APPENDIX E

RISK ASSESSMENT FOR THE SPILL PROGRAM DESCRIBED IN THE 2000 DRAFT BIOLOGICAL OPINION

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E.1 Executive Summary

This paper addresses the 120% dissolved gas ceiling in light of the findings of the “Spill and 1995 Risk Management” report (1995 report) prepared by the region’s fishery agencies and tribes, the findings of research before and during implementation of the 1995 Biological Opinion, and the results of the physical and biological monitoring program conducted from 1995 to the present. Two spill program scenarios are evaluated using the SIMPAS model, which compares the potential juvenile salmonid survival improvement due to increased spill against the risks of increasing total dissolved gas above the 110% water quality standard. NMFS concludes in this updated assessment that the risk associated with a managed spill program to the 120% total dissolved gas (TDG) level is warranted by the projected 4-6% relative increase in system survival of juvenile salmonids. Recent research and biological monitoring results support the findings of the 1995 report which predicted that TDG in the 120 to 125% range, coupled with vertical distribution fish passage information that indicates most fish migrate at depths providing some gas compensation, would not cause juvenile or adult salmon mortalities that would exceed the expected benefits of spillway passage. We find little evidence that this expected survival improvement would be reduced due to gas bubble trauma-related mortality. The NMFS also concludes that physical and biological monitoring of gas bubble trauma signs can continue to be used to reflect dissolved gas exposure in adult and juvenile salmon migrants.

E.2 Introduction and Background

Risk assessment is the comparison of alternative paths of action to determine the probability of an adverse outcome. The “Spill and 1995 Risk Management” report (1995 report) was based on a risk model described by (Rowe, 1997). In this model, risk is characterized and managed through identification of the hazards and the degree of exposure to the hazards associated with different paths of action. In the 1995 report two paths of juvenile fish passage are compared: a) juvenile fish are either routed through turbines and subjected to the hazards, physical changes in pressures, etc.; or, b) the juveniles can be routed over project spillways by increasing the volume of water spilled at the project. The main hazard involved in the second alternative is the potential effect of dissolved gas supersaturation and the debilitating, and potentially lethal gas bubble disease. The 1995 report found that, within limits, spill had merit when compared to turbine passage. As a result of that report the NMFS recommended spill to achieve 80% fish passage efficiency up to a gas level of 120% in the tailrace (and 115% in the forebay) at mainstem hydroprojects passing juvenile salmon.

The region now has five years experience in implementing the 1995 Biological Opinion spill program. There has been some additional dissolved gas research conducted. Moreover, there are now five years of physical and biological monitoring results available to indicate the actual results of the spill program adopted by NMFS in 1995. Finally, the NMFS SIMPAS model, which is used to estimate the projected survival effects of various management alternatives, was updated in 2000 with the most recent quantitative input to various fish passage functions. This model provides a means to predict the project and system survival effects for listed juvenile salmonids of different spill levels. The purpose of this paper is to investigate the risk to salmonids of TDG levels greater than the 110% water quality standard. This paper does not include an assessment of risk to other aquatic species. For further information on the risk to other aquatic species, see Schrank et al.1996 and 1997; Ryan and Dawley 1998; and Ryan et al. 2000.

E.2.1 1995 Spill and Risk Management Report

In 1995 a group of the region's agencies and tribes developed "Spill and 1995 Risk Management," a report evaluating the relative risks of alternate strategies for passage of juvenile salmonids at Columbia River basin hydroelectric projects. The two main passage routes scrutinized were passage through turbines and voluntary spill at the FCRPS projects. The work was done jointly by technical staffs of the Columbia River Intertribal Fish Commission, the Idaho Department of Fish and Game, the Oregon Department of Fish and Wildlife, and the Washington Department of Fish and Wildlife. Also contributing to the report efforts were the U.S. Fish and Wildlife Service, National Marine Fisheries Service and Fish Passage Center.

Spill has long been known as a valid and relatively safe strategy to increase passage efficiency and improve survival of juvenile migrants. However, spill generates dissolved gas supersaturation which represents a risk to fish if the gas level is too high. When the 1995 report was written, there had already been approximately thirty years of laboratory and field research on the subjects of spill, total dissolved gas (TDG) production, the biological effects of dissolved gas supersaturation, and other hydroelectric project effects on juvenile and adult salmonid passage. The 1995 report reviewed the research of spill, its effect on dissolved gas generation and subsequent gas bubble disease trauma (GBT) and mortality in fish. A mathematical assessment of relative risks was then conducted based on an analysis of the available quantitative information concerning direct fish mortality from both turbine and spill passage. The 1995 report concluded that, as long as spill-generated TDG levels did not exceed 120-125% supersaturation, the risk of passing juvenile salmonids through the spillways remained lower than the risk of passing juveniles through turbines. The 1995 assessment also indicated this same level of TDG would not harm adult salmon.

E.2.2 NMFS 2000 approach

The dissolved gas water quality standard was established in the 1970's by the Environmental Protection Agency. This standard is enforced by the appropriate water quality agencies within each of the states.

The dissolved gas standard is limited to a dissolved gas supersaturation of 110%, applies to all fish and aquatic life, and incorporates a margin of safety. Since the implementation of the first Biological Opinion, the states recognized the value of spill to increasing the survival of downstream migrants and have granted temporary waivers of the TDG standard to a level of 115% TDG in project forebays and 120% TDG in tailraces during the juvenile migration season. The pertinent question in this risk analysis concerns the increase in juvenile survival represented by the additional 5-10% of dissolved gas permitted by the temporary waiver limits.

The NMFS employed the SIMPAS model to evaluate the potential increase in juvenile survival due to the difference in spill levels generating TDG of 110% or 120% supersaturation. The SIMPAS model includes all of the current information on species-specific fish passage parameters including spill efficiency; fish guidance efficiency; spill/gas caps, turbine, spillway, sluiceway, and bypass survivals; and diel passage patterns.[1]

The increase in survival due to the added spill is compared to the risk potential due to the added 5-10% of TDG. This is addressed by reviewing the results of five years of monitoring TDG levels during 1995 - 1999 spill seasons and the biological reaction detected in the juvenile migrant population by the monitoring program. Additionally, the results of research during this same time period are reviewed to validate the monitoring program methods and verify the assumptions used in the SIMPAS modeling analysis.

E.3 1995 Turbine versus Spill Mortality Risk Assessment

E.3.1 Juvenile Salmonid Assessment

The presence of hydroelectric projects on the Columbia and Snake rivers impedes salmonid migrations (Raymond 1969, 1979). Passage of juveniles through turbines, bypass systems, and spill represent sources of injury and mortality (NMFS 2000a). For example, recent NMFS studies of turbine survival for yearling chinook in the Snake River produced estimates of 92.0, 86.5, and 92.7% at Little Goose, Lower Monumental and Lower Granite dams in 1993, 1994, and 1995, respectively. Steelhead survival from turbine passage at Little goose in 1997 was 93.4% (Muir et al., In review: No. Am. J. Fish. Mgt.).

