperature = 21.75 °C

Figure 4: Predicted Dissolved Oxygen, Total Dissolved Nitrogen and Total Dissolved Gas for Unit 5

The amount of air that can be injected to increase dissolved oxygen may be limited by the resulting levels of total dissolved gas (TDG). As shown in Figure 3, preliminary modeling of the Unit 5 draft tube indicates that an air flow of about 215 scfs (13,000 scfm) results in 115% TDG, and a DO uptake of about 2 mg/L. This flow rate was used as the maximum design condition for Unit 5. The DBM considers only nitrogen and oxygen in tracking gas content of the water and bubbles. Other gases may need to be considered in future analyses.

Air Supply Pipe Sizing:

The pressure requirements for the air supply equipment will be a function of the draft tube operating pressure and piping losses in the supply piping. A preliminary evaluation of the air supply pressure requirements was performed using a pipe flow model (CFSIM-Schohl 2003). The following piping arrangement was evaluated:

- 16 inch pipe from the air supply equipment on the top deck (elevation 1852) down the stairs to the pump room (elevation 1769) – approximately 250 feet
- Tee into existing 8 inch depression air piping
- Existing 8 inch pipe from pump room to and around draft tube discharge chamber – approximately 250 feet total
- Four – 4 inch pipes into the draft tube wall
- 12 psig at the draft tube water flow

This evaluation indicated that a pressure of 27 psig would be needed to move 13,000 scfm of air through the air supply piping. Actual pipe routing, valves and fittings may result in additional pressure losses. Therefore a design condition of 30 to 35 psi was used for conceptual blower specifications.

Blower Description:

Two blowers were specified to provide a total of 13,000 scfm at 30 to 35 psig.

- Size - rough dimensions for each blower: (final dimensions will depend on motor selected)
    - Width - 80 inches (approximate)
    - Height to discharge flange - 57 1/4"
    - Overall height - 70" (Dependant on type and brand of motor selected)
    - Length - 104" (Dependant on type and brand of motor selected)
- Power requirements – 900 to 1,000 HP each
    - 13.8 KV motor
- Cooling requirements
- Noise level – 85 dBA
- Enclosure – required to control noise
-

Operation:

The blowers would operate with turbine operation. Operation of one blower would provide approximately 1 mg/L of DO uptake; two blowers would provide approximately 2 mg/L.

Costs

Capital Costs

Table 1 presents estimated capital costs for systems to provide 1 and 2 mg/L of DO uptake. These preliminary costs are on the order of plus or minus 50%. More detailed studies of the plant layout, pipe routing, power supply availability, etc. will be necessary to arrive at better estimates.

Brownlee Unit 5 Forced Air Aeration- Capital Cost Estimate

To increase DO 1 mg/L		To increase DO 2 mg/L	
Blower (1 at 6,500 scfm)	$375,000	Blower (2 at 6,500 scfm)	$ 665,000
Building	$ 60,000	Building	$ 80,000
Equipment	$ 12,000	Equipment	$ 13,000
Electrical switch gear	$ 70,000	Electrical switch gear	$ 105,000
Lights, heat, etc	$ 15,000	Lights, heat, etc	$ 15,000
Pipes and fittings (12in)	$100,000	Pipes and fittings (16in)	$ 130,000
Power and control conduit	$ 12,000	Power and control conduit	$ 20,000
Power and control wiring	$ 25,000	Power and control wiring	$ 40,000
Cooling water pumps and piping	$ 10,000	Cooling water pumps and piping	$ 15,000
Transformers	$ 55,000	Transformers	$ 85,000
Valves	$ 25,000	Valves	$ 40,000
Fans	$ 35,000	Fans	$ 35,000
Distribution manifold	$ 50,000	Distribution manifold	$ 50,000
Subtotal	$844,000	Subtotal	$ 1,293,000
Engineering	$100,000	Engineering	$ 120,000
Total	**$944,000**	**Total**	**$ 1,413,000**

Table 1: Estimated Costs for Forced Air Installation at Unit 5

Operating Costs

The operating costs include blower power consumption costs, the turbine energy losses due to the injection of air and blower maintenance costs Blower power consumption costs can be estimated by the equation:

$$C=(hp \times 0.746kw / hp \times R \times T) / E_m$$

Where C = blower power consumption costs
hp = blower horsepower
R = cost of electricity (\$/kwh)
T = number of hours operated
E_m = blower motor efficiency

Blower motor efficiency can be assumed to be 90%

Based upon previous experience for an air/water flow rate ratio 0.009 (107/12000) for a 1 mg/l increase, turbine efficiency loss would be on the order of 0.5%. For an air/water flow rate ratio 0.018 (215/12000) for a 2 mg/l increase, turbine efficiency loss would be on the order of 1%. Therefore, aeration induced energy losses can be approximated by the equation:

$$E_t = 0.01 \times P \times R \times T$$

Where:
E_t = cost of energy lost (\$)
P = turbine power output (kw)
R = value of electricity (\$/kwh)
T = number of hours of operation

Based upon past experience, blower maintenance costs could be expected to be on the order of \$10,000/year.

The total annual operational costs of aeration using forced air would therefore be $C + E_t +$ \$10,000.

Application of Forced Air to Units 1 - 4

Description

Based upon the results of the tests conducted in August 2000 on Brownlee Unit 4, the amount of DO uptake available by applying turbine venting techniques to the existing turbines may be limited to less than 1 mg/L unless more costly modifications are made. Therefore, a forced air system using blowers to inject air into the existing vacuum breaker piping is being investigated.

Air Supply Requirements

The data from the 2000 tests indicate that the DO uptake efficiency for Units 1-4 would be on the order of 20% (as shown in Figure 3). Or that about 0.6 mg/L of DO uptake can be expected for every 1% air by volume in the draft tube as shown in the DBM results presented in Figure 5. Therefore, based upon a water flow of about 6000 cfs, an air flow of 210 cfs would be needed to increase the DO by 2 mg/L. TDG levels are predicted to be about 111% at this air input rate.

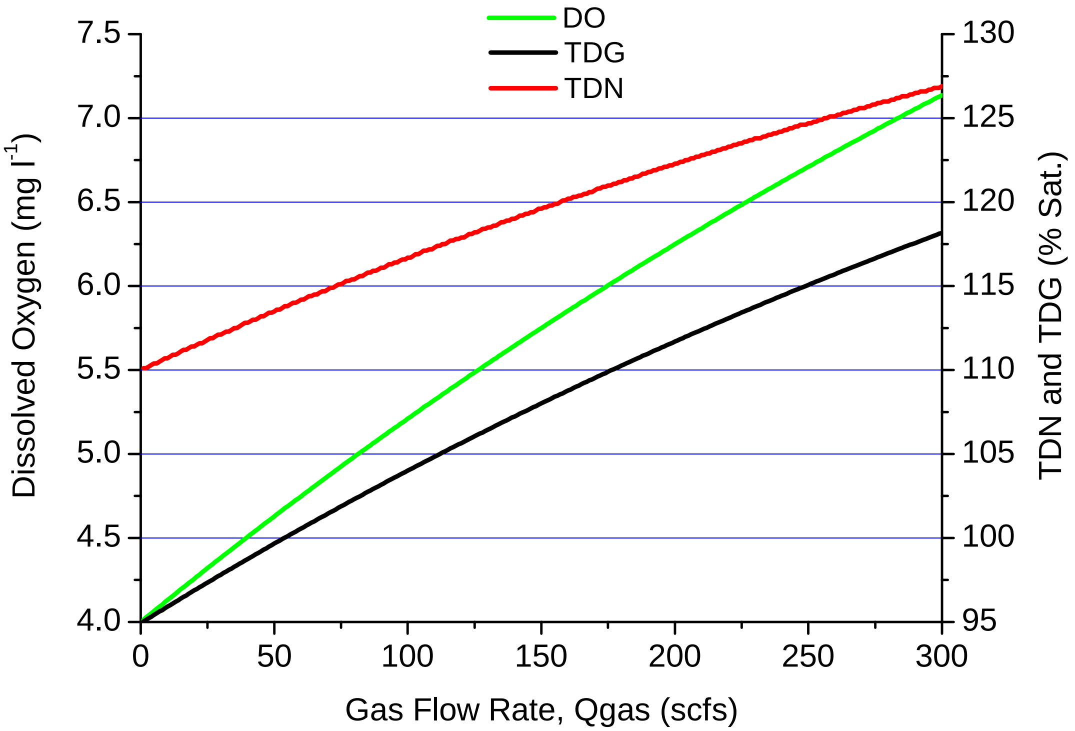


Figure 5: Predicted Dissolved Oxygen, Total Dissolved Nitrogen and Total Dissolved Gas for Units 1 – 4

For Units 1-4 initial conditions:
Q = 5000 cfs
Incoming DO content = 4.0 mg/L

Bubble radius = 1.3 mm
TDG = 96%
TDN = 110%
TWE = 1802.6 ft
Water temperature = 21.75 °C

Blower Description:

There appears to be sufficient space on the draft tube floor level to locate moderate sized blowers, and the vacuum breaker piping is accessible at convenient locations. Details of blower location and pipe routing would need to be further investigated.

