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Walla Walla District

Numerical Model Analysis of System-wide Dissolved Gas Abatement Alternatives

Draft Report

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1 Introduction

The management of water resources in the Columbia River Basin requires attention to many complex economic, sociological, and ecological issues. One of the central issues is the impact of the Columbia and Snake River dams on the ecology of the river system. Of particular concern, are the impacts on anadromous salmonid species, several of which are listed as threatened or endangered. One of the current operational strategies to benefit migrating juvenile salmonids is focused on increasing spillway flows at these dams with the goal of reducing overall migration times and decreasing the number of migrants passing through turbines and other non-spill routes ((NMFS, 1995)).

Increased spillway discharges to aid fish passage, or to conform with flood or reservoir management rules, or to meet varying power generation demands also introduce supersaturated levels of dissolved gases into the river. The supersaturated gas levels increase the potential for violation of water quality standards (USEPA, 1985) and can cause fish to develop gas bubble trauma which can be fatal (Weitkamp and Katz (1980), Fidler (1988)). The evaluation of potential physical modifications to the dams or alternative operational strategies requires quantitative understanding of the linkages between dissolved gas production mechanisms, project operations, dissolved gas transport, water quality criteria, and the exposure of fish to potentially harmful levels of dissolved gases.

The U. S. Army Corps of Engineers Dissolved Gas Abatement Study (DGAS[1]) is examining measures to reduce dissolved gas produced by the eight federal hydroelectric dams on the Lower Columbia and Snake Rivers. These measures include a number of structural and operational modifications to the dams to reduce dissolved gas concentrations produced by spillway discharges and thus move toward meeting water quality criteria and reduce potential mortality from gas bubble trauma. Implementation of these measures may also provide additional operational flexibility to increase spillway discharges for fish passage purposes.

DGAS will use the relative performance of each alternative measure in reducing dissolved gas concentrations as one basis for comparing the various alternatives. During FY1998, numerical models of river hydrodynamics, dissolved gas transport, and gas bubble trauma were developed. In this study, the numerical hydrodynamics and gas transport models were used as the tools to perform the comparative analysis of the different gas abatement alternatives for the Lower Columbia and Snake River systems.

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1.1 Background

A framework for the quantitative analysis of gas abatement alternatives must include the following elements: dissolved gas production (source-term), transport in the environment, exposure of

[1] Acronyms and abbreviations used in the document are listed and defined in appendix A

species of concern, and risk assessment. Each of these elements are linked at the “small” scale of individual reservoirs and the larger scale of the entire river system.

The production of dissolved gas, or the source-term, at each individual dam is a function of the structural configuration of the project spillway and stilling basin, tailrace bathymetry, and project operations. Field observations at Columbia and Snake River projects indicate that gas production is primarily related to spill bay discharge and tailwater depth. Spillway gas production does not appear to have a strong relationship to the gas concentration in the upstream forebay. Observations also show that flows through the powerhouse pass through upstream forebay total dissolved gas (TDG) to the downstream tailrace with little change in concentration. Thus, the spillway discharges act to erase the influence of TDG introduced from upstream projects and powerhouse discharges pass forebay TDG through to the tailrace. Therefore as spill flows become a higher percentage of the overall river discharge at a given project, TDG in the receiving reservoir becomes dominated by local gas production and increasingly less “connected” to operations at upstream projects. Effectively, TDG in the river system has a memory of upstream inputs which limits the downstream range of effectiveness of gas abatement measures implemented at projects upstream of a particular reservoir as spillway discharges increase.

Gas production relationships for dams on the Lower Columbia and Snake Rivers have either been physically-based (mechanistic) or observational-based (regressions). Examples of attempts to formulate mechanistic production equations are provided in the works of Roesner and Norton (1971) and more recently by Geldert et al. (1998). In DGAS, the regression approach based on field measurements of TDG has been adopted ((USACE, 1999)).

Field observations have revealed the potential importance of another process that, while strictly speaking is a transport process, has been included in the gas production element. This process is the entrainment of water discharged through the powerhouse into the spillway flow. The high-velocity of the spillway flow relative to the adjacent powerhouse flow creates a jet. One of the fundamental properties of jets is that they entrain ambient fluid ((Fischer et al., 1979)). Although dependent on several factors, the rate of entrainment, or dilution, of a simple jet is proportional to its initial discharge and distance from its point of origin. Field observations indicate that the mass transfer processes between bubbles in the spill flow and entrained powerhouse water act to bring the powerhouse water to the same gas concentration as created in the spillway. This decreases the dilution capacity of the powerhouse discharge and further acts to reduce system memory. Estimates of entrainment rates vary with each project (see Appendix B) and in some cases they are proportional to spillway discharge and in others they appear to be nearly constant, which differs from what occurs in a simple jet. Empirical estimates of powerhouse water entrainment are included in the gas production relationships, but additional investigations should be done to improve understanding of this process.

The relationships used to estimate dissolved gas production provide the source term which drives the other elements of the analysis. Thus, uncertainties in TDG production will propagate directly to the transport, exposure, and risk assessment elements. This is especially critical for the analysis of proposed abatement structures for which field observations currently do not exist upon which to develop reliable gas production relationships.

The dissolved gas produced at the spillway and passed through the powerhouse are transported downriver and the concentrations are affected by advection, dispersion, and dilution. Advection carries the TDG downstream with the velocity in the river channel which is principally function of the total river discharge, channel roughness, and bathymetry. Exceptions include the project tailrace and tributary confluences where the discharge distribution will alter the lateral velocity profile in the channel. Dissolved gas is mixed both vertically and laterally as it is advected downstream. Observations show that vertical mixing of TDG occurs very rapidly and that TDG stays fairly vertically mixed in the relatively shallow reservoirs in the Lower Columbia and Snake Rivers. Lateral mixing across the channel acts to mix TDG produced at a spillway with powerhouse or tributary flows. Given a sufficient distance downstream from a source, TDG will tend to become evenly distributed bank-to-bank across the river. Tributary flows can act to dilute or elevate mainstem TDG levels depending on the TDG concentration in the tributary.

Additional processes can act to create sources and sinks of dissolved gas in the river. Gas exchange at the air-water surface of the river is a process that acts as either a source or sink of dissolved gas. For supersaturated water, the exchange process acts to reduce TDG in the river and move it toward equilibrium with the saturation concentration of air. Rates of air-water gas exchange generally increase with wind speed as waves and turbulence are produced ((O'Connor, 1982)). Degassing through air-water exchange can be a very important process in reservoirs which are longer, shallow, or subject to more intense wind-waves. Biological activity can also act as a source/sink process.

The environmental transport models for dissolved gas are derived by applying the conservation of mass principle to a fluid volume. The numerical models transport TDG concentration, which is mass per unit volume. Measurements of TDG are made in units of TDG pressure (typically mmHg). The TDG production regression equations are also given in terms of TDG pressure. The conversion between TDG pressure (or saturation) and concentration (and vice versa) is a function of water temperature, pressure, salinity, and, for saturation, the barometric pressure ((Colt, 1984)). This creates an apparent source/sink process whereby the saturation of a fixed concentration of TDG will increase or decrease as the water temperature increases or decreases, respectively. Thus, the analysis framework must also consider the variation of water temperature. Note that similar fluctuations in saturation can be caused by changes in barometric pressure without any corresponding change in TDG concentration.

The exposure and risk assessment elements consider the effects of elevated TDG on the ecological system, water quality criteria, and the probability of occurance of harmful exposure or violations of quality criteria. These elements are strongly linked to physical locations in the river system and time. For example, spillway discharges typically vary over a single day and the highest TDG levels will be biased toward the shore where the spillway is located.

During the previous phases of DGAS, a set of simulation models and supporting data was developed to provide the quantitative analysis framework to encompass the elements described above. Hydrodynamics and environmental transport are simulated using two models: the two-dimensional depth-averaged (2D) MASS2 model and the one-dimensional cross-sectional averaged (1D) MASS1 model. The 2D model addresses the requirement to describe the lateral variation of TDG levels across the river which can impact fish and habitat. In addition, lateral variations of TDG must be accounted for because water quality criteria at the project tailwater are imposed at monitoring stations which are located along the shoreline. Since a 2D model of an entire season can be computationally expensive (in terms of computer time) to perform, the MASS1 model was employed to perform system-wide screening analyses, examine different operational rules, and provide a means to generate boundary conditions to reduced area 2D models. Fish exposure and gas bubble trauma models were developed that linked to the MASS2 model in order to account for lateral TDG variations.

In FY1998, the MASS2 2D depth-averaged model was applied to the Lower Columbia and Snake River systems ((Richmond et al., 1999). The 2D model simulates the depth-averaged (plan view) values of water surface elevation, velocity, temperature, and gas concentration. This model also includes the hydro-project (spillway and turbine) gas production relations that were developed by the USACE Waterways Experiment Station. The model was calibrated and verified using river velocity and gas concentration data that were collected by the DGAS field data measurement task (USACE (1999)).

The MASS1 model was developed in 1996 for an earlier phase of DGAS and it has been applied to several other studies in the Columbia River basin. For the Lower Snake River Feasibility Study, the MASS1 model was applied to simulate long-term water temperatures in the Lower Snake River for current impounded conditions and for unimpounded conditions with the existing dams removed ((Perkins and Richmond, 1999)). MASS1 is also currently being used to simulate unsteady flow conditions in the Hanford Reach of the Columbia River to assess the effects of Priest Rapids Dam operations on juvenile fish stranding. The time-varying water surface elevations simulated by MASS1 are one of the key components in a habitat suitability model for the Hanford Reach currently under development.

The original scope of DGAS included quantitative analysis of the biological benefits associated with different gas abatement alternatives. It was for this purpose that the Fish Individual Numerical Simulator (FINS) model (see Appendix G) and the dynamic gas bubble trauma model (DGBT) (Fidler (1998)) were developed. The FINS model links the detailed hydrodynamic simulations of river flow, dissolved gas transport, and water temperature from the MASS1 model with an individual-based model of fish migration to develop simulated dissolved gas exposure histories of individual fish. These exposure histories can be used to estimate levels of fish injury and mortality caused by dissolved gas supersaturation for different gas abatement alternatives using the DGBT model. These linkages were one of the key reasons that a two-dimensional modeling system was developed. After the initial development of the FINS and DGBT models, the quantitative analysis of biological benefits was changed to a qualitative analysis that would not require the use of these models (FINS and DGBT) for the alternatives comparison phase of DGAS. In this phase of DGAS, the parameterization of FINS was completed using radio telemetry data collected in the McNary pool. Note that FINS serves as a general framework that could be applied to the analysis of other anadromous or resident fish issues such as the effects of water temperature or predation.

1.2 Purpose

The purpose of this report is to present the results of the comparison analysis of the various scenarios using one- and two-dimensional models. These results provide supporting information that will be used to decide which of the scenarios is most appropriate for further study and/or installation.