The most benign method for improving passage at the projects is to pass fish over the project, through the spillway, avoiding the powerhouse altogether (NMFS 2000a; ISAB 1999). The range of spillway

[1] For a more complete description of the SIMPAS model and a listing of its passage parameters, see Appendix B of the NMFS draft 2000 Biological Opinion.

mortality for standard spillway structures is 0-2% (Whitney et al. 1997).

The 1995 report assessed the risks of turbine passage and spill as alternate routes of passage through FCRPS hydropower projects. Specifically, the 1995 assessment compared the anticipated mortalities from turbine passage with mortalities that could occur from elevated TDG due to spill and associated effects of gas bubble trauma (GBT). It was hypothesized that the mortality due to controlled dissolved gas levels from the NMFS spill program would be less than that due to turbine passage.

The methods used to accomplish this assessment required the estimation of turbine mortality under different river management (spill/no spill)schemes and estimation of mortality caused by TDG created by increased spill. The turbine mortality was then used as a benchmark to compare with the projected mortality from TDG under increased spill programs. At some level of TDG, juvenile mortality due to gas supersaturation will equal or exceed that due to turbine passage. Spill-generated TDG levels above that point would be increasingly detrimental to juvenile migrants.

Turbine mortality estimates were derived from 1992 Smolt Monitoring Program (SMP) data. The SMP data provided a measure of fish population size and timing. The numbers of fish passing through turbines were estimated by applying the fish guidance efficiencies identified in the Columbia Basin Fish and Wildlife Authority's Detailed Fishery Operating Plan to the population figures. The population numbers were also adjusted to reflect fish capture for the transportation program and for losses to the population from reservoir mortalities. Finally, the river project operations component of the assessment was chosen to represent three levels of spill:

1) Hydrosystem operated for power generation only (baseline, no spill)
2) Hydrosystem operated according to 1992 Biological Opinion spill
3) Hydrosystem operated to 80% fish passage efficiency (up to 115/120% TDG spill caps)

Each of the three operational scenarios provided an estimate of juvenile turbine mortality under the conditions described.

The estimates of mortality due to TDG were more difficult. In the mid-1990's the available bioassay determinations of lethal TDG levels had been conducted primarily in shallow water laboratory conditions. These research conditions are not representative of those experienced by migrating juveniles. The Columbia River is sufficiently deep throughout the FCRPS that migrants could benefit from depth compensation for supersaturated conditions. In 1995 many fisheries scientists believed depth compensation was a significant factor in determining fish responses to TDG.

Because of the depth limitation, the laboratory TDG bioassay data were not used in the 1995 assessment. Dissolved gas mortalities were estimated using the results of in situ field studies in which fish were exposed in live cages and held at specified depths. Therefore, the exposures and amount of depth compensation experienced by the test fish were more representative of the condition experienced by migrants. The dissolved gas mortality functions were calculated from data for coho, chinook and steelhead exposed at representative depths, to gas levels ranging from 110 to 140% and for time periods from 3 to 92 days. (Ebel 1969; Beiningen and Ebel 1969; Ebel 1971; Weitkamp and Turner 1974; Blahm et al. 1976; Dawley 1986; and Dawley and Toner 1994). The mortality function for dissolved gas was developed statistically and described the percent of fish mortality as a function of TDG. The analysis also included consideration of exposure duration, species and depth. The data were fitted to a logistical model.

The risk model used by the agencies and tribes in 1995 is demonstrated in Figure 1. This is a plot of turbine mortality (y-axis) against percent dissolved gas (x-axis). The calculations of mortality, in numbers of juvenile fish, estimated the difference in project mortality between a no spill (maximum turbine passage and mortality) and an 80% fish passage efficiency (FPE) scenario (minimum mortality due to maximized spill). The difference in mortality between these two extremes was termed a mortality "ceiling," and represents the expected benefit of 80% FPE spill up to the gas cap excluding TDG-induced mortality. The expected benefit in terms of number of fish is shown as a horizontal line in Figure 1. The sigmoid line in the figure is an example of a mortality function curve, which represents the estimated loss of fish due to TDG. The point where the turbine mortality line and gas mortality curve intersect determines the point where the mortality due to dissolved gas from spill equals that due to turbine passage. That is, additional spill and resulting gas would be predicted by the model to kill more fish than would turbine passage.