Two blowers were specified to provide a total of 13,000 scfm at 20 to 25 psig.

- Size - rough dimensions for each blower: (final dimensions will depend on motor selected)
    - Width - 80 inches (approximate)
    - Height to discharge flange - 57 1/4"
    - Overall height - 70" (Dependant on type and brand of motor selected)
    - Length - 104" (Dependant on type and brand of motor selected)
- Power requirements – 800 to 900 HP each
    - 13.8 KV motor
- Cooling requirements
- Noise level – 85 dBA
- Enclosure – required to control noise
-

Costs

Table 4 presents estimated capital costs for systems to provide 1 and 2 mg/l DO uptake for Units 1-4. These preliminary costs are per unit and on the order of plus or minus 50%. More detailed studies of the plant layout, pipe routing, power supply availability, etc. will be necessary to arrive at better estimates.

Brownlee Unit 1 - 4 Forced Air Aeration- Capital Cost Estimate			
To increase DO 1 mg/L		**To increase DO 2 mg/L**	
Blower (1 at 6,500 scfm)	$375,000	Blower (2 at 6,500 scfm)	$ 665,000
Electrical switch gear	$ 70,000	Electrical switch gear	$ 105,000
Pipes and fittings (12in)	$100,000	Pipes and fittings (16in)	$ 130,000
Power and control conduit	$ 12,000	Power and control conduit	$ 20,000
Power and control wiring	$ 25,000	Power and control wiring	$ 40,000
Cooling water pumps, piping	$ 10,000	Cooling water pumps, piping	$ 15,000
Transformers	$ 55,000	Transformers	$ 85,000
Valves	$ 25,000	Valves	$ 40,000
Subtotal	$672,000	Subtotal	$1,100,000
Engineering	$100,000	Engineering	$ 120,000
Total	**$772,000**	**Total**	**$1,220,000**

Table 4: Estimated Costs (per unit) for Forced Air Installation at Units 1 - 4

Operating Costs

The operating costs include blower power consumption costs, the turbine energy losses due to the injection of air and blower maintenance costs. Blower power consumption costs can be estimated by the equation:

$$C=(hp \times 0.746kw / hp \times R \times T) / E_m$$

Where C = blower power consumption costs
hp = blower horsepower
R = cost of electricity ($/kwh)
T = number of hours operated
E_m = blower motor efficiency

Blower motor efficiency can be assumed to be 90%

Based upon previous experience for an air/water flow rate ratio 0.017 (105/6000) for a 1 mg/l increase, turbine efficiency loss would be on the order of 1%. For an air/water flow rate ratio 0.033 (210/6000) for a 2 mg/l increase, turbine efficiency loss would be on the order of 2%. Therefore, aeration induced energy losses can be approximated by the equation:

$$E_t = 0.02 \times P \times R \times T$$

Where:
E_t = cost of energy lost ($)
P = turbine power output (kw)
R = value of electricity ($/kwh)
T = number of hours of operation

Based upon past experience, blower maintenance costs could be expected to be on the order of $10,000/year.

The total annual operational costs of aeration using forced air would therefore be C + E_t + $10,000.

References:

Harshbarger, E. Dean, Mark H. Mobley, and W. Gary Brock, “Aeration of Hydroturbine Discharges at Tims Ford Dam using Penstock Oxygen Injection and Turbine Air Injection” ASCE 1st International Conference on Water Resources Engineering, San Antonio TX, August 1995

Schohl, Gerald, A. “Users Manual for LOCKSIM, Hydraulic Simulation of Lock Filling and Emptying Systems”, Tennessee Valley Authority, August 1998

Appendix A: Discreet Bubble Model Overview

In all oxygenation devices, gas bubbles in contact with water produce interfacial transfer of oxygen, as well as nitrogen and other soluble gases. Bubble size is a critical parameter in these diffused-bubble systems because it determines the interfacial surface area, bubble-rise velocity, and mass-transfer coefficient. In addition, bubble size may vary significantly as the bubbles pass through the system, especially when pure oxygen is used. For these reasons, Wüest et al. (1992) used a discrete-bubble model to account for changes in the volume (due to gas transfer, hydrostatic pressure, and surrounding water temperature) of individual bubbles rising within a bubble plume.

The discrete-bubble model, first adopted by Wüest et al. (1992), is applied to bubbles that travel in plug flow through the draft tube. The initial bubble size and the rate of bubble formation are assumed to be constant at a given water flow rate but are also functions of the water flow rate and are turbine specific. Bubble coalescence and mass transfer of gases other than nitrogen and oxygen are considered negligible. The water and air temperatures are assumed to be equal and constant.

The mass-transfer flux (for either oxygen or nitrogen) across the surface of a bubble is

$$J = K_L \left(C_s - C\right) \quad (\text{mol m}^{-2}\ \text{s}^{-1}) \qquad (1)$$

where K_L is the mass transfer coefficient, C_s is the equilibrium concentration at the gas/water interface, and C is liquid concentration. Henry's law is used to calculate the equilibrium concentration, or

$$C_s = HP_i \quad (\text{mol m}^{-3}) \qquad (2)$$

where H is Henry's constant and P_i is the partial pressure of the gas at a given location. Combining Equations 1 and 2 yields

$$J = K_L \left(HP_i - C\right) \quad (\text{mol m}^{-2}\ \text{s}^{-1}). \qquad (3)$$

Substituting the surface area of a bubble of radius r gives the rate of mass transfer for a single bubble as

$$\frac{dm}{dt} = -K_L \left(HP_i - C\right) \cdot 4\pi r^2 \quad (\text{mol s}^{-1}). \qquad (4)$$

The vertical location of the bubble is related to the bubble rise velocity, v_b, and the vertical water velocity, v, by

$$\frac{dz}{dt} = v + v_b \quad (\text{m s}^{-1}) \tag{5}$$

where z is the centerline distance in the draft tube. It is important to note that the sign of the bubble rise velocity, v_b changes depending on the location in the draft tube and the direction of flow. In the case of vertical, downward flow, the sign of v_b is negative (the sign of the water velocity, v, is always positive), resulting in longer contact time as the bubble is "rising" in downward moving water. Where the draft tube is horizontal, v_b is set to zero. It was assumed that the bubbles are still dispersed in the water at this point. However, at lower water flow rates coalescence was accomplished by using a larger bubble size at lower flow velocities, which effectively reduced the surface area to volume ratio, simulating the effect of bubble coalescence. For vertical, upward water flow, the sign of v_b is positive, resulting in shorter contact time as the bubble is now "rising" in the same direction as the moving water. Combining Equations 4 and 5 gives the mass of gaseous species transferred per bubble per unit distance of the draft tube

$$\frac{dm}{dz} = -K_L\left(HP_i - C\right)\cdot\frac{4\pi r^2}{v + v_b} \quad (\text{mol m}^{-1}). \tag{6}$$

The number flux of bubbles entering the draft tube, N, is calculated from the initial bubble volume, V_o, and the actual volumetric gas flow rate at the diffuser, Q_o, or

$$N = \frac{Q_o}{V_o} \quad (\text{s}^{-1}). \tag{7}$$

Multiplying Equation 6 by N and expressing it in terms of M, the molar flow rate of gas, yields

$$\frac{dM}{dz} = -K_L\left(HP_i - C\right)\cdot\frac{4\pi r^2 N}{v + v_b} \quad (\text{mol m}^{-1}\ \text{s}^{-1}). \tag{8}$$

Equation 8 is then integrated numerically, for both oxygen and nitrogen, to obtain the change in the molar flow rate when the gas bubble is in contact with the water. This value is used to incrementally calculate the aqueous-phase concentration as a function of time. Note that in Equation 8, H is a function of water temperature, while v_b and K_L are functions of r, the radius of the bubble. The bubble radius changes in response to decreasing hydrostatic pressure as well as the amount of oxygen and nitrogen transferred between the bubble and the water. As summarized in Table C-8, relationships for v_b and K_L were developed by Wüest et al. (1992) based on experimental data for bubble rise velocity (Haberman and Morton, 1954) and the mass transfer coefficient (Motarjemi and Jameson, 1978).