Simulation results presented are intended to be used to perform a relative comparison of the various scenarios. They are not intended to represent or reproduce any historic TDG levels or event. The models were used only to rank the performance of the various scenarios.

The primary objectives of the project were:

- Develop methods for optimizing the computing environment (hardware and software) for system-wide and individual pool analysis of gas abatement alternatives. This objective also included methods of archiving, retrieving, and analyzing model outputs.

- Review the available historical operational records (regulated discharges) for the Lower Snake and Columbia Rivers. Recommend up to 3 periods of record for use in the baseline and analysis of gas abatement alternatives. The period of record encompasses the 5 month April-August time period.
- Complete the coding, parameterization, and verification of FINS migrant exposure model. FINS was parameterized using radio telemetry data collected in McNary pool during an earlier phase of DGAS. The FINS model was completed and simulations performed for the McNary pool only.
- Perform simulations using the 1D, 1D/2D hybrid , and full-pool 2D models for the current (1998) physical configurations of the dams. These are referred to as the “baseline” simulations.
- Perform simulations using the 1D and 1D/2D hybrid models for a set of gas abatement alternatives called the “fast-track” scenarios. The fast-track alternatives represent gas abatement measures that could be implemented in the near-future or could be given a high priority for implementation.
- Perform simulations using the 1D and 1D/2D hybrid models for a set of gas abatement alternatives called the “long-term” scenarios. The long-term alternatives represent gas abatement measures that would be more costly and take more time to implement, e.g. additional spillway bays, than the fast-track alternatives.

1.3 Organization

The report is organized into a main document and several appendices due to the large number of figures and tables that were required to present the results from the models. The main report describes the overall modeling approach, a fairly complete presentation of the one-dimensional model results, and example two-dimensional model results for only two pools (reservoirs). Separate appendices present additional details about the configuration of the models, complete results for the one-dimensional model application, complete results for the application of the two-dimensional model, and verification simulations for the one-dimensional model. The report documents are provided on the CD-ROM in Adobe PDF format which can be viewed and printed using the freely-available Adobe Acrobat Reader software.

In addition to the tables and figures presented in the main report and appendices, many additional analyses and statistical summaries of the model results were produced for use by the Water Quality Task of DGAS.

Two separate reports describing the selection of hydrologic period of record and completion of the FINS model were produced and reviewed earlier in the project. These companion documents are provided in electronic form (as Adobe PDF files) on the CD-ROM.

2 Model Alternative Comparison Strategy/Methodology

The simulations were performed to evaluate potential physical and operational modifications to reduce TDG production at lower Columbia and Snake River projects. Two hydrodynamic and water quality simulation models were used; the one-dimensional MASS1 and the two-dimensional depth-averaged MASS2 models. In addition, these two models were combined to form a hybrid 1D/2D model.

The MASS1 model was used to simulate flow, water temperature, and total dissolved gas (TDG) transport for several system-wide scenarios being evaluated by DGAS. Three sets of simulation scenarios are have been analyzed using the 1D model.

A hybrid model combining MASS1 and the MASS2 model was also used to simulate flow, water temperature, and TDG fate for a subset of the scenarios analyzed using MASS1. The results of these 2D simulations will be used to evaluate the spatial effects of the selected scenario within each pool, particularly on water quality criteria and habitat.

2.1 Simulation Models and Their Roles

2.1.1 MASS1 - One Dimensional Cross Section Averaged

MASS1 is a one-dimensional, unsteady hydrodynamic and water quality model for river systems. Being one-dimensional, the MASS1 model is only able to calculate cross-sectional average values of hydraulic and water quality conditions in the river and/or reservoir system. Thus, only single values of water surface elevation, discharge, velocity, concentration, temperature are computed at each point in the model at each time interval. Lateral and vertical variations of these quantities are not simulated. The MASS1 model simulates a branched (tree-like) channel system. Looped channel systems cannot be simulated with the current version of MASS1. A detailed description of the mathematical formulation of MASS1 is presented in Appendix B, Section 2.

The region simulated by MASS1 extended downstream from Dworshak dam on the North Fork of the Clearwater, Orofino on the Clearwater main stem (RM 41), below the mouth of the Grand Rhonde on the Snake (RM 169), and Priest Rapids dam on the Columbia (RM 397) to about Astoria on the Columbia (RM 21). This region is shown in Figure 2.1. In all, over 600 river miles of lower Columbia and Snake basins were simulated, including the effects of ten hydroelectric projects. Calibration and verification of MASS1 for this region is presented in Appendix F.

The 1D simulation of fast-track scenarios was the initial screening evaluation. Of the five fast-track scenarios, four were selected for further study, and were simulated with the hybrid 1-D/2-D model. Both models were used to simulate the three long-term scenarios.

2.1.2 MASS2 - Two Dimensional Depth Averaged

MASS2 is a two-dimensional-depth averaged hydrodynamics and transport model. The model simulates time varying distributions of the depth-averaged velocities, water, temperature and dissolved gas. The model is coded in standard FORTRAN90 and runs on a variety of platforms.

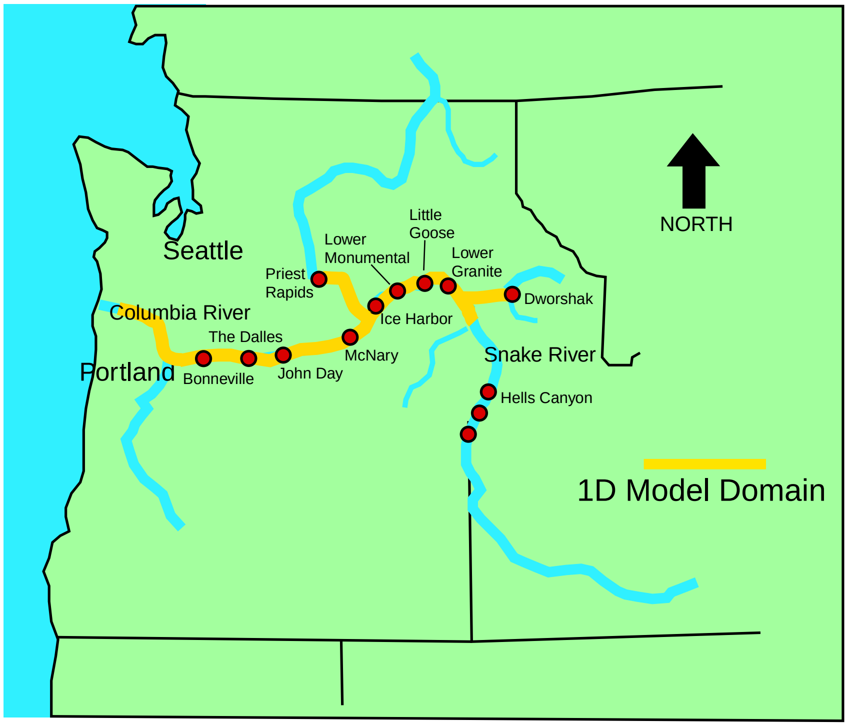

Figure 2.1: Region modeled by the one-dimensional model MASS1.

The model is an unsteady finite-volume code formulated using the general principles described by Patankar (1980). The model uses a structured multi-block scheme on a curvilinear grid system. The coupling of the momentum and mass conservation (continuity) equations is achieved using a variation of Patankar (1980) SIMPLE algorithm extended to shallow-water flows by Zhou (1995). A more detailed description of the model is presented in Appendix B, Section 3.

The region simulated by MASS2 extended downstream from the mouth of the Clearwater on the Snake River and Clover Island, near Kennewick, Washington, on the Columbia River to about Columbia rivermile 110 (near Portland International Airport). This area is shown in Figure 2.2. Within this region, each reservoir or river-reach was configured as an individual model domain. This allows for each domain to be simulated separately or linked together to cover a multiple reservoirs in the river system. The calibration/verification of MASS2 for this region is presented in Richmond et al. (1999).

2.1.3 One/Two-Dimensional Hybrid

The 1D/2D hybrid approach provides the most detail near the tail race of each project where TDG levels are highest and where their lateral variation across the channel is greatest. By reducing the extent of the model domain, the simulations can be performed for a relatively low computational cost.

The 1D/2D hydrbid model was used to further evaluate scenarios appearing to have the most benefit in the 1D simulations. The 1D/2D hybrid simulation was used to evaluate gas levels at

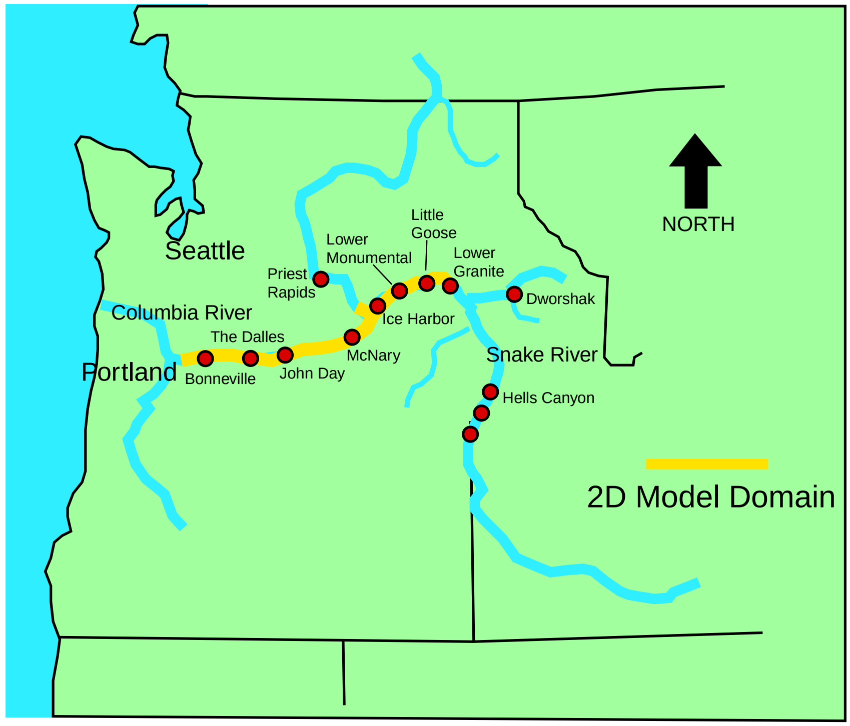

Figure 2.2: Region modeled by the two-dimensional model MASS2.

project tailwater FMS (fixed monitor station[1]) locations. The hybrid 1D/2D model simulates TDG transport and variation both longitudinally (along the river) and laterally (across the river) for a short distance (about 10 miles) downstream of each project, and only the longitudinal (1D) variation elsewhere. As described before, the 1D model simulates only longitudinal transport and variation, i.e. a single, cross-sectional average value of TDG saturation is estimated at a single river mile.

From the hybrid 1D/2D simulation and analysis, a single scenario was chosen to be further evaluated using a full 2D model of the lower Columbia and Snake River. In the full 2D model, both longitudinal and lateral TDG transport for the entire lower Columbia and Snake Rivers.