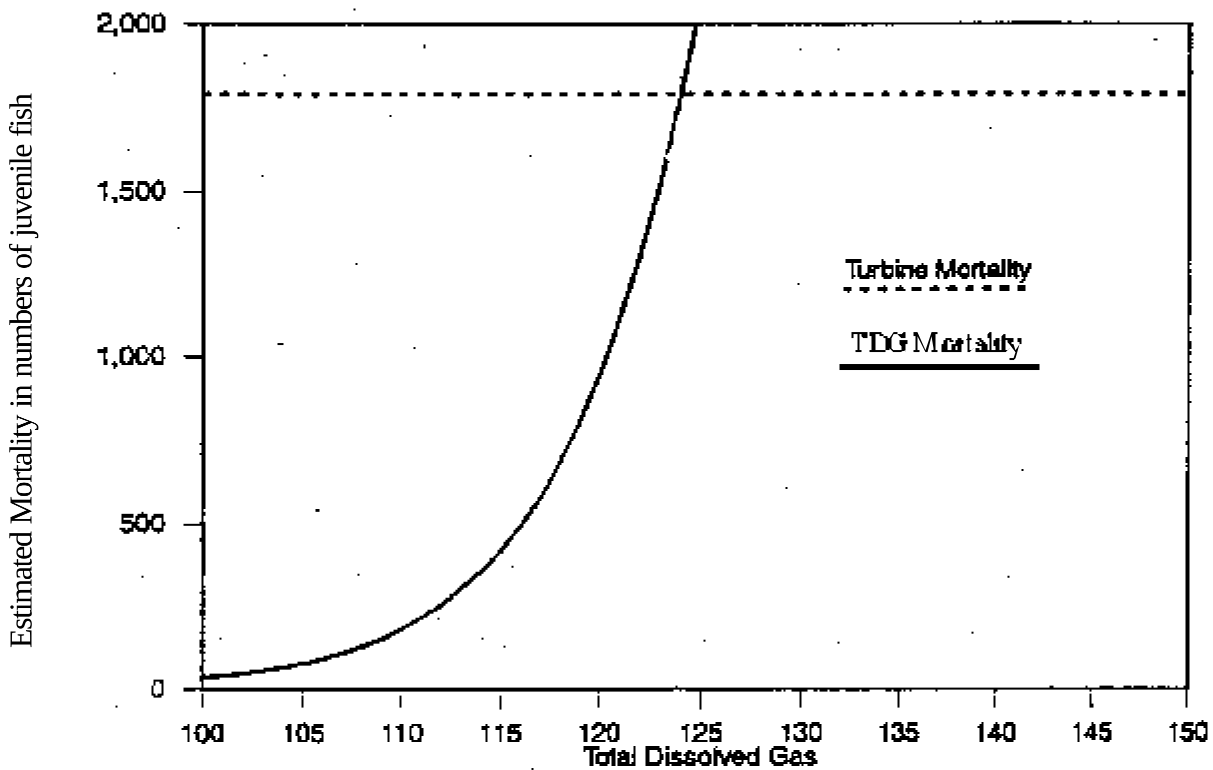

Figure 1. Risk Assessment Model Example

A shortcoming of the risk assessment model is determining how to incorporate exposure time in the mortality function. For this reason the 1995 report assessed risk in two time frames, i.e., the model assumed that dissolved gas mortality was either instantaneous at the project or after an exposure period equal to the travel time from Ice Harbor to Bonneville dam. Even with such a gross over-simplification, the dissolved gas concentration, at which no further benefit could be achieved through increasing spill, exceeded the 120% tailrace gas cap set by the NMFS 1995 Biological Opinion.

The 1995 report concluded that spill provided a safe route of project passage compared to turbines up to the spill levels that would generate a downstream gas equivalent to 120-125% TDG in the tailraces.

E.3.2 Adult Salmonid Assessment

The 1995 report estimated potential adult mortality due to elevated dissolved gas levels for chinook, sockeye and steelhead. Using published laboratory and field mortality data for these species, the assessment focused on a TDG range of 115 to 130% and on actual river conditions and spill levels during the spring and summer. The analysts made two assumptions at the outset: 1) there would be no dissolved gas-related mortality at gas levels less than 110%; and 2) only fish occupying water depths less than three meters would be vulnerable to gas bubble disease. The latter assumption factored in effects of depth compensation.

The model that was developed estimated the size of the population exposed, the exposure time, and the expected mortality for fish within three depth zones (0-1, 1-2, and 2-3 meters). Mortality was estimated by regression analysis for spring chinook, sockeye, and summer and winter steelhead.

The analysis projected no adult chinook, sockeye or steelhead mortalities at 115% or 120% TDG, assuming depth compensation. Mortality for summer chinook and sockeye was predicted to increase between 125% and 130% TDG. Predicted mortality of steelhead at 125% and 130% was less than those for chinook and sockeye due to the timing of migration of these species.

Another step taken in this 1995 analysis considered the fate of the juveniles protected by an increased spill program, i.e., those juveniles that were spilled and avoided turbine passage. The anticipated increase in numbers of juveniles was converted to an estimated survival to adult number. This adult equivalent estimate was also used to assess the impact of TDG on the adult population.

E.4 2000 Turbine Mortality versus Spill Mortality Assessment

The development of the draft 2000 Biological Opinion analyzed the biological effects of many actions, strategies and scenarios acting separately or in concert. To assist in this biological analysis, a Biological Effects Team (BET) was formed. The BET was one of five teams formed to assist in the Section 7 consultation process. It was agreed that the biological effects of juvenile salmonid passage measures, including spill, would be evaluated by the BET and NMFS using the SIMPAS model. The details of the biological effects analysis and the SIMPAS model are discussed in Appendix B of the draft 2000 Biological Opinion.

The SIMPAS model is particularly appropriate to apply to consideration of spill questions because it accounts for successful passage through each route available to juvenile fish, including turbines, sluiceway, surface and conventional fish bypass, and spillways. The model also accounts for juvenile fish transportation and reservoir passage. The model outputs are in terms of juvenile survival estimates at each project individually and on a system basis. The SIMPAS model used in the 2000 Biological Opinion analysis included the latest qualitative and quantitative information regarding spill efficiency, fish guidance efficiency, turbine survival, bypass survival, spill/gas caps, spillway survival, sluiceway survival and diel passage patterns (NMFS 2000 a-d).

In this analysis the spill scenarios were analyzed using the SIMPAS model. In these studies it was assumed that the draft 2000 Biological Opinion reasonable and prudent alternative (RPA) spill program is fully implemented. The RPA condition was selected because the long-term TDG goal (i.e., over the next 10 years or so), as stated in Section 9.6.1.7.1 on page 9-99 of the draft 2000 Biological Opinion, is to reach the 110% standard in all critical habitat in the Columbia and Snake river basins, including the mainstem. However, achievement of this goal in the long-term still requires juvenile fish system survival levels to be consistent with the performance standards for the mainstem FCRPS hydropower projects (see Section 9.2.2.2.1 of the draft 2000 Biological Opinion).

The spill conditions used in the SIMPAS model reflect current state water quality guidelines. The present Washington and Oregon water quality limit for TDG is 110%. Each year since 1995 the states have temporarily waived the 110% limit and allowed spill to a gas level not to exceed of 115% in project forebays or 120% in the tailrace. The modeled spill volumes are based on the current Corps estimates of spill that are expected to yield the aforementioned levels of TDG supersaturation. A 1995 water condition was selected for these spill studies because it is considered an approximate average water condition.[2] In addition, the 1995 water year resulted in involuntary spill only at McNary dam.

For this assessment, SIMPAS survival modeling was conducted for juvenile spring chinook (yearling), juvenile fall chinook (subyearlings) and juvenile steelhead migrants under 110% TDG spill levels and under 115/120% TDG spill levels. The additional spill at the 115/120% TDG spill levels would provide a relative improvement in inriver system survival for juvenile spring chinook yearlings of 5.7%. Similarly, the increases in relative inriver system survival for subyearling chinook and juvenile steelhead are estimated to be 4.9% and 3.9%, respectively.

E.5 Summary of Biological Monitoring since 1995

The 1995 Biological Opinion called for physical and biological monitoring programs to accompany implementation of the spill programs. The purpose of the monitoring was to track and record spill, dissolved gas and effects on aquatic biota. Through the physical monitoring program, approximately 40 dissolved gas saturometers were deployed at various forebay and tailrace stations throughout the FCRPS. Some monitoring stations have also been established and operated by the Mid-Columbia Public Utility Districts.

[2] Specifically, the 1995 modified April-August runoff volume at Lower Granite Dam on the Snake River was 22.4 million acre-feet (maf), or 98% of average, while the April-August runoff volume for the Columbia River at The Dalles was 86.1 maf, or 94% of average.