The discrete-bubble model has been verified with diffused-bubble oxygen transfer tests conducted in a 14-meter deep tank at three air flow rates. All of the test data were predicted to within 15 % (McGinnis and Little, 2002). The range of bubble diameters during the test (0.2 to 2 mm) spanned the region of greatest variation in rise velocity and mass-transfer coefficient. This approach has subsequently been successfully applied to airlift aerators (Burris and Little, 1998; Burris et al. 2002), the Speece Cone (McGinnis and Little, 1998), linear and circular bubble-plume diffuser (Wüest et al. 1992, Little and McGinnis, 2001, McGinnis et al. 2001) and side stream super-saturation systems.

REFERENCES

Burris, V. L., and J. C. Little. 1998. Bubble dynamics and oxygen transfer in a hypolimnetic aerator. Water Science & Technology **37**:293-300.

Burris, V. L., D. F. McGinnis, and J. C. Little. 2002. Predicting oxygen transfer rate and water flow rate in airlift aerators. Water Research **36**:4605-4615.

Haberman, W. L., and R. K. Morton. 1954. An experimental study of bubbles moving in liquids. Proc. Am. Soc. Civ. Eng. **80**:379-427.

Little, J. C., and D. F. McGinnis. 2001. Hypolimnetic oxygenation: Predicting performance using a discrete-bubble model. Water Science & Technology: Water Supply **1**:185-191.

McGinnis, D. F., and J. C. Little. 1998. Bubble dynamics and oxygen transfer in a Speece Cone. Water Science & Technology **37**:285-292.

McGinnis, D. F., and J. C. Little. 2002. Predicting diffused-bubble oxygen transfer rate using the discrete-bubble model. Water Research **36**:4627-4635.

McGinnis, D. F., J. C. Little, and A. Wüest. 2001. Hypolimnetic oxygenation: Coupling bubble-plume and reservoir models. Proceedings of Asian Waterqual 2001, First IWA Asia-Pacific Regional Conference, Fukuoka, Japan.

Motarjemi, M., and G. J. Jameson. 1978. Mass transfer from very small bubbles - The optimum bubble size for aeration. Chemical Engineering Science **33**:1415-1423.

Wüest, A., N. H. Brooks, and D. M. Imboden. 1992. Bubble plume modeling for lake restoration. Water Resources Research **28**:3235-3250.

Hells Canyon Complex Final License Application
Additional Information Requests
WQ-1

Dissolved Oxygen Augmentation in the Transition Zone

November 2004

Executive Summary

Mobley Engineering, Inc. has provided a detailed conceptual design for an oxygen diffuser system for the Brownlee Reservoir transition zone. The line diffuser design is well suited for the transition zone and the conceptual design for this application utilizes standard line diffuser details to efficiently place oxygen in the water depths available. The conceptual diffuser system for the transition zone would place 17 to 34.6 tons of oxygen per day into the reservoir. Two diffuser lines are routed upstream of the oxygen supply facility to directly place oxygen in a 2-mile stretch of the reservoir. Supply lines from the oxygen supply facility would be routed in a trench under the road and then underwater to the deepest part of the reservoir. The transition zone system would operate 24 hours a day with manual oxygen flow rate adjustments, as needed, to meet seasonal demands.

Advantages of the line diffuser design

- Proven system
    - Currently in operation at nine hydropower installations
    - Systems in operation since 1994 with minimal maintenance or repairs
- High oxygen transfer efficiency to minimize operating costs
    - 85% to 90% at depths available at location
- Provides a wide range of oxygen flow rates while maintaining oxygen transfer efficiency and uniform distribution.

- Diffuser is resistant to damage
    - Inaccessible to the public
    - Nothing exposed on reservoir surface
    - Independent flow control to 15 foot long diffuser sections
- Easily re-floated if relocation is desired
- Can be supplied with oxygen supplied from cryogenic tank or PSA system
- Conceptual design provides two diffusers to allow control of oxygen input distribution over two river miles.

Cost estimate

- $835,000 (Reservoir Diffusers Only)
- Includes
    - Two, 6,100 foot long line diffusers
    - 6,800 feet of underwater supply piping
    - Stainless steel supply piping onshore
    - Flow distribution manifold
    - System startup, manuals and operator training

Summary

The conceptual design includes materials, equipment and labor from a piping interface point at the oxygen supply facility. The system provides high oxygen transfer efficiency, wide flow rate adjustment capability and can be relocated if necessary.

Introduction

At the request of Idaho Power Company, Mobley Engineering, Inc. (MEI) has prepared the following oxygenation diffuser system conceptual design for the Brownlee Reservoir. The conceptual design is in support of Idaho Power's final license application for the Hells Canyon Complex.

MEI provides design and installation of diffuser systems based on the porous hose line diffuser originally developed for the Tennessee Valley Authority as shown in Figures 1 and 2. Line diffuser oxygen distribution systems are currently in operation at six TVA hydropower projects, Duke Energy and Pennsylvania Power and Light hydropower projects, and the U.S. Army Corps of Engineers (USACE) Richard B. Russell Dam, as well as five water supply reservoirs. The porous hose line diffuser design and MEI have a proven record for successful hydropower oxygenation system installations, with systems in operation since 1994. Each application requires a site-specific design to match the best attributes of the oxygen distribution system to the specific conditions at each project.

Distribution Capacity

The conceptual design is based on a distribution capacity of 1,125 tons or 2250 tons over 65 days as specified by Idaho Power:

Transition Zone

The oxygen to be delivered to the reservoir is:

Total Oxygenation: 1125 tons/year or 2250 tons/year
Maximum Daily: 34.6 tons/day
Average Daily: 17.3 tons/day

The actual oxygen flow rate, annual usage and diffuser system capacity will depend on the oxygen transfer efficiency of the system at design conditions. The line diffuser design has a proven record as a very efficient system. The efficiency is achieved by spreading small oxygen bubbles over a large volume of the reservoir. Since the line diffuser is a free bubble system, the water depth available will control the actual transfer efficiency as a function of mass transfer driving force and bubble contact time.

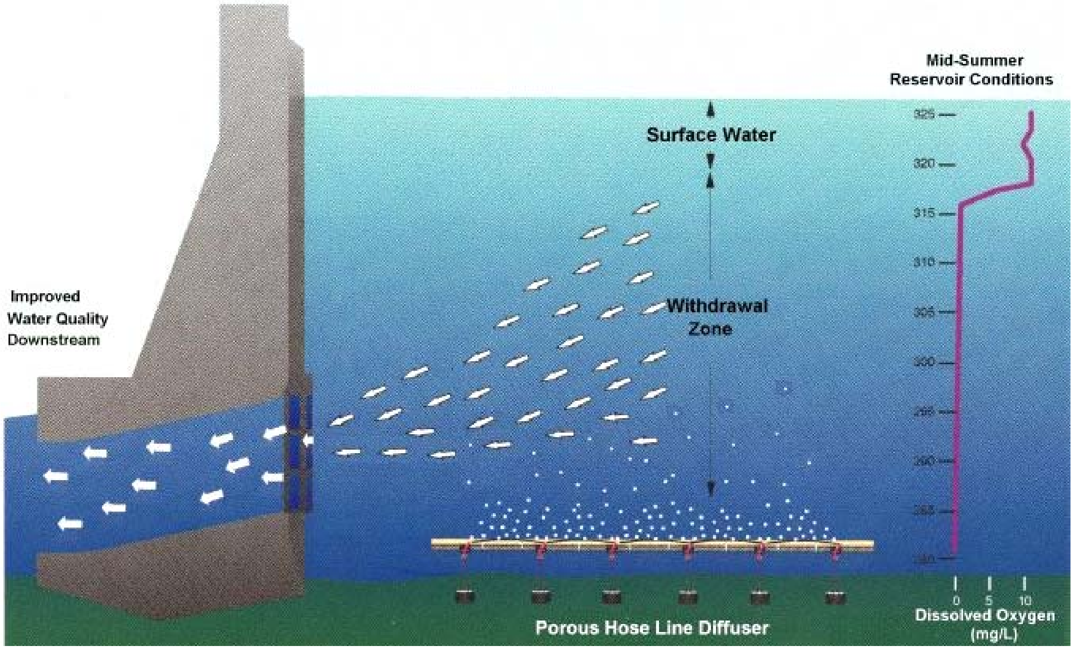


Figure1: Schematic View of Reservoir Diffuser and Turbine Withdrawal (Mobley 1996)