2.2 Scenario Formulation

A simulation scenario is defined by selecting a set of hydrology, meteorology, project structural configuration, and spill management rules. The scenarios use a consistent set of three hydrologic conditions composed of actual hourly flows at each project and the same meteorology for all cases (described in Section 2.2.1). Thus, the simulations compare different structural alternatives over a range of spill flows and the performance of different spill management rules for different runoff conditions.

The simulated scenarios were categorized into three sets. The first is a set of five scenarios in

[1] Section A.4 describes the water quality monitoring network.

which physical modifications would be made to individual projects. These modifications were selected from the "Fast-Track" list of dissolved gas abatement alternatives presented at the November 8, 1999 FFDRWG[2] meeting. The fast-track scenarios were composed of sets of project alternatives that were judged to be the best candidates out of a large set of potential alternatives studied in the DGAS 60% draft report (USACE, 1999). Section 2.2.3 describes these scenarios.

The second set were the "Long-Term" scenarios which included gas abatement alternatives which could be considered once the "Fast-Track" alternatives have been implemented. These alternatives would require a longer time to implement, involve dramatic project modifications such as additional spillway bays, but provide improved gas abatement performance. Section 2.2.4 describes these scenarios. These alternatives were also presented at the November 8, 1999 FFDRWG.

The third set compares the effects of varying spill management strategies or rules, and are called the "alternative spill" scenarios. In these simulations, the fraction of the river spilled was varied according to two different sets of management rules without any physical modification to the projects. These are described in Section 2.2.5.

All of these alternatives were compared to a baseline or "no-action" scenario meant to represent current system conditions. This scenario is documented in Section 2.2.2.

2.2.1 Consistent Comparison Conditions

Simulations were performed using the observed river flows for three separate spill seasons: a low flow season (1994), a medium-high flow season (1996) and a high flow season (1997). For the last 20 years of record at The Dalles USGS gage 1997 had the highest runoff volume during April through August ranking 20 out of 20 (or 20/20). The 1994 and 1996 years ranked 4/20 and 18/20, respectively. The 1994 and 1997 years were selected for study at the March 5, 1999 FFDRWG meeting. The 1995 year was selected as a medium flow year (ranking 11/20) and simulations using that hydrology were to be done following completion of the initial low and high flow cases. Instead of 1995, the 1996 year was selected to coordinate results from this study with other dissolved gas studies being undertaken by Bonneville Power Administration and the US Army Corps of Engineers, Seattle District.

Even though the historical low flow (1994) hydrology has small spill discharges, it is still important to include it to document the performance of the alternatives if spill discharge is minimal. This demonstrates the potential to achieve water quality standards for lower flow conditions.

Each alternative was simulated for the spill season, April 1 through September 1, of three years: low (1994), medium-high 1996), and high (1997) flow. Some key aspects of the simulations are as follows:

- Actual observed spill was used to estimate TDG production; no attempt was made to optimize the spill for any particular objective, or adjust the spill for current operation criteria (except for the alternative spill scenarios, Section 2.2.5).

- Spillway dissolved gas levels were computed in advance of the simulation, and so, used forebay fixed monitor temperature and barometric pressure (from 1997) to estimate gas concentrations.

[2] Fish Facilities Design Review Working Group

- The same meteorology (1997) was used for all three simulation years, so only hydrologic‘ differences between years would be present.

- The same upstream water quality (temperature from 1997 and 100% gas saturation) was used at upstream inflow points, so only hydrological differences between years would be present.

- Priest Rapids forebay water quality was estimated using a MASS1 application to the mid-Columbia River (from Grand Coulee to Priest Rapids) which included 1997 meteorology, 1997 water quality in the Grand Coulee forebay, and the hydrology for each of the three simulation seasons.

2.2.2 Baseline System-wide Scenario Definition

The baseline scenario represented the current configuration, or “no-action” scenario. The current physical configurations (and associated TDG production) of all the projects were assumed, the 1998 spill patterns were used, and the historical spill and powerhouse discharges were utilized. Many of the spill patterns used were highly nonuniform. The details of project gas production and spill patterns for the baseline scenario are presented in Appendix B (Section 5.1). Thus, the baseline simulations are not configured to duplicate the historical conditions that occurred during a given hydrologic scenario. For example, it is not appropriate to compare the simulated TDG levels for the low-flow (1994) case to measured TDG levels from the FMS system during the 1994 spill season.

2.2.3 Fast-Track System-wide Scenario Definition

The system-wide fast-track scenarios combined some of the various gas abatement alternatives (designated as fast-track in USACE, 1999) at each project.

Four fast-track system-wide scenarios were simulated:

1. This scenario is used to examine the possible benefit of project spill pattern changes only. Current project configurations were assumed, but the spill pattern was changed at all projects so that spill was evenly distributed *only over bays with deflectors.* At The Dalles, having no deflectored bays, a uniform pattern over all bays was assumed. A uniform spill pattern tends to lower gas production at those projects where the spill pattern is highly nonuniform. The high spill flow through a few bays is spread over many bays, thus lowering the gas production.

2. Starting with the baseline scenario, it was assumed deflectors would be installed in any spill bays in which they were are not currently installed, except for The Dalles, where current conditions were used. At each project with a full compliment of of deflectors, a uniform spill pattern was assumed (except at Lower Granite).

3. In addition to the modifications of scenario # 2, powerhouse/spillway flow divider walls would be installed on those projects susceptible to powerhouse flow entrainment, and The Dalles dam was assumed to have a full complement of deflectors installed..

4. In addition to the scenario #3 modifications , raised tail races would be installed at those projects which might benefit most (Lower Granite, Little Goose, Lower Monumental, McNary, and Bonneville).

Changes to individual projects in these scenarios are summarized in Table 2.1.

Table 2.1: Fast-Track Alternatives Model Simulations

Project	**Baseline**	**No. 1**	**No. 2**	**No. 3**	**No. 4**
Lower Granite 8/8	Standard Spill	Uniform Spill	Standard Spill	Uniform Spill Power House/Spillway-Wall	Uniform Spill Power House/Spillway-Wall Raised Tail Race
Little Goose 6/8	Uniform Spill 6/8	Uniform Spill 6/8	2 Deflectors Uniform Spill	Uniform Spill 8/8 Power House/Spillway-Wall	Uniform Spill 8/8 Power House/Spillway-Wall Raised Tail Race
Lower Monumental 6/8	Uniform Spill 6/8	Uniform Spill 6/8	2 Deflectors Uniform Spill	Uniform Spill 8/8 Power House/Spillway-Wall	Uniform Spill 8/8 Power House/Spillway-Wall Raised Tail Race
Ice Harbor 10/10	Standard Spill	Uniform Spill	Standard Spill	Standard Spill	Standard Spill
McNary 18/21 (22*)	Standard Spill	Uniform Spill 18/22	Uniform Spill 22/22	Uniform Spill 22/22 Power House/Spillway-Wall	Uniform Spill 22/22 Power House/Spillway-Wall
John Day 18/20	Standard Spill	Uniform SPill 18/20	Standard Spill 20/20	Uniform Spill 20/20	Uniform Spill 20/20
The Dalles 0/23	Standard Spill	Uniform Spill	Standard Spill	Uniform Spill 23/23	Uniform Spill 23/23
Bonneville 13/16 (18**)	Standard Spill	Uniform Spill 13/19	Uniform Spill 18/18	Uniform Spill 18/18	Uniform Spill 18/18 Raised Tail Race

* McNary has 22 spillway bays, but only 21 are currently operational.
** The Bonneville standard spillway patterns limits bays 1 and 18 to a 4-inch gate opening.

2.2.4 Long Term System-wide Scenario Definition

The changes to the project configurations for the system wide long-term scenarios are defined in Table 2.2. The long-term scenarios combine the fast-track scenario options with the addition of spillway bays at each project, except for Bonneville, where submerged radial gates would be installed. Appendix B presents a complete description of the project alterations that includes gas production relationships and figures showing the layout of the additional spillway bays.

Table 2.2: Individual project modifications for the long term system-wide scenarios.

	Scenario		
Project	**Long Term #1**	**Long Term #2**	**Long Term #3**
Bonneville	Fast-Track #4	Fast-Track #4	Submerged Radial Gates Uniform Spill
The Dalles	Fast-Track #3	Fast-Track #3	Fast-Track #3
John Day	Additional Bays (6) Nonuniform Spill[a]	Additional Bays (6) Nonuniform Spill[a]	Additional Bays (6) Nonuniform Spill[a]
McNary	Fast-Track #3	Additional Bays (9) Uniform Spill	Additional Bays (9) Uniform Spill
Ice Harbor	Fast-Track #1	Fast-Track #1	Divider Wall Only Uniform Spill
Lower Monumental	Fast-Track #3	Fast-Track #3	Additional Bays (9) Divider Wall Uniform Spill
Little Goose	Fast-Track #3	Additional Bays (9) Divider Wall Uniform Spill	Additional Bays (9) Divider Wall Uniform Spill
Lower Granite	Additional Bays (9) Uniform Spill	Additional Bays (9) Divider Wall Uniform Spill	Additional Bays (9) Divider Wall Uniform Spill

[a]The additional bays would be opened first, one at a time, up to a flow of 6300 cfs. After all new bays are open, spill would be distributed evenly over the original 20 bays.

2.2.5 Alternative Spill System-wide Scenario Definition

It is reasonable to question whether using the actual spill in alternative comparison simulations, particularly in 1994, is valid. In 1994, operations were not subject to the current operational criteria, and consequently spills may not be as high as they would be if 1994's hydrology occured today. The low flow (1994) season hydrology can be viewed as a set of low spill operations against which to compare alternate spill management rules.

In order to address this question, two other simulation scenarios were developed. In these scenarios, the hourly spill for each project (something other than the observed) was based on a set of rules. The spill was computed in advance of the simulation, then the #2 fast-track system-wide alternative, described in Section 2.2.3, was simulated using the computed spills.

The first scenario was called "Spill Cap", where spill was set based on the 1998 Dissolved Gas Management Plan. This scenario is discussed in Section 2.2.5. The second scenario was called "Spill Management", where spill was set based on a TDG saturation limit in the spillway (based on the available production functions). This scenario is discussed in Section 5.

The model was run using the low (1994), medium-high (1996), and high (1997) flow hydrologies. The purpose of simulating the medium-high and high cases was to document the performance of the same spill management rules for higher runoff conditions.

These simulations illustrate the range of operational possibilities during low flow seasons. They also illustrate a methodology using the MASS1 model whereby the operation of given set of project configurations could be fine tuned to meet, or attempt to meet, varying objectives.