The biological component of the monitoring program requires collection and examination of juveniles and adult salmonids for GBT. Juveniles are collected as the fish pass through the juvenile collection/bypass facilities at Lower Granite, Little Goose, Lower Monumental, Rock Island (a Mid-Columbia PUD project), McNary and Bonneville dams. The fish are inspected for fin, eye and lateral line signs of GBT. Adults are examined at Bonneville and Lower Granite dams. Adult examinations have also occurred at Priest Rapids and Three Mile (Umatilla River) dams. All adults are examined for signs of GBT in the fins and eyes. The detailed results of the physical and biological monitoring programs are reviewed in an annual report to the Oregon Department of Environmental Quality (ODEQ) (NMFS 2000).

E.5.1 Results of the Physical Monitoring Program, 1995 - 1999

The physical monitoring program results from 1995-99 need to be differentiated into two conditions to better understand the potential impact of the NMFS spill program on salmonids. The two spill conditions are: 1) a spill program managed or planned to provide Biological Opinion spill levels within 115/120% TDG; and 2) involuntary, or forced spill conditions. The first condition is controllable, i.e., spill for fish can be managed much of the time within the state water quality limits in average to below average runoff conditions, while the second condition is uncontrollable and is the result of average to above average runoff creating high river flows that exceed the hydraulic capacity of FCRPS powerhouses. The difference in these two spill conditions are reflected in the percentage of days during the spring and summer migration periods when TDG exceeded 120% and 130% in the tailraces of lower Snake and Columbia river dams. For example, 1995 was the only year during this period with near average runoff. The percent of days exceeding 120% and 130% TDG in 1995 was only about 8% and 2%, respectively. These exceedances were due to short periods of involuntary spill, and due to lack of gas abatement structures at Ice Harbor and John Day dams. Thus, most of the time during the 1995 migration period gas levels were managed to remain below 120% TDG.

That was not the case for the higher runoff years of 1996 through 1999. In most of these years there were stretches of days where the flows exceeded hydraulic capacity and caused involuntary spill. The highest runoff years were 1996 and 1997, which experienced 130% and 155% of average runoff in the Snake River and 122% and 121% of average runoff in the Columbia River, respectively. The 1997 April to August runoff volume at Lower Granite Dam on the Snake River, for example, was the third highest since 1928. During these two years, the percent of days exceeding 120% and 130% TDG was about 48% and 15-22%, respectively. Again, these exceedances were largely due to periods of involuntary spill. In 1998 and 1999, runoff was 112% and 119% of average in the Snake River and 98% and 118% of average in the Columbia River, respectively. During those years, the percent of days during the migration period exceeding 120% ranged between 16-18%, respectively, with only one day in 1998 exceeding 130% TDG. Most of those exceedances were due to periods of involuntary spill.

However, the tailraces of John Day and Ice Harbor dams regularly exceeded the state 120% waiver limit in 1995 through 1997. Additionally, Ice Harbor tailwater exceeded 130% almost 44% of the migration period in 1996, and the John Day tailwater exceeded that level about 48% of the time in 1997. This was largely due to the high runoff volumes and flows frequently exceeding the hydraulic limits of these projects, but also due to lack of gas abatement structures at Ice Harbor and John Day dams. The installation of gas abatement structures at both Ice Harbor and John Day dams in 1998 and 1999 contributed to the reductions observed in the gas levels in the tailwaters of those projects. For example, installation of gas abatement structures at both projects were effective in reducing the number of days exceeding the TDG waiver level on average by about 50 and 10 days, respectively, in both of those years.

E.5.2 Results of the Biological Monitoring Program, 1995 - 1999

The biological monitoring program has been implemented each spring and summer since 1995. The results from 1995-1999 are evaluated and presented in the NMFS annual reports to ODEQ (NMFS 1996 through 2000). On capture, the juvenile fish are anesthetized and examined for presence and severity of GBT signs. The severity of the signs is ranked according to the criteria in **Table E-1**, with Rank 3 and 4 classified as severe.

Table E-1. Gas bubble trauma criteria for ranking prevalence and severity of signs (NMFS 1997)

Rank	% area covered with bubbles
0	0
1	1 - 5%
2	6 -25%
3	26 - 50 %
4	> 50%

Gas bubble trauma signs, i.e., bubbles and blisters in the fins, eyes, gills, lateral line, mouth and skin, have been recognized since the late 1960's. However, no clear correlation has been made between the various signs and mortality. Although it is generally accepted that the proximate cause of death in fish is gill emboli (Maule et al. 1997), a non-lethal technique has never been developed to examine gill lamellae. Therefore, fin bubbles continue to be the sign conventionally used to monitor and rank for biological effects of TDG supersaturation.

An important application of the GBT ranking system is management of the Biological Opinion spill program. Early in the spill program implementation it was determined that action to reduce voluntary spill and the level of TDG would be initiated if more than 5% of the fish examined exhibited bubbles covering 25% or more (Rank 3) of the surface of any unpaired fin, or if 15% of the fish examined show any bubbles on unpaired fins. These are referred to as the spill program "action levels." These action levels incorporate a margin of safety and are based on uncertainties raised in earlier USGS-BRD research (Maule et al. 1997a and 1997b). These studies indicated significant mortality did not occur in the test fish until approximately 60% of the exposed population exhibited bubbles in the fins or 30% displayed bubbles covering 25% or more of any unpaired fin. The action levels were then reduced primarily because the research results thus far have indicated a substantial uncertainty between fin bubble percentage and the onset of mortality.

Table E-2. Summary of Severe GBT signs monitored at Lower Granite, Little Goose, Lower Monumental, Ice Harbor, McNary, John Day and Bonneville Dams.

Year	# of Fish Examined	# of Severe Signs	Percent
1995	71,230	0	0.00
1996	38,925	47	0.12
1997	42,751	117	0.27
1998	46,498	6	0.01
1999	25,184	0	0.00

The data in **Table E-2** were reported in the 2000 NMFS annual report to the ODEQ. Reported is the number and percentage of the juveniles with severe GBT signs (Rank 3 or 4) that were observed in fish collected during the past five years. From **Table E-2**, incidences of severe signs occurred primarily in 1996 and 1997. The management strategy for the spill program is to reduce spill in response to occurrences of these severe signs. This has never happened during managed, or voluntary spill conditions. For example, in 1996 and 1997, when severe GBT signs were recorded, spill reduction was not an option due to the high runoff conditions that exceeded hydraulic capacity of FCRPS powerhouses. There were also six instances of severe or action level signs in 1998. These occurred during the early part of the spill season when flows were large and the spill that was responsible for the elevated TDG was again due to involuntary conditions (Filardo, personal communication).