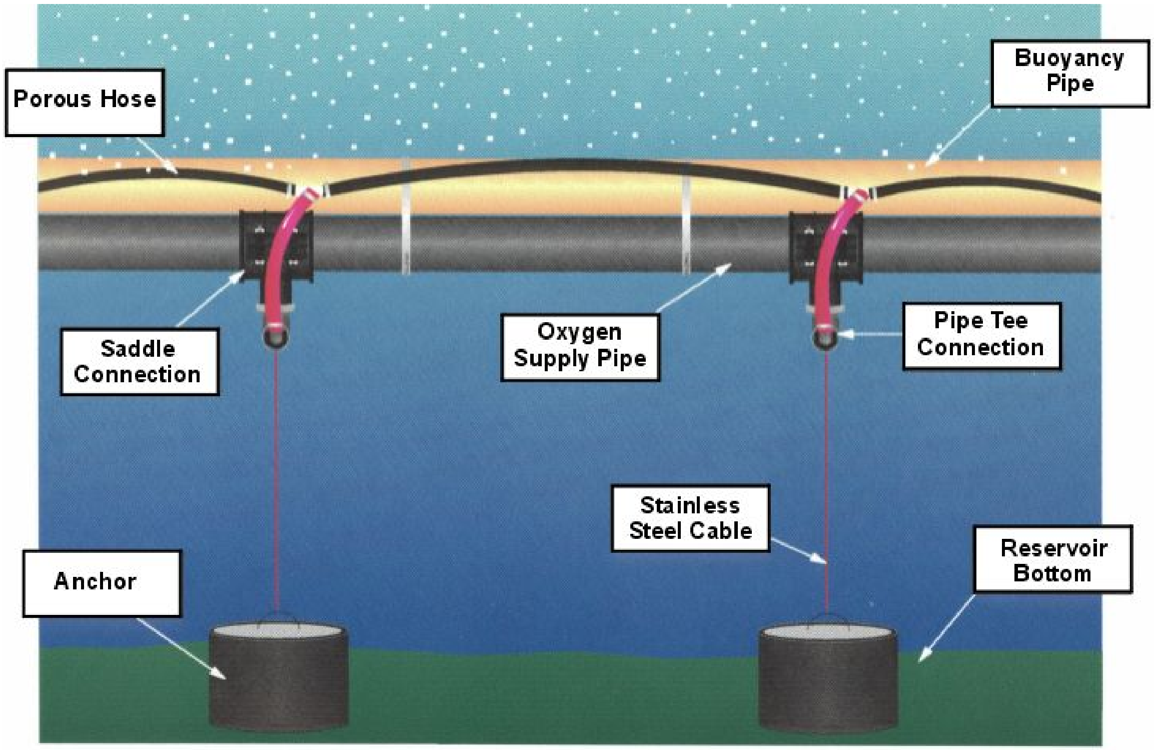


Figure 2: Line Diffuser Assembly Details (Mobley, 1996)

Depths Available

The potential oxygen system location in the reservoir transition zone between Tunnel Rock and Springs Recreation Area provides river cross sections that are 1,000 to 1,200 feet wide and with bottom elevations from approximately 1990 to 2020 feet, as shown for representative cross sections in Figure TZ1. At normal expected reservoir elevations during oxygenation, this location would provide depths of 65 to 85 feet.

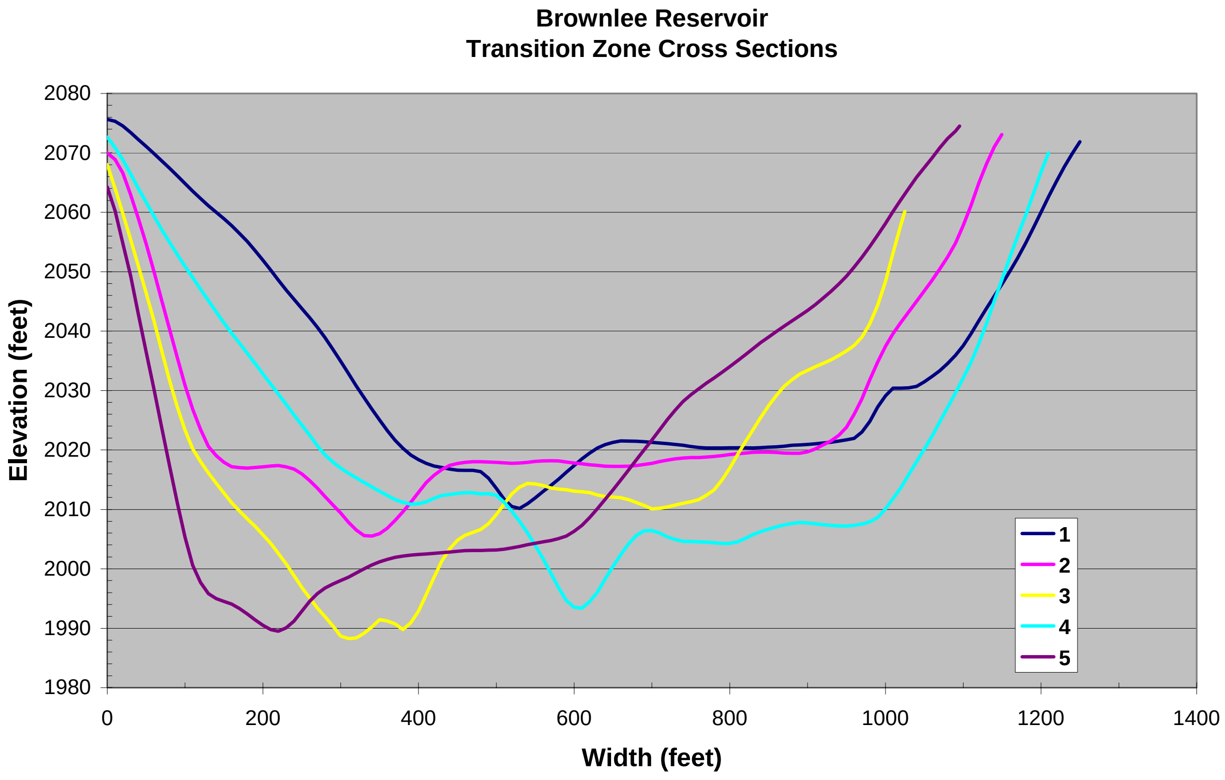


Figure TZ1: Transition Zone Cross-Sections

Predicted Oxygen Transfer Efficiency

The reservoir depth at the transition zone is sufficient to provide high oxygen transfer efficiency (OTE) from bubbles placed in the water using diffuser systems as shown in the bubble plume model results in Figure TZ2. The transition zone conceptual diffuser design utilizes a porous hose design that is capable of handling a large range of flow rates with minimal loss of oxygen transfer efficiency at high flow rates. The conceptual design will operate at oxygen flow rates of 0.03 to 0.07 scfm per foot to provide the specified average and maximum oxygenation rates respectively and obtain acceptable transfer efficiencies at high flows and low HWEL if those conditions should exist. The diffuser design bubble plume analysis predicts maximum oxygen transfer at elevations over 2050 but restricted OTE at 2030.