Spill Cap

In this scenario, spill at each project was chosen in accordance with the rules stipulated in the *1998 Total Dissolved Gas Management Plan*[3], except that power generation requirements were not considered. It was assumed that, regardless of conditions, the powerhouse had a constant maximum capacity for flow and that discharge through the powerhouse could be anything up to the maximum. The assumed maximum powerhouse hydraulic capacity was based on the average project head observed during all of the simulated spill seasons. At the average head, the maximum turbine flow at 1% efficiency for each turbine was summed, as shown in Table 2.3. This sum was reduced by assuming 1 unit off line in Snake projects, and two units off line in Columbia projects.

Project spill was computed on an hourly basis. The process involved assigning a voluntary spill, a generation flow, and an involuntary spill based on the total project flow. The specific steps were as follows:

1. If the hourly total project flow does not exceed the trigger flow in Table 2.4, "voluntary" spill was considered to be zero.

2. For projects with a 12-hour spill duration in Table 2.4, voluntary spill could only occur at night between the hours of 6:00 pm and 6:00 am. Outside that interval, voluntary spill was considered to be zero.

3. If it was not set to zero in 1 or 2, voluntary spill was set to the spill cap in Table 2.4, and was subject to the limits listed there, if any. For Bonneville, the maximum spill limit of 75 kcfs was applied during the day (6:00 am to 18:00 pm).

[3]URL: http://www.nwd-wc.usace.army.mil/TMT/1998/tdgmgt98.htm

4. The project generation flow was set to the difference between total project flow and the voluntary spill.

5. When the generation flow from 4 was higher than the powerhouse hydraulic capacity (Table 2.3), the excess was added to the spill (involuntary spill).

6. Spillway ΔP was computed given the project spill determined in 3 and 4.

7. Spillway TDG concentration was computed from ΔP using the (1997) barometric pressure and temperature from the project's forebay FMS.

The hourly spills computed for this scenario are compared to the actual spills in Appendix C, Section 1.3.1.

Table 2.3: Basis of assumed powerhouse hydraulic capacity used in the spill cap scenario. Listed turbine capacities are the maximum turbine flow at 1% efficiency and the average head (difference between forebay and tailwater stage).

Project	**Average Head** (ft)	**Turbine Capacities** (kcfs)		**Full PH Capacity** (kcfs)	**Reduced PH Capacity** (kcfs)	**Capacity Reduction**
LWG	98.6	3@	21.2			
		+3@	20.3	124.7	103.5	Unit 1 offline
LGS	95.7	3@	21.2			
		+3@	20.0	125.0	103.3	Unit 1 offline
LMN	96.9	3@	21.7			
		+3@	19.1	122.7	101.0	Unit 1 offline
IHR	93.9	3@	12.3			
		+3@	17.9	90.4	78.2	Unit 1 offline
MCN	71.0	14@	12.1	170.0	145.7	2 units offline
JDA	100.6	20@	20.8	416.3	374.7	2 units offline
TDA	77.3	14@	15.2			
		+8@	16.6	345.9	314.1	Units 1 & 15 offline
BON	52.9	10@	11.8			
		+8@	17.3	256.2	227.1	Units 1 & 11 offline

Spill Management

In the Spill Management scenario, the spill at each project was chosen so that *spillway* TDG saturations would meet an arbitrary target. In this study 120% was used, but any level could have been chosen. Project spill was computed in advance of the simulation as follows:

1. Given, the specified spillway saturation (120%), the excess TDG pressure, ΔP, was computed using 1997 barometric pressure from the project's forebay fixed monitor.

Table 2.4: Summary of 1998 TDG spill management plan project spill requirements.

Project	**Trigger Flow** (kcfs)	**Spill Duration** (hours)	**Spill Cap** (kcfs)	**Other Limits** **Minimum**	**Maximum**
LWG	85.0	12	45.0		
LGS	85.0	12	60.0		35% of river
LMN	85.0	12	40.0		50% of river
IHR		24	75.0		
MCN		12	160.0		
JDA		12	180.0	25% of river	60% of river
TDA		24	230.0	30% of river	64% of river
BON		24	120.0	50 kcfs	75 kcfs (day)

2. The project's gas production equation was solved for spill per bay, q_s, allowing q_s to be computed as a function of ΔP.

3. It was assumed that spill was only on deflectored bays, and that the spill was uniformly distributed over those bays. This was necessary in order to directly solve for a project spill. Any other combination would have required some iterative procedure to find spill from ΔP.

4. The "target" spill was computed as q_s, from 2, times the number of deflectored bays at the project.

5. If the total project flow was less than the target spill, the spill was set to the total project flow. Otherwise, spill was set to the target spill.

6. The project generation flow was set to the difference between project flow and the spill from 5.

7. When the generation flow from 6 was higher than the powerhouse hydraulic capacity, the excess was added to the spill.

8. Spillway ΔP was computed given the project spill determined in 5 and 7.

9. Spillway TDG concentration was computed from ΔP using the barometric pressure and temperature from the project's forebay monitor.

Comparisons of the simulated hourly spill with actual spill at each project and simulated season are in Appendix C, Section 1.3.2.

3 Results and Discussion

The simulation models, MASS1 and MASS2, were run for the gas abatement scenarios over the April 1 through September 1 season and the time-varying results were analyzed to assess the comparitve performance of the alternatives. The essential results for the fast-track, long-term, and alternative-spill rules scenarios are presented in this chapter. The complete results for the alternatives simulations are presented in Appendices C, D, and E.

A probabalistic approach was adopted in performing and analyzing the simulations rather than a "design-flow" methodology. The probalistic approach relies on computing cumlative frequency distributions for various criteria using each model-simulated time-series of dissolved gas concentrations. This approach provides information about how frequently water quality criteria may be violated a particular compliance point or over a spatial area. Such an approach accounts for the unsteady nature of real river conditions and shows how the TDG levels of the system respond to imposed operational, hydrologic, and meteorlogical conditions. A "design-flow" approach based on analyzing TDG responses to a set of steady-state forcing conditions does not capture the true variability of the river system.

The simulation results make frequent use of the terms "project" and "pool". Project refers to the dam itself and its immediate upstream '(forebay) and downstream (tailwater) regions. Pool refers to the reservoir formed upstream of a project. Thus the John Day Pool refers to the region of the Columbia River extending upstream from the John Day Dam (project) to the tailwater of the McNary Dam. Therefore, TDG in the John Day pool comes from spill at McNary Dam and from sources upstream of McNary Dam through its powerhouse. The tidal reach is an exception to this convention since there is no project at its downstream end.

3.1 System-wide One-Dimensional Simulations

Hourly simulated TDG saturations from the MASS1 model for the fast-track and long-term scenarios were statistically summarized in order to compare the effects of each scenario. Simulated hourly saturation values were recorded at three important locations:

- the spillway average (*does not* include any powerhouse TDG), denoted as "sp" in results tables,
- the cross section average at the tailwater FMS location, "fms", and
- the cross section average at the downstream forebay[1] FMS location, "fb".

From these hourly values a cumulative frequency distribution (CFD) curve was developed, showing the percentage of time any given value of TDG was exceeded during the simulated season. For example, a set of CFD curves is shown in Figure 3.2 for the Tidal reach below Bonneville dam. The topmost graph of Figure 3.2 shows CFD's for the TDG saturation in the spillway only. Bonneville had the same configuration for the Fast-Track#3 and Fast-Track#4 scenarios, so they have the same

[1] For the tidal reach, this is considered to be the KLAW monitor.

CFD curve. These figures can be use to compare performance over the entire range of flows during a season. Appendix C presents plots similar to Figure 3.2 for each pool and simulated season.

Several statistics were also computed from the simulated TDG saturation values:

- **10% and 25% exceedance.** This is the value TDG saturation exceeded 10% and 25% of the season in hourly simulated values. This value can be read directly off of the CFD plots. Tables comparing these exceedance levels are included in Appendix C. Line graphs of the 10% exceedance values are shown for the entire lower Columbia and Snake Rivers in Figure 3.1 for the medium/high year (1996).

- **10% and 25% exceedance of the daily highest 12-hour average.** For each calendar day in the hourly simulated TDG saturation, the highest 12 hours were averaged, producing a single value for each calendar day. The TDG saturation level exceeded 10% and 25% of the time in these daily values were compared.

- **time exceeding water quality waiver** The simulated hourly TDG data was examined to determine the number of days the waiver to water quality standard was violated. Table 3.1 compare the results from the medium/high flow year with these values. Several waiver criteria have been defined by the States of Washington and Oregon, as well as NMFS. Water quality waiver in this report refers to the measure computed above based on the daily highest 12-hourly values. This criteria closely corresponds to the Oregon and NMFS waiver definitions.

By using the values above the comparison of alternatives is presented in terms of compliance, or noncompliance, with water quality standards. A complete set of tables and line graphs comparing the scenarios with these values is in appendix C.

3.1.1 Fast-Track Scenarios

Some key observations from the fast-track scenario simulation results are:

- The installation of additional deflectors at Bonneville, in fast-track scenarios 3 and 4, increases TDG levels at higher spills (Figure 3.2). This result corresponds with the shape of the gas production curves for deflectored and non-deflectored bays at Bonneville.

- Similar results occurred with the addition of deflectors at The Dalles, though not as dramatically.

- Adding deflectors at John Day provides very little benefit over just switching to a uniform spill pattern. This can be seen particularly in the upper graph of Figure 3.4.

- The effect of any of the fast-track scenarios in the Snake River is completely diminished at the McNary dam forebay and nearly so at the Ice Harbor fixed monitor, (Figure3.6). Therefore, changes made to Snake River projects would need to be justified by local improvements in gas levels, rather than any improvement in the Columbia River.

- The 1996 and 1997 years yield similar results. Consideration should be given to including 1995 as a medium flow hydrology.

For the set of Fast-Track scenarios that were defined, there doesn't appear to be a scenario that is clearly better than the other, nor one clearly worse. In general, it appears that the #3, and #4, scenarios provided the most benefit in the Snake River, while having little effect in the Columbia. However, the gas production characteristics of a raised tailrace or a divider wall have not been field tested and are more uncertain than production equations for deflectors. The Columbia derives more benefit from the #2 scenario and from deflector installation at The Dalles in the #3 scenario. While the #4 scenario appears to be beneficial for the Snake River, there is uncertainty in gas production estimation. There are also indications that construction of such an alternative would not be feasible, either financially or physically. For these reasons, the #4 scenario was not considered further. The relative performance of the scenarios established in the 1D simulations did not change when comparing TDG levels from the hybrid simulations at the actual FMS location.