The Smolt Monitoring Program in 1995 through 1999 has collected and observed a total of 192,832 juvenile salmonids for signs of gas bubble trauma in the mainstem Snake and lower Columbia rivers. Of the fish observed, a total of 3,033, or 1.6%, showed some signs of gas bubble trauma in their paired fins. The magnitude of the yearly incidence of signs was related to the magnitude of exposure to total dissolved gas. For 1996 and 1997, the higher levels of total dissolved gas observed were associated with higher percentages of signs of gas bubble trauma in salmonids (3.2 to 3.3%). Whereas, in 1995, 1998 and 1999 with lower levels of total dissolved gas, the percentage of fish showing signs ranged from only 0.04 to 0.7%.

Figures E-2 and E-3 depict the results for yearling chinook and steelhead sampled in the lower Snake and lower Columbia rivers that were observed with signs of GBT and displays them relative to the gas levels experienced and the resultant ranked response. From the graph it is apparent that few fish that were exposed to total dissolved gas levels below 120% exhibited GBT signs. However, fish with signs of gas bubble trauma that were exposed to gas levels greater than 120% showed an increasing trend in both incidence and severity. The more severe signs of Rank 3 follow a similar pattern but do not begin to appear until TDG exceeds 116-120%. Rank 3 signs become more prevalent above 131% TDG. However, these more severe signs affect only about 0.5% of the fish collected throughout the five years of the monitoring program.

Steelhead sampled through the Smolt Monitoring Program over the same five-year period that displayed signs of gas bubble trauma showed exactly the same trends in incidence and severity as did the chinook. As with the chinook, Rank 3 signs become more prevalent above 131% TDG and only affect about 1% of the fish collected throughout five years of the program.

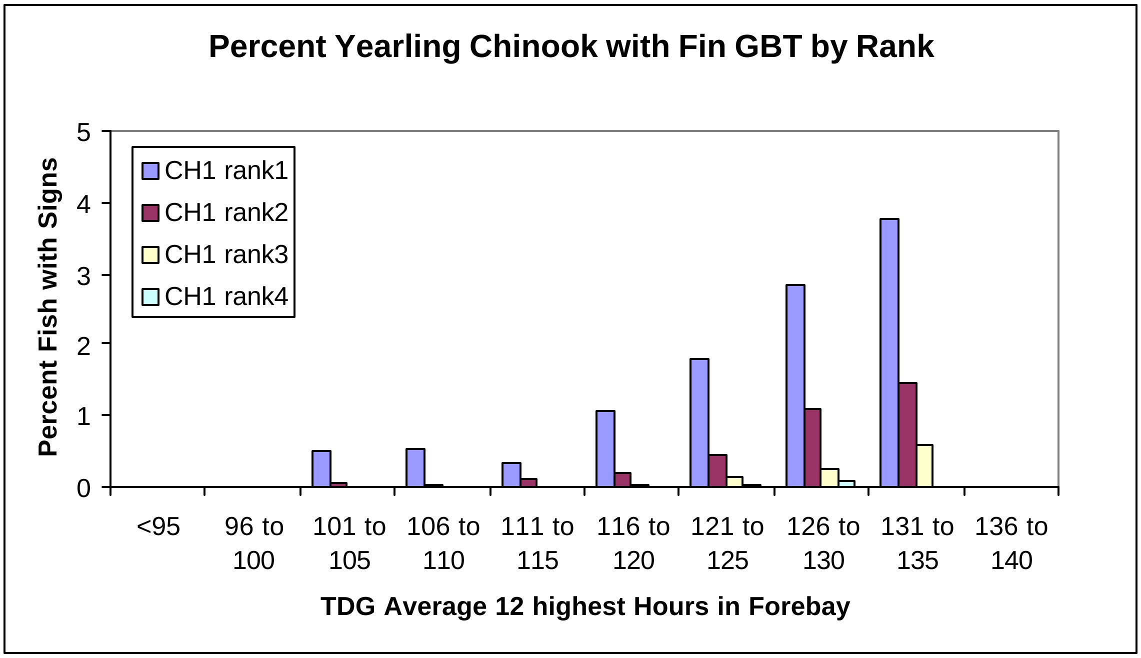

Figure E-2. The percent yearling Chinook salmon examined for GBT during 1995-99 that exhibited fin bubbles of rank 1 through 4 versus forebay TDG levels (average of 12 highest hours) measured the day the fish were examined (Rock Island Dam monitoring not included).

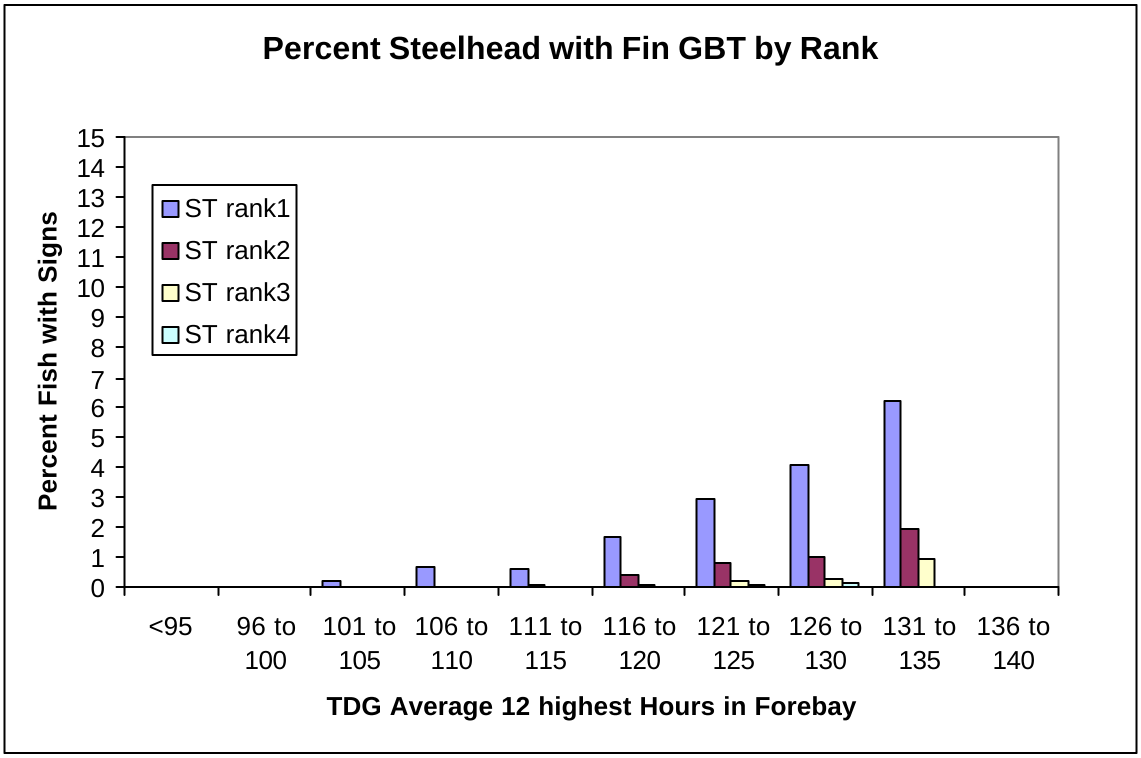

Figure E-3. The percent of Steelhead examined for GBT during 1995-99 that exhibited fin bubbles of rank 1 through 4 versus forebay TDG levels (average of 12 highest hours) measured the day the fish were examined (Rock Island Dam monitoring not included).