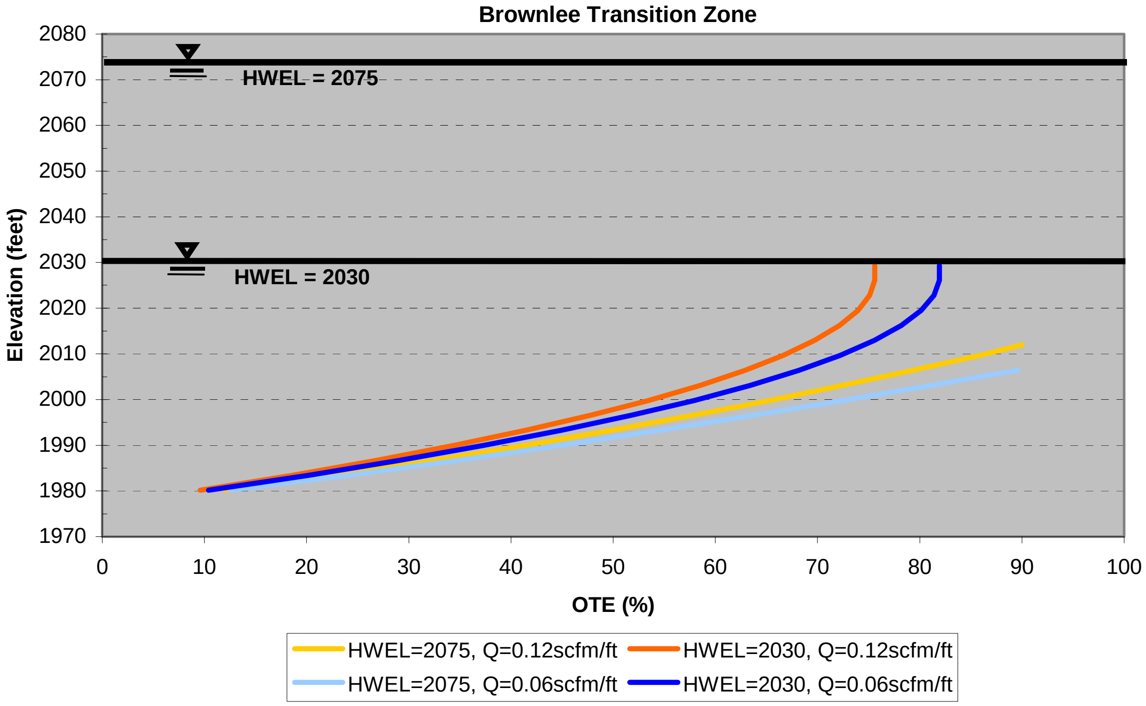


Figure TZ2: Oxygen Transfer Predictions for Brownlee Transition Zone

System Capacity Calculations

Given design information from site plans and the OTE evaluation, the capacity and piping requirements for the oxygenation system were calculated. The results are presented in Table TZ1:

Brownlee
Idaho Power Company

SYSTEM DESIGN CALCULATIONS

Mobley Engineering
Norris, Tennessee
11/22/04

				Maximum		**Average**	
DESIGN REQUIREMENT: DO UPTAKE INTO WATER				34.6	tons per day	17.3	tons per day
DESIGN DO UPTAKE EFFICIENCY: estimated at 75 feet average de diffuser at 1992 to 2012, WSEL at 2077 - (65 to 85 feet deep)				85%		90%	
DESIGN OXYGEN FLOW @ UPTAKE EFFICIENCY:				41	tons per day	19.2	tons per day
DESIGN SAFETY FACTOR:				1.15		1.15	
DESIGN OXYGEN SYSTEM CAPACITY				47	tons O2/day	22.1	tons O2/day
				1.95	tons O2/hr	0.92	tons O2/hr
				785	SCFM	371	SCFM
				47,085	scfh	22,244	scfh
TOTAL LINE DIFFUSER LENGTH:		0.065	scfm/ft	12,200	feet	0.030	scfm/ft
				2.31	miles		
DIFFUSER DESIGN:	Number of Line Diffusers			2			
	Total Diffuser Flow			**785**	**scfm**		
	Diffuser Line Length (each)			6,100			
	Total Diffuser Line Length			**12,200**	**feet**		
	Underwater Supply Line			800	feet		
	Underwater Supply Line			6,000	feet		
	Total Underwater Supply Line Length			**6,800**	**feet**		
	Underground Supply Line			500	feet		
	Total Underground Supply Line Length			**1,000**	**feet**		

Table TZ1: System Capacity and Piping Requirements

Length of Diffuser Lines Required

A porous hose design was used with a flow of 0.065 scfm per foot of diffuser length during the maximum design capacity operation rate of 47 tons per day (34.6 t/d at 85% OTE w/ 1.15 safety factor) resulting in a total diffuser length of 12,200 feet. Two diffuser lines, each 6,100 feet long could be run upstream of the oxygen supply facility to spread oxygen input into more than two full miles of the reservoir as shown in the layout in Figure TZ3. A flow rate of 0.06 scfm is the standard maximum rate used on many current installations. At the average daily flow, the diffuser would operate at approximately 0.03 scfm per foot to provide very high efficiency.

Transition Zone Diffuser Location

The potential oxygen system location for the Brownlee Reservoir transition zone is between Tunnel Rock RM 324.2 and Spring Recreation Area 326.7, as shown in Figure TZ3. The line diffuser is well suited for application at the transition zone. The diffuser is capable of achieving high oxygen transfer in the water depths available and is not expected to have any problems related to river velocities or sedimentation in this location. The diffuser installation is designed to spread the specified oxygen capacity over approximately 2.3 river miles, maintain desired water depths and stay clear of Spring Recreation Area.

Supply Piping Requirements

Diffuser installations at this location will have underwater supply lines near cross section 5 at Rock Tunnel approximately 500 to 700 feet long. Piping on shore would extend in a trench from the oxygen supply facility, under the road and down the bank to the waterline. This pipe would be stainless steel and left exposed and anchored where a trench is not feasible. Additional protection using a riprap covering may be desirable.

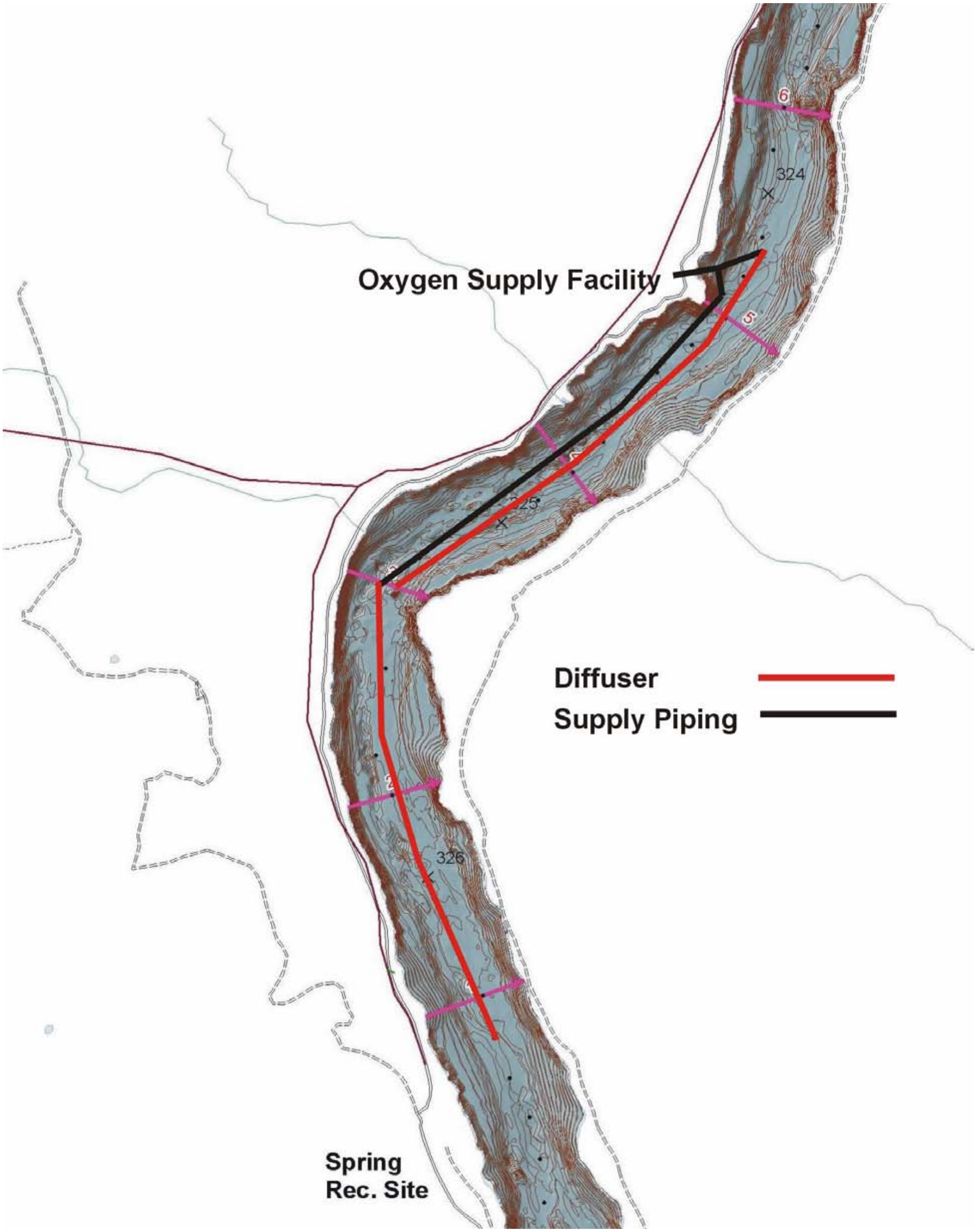


Figure TZ3: Potential Oxygenation System Location for Brownlee Reservoir Transition Zone