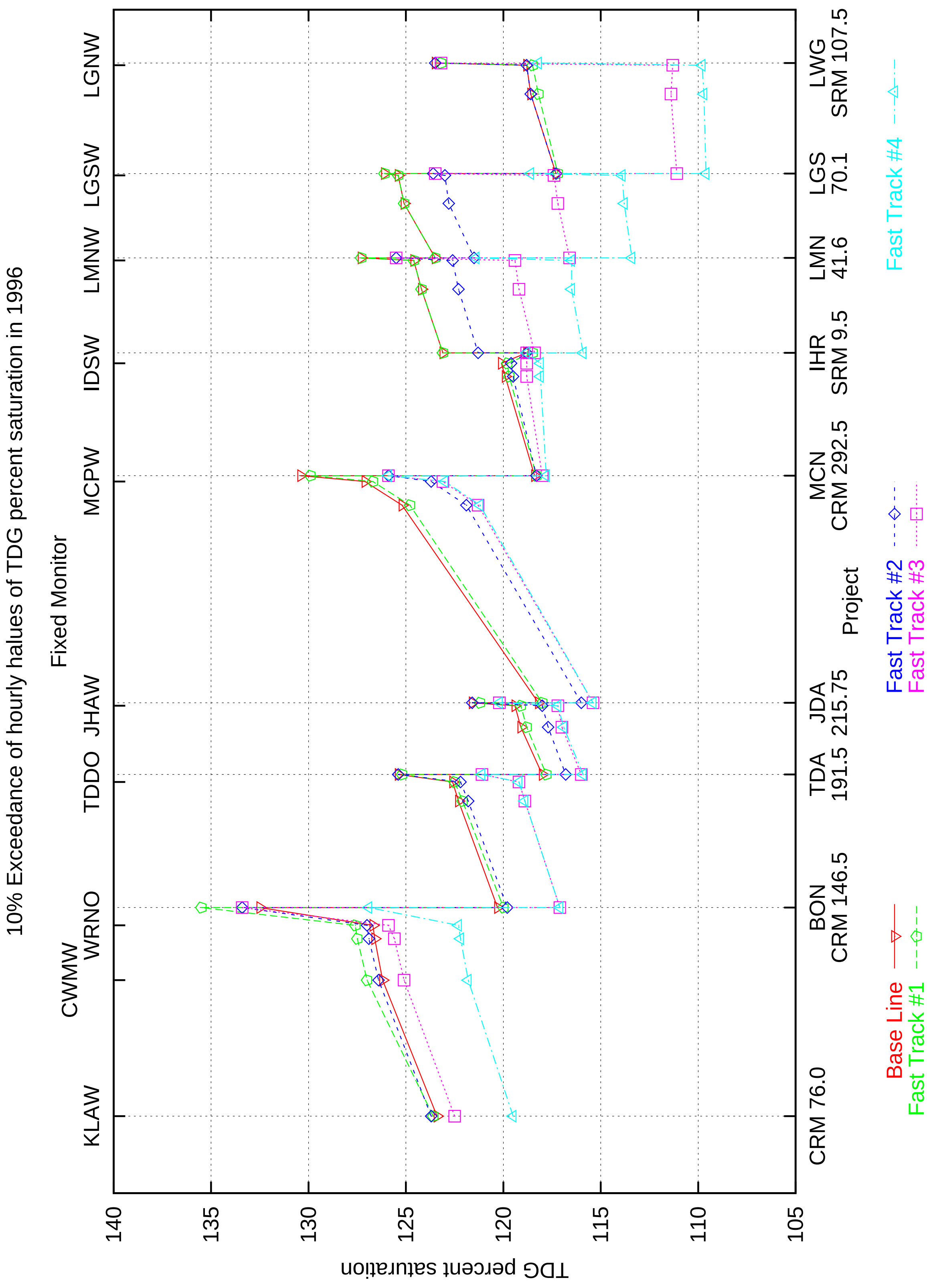

Figure 3.1: Comparison of the 10% exceedance of hourly halues of TDG percent saturation of MASS1 time series output: medium flow season (1996)

Table 3.1: Percentage of exceeding the water quality waiver of daily highest 12-hour average of TDG percent saturation of MASS1 fast track time series output: medium flow season (1996)

Location	Project	River Mile	Baseline		Fast Track #1		Fast Track #2		Fast Track #3		Fast Track #4	
			Days	%	Days	%	Days	%	Days	%	Days	%
Spillway	LWG	SRM 107.5	42	25.1	38	22.8	42	25.1	38	22.8	9	5.4
> 120	LGS	SRM 70.1	55	32.9	55	32.9	41	24.6	41	24.6	15	9.0
	LMN	SRM 41.6	54	32.3	54	32.3	46	27.5	46	27.5	31	18.6
	IHR	SRM 9.5	16	9.6	13	7.8	16	9.6	16	9.6	16	9.6
	MCN	CRM 292.5	67	40.1	60	35.9	42	25.1	41	24.6	41	24.6
	JDA	CRM 215.75	30	18.0	24	14.4	30	18.0	21	12.6	21	12.6
	TDA	CRM 191.5	136	81.4	130	77.8	136	81.4	31	18.6	31	18.6
	BON	CRM 146.5	153	91.6	121	72.5	69	41.3	69	41.3	55	32.9
FMS	LWG	SRM 106.75	16	9.6	14	8.4	16	9.6	1	0.6	0	0.0
> 120	LGS	SRM 69.5	53	31.7	53	31.7	39	23.4	8	4.8	0	0.0
	LMN	SRM 40.75	41	24.6	41	24.6	37	22.2	23	13.8	3	1.8
	IHR	SRM 6.0	20	12.0	19	11.4	18	10.8	15	9.0	12	7.2
	MCN	CRM 290.5	51	30.5	43	25.7	37	22.2	36	21.6	36	21.6
	JDA	CRM 214.75	16	9.6	14	8.4	9	5.4	4	2.4	4	2.4
	TDA	CRM 189.0	37	22.2	37	22.2	36	21.6	15	9.0	15	9.0
	BON	CRM 140.5	71	42.5	70	41.9	56	33.5	46	27.5	34	20.4
Forebay	LGS	SRM 70.1	32	19.2	33	19.8	32	19.2	8	4.8	0	0.0
> 115	LMN	SRM 41.6	64	38.3	62	37.1	58	34.7	36	21.6	11	6.6
	IHR	SRM 9.5	58	34.7	56	33.5	49	29.3	38	22.8	25	15.0
	MCN	CRM 292.5	46	27.5	46	27.5	46	27.5	46	27.5	44	26.3
	JDA	CRM 215.75	37	22.2	35	21.0	29	17.4	27	16.2	26	15.6
	TDA	CRM 191.5	36	21.6	35	21.0	34	20.4	29	17.4	29	17.4
	BON	CRM 146.5	81	48.5	73	43.7	76	45.5	35	21.0	35	21.0
	TID	CRM 122.0	141	84.4	130	77.8	82	49.1	70	41.9	58	34.7
	TID	CRM 76.0	107	64.1	91	54.5	69	41.3	53	31.7	37	22.2

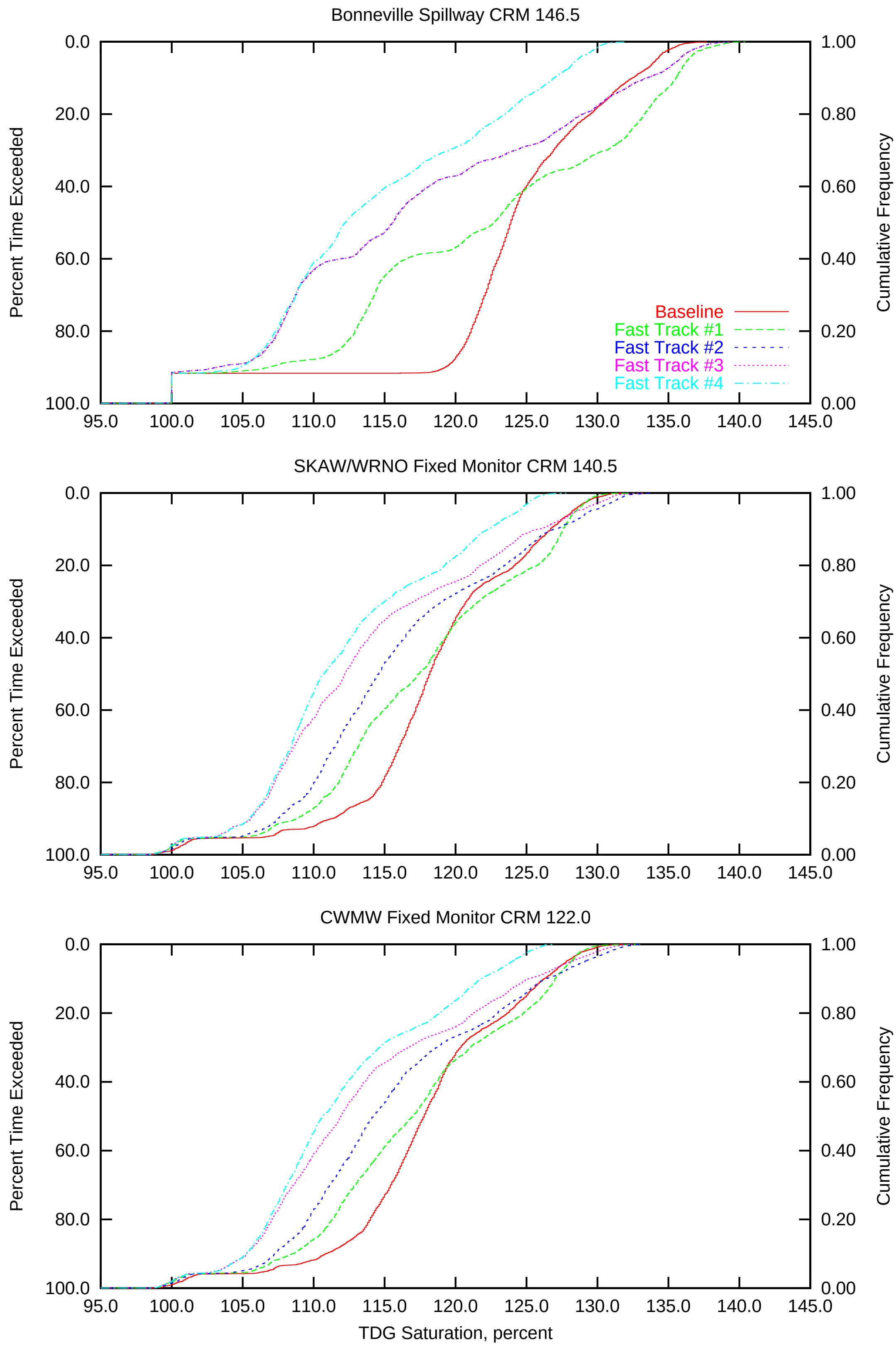

Figure 3.2: Comparision of simulated TDG saturation cumulative frequency distributions for locations in the tidal reach during a medium flow (1996) season.