E.5.3 Adult Monitoring

Since 1996 adult salmonids have routinely been examined for the effects of TDG exposure during their upriver migration. The fish have been collected at Bonneville and Lower Granite dams, and less regularly at Ice Harbor, Priest Rapids and Three Mile dams. Due to the high value of each adult fish and potential mortality due to handling, adult sampling for GBT is conducted as an activity ancillary to other adult research. A summary of the results of four years of adult fish monitoring is shown in **Table E-3**.

Table E-3. Adult salmonid GBT recorded at FCRPS projects between 1996 and 1999.

Summary of adult salmonid GBT monitoring for 1996.

Site	Species	# Fish Examined	#Fish With GBT Signs	Percent Signs
Bonneville	Chinook	*	4	.2%
	Steelhead	*	3	.1%
	Sockeye	*	1	.05%
Lower Granite	Chinook	2652	4	.1%

* BON Total number of fish examined = 2026

Summary of adult salmonid GBT monitoring for 1997.

Site	Species	# Fish Examined	#Fish With GBT Signs	Percent Signs
Bonneville	Chinook	1042	5	0.5%
	Steelhead	336	24	7.1%
	Sockeye	648	101	15.6%
Lower Granite	Chinook	6312	5	0.1%
Priest Rapids	Chinook	280	9	3.2%
	Steelhead	95	2	2.1%
	Sockeye	852	36	4.2%

Summary of adult salmonid GBT monitoring for 1998

Site	Species	# Fish Examined	#Fish With GBT Signs	Percent Signs
Bonneville	Chinook	729	0	0.0
	Steelhead	260	0	0.0
	Sockeye	184	0	0.0
Lower Granite	Chinook	3755	4	0.1

Summary of adult salmonid GBT monitoring for 1999

Site	Species	# Fish Examined	#Fish With GBT Signs	Percent Signs
Bonneville	Chinook	745	0	0.0
	Steelhead	273	0	0.0
	Sockeye	184	0	0.0

Lower Granite	Chinook	3755	4	0.1

As in the juvenile monitoring, the spring of 1997 represented the period of highest dissolved gas and the most significant degree of GBT in adult salmonids since the start of the Biological Opinion spill program. In 1997, due to high runoff and forced spill conditions, TDG below Bonneville Dam was 135% or higher for 16 days and greater than 130% for 24 days. During the spring and early summer gas levels remained above 125% for an extended period in many sections of the river. Sockeye were the most affected in 1997 with 15.6% of the fish collected at Bonneville Dam displaying signs of GBT. At Priest Rapids Dam, 4.2% of the sockeye collected were also affected. No sockeye were collected at Lower Granite Dam. During this same period, the percentages of the chinook populations afflicted with GBT at Bonneville, Lower Granite and Priest Rapids dams were 0.5, 0.1 and 3.2%, respectively. In the others years of monitoring, i.e., 1996, 1998 and 1999, the number of fish collected at the sampling sites displaying signs of GBT was very small. In some cases, e.g., at Bonneville Dam, none of the fish caught showed signs of GBT.

The action levels established by NMFS for adults are more stringent than those for juveniles. The adult levels stipulate reduction of spill if two or more fish in a single day at a sampling site are observed to have external signs of GBT. Action would also be prompted if signs are found on one fish on two or more sampling periods at the same project. The results of the monitoring program indicate the only occasions when the action levels were surpassed occurred in the high spill years of 1996 and 1997. However, the large amount of involuntary spill in those years eliminated the ability of river managers to respond to the action levels by reducing spill and associated TDG levels.

E.5.4 Resident Aquatic Species

The sensitivity of resident fishes and invertebrates to TDG supersaturation was investigated in the early 1990's. Fish species observed for GBT signs included suckers, sculpins, sticklebacks and several minnows as well as crayfish, clams, and insect larvae. Gas exposure levels ranged from 117% to 130%. Only rarely were GBT signs observed (Toner, 1993). It was concluded that resident fishes and invertebrates are relatively tolerant of elevated TDG.

More recent studies have concluded that the current knowledge of TDG effects on resident fish allows reliance on a model to predict signs in resident species based on physical measurements of TDG. Ryan and Dawley (1998) investigated the responses of resident fishes held in net pens. They observed a relationship could be developed to predict signs at various TDG levels for resident species. Shrank et al. (1998) continued these studies and developed an algorithm model that provides the predictions of GBT signs in resident fishes where continuous TDG monitoring is available. They concluded that extensive biological monitoring of resident species is unnecessary.

E.6 Summary of Research Results

E.6.1 Mortality

Seasonal periods of high spill and gas supersaturation in the Columbia River basin system have been a problem for decades. The impact of high total dissolved gas on the aquatic species of the rivers has been recognized and well documented (Beiningen and Ebel 1970; Ebel et al. 1975; and Weitkamp and Katz 1980). The precise relationship between dissolved gas and fish mortality was unknown in the 1960's and 1970's. Early studies did, however, demonstrate a relationship between biological effects and TDG level, exposure duration, depth of exposure, water temperature, species, fish condition, and life stage (Ebel et al. 1975; Blahm et al. 1973; Dawley et al. 1973; Dawley and Ebel 1975; Blahm 1975; Weitkamp 1976; Weitkamp and Katz 1980; and Jensen et al. 1986).

Ebel et al. (1975) reviewed the findings of several bioassay studies and reported substantial fish mortality occurs at 115% TDG after 25 days of exposure in shallow water. Blahm (1973) recorded 98% (chinook) and 80% (coho) mortality at greater than or equal to120% TDG at a depth of 1 meter. However, in 2.5 meters depth at the same TDG level, mortalities were reduced to 8.7 and 4.2%, respectively. If fish are allowed access to deeper water during the tests, mortality will be observed at TDG levels greater than 120% after longer than 20 days. Dawley et al. (1975) found all species tested in deep water tanks reached 50% mortality in 24 hours at 130% TDG and no recorded deaths at 110% TDG in 24 hours.