Operational Requirements

The operation of the transition zone oxygen systems is expected to be a steady flow of oxygen that could be adjusted daily or weekly to meet seasonal oxygen needs. The diffuser system has the ability to maintain a uniform flow of oxygen over the full length of the diffuser for a wide range of flow rates. The diffuser is capable of handling flows higher than the design flow of 0.07 scfm per foot but oxygen transfer efficiency would eventually be reduced. A good distribution is generally obtained at 25% of maximum design flow. As the oxygen flow is turned down below 25%, the oxygen will tend to be distributed toward the supply end of the diffuser. For this application, the distribution of the oxygen along each diffuser is not expected to be critical, so turn down to nearly zero flow will be possible with good results. Independent control of each diffuser would provide control to direct oxygen input to different distances upstream of the supply facility as desired.

Distribution Manifold Requirements

A distribution manifold is required to control the flow of oxygen from the oxygen supply facility to each of the diffuser lines. The supply pressure would be controlled by the main supply line from the oxygen vendor. On the distribution manifold, a flow control valve would be provided for each diffuser and total flow indicator provided on the main line. Manual oxygen flow control valves would be used for controlling the consistent flow rates for long periods, such as expected for the transition zone. These flow control valves would maintain the manually set flow rate, even with changes in downstream pressure due to reservoir elevation fluctuations.

General Oxygen Supply System Requirements

The system will require an oxygen delivery capacity of 47 tons per day (update to match table 47,000 scfh) for 24 hours per day operation at delivery pressures from 100 to 120 psi.

The continuous flow operation of the transition zone oxygen system may be suitable for oxygen supply alternatives other than liquid oxygen. Pressure swing adsorption (PSA) systems are well suited for 24-hour/day operations but may not be economical if operated for short-term seasonal use each year.

The delivery pressure requirements can be decreased somewhat during detailed diffuser design using larger pipe sizes and flow control orifice diameters, and may be desirable if a PSA system is chosen for oxygen supply. The lower limit for design of the supply pressure would be about 80 psi, approximately 30 psi over hydrostatic pressure at maximum HWEL.

Cost Opinion (+/- 30%) For The Distribution System Installation

TZ2 Cost estimates for the conceptual design are shown in Table.

Brownlee Oxygen Distribution System

Annual Oxygen Placement (tons)	Oxygen Supply Capacity Required (tons/day)	Number of Diffusers	Total Diffuser Length (feet)	Diffuser and Supply Line Cost	Manifold and Supply Piping Cost	Total Cost
1125 or 2250	47	2	12,200	$ 740,000	$ 95,000	$ 835,000

Table TZ2: Cost Opinion for Transition Zone Oxygenation System

These costs include the diffusers, supply piping, distribution manifold and flow controls. Oxygen supply facility costs are not included.

Construction Schedule and Requirements

The construction of the diffuser systems transition zone will require 8 to 10 weeks. It is desirable to have the oxygen supply facility fully operational before MEI crews arrive onsite. The diffuser construction will require:

- Nearby boat access point
- Material lay down and assembly areas
- Temporary rope anchor points in and along the old river channel
- Electric power (a generator will be used if 110V not available)
- A patrol boat to control public boating activities during diffuser deployment

The assembly area will need direct access to the reservoir. The pipe lay down area could be located across the road. Boat access at the assembly area is desirable; otherwise, the nearest boat ramp area could be used for boat access. A nearby boat ramp could also be used for diffuser assembly and then the diffusers could be towed on the water to the supply facility location. Part of the boat ramp and parking area would need to be closed to the public during construction.

Potential Maintenance Costs

Table TZ3 presents estimated maintenance costs. The diffuser has nothing visible on the water surface and is designed to resist damage. Porous hose diffusers have been installed and operated by TVA since 1994, with no need for diffuser maintenance. The diffusers are inspected from the surface at startup and at intervals during summertime operation to identify any problems. It is expected that the porous hose would need to be replaced approximately every 10 years. The line diffuser is designed to be re-floated for maintenance as needed and replacement of the porous hose could be accomplished in a matter of days.

Brownlee Oxygen Distribution System

	Diffuser Inspection	10 Year Diffuser Replace	Total Annual Cost
Maintenance	$5,000	$15,000	$20,000

Table TZ3: Estimated Maintenance Costs for Brownlee Transition Zone

Special Conditions and Concerns

- Relocation Transportability
    - The line diffuser is designed to be easily re-floated for maintenance and can be deployed in a different configuration as needed.
    - Extension of the oxygen input further downstream may require additional underwater supply piping and eventual relocation of the oxygen supply facility.
- Design of diffuser(s) in riverine conditions:
    - The location currently under consideration is occasionally in the riverine portion of the reservoir during wet years and may be subject to high water velocities or sedimentation buildup.
    - Seasonal operation of the diffusers should clear the porous hoses.
    - Heavy anchoring and low profile design of the line diffuser is expected to hold the diffuser in place during high flows.

Recommendations

- Additional diffusers should be considered for deployment downstream of the oxygen supply facility:
    - To provide control of oxygen placement over up to a total of over 4 river miles.
    - Avoid initial relocation costs to move diffusers downstream.
- Supply pipe routing
    - Stainless steel oxygen supply pipelines are recommended to avoid additional measures that may be required to protect HDPE piping from traffic loads, vandalism and UV degradation.

Oregon
Theodore R. Kulongoski, Governor

Department of Environmental Quality
2146 NE 4th Street, Suite 104
Bend, OR 97701
(541) 388-6146
Eastern Region
Bend Office

January 10, 2005

Ralph Myers
Water Quality Program Supervisor
Idaho Power Company
P.O. Box 70
Boise, ID 83707

Pete Newton
Idaho Power Company
P.O. Box 70
Boise, ID 83707

Re: Hells Canyon Complex Hydroelectric Project; FERC Project No. 1971; ODEQ Comments on Draft Response to Additional Information Requests for WQ-1 (Dissolved Oxygen Augmentation), WQ-2(a) (Temperature Control, Conceptual Design Report), and OP-1(e) (Operational Scenarios – Water Quality).

Dear Mr. Myers and Mr. Newton:

The Oregon Department of Environmental Quality (ODEQ) has received a number of compact disks (CDs) containing Idaho Power Company's (IPC) draft response to additional information requests (AIRs) issued by the Federal Energy Regulatory Commission (FERC). As requested, ODEQ has reviewed and prepared the enclosed comments on IPC's draft response to the three draft AIRs responses identified above. ODEQ understands that per FERC's request, our comments will be considered and included in IPC's final response to AIRs.

Considering the tight timeline for requested comments, these comments are being provided by electronic facsimile as well as by overland mail to meet the January 10, 2005 deadline.

Please contact me if you have any questions or need clarification regarding these comments.