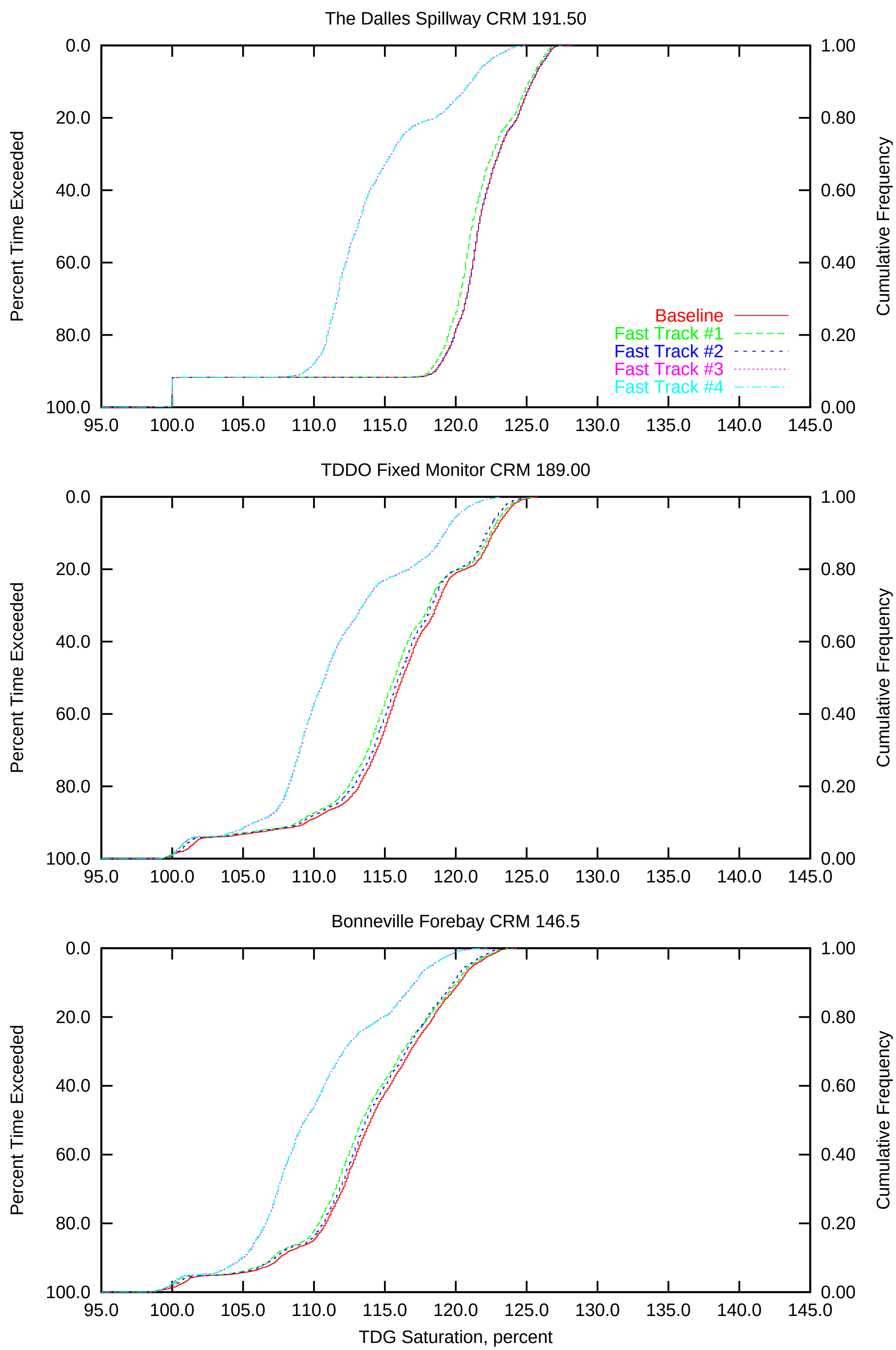

Figure 3.3: Comparision of simulated TDG saturation cumulative frequency distributions for locations in Bonneville pool during a medium flow (1996) season.

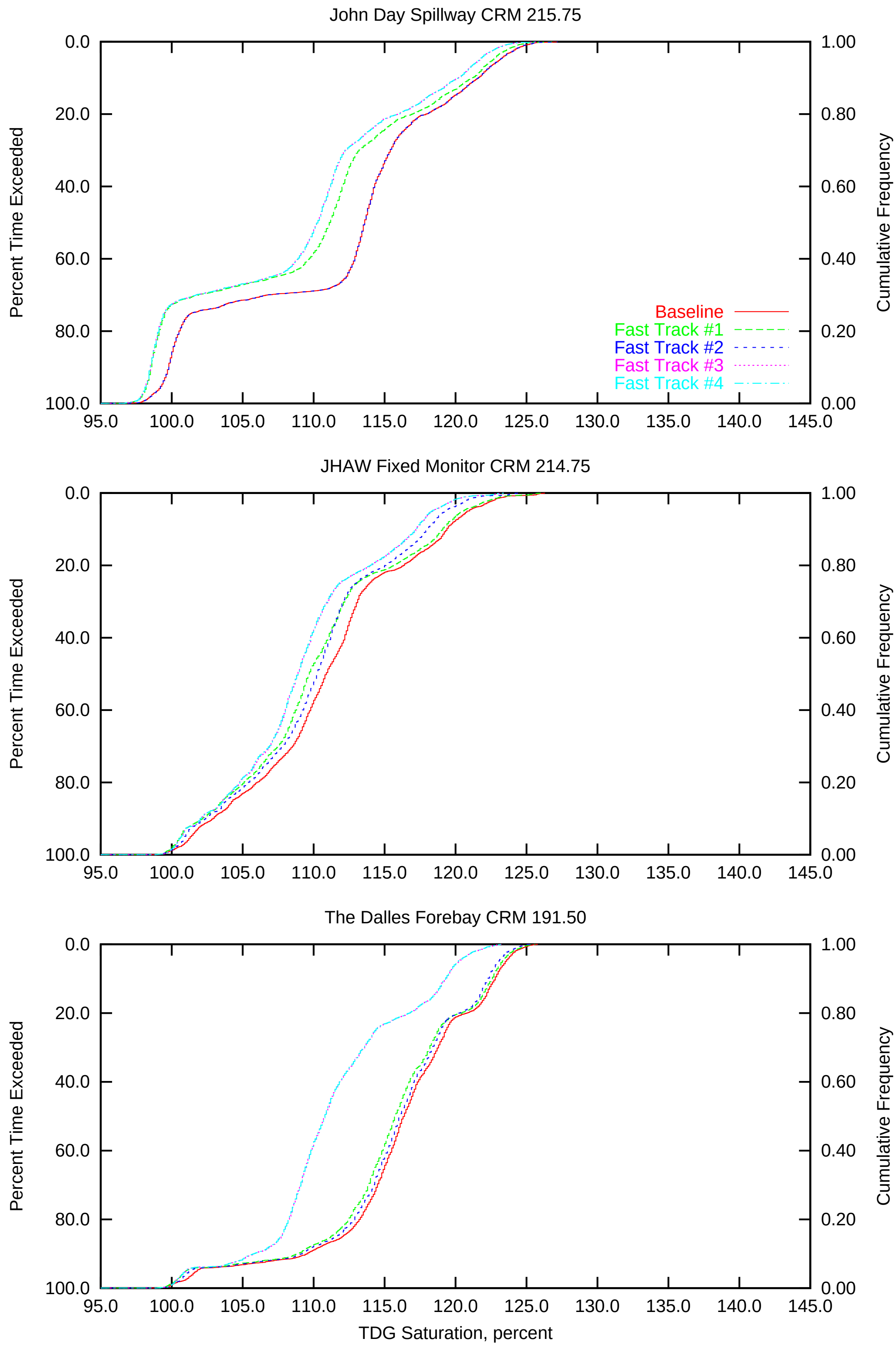

Figure 3.4: Comparision of simulated TDG saturation cumulative frequency distributions for locations in The Dalles pool during a medium flow (1996) season.

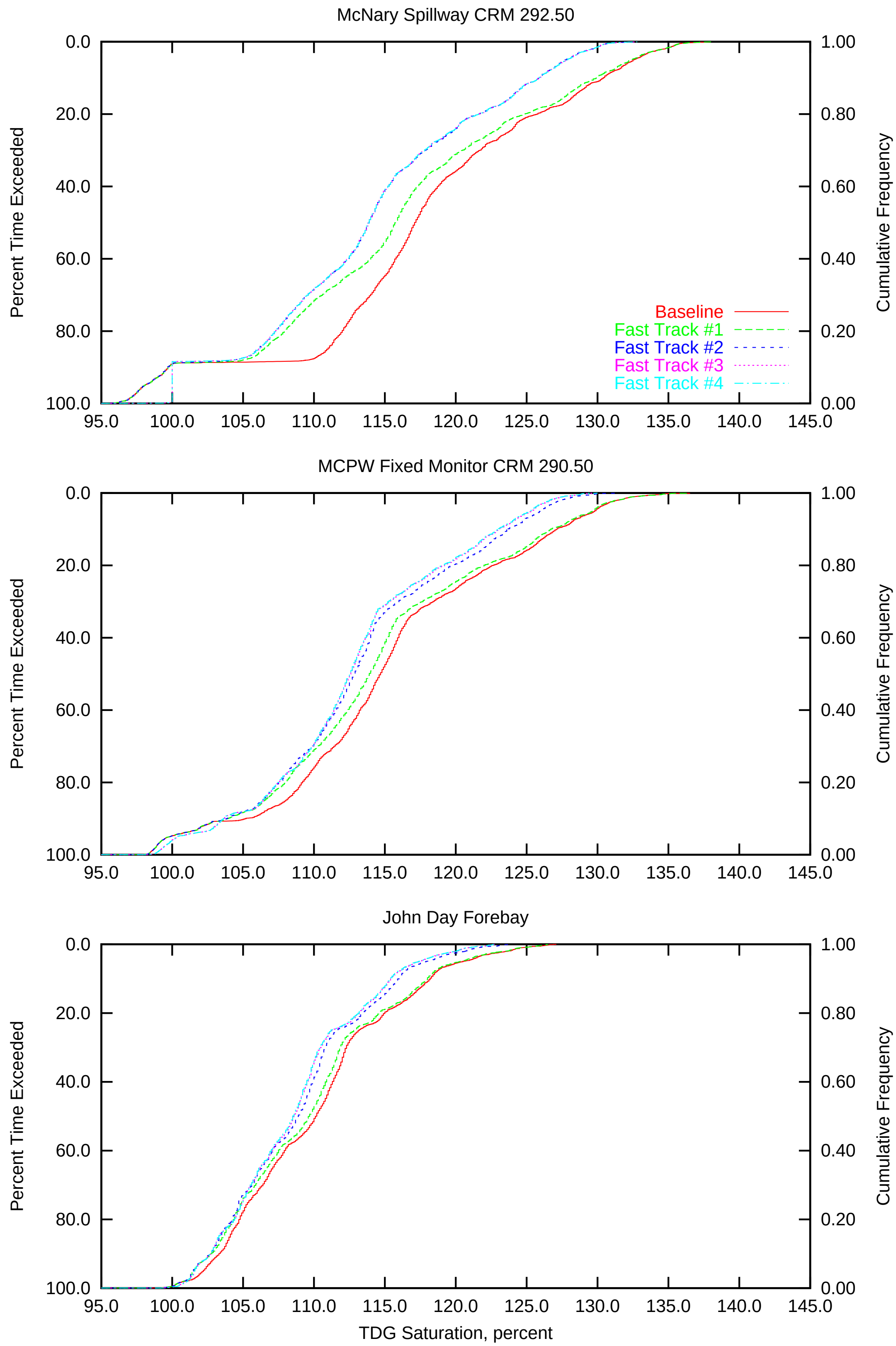

Figure 3.5: Comparision of simulated TDG saturation cumulative frequency distributions for locations in John Day pool during a medium flow (1996) season.