Efforts to protect fish in the late 1960's and through the 1970's focused on determining a lethal TDG threshold. Most of the research investigated dissolved gas levels ranging from 110 to 140% TDG supersaturation. However, many of the early studies were conducted in shallow laboratory tanks and found mortalities at 115% TDG following 3-4 weeks of exposure (Dawley and Ebel 1975). Based on these early bioassays, the EPA set the dissolved gas standard at 110% TDG. However, it has been suggested that defensible gas limits for a free-flowing river environment could be set as high as 120% TDG (Weitkamp and Katz 1980).

E.6.2 Gas Bubble Trauma Signs

Columbia River fish managers realized early that the effects of TDG on fish populations could not be assessed merely on the physical measurements of dissolved gas. Knowledge of the incidence, severity and progression of GBT signs was essential.

An important finding in early research was that death from TDG exposure can occur in the absence of any external signs (Meekin and Turner 1974, Weitkamp 1975, and Bouck et al. 1976). Signs of GBT were found to be most severe in lower, marginally lethal gas supersaturation exposures (Bouck et al. 1976). Several researchers observed that fish that do not die from GBT may undergo a reduction in prevalence and severity of signs on return to air-equilibrated water (Meekin and Turner, 1974, Blahm et al. 1973, Weitkamp 1974, Knittel et al. 1980, and Dawley and Ebel 1975). Ebel et al. (1975) also noted that the signs of GBT disappear after death. The results from these early studies indicate that monitoring migrants for signs of GBT is necessary as the biological threshold indicator of TDG supersaturation stress. However, there is no clear set of signs, or a clear time correlation between TDG level and exposure duration, that allows prediction of impending fatality.

The signs of GBT in adults are like those observed in juveniles. These include emphysema, circulatory emboli, tissue necrosis, and hemorrhages in brain, muscle, gonads and eyes (Weitkamp and Katz, 1980). Nebeker et al. (1976) found death in adults was due to massive blockages of blood flow due to gas emboli in the heart, gills and other capillary beds. Investigators in the 1970's reported finding many and varied lesions in fish exposed in the 115 - 120% TDG range in shallow water. At higher gas exposures, e.g.,120 - 130% TDG, death frequently ensued before appearance of GBT signs (Bouck et al. 1976). External signs of GBT, e.g., blisters forming in the mouth and fins of fish exposed to chronic high gas often disappeared rapidly following death. The signs were largely gone within 24 hours (Countant and Genoway 1968).

Recent studies have pursued the relationship of exposure to TDG supersaturation and the presence, progression, severity and relevance of GBT signs, especially as related to the monitoring program. Maule et al. (1997) found that no single GBT sign can be relied on as the sole precursor of lethal conditions in the field. However, GBT signs did worsen with longer exposure to the conditions. However, it is necessary to better understand the severity and prevalence of signs in several tissues and relate it to exposure time and adverse reactions. The conventional signs used in GBT studies and monitoring are the lateral line, fins, and gill filaments.

According to Maule et al. (1997a), Elston et al. (1997), and Hans et al. (1999), and Mesa et al. (1999), each of the following tissues manifests unique tissue bubble characteristics:

Lateral line	Earliest tissue to display signs
	Signs may disappear quickly
	Progressive worsening with time
	Low degree of individual specimen variation
	Progressiveness of sign is indicator of exposure severity
	May not be relevant in chronic exposure to low TDG
Fins	Bubbles may not develop in acute exposure
	High prevalence in most exposures
	Progressive worsening with time
	Bubbles are persistent
	Quantitative ranking of severity difficult
Gills	Bubbles proximate cause of mortality
	Little progression with time
	High degree of variation
	Poor predictors of severity
	Difficult to observe and quantify

Bubbles may collapse easily on recompression

Maule et al. (1997) reviewed the implications of their findings with lateral line, gill and fin signs as they might relate to monitoring programs. In their findings, lateral line bubbles were often the first observed, showing progression with exposure and displaying little variation between specimens, but developing slowly under chronic, low gas treatments. Gill bubbles were usually the likely cause of death but do not progressively worsen. Individual variations were high in gill bubbles. Although fin bubbles are prevalent and worsen with time, the practical use of fin bubbles as an indicator is hindered by lack of a rigorous quantitative method for evaluating severity. Mesa et al. (1999) summarized the relationship of the findings of studies of GBT signs. Mesa pointed out the usefulness of the progressive nature of signs to monitoring programs but also highlighted the following impediments:

1. Variability in persistence of GBT signs
2. Inconsistent relation of GBT signs to mortality
3. Insufficient knowledge of relation between exposure history and GBT sign development
4. Extreme amount of variability of GBT signs

In spite of this, Maule et al. (1997) observed that GBT is most often progressive and its severity is a function of TDG level and exposure time. If a group of fish is exposed to TDG supersaturation for a sufficiently long period, the outcome is not in question. Signs of GBT will develop. Therefore, careful, rigorous monitoring of a population of migrants as they move through the FCRPS will detect GBT. If the TDG is low and the passage time exceeds the threshold time for development of signs, the juveniles will have moved beyond dissolved gas effects of the river.

E.6.3 Depth Compensation

Gas solubility increases with increasing pressure. For each meter of depth there is a 10% reduction in the TDG saturation level relative the surface saturation (Weitkamp and Katz, 1980). By the mid-1970's, several researchers had gathered information suggesting that depth compensation occurs and has the biological effect that gas solubility calculations would predict. Weitkamp (1976) observed that juvenile salmonids held in live cages up to 4 meters deep in the Columbia River suffered no mortalities in test ranges from 119 to 128% TDG. Dawley et al. (1975) conducted tests in a 10 meter deep tank and found no steelhead mortality at 130% TDG and no spring chinook mortality at 133 % TDG. GBT signs were noted in both species, however.

The advances of technology have provided opportunity to study depth compensation more closely. Using a pressure-sensitive radio frequency tag accurate to 0.3 meters of the true depth, Maule et al. (1997) observed that salmonids may migrate at protective depths. In this pilot study few fish were successfully tagged and tracked. The data were insufficient for statistical analysis. However, the results suggested that the depth of the tagged fish would compensate for a surface TDG level of up to approximately 124%.

In subsequent years Beeman et al. (1998 and 1999) employed depth-sensitive radio tags to determine depths of juveniles from Ice Harbor to McNary Dam. The 1997 studies indicate that fish were tracked at depths between 1.8 and 2.5 meters in water with a surface TDG level of 120%. The depths recorded would have provided protection and reduced the risk of gas bubble disease. The next year the median depth of juveniles in McNary pool was sufficient to protect fish from TDG levels of between 117-124%. This level of depth compensation is enough to negate predicted mortalities from the mid-1970's laboratory studies conducted in shallow water. It also may explain why the annual biological monitoring program detects fewer GBT signs than might be expected. The authors of these studies concluded a voluntary spill program with gas caps of 115% in forebays and 120% in tailraces can be expected to prevent gas bubble trauma in juvenile chinook and pose little threat to the more sensitive steelhead.