Sincerely,
Paul C. DeVito

Paul A. DeVito
Hydroelectric Specialist

PAD/rm
Enclosures:
  Attachment 1: Comments on AIR WQ-1 (Dissolved Oxygen Augmentation)
  Attachment 2: Comments on AIR WQ-2(a) (Temperature Control, Conceptual Design)
  Attachment 3: Comments on AIR OP-1(e) (Operational Scenarios – Water Quality)

Attachment 1

ODEQ Comments on AIR WQ-1 (Dissolved Oxygen Augmentation)

Section	Comment
1.	While IPC's final license application (FLA) indicates a proposal to inject 1450 tons/yr of oxygen into Brownlee Reservoir to address IPC's anticipated Total Maximum Daily Load (TMDL) load allocation for dissolved oxygen (DO), ODEQ recognizes that IPC's revised proposal to inject 1125 tons/yr is consistent with the approved final TMDL load allocation for the Hells Canyon Complex (HCC).
2.1.	ODEQ agrees that the 2001 Mobley Engineering Report regarding the August 2000 studies conducted on Brownlee turbine unit #4 should be considered in the context of subsequent study results and methods employed by IPC's Power Production Department in 2004. Per IPC's indicated results, it appears that the FLA proposed turbine venting, a relatively low-cost alternative involving the installation of 'hub baffles', would not provide DO benefits to any of the similarly configured turbine units 1 through 4. What is the basis for the stated assumption that the addition of the FLA proposed blower system on turbine unit 5, combined with turbine venting, would provide an increase in DO concentration of the Brownlee Reservoir discharge of 1 mg/L? Is the specified 1 mg/L a calculated or estimated concentration? Under what conditions of turbine inflow DO concentration would this level of improvement be expected? Is the stated 1 mg/L improvement based upon the total contemporary discharge from Brownlee Reservoir or only that discharging from unit 5? The draft report identifies that IPC has, in addition to investigation turbine venting, has also investigated turbine aeration at units 1 through 4 at the Brownlee Powerhouse. What are the details of the DO improvement and associated costs for turbine aeration of units 1 through 4? Please specify how the DO improvement and costs numbers were developed. It is stated in the draft report that IPC is not considering proposal of this measure since such DO improvement would go beyond that necessary to satisfy the TMDL load allocation for DO. ODEQ would like to point out, however, that the TMDL did not evaluate IPC's DO impact to the Snake River downstream of the HCC, including contribution to seasonal non-attainment of Oregon and Idaho state water quality standard criteria for DO. Thus, IPC should seriously consider this and other DO improvement measures as a means of addressing IPC DO impacts in the lower river that are not provided for by complying with the TMDL load allocation alone. What would the expected impact on total dissolved gas be if forced air blowers were employed at the five different turbine units?
2.2.1.	ODEQ appreciates IPC's consideration of relevant factors relative to the conceptual

	siting of the Brownlee Reservoir DO injection system. As identified by IPC, during the early stages of TMDL implementation, significant improvement in the quality (nutrient and dissolved oxygen levels) of water entering the reservoir from the upper Snake River Basin may not yet be realized, and should be considered in the locating of DO injection system. However, as also noted, under conditions of higher flow years or improved influent water quality, locating the DO injection system further downstream within the reservoir may provide greater benefit than at the proposed centering at River Mile (RM) 325. White sturgeon and other sensitive fish species may realize significant benefit if the design and implementation of the injection system allowed for its annual relocatation. ODEQ requests that IPC explore alternatives aimed at overcoming the difficulties of annual relocation. If such investigation does not reveal viable options to allow for as-needed (pending flow and inflow water quality) annual relocation, the frequency and capability of such relocation should be specified.
2.2.2.1.	Considering costs and concern for high levels of nitrogen adsorption, as well as other identified criteria of concern, ODEQ concurs with IPC's conceptual proposal to inject pure oxygen as opposed to atmospheric gas to improve DO concentrations.
2.2.2.2.	Is bio-fouling a concern for the proposed diffuser system? If so, how will it be addressed? What special maintenance or precautions need to be employed to ensure the long-term proper operation of diffuser system and related injection facilities? Can necessary repairs be readily made in situ?
2.2.3.	As identified, the TMDL provides significant flexibility regarding the implementation of IPC's DO load allocation. Such intended flexibility was provided to allow adaptive management and to make the most of efforts to improve reservoir DO concentration and benefit impacted species. Ultimately, a DO management plan will need to be developed that documents how DO improvement measures will be adaptively managed/implemented to benefit water quality and impacted species. The conceptual plan appears to incorporate some desired adaptive management capability allowed for under the flexible TMDL load allocation including an annually-moderated, 10-year-averaged DO load allocation, and the capability to potentially relocate the injection system at some yet-to-be-identified frequency to address different flow years and influent water quality. ODEQ supports such an approach considering the factors identified above and also in consideration of inherent uncertainties related to effective water quality modeling of the system and predicted improvements.
2.3.1.	See also related comments provided for Section 2.1. The annual average estimated costs provided in the summary table do not comport with that of Table 4. The summary table total estimated annual average cost for the five units is $50,000 greater than Table 4. Do the estimated annual costs take into account times of non-operation of turbines? What would the additional annual costs be for further increments of DO improvement beyond 1 mg/L?
2.3.2.	What would the associated costs be for relocating or extending the conceptually proposed reservoir aeration system to address changing reservoir influent water quality and annual flow conditions (see comments to Section 2.2.1.)? Are there alternatives to the proposed system that would provide similar or greater DO benefit that would be less costly or difficult to relocate?

2.4.	While Figures 46 through 50 provide useful depictions of simulated hourly DO concentration in the Hells Canyon Dam discharge under proposed operations with and without reservoir aeration and turbine aeration, simulation in terms of percent concentration is also needed for comparison with the two states' DO water quality standards.
3.	The consultation record should clearly indicate that while a 30-day commenting period was provided, a collaborative forum for stakeholder discussion and input regarding the draft AIR response was not provided. ODEQ understands that IPC proposes to provide presentation and discussion of the final AIR response reports to stakeholders during settlement negotiations to clarify IPC's AIR final responses, provide for related discussion, and to aid the determination of any additional information needs or revised presentation. ODEQ believes this should be clearly articulated in the final report.

JAN 21 2005

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
525 NE Oregon Street
PORTLAND, OREGON 97232-2737

F/NWR5

January 10, 2005

Craig Jones, Project Manager
Idaho Power Company
PO Box 70
Boise, ID 83707

Dear Mr. Jones:

The National Marine Fisheries Service (NOAA Fisheries) is pleased to provide you with comments regarding Additional Information Request WQ-1 - (Dissolved Oxygen Augmentation), and WQ-2(a) - (Temperature Control, Conceptual Design Report). We look forward to working with Idaho Power Company in the coming months to further refine these concepts.

Sincerely,

Keith Kirkendall

Keith Kirkendall, Chief
FERC & Water Diversions Branch
Hydropower Division

cc: Ralph Myers (IPC)
Pete Newton (IPC)

NOAA Fisheries' Comments on Idaho Power Company's Response to FERC Additional Information Request WQ-1: Dissolved Oxygen Augmentation Draft Report.

January 10, 2005

NOAA Fisheries appreciates Idaho Power Company's (IPC) effort to comply with FERC Additional Information Request WQ-1 by providing analysis to better identify effective means of mitigating for the continued effect of the Hells Canyon Complex (HCC) on dissolved oxygen levels in the Snake River. To assist IPC in this effort, NOAA Fisheries offers the following comments.

General Comments

1. We appreciate that IPC has had relatively little time to develop this document. However, the lack of references to specific tables and figures in the text make this document very difficult to read.

Introduction

2. We support IPC's desire to fully implement its TMDL responsibility of 1125 tons/yr of oxygen, in keeping with its allocation in the final Snake River - Hells Canyon TMDL. However, we note that many of the examples referenced in WQ1 describe that initially, additional oxygen was necessary to overcome the effect of anoxic sediments resulting from decades of rotting organic matter. We urge IPC to assess the additional oxygen (or period of delivery) that would be necessary to overcome this likely obstacle to successful implementation.

Response to WQ-1(a)

3. We agree, based on the information provided, that turbine venting in units 1 – 4 would not effectively increase DO in waters released from Brownlee Dam. We therefore do not understand why IPC has continued to assume in its modeling that DO concentrations in outflows would be increased by about 1 mg/L, as a result (at least in part) of these same proposed structures. Is IPC confident that this improvement can be accomplished solely through the proposed blower system in unit 5?

Response to WQ-1(b)

4. Based on the information provided, it appears that the conceptual oxygen injection system would only be effective in elevating dissolved oxygen levels within a few miles of RM 325 under the low flow conditions modeled. While this will nominally meet the mandated TMDL requirement it will provide very little in

the way of increased oxygen levels downstream of Brownlee Dam (Figures 5 – 20 of the report). Simply meeting TMDL levels will not materially affect deficiencies in downstream DO levels, in the near term. NOAA Fisheries suggests that injecting dissolved oxygen in multiple locations – though more expensive – is likely to be a more effective means of providing "the most benefit under current conditions." Hopefully, an alternative that increases oxygen levels in a larger proportion of the reservoir and in downstream waters can be developed. We would encourage you to search for an additional suitable site near RM 316.