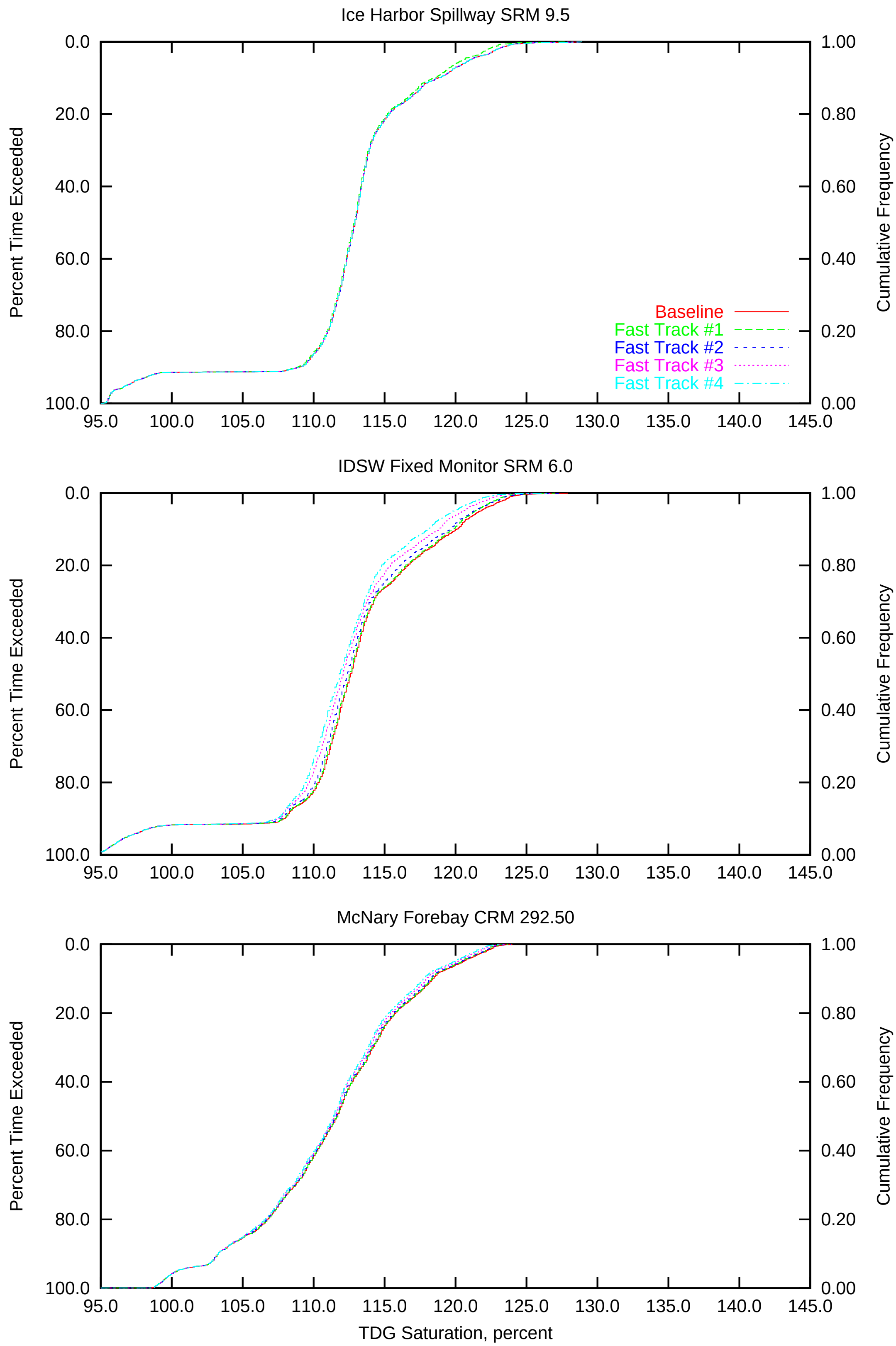

Figure 3.6: Comparision of simulated TDG saturation cumulative frequency distributions for locations in McNary pool during a medium flow (1996) season.

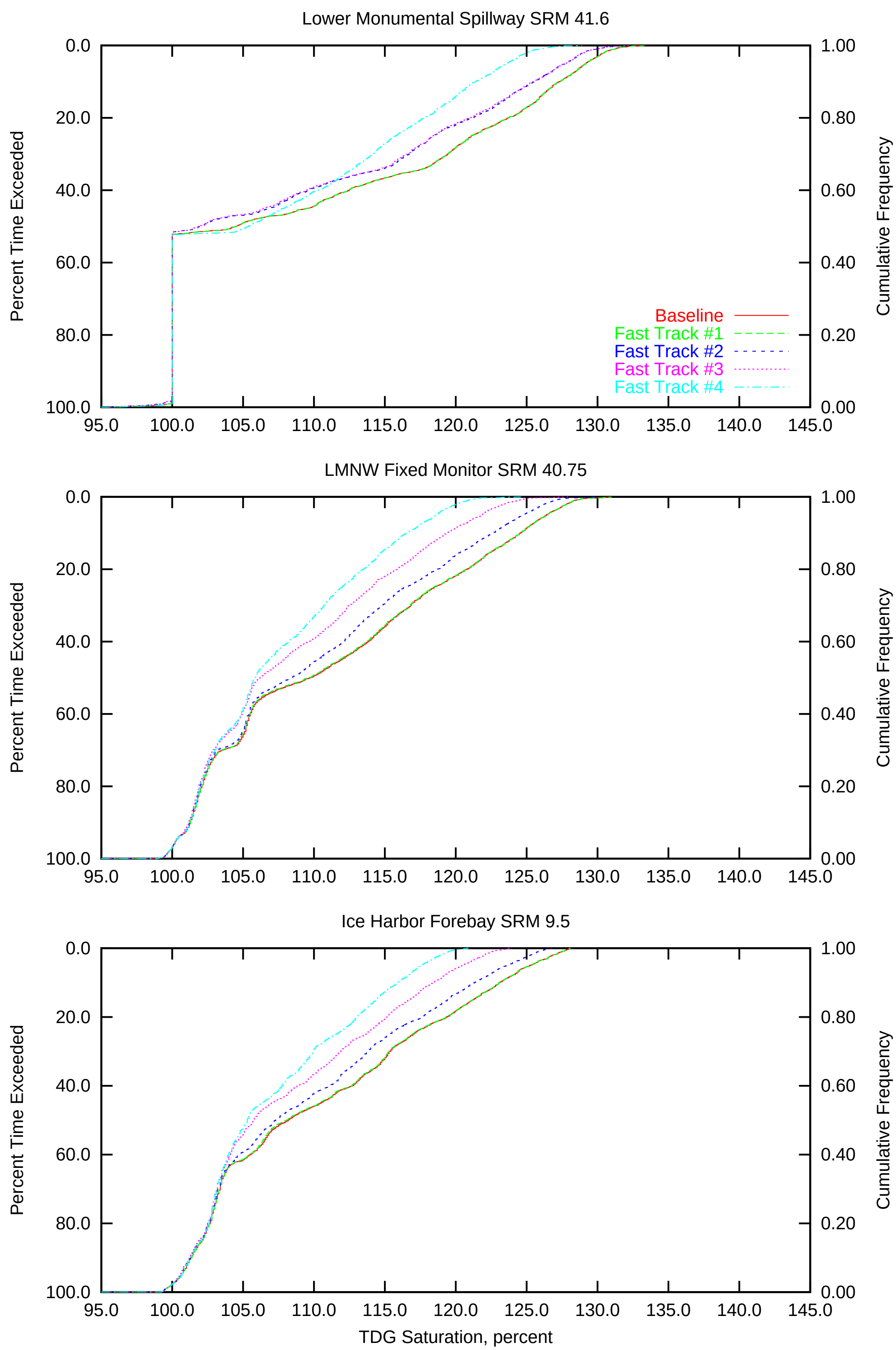

Figure 3.7: Comparision of simulated TDG saturation cumulative frequency distributions for locations in Ice Harbor pool during a medium flow (1996) season.

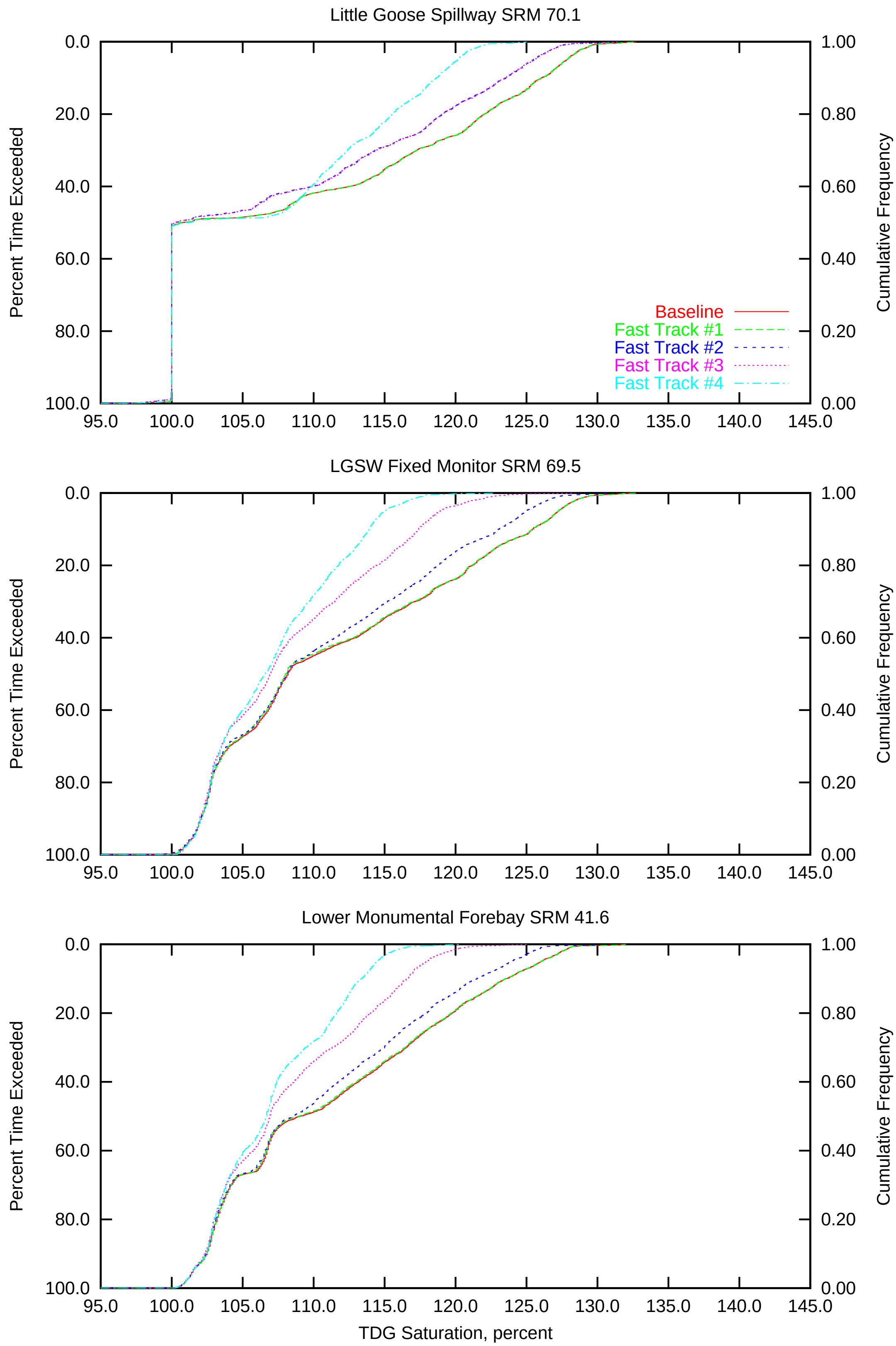

Figure 3.8: Comparision of simulated TDG saturation cumulative frequency distributions for locations in Lower Monumental pool during a medium flow (1996) season.

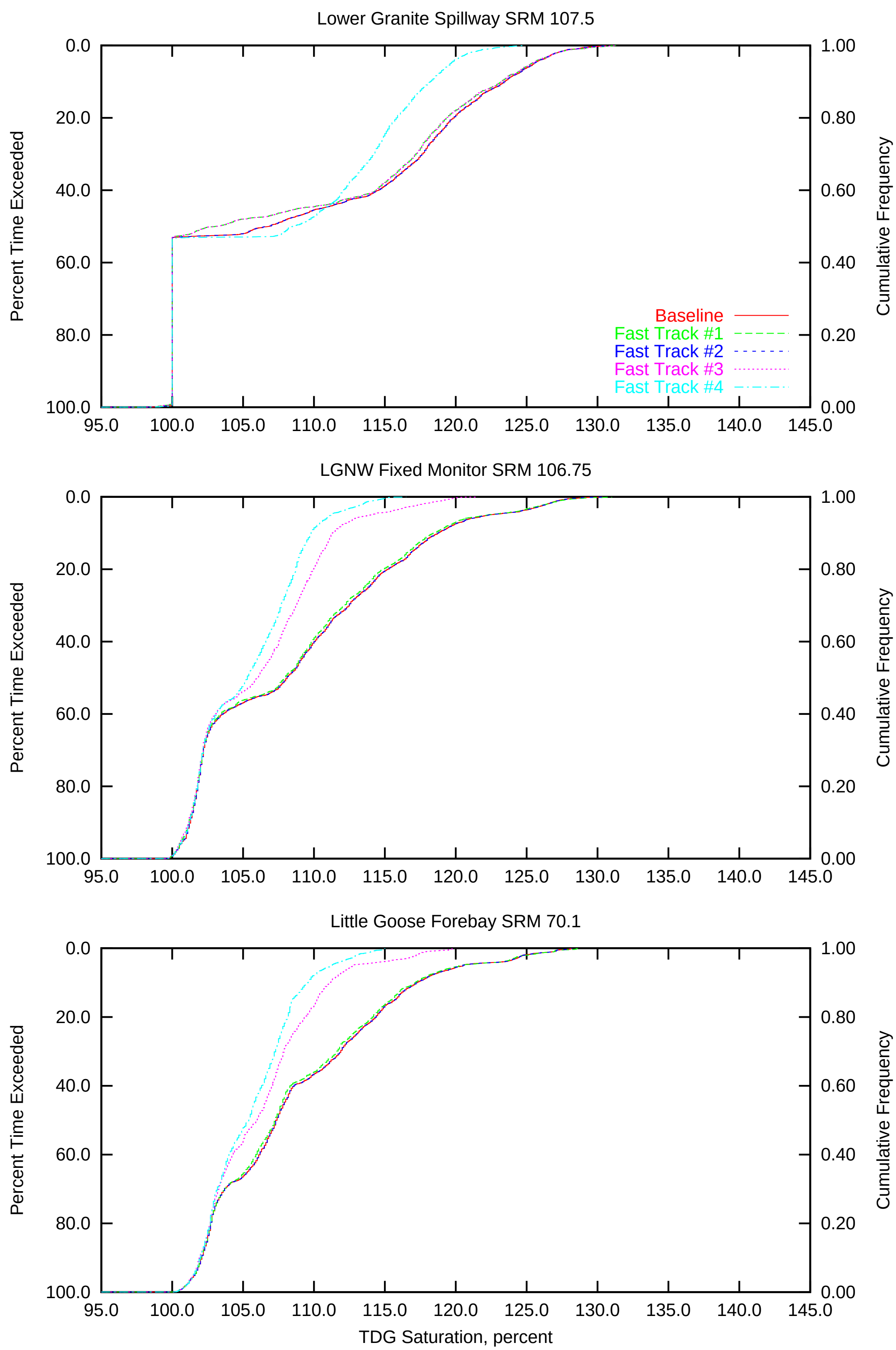

Figure 3.9: Comparision of simulated TDG saturation cumulative frequency distributions for locations in Little Goose pool during a medium flow (1996) season.

3.1.2 Long Term Scenarios

The long-term scenarios defined in Table 2.2 were simulated using MASS1 for only the medium-high flow season (1996). The results are summarized in a profile plot (Figure 3.10) and in CDF plots for each pool (Figures 3.11 through 3.18).

Important observations from the long-term scenario simulation results are:

- Additional spill bays lower the unit discharge per bay resulting in dramitically lower TDG levels. This can be seen in Table 3.2.
- Long-term option # 3 allows the system to meet water quality criteria at the downstream FMS location over the most of the season.
- TDG is also reduced at the forebay locations with the Snake River showing better perfomance than the Columbia River in meeting the 115 % criteria.
- The submerged radial gate option at Bonneville does not produce TDG because it was designed to meet that objective; the benefit this option is reduced at the downstream tidal reach location because no additional improvements are implemented at The Dalles (other than fast-track option # 3).

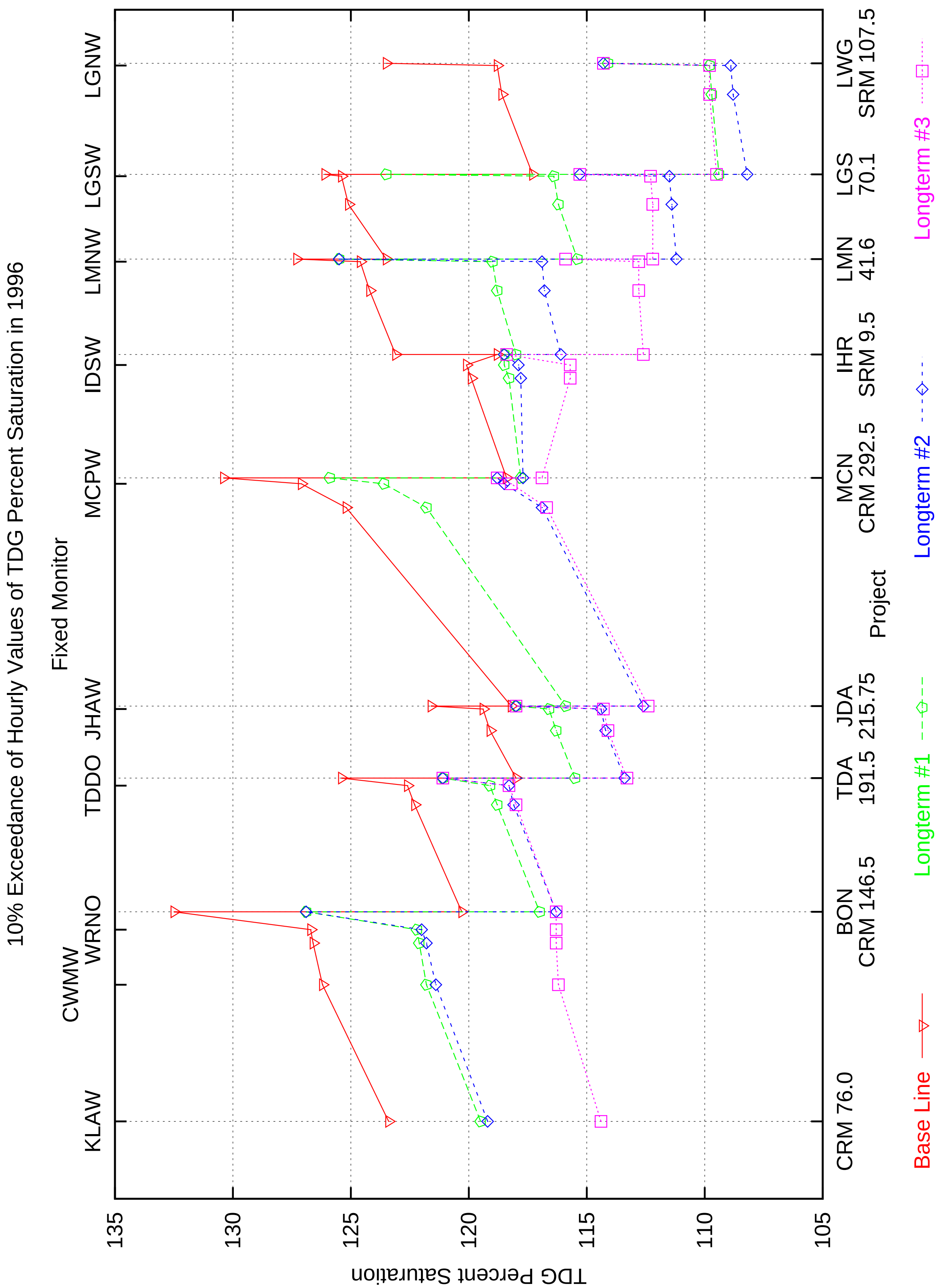

Figure 3.10: Comparison of the 10% exceedance of of TDG Percent Saturation of MASS1 time series output: Medium Flow Season (1996)

Table 3.2: Percentage