Gray and Haynes (1977) reported that spring and fall chinook adults implanted with pressure-sensitive radio transmitters swam deeper in gas supersaturated water than in air-equilibrated conditions. They concluded that 89% of the test fish migrated at a depth providing compensation for gas levels that would normally prove lethal.

More recent studies have employed a data storage radio tag to record both the depth and temperature history of migrating adults. Preliminary analysis of results indicate the tagged fish migrate in the depth range of 1.5 to 4 meters, some deeper than 4 meters. Thus it appears that the majority of the chinook or steelhead adults may be negotiating the lower Snake River at compensatory depths for gas levels to at least 130% (Bjornn, personal communication, 2000).

E.7 Conclusions

The term “risk assessment” was described earlier as the comparison of alternative paths to consider the probability of adverse action. It was determined using the SIMPAS model that a relative increase of 4-6% system survival of juveniles would result from spill up to the Biological Opinion gas cap, i.e., 120% TDG, as compared to spilling to the 110% water quality standard. The question is whether there is any adverse effect resulting from the 10% increase in TDG. The potential adversity of this TDG increase can be judged by reviewing the findings of the 1995 report, the information gained in the last five years of monitoring, and from relevant research.

The risk assessment in the 1995 report developed an estimate of turbine mortality and compared it to a dissolved gas mortality curve. The report concluded that, at the point where projected dissolved gas mortality equaled the lethality of turbine passage, higher TDG levels due to additional spill beyond a certain point would be counter-productive. That point ranged between 120-125% TDG. The assessment was conducted for spring, summer, and fall chinook, sockeye and steelhead -- the salmonid species of concern. The 1995 report concluded that a spill level of 120-125% TDG represented a conservative, controllable and reasonable risk when compared to turbine passage. Since a managed Biological Opinion spill program will result in gas up to120% TDG, spill to this gas level is expected to provide a safer route of project passage as compared to turbine passage.

The 1995 report also strongly urged that monitoring programs should be established to track the physical dissolved gas and monitor for signs of GBT. The results of five years of physical monitoring have shown that total dissolved gas generated, as a result of implementing the Biological Opinion spill program, is adequately detected and recorded. During periods when water conditions provide an opportunity to implement voluntary spill to increase fish passage efficiency, the spill and resulting dissolved gas can be managed to comply with the temporary state dissolved gas waivers. In periods of involuntary spill, the sensitivity of the monitoring system records the frequency, intensity and durations of high levels of gas supersaturation as was seen in 1996 and 1997. The physical monitoring system can also demonstrate the beneficial effects of construction and operation of gas abatement structures. For example, following construction of the Ice Harbor and John Day spillway deflectors, the gas abating effects of these structures were illustrated in the physical monitoring data.

The biological component of the five-year monitoring program is consistent with the dissolved gas records. During periods when the TDG exceeds the waiver limits, a biological effect has been recorded in both the smolt and adult monitoring program (**Tables E-2 and E-3**). For example, severe signs (Rank 3) of GBT were restricted to the years 1996 and 1997 during the periods of highest involuntary spill, which resulted in TDG levels of 130% or more on many days. Although severe signs have been noted in the monitoring program, such instances were rare and confined to periods of involuntary spill with gas levels greater than the 120% TDG level.

Gas bubble trauma in juvenile salmonids can be observed at all gas levels. Even at a relatively low gas supersaturation level of 110%, signs may develop if the exposure length is long and water depth is shallow. However, based on five years of data from the biological monitoring program, the average incidence of GBT signs has been low. The accumulated data on GBT in chinook and steelhead indicate that few GBT signs are observed below 120% TDG. When fish with signs are exposed to gas levels greater than 120%, there is an increasing trend in sign incidence and severity. A similar pattern is observed in fish with the more severe Rank 3 and 4 signs. Only few fish with severe signs are detected until TDG approaches 130% and signs do not begin to increase in prevalence until TDG is between 121-125%. Finally, the overall number of fish affected with GBT signs proved to be less than originally assumed in the 1995 report.

The monitoring program for adult salmonids reflects a very similar profile of gas bubble signs and TDG relationship. For example, when the inriver TDG level is below 120% very few adult fish, in some cases no fish, display signs of gas trauma. The states of Oregon and Washington used this information, coupled with the extreme importance of adult migrants to the salmon recovery efforts, to dispense with continued adult monitoring (and associated handling) requirements in the water quality waiver stipulations in 1999. Investigators have observed adult tolerance to TDG and hypothesized it is attributable to the migration depth of adult salmonids. The depth-sensitive radio tags being used in adult migration studies are now providing corroboration that adults migrate at depths up to 4 meters and are afforded depth compensation protection from GBT. Thus NMFS believes the 120% tailrace gas cap of the 1995 Biological Opinion places no special TDG burden on adult migrants.

The results of the 1995-1999 monitoring program are consistent with many of the reports available in the dissolved gas and gas bubble disease research literature. In the late 1960's and the 1970's many studies were conducted using dissolved gas exposures in the 110 to 140% TDG range. In deep tank or field studies, few effects were noted below 120% TDG unless the exposure periods were very long, i.e., in terms of weeks.

From analysis of the biological monitoring program, NMFS concludes that biological monitoring of GBT signs can continue to be used to reflect dissolved gas exposure in adult and juvenile salmon migrants. The monitoring program also indicates that the prevalence of these signs in the adult and juvenile salmonid migrant populations is well below the action levels supported by GBT mortality research, as long as TDG levels are kept below the levels recommended in the draft 2000 Biological Opinion.

We also conclude the reason for the apparent contradiction between the current 110% TDG water quality standard limit and the Biological Opinion TDG limits is due to the effect of depth compensation resulting from the observed migrating depth of adult and juvenile salmonids. Finally, we conclude that the risk associated with a 10% exceedance of the 110% TDG standard is more than compensated for by the relative improvement of an estimated 4 to 6% FCRPS passage survival for juvenile salmon. In fact, we find little evidence that this survival improvement would be reduced at all due to GBT-related mortality.

In considering these conclusions, it should be kept in mind that this assessment was narrowly focused on salmonid migrants in the relatively deep water mainstem reaches of the Columbia and Snake rivers and was set against the mitigating factor of improved system passage survival. The application of these conclusions towards a change in the national or state water quality standards would be inappropriate without additional research and monitoring data concerning other aquatic species and habitats.

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