5. We agree with IPC's concept (see report at page 9) of building a robust system that could effectively deliver much more oxygen than is minimally required by the TMDL. As proposed, we understand that the delivery capacity of this system is 34.6 tons/day – double that needed to provide 1125 tons/yr as required in the TMDL. This modeling suggests that a more effective strategy for effectively improving dissolved oxygen levels might be to inject much more oxygen in low flow years and much less or none at all in high flow years. Such an operation could be tailored to meet the TMDL requirement by providing average annual deliveries of 1125 tons/yr. NOAA Fisheries supports the construction of a system that retains substantial operational flexibility (see report at page 10).

6. We support IPC's concept of tailoring operations to anoxic conditions within the reservoir as described on page 10 and Table 2 of the report

7. We have previously noted (see comment 2 above) the sediment oxygen demand that will likely impede the initial success of oxygen injection. We again suggest that IPC plan to inject additional oxygen during an initial operational phase to reduce the amount sediment oxygen demand. This action would also provide additional benefits with respect to the water quality parameters of concern evaluated in section 2.4.3 of the report.

Response to WQ-1(c):

8. IPC's analysis indicates that forced air blowers in Brownlee's turbine units are relatively expensive (compared to the oxygen injection system for example). We suggest that injecting oxygen, in combination with several of the proposed temperature control structures, might provide a more cost effective method of increasing dissolved oxygen levels in Brownlee outflows. Our comments in response to WQ-2 will provide more detailed suggestions with respect to this concept. Alternatively, IPC might consider discussing with the water quality and fisheries agencies (and other interested parties) the potential for funding upstream nutrient reduction activities as a more cost-effective alternative for meeting its TMDL allocation and increasing dissolved oxygen concentrations within and downstream of the HCC. Figures 46 through 50 of the report certainly suggest that such potential exists.

IDAHO POWER COMPANY
P.O. BOX 70
BOISE, IDAHO 83707

Ralph Myers
Water Quality Program Supervisor
Environmental Affairs

Phone 208-388-2358
Fax 208-388-6902
E-Mail rmyers@idahopower.com

December 7, 2004

Paul DeVito
Oregon Department of Environmental Quality
2146 NE Fourth Street, Suite 104
Bend, OR 97701

Re: Hells Canyon Additional Information Request WQ-1 (Dissolved Oxygen Augmentation)

Dear Mr DeVito:

In a letter dated May 4, 2004, the Federal Energy Regulatory Commission (FERC) issued to Idaho Power Company (IPC) an additional information request (AIR) for the Hells Canyon New License Application.

In AIR WQ-1 (Dissolved Oxygen Augmentation), the FERC requested specific information related to dissolved oxygen augmentation and directed IPC to consult with the Oregon and Idaho Departments of Environmental Quality and NOAA Fisheries. Therefore, IPC is requesting your review and comments regarding IPC's draft response to AIR WQ-1.

The draft response is enclosed on a CD. Because of the tight time constraints imposed by the FERC for this AIR, your comments must be delivered to me by no later than January 10, 2005 for inclusion in the final response to this AIR that will be filed with the FERC. Comments received after this 30-day review period may not be included in the final response.

Please contact me if you have questions or need clarification.

Sincerely,

Ralph Myers

Ralph Myers
Water Quality Program Supervisor

REM/da
Enclosure
Cc: Jim Tucker, IPC
Nathan Gardiner, IPC
Craig Jones, IPC
Jim Vasile, DWT

IDAHO POWER

IDAHO POWER COMPANY
P.O. BOX 70
BOISE, IDAHO 83707

Ralph Myers Phone 208-388-2358
Water Quality Program Supervisor Fax 208-388-6902
Environmental Affairs E-Mail rmyers@idahopower.com

December 7, 2004

Ritchie Graves
NOAA Fisheries
525 NE Oregon Street, Suite 500
Portland, OR 97232

Re: Hells Canyon Additional Information Request WQ-1 (Dissolved Oxygen Augmentation)

Dear Mr. Graves:

In a letter dated May 4, 2004, the Federal Energy Regulatory Commission (FERC) issued to Idaho Power Company (IPC) an additional information request (AIR) for the Hells Canyon New License Application.

In AIR WQ-1 (Dissolved Oxygen Augmentation), the FERC requested specific information related to dissolved oxygen augmentation and directed IPC to consult with the Oregon and Idaho Departments of Environmental Quality and NOAA Fisheries. Therefore, IPC is requesting your review and comments regarding IPC's draft response to AIR WQ-1.

The draft response is enclosed on a CD. Because of the tight time constraints imposed by the FERC for this AIR, your comments must be delivered to me by no later than January 10, 2005 for inclusion in the final response to this AIR that will be filed with the FERC. Comments received after this 30-day review period may not be included in the final response.

Please contact me if you have questions or need clarification.

Sincerely,

Ralph Myers

Ralph Myers
Water Quality Program Supervisor

REM/da
Enclosure
Cc: Jim Tucker, IPC
Nathan Gardiner, IPC
Craig Jones, IPC
Jim Vasile, DWT

IDAHO POWER
IDAHO POWER COMPANY
P.O. BOX 70
BOISE, IDAHO 83707

Ralph Myers		Phone	208-388-2358
Water Quality Program Supervisor		Fax	208-388-6902
Environmental Affairs		E-Mail	rmyers@idahopower.com

December 7, 2004

Kate Kelly
Idaho Department of Environmental Quality
1445 North Orchard
Boise, ID 83706-2239

Re: Hells Canyon Additional Information Request WQ-1 (Dissolved Oxygen Augmentation)

Dear Ms. Kelly:

In a letter dated May 4, 2004, the Federal Energy Regulatory Commission (FERC) issued to Idaho Power Company (IPC) an additional information request (AIR) for the Hells Canyon New License Application.

In AIR WQ-1 (Dissolved Oxygen Augmentation), the FERC requested specific information related to dissolved oxygen augmentation and directed IPC to consult with the Oregon and Idaho Departments of Environmental Quality and NOAA Fisheries. Therefore, IPC is requesting your review and comments regarding IPC's draft response to AIR WQ-1.

The draft response is enclosed on a CD. Because of the tight time constraints imposed by the FERC for this AIR, your comments must be delivered to me by no later than January 10, 2005 for inclusion in the final response to this AIR that will be filed with the FERC. Comments received after this 30-day review period may not be included in the final response.

Please contact me if you have questions or need clarification.

Sincerely,

Ralph Myers

Ralph Myers
Water Quality Program Supervisor

REM/da
Enclosure
Cc: Jim Tucker, IPC
Nathan Gardiner, IPC
Craig Jones, IPC
Jim Vasile, DWT

IDAHO POWER COMPANY
P.O. BOX 70
BOISE, IDAHO 83707

Ralph Myers
Water Quality Program Supervisor
Environmental Affairs

Phone 208-388-2358
Fax 208-388-6902
E-Mail rmyers@idahopower.com

December 7, 2004

Bob Lohn
NOAA Fisheries
525 NE Oregon Street, Suite 500
Portland, OR 97232-2737

Re: Hells Canyon Additional Information Request WQ-1 (Dissolved Oxygen Augmentation)

Dear Mr. Lohn:

In a letter dated May 4, 2004, the Federal Energy Regulatory Commission (FERC) issued to Idaho Power Company (IPC) an additional information request (AIR) for the Hells Canyon New License Application.

In AIR WQ-1 (Dissolved Oxygen Augmentation), the FERC requested specific information related to dissolved oxygen augmentation and directed IPC to consult with the Oregon and Idaho Departments of Environmental Quality and NOAA Fisheries. Therefore, IPC is requesting your review and comments regarding IPC's draft response to AIR WQ-1.

The draft response is enclosed on a CD. Because of the tight time constraints imposed by the FERC for this AIR, your comments must be delivered to me by no later than January 10, 2005 for inclusion in the final response to this AIR that will be filed with the FERC. Comments received after this 30-day review period may not be included in the final response.

Please contact me if you have questions or need clarification.

Sincerely,

Ralph Myers

Ralph Myers
Water Quality Program Supervisor

REM/da
Enclosure
Cc: Jim Tucker, IPC
Nathan Gardiner, IPC
Craig Jones, IPC
Jim Vasile, DWT

Idaho Power Company
Hells Canyon Complex (FERC Project No. 1971)
WQ-1 Additional Information Request - Consulting Entities List

Kate Kelly	Idaho Department of Environmental Quality
Bob Lohn	NOAA Fisheries
Ritchie Graves	NOAA Fisheries
Paul DeVito	Oregon Department of Environmental Quality

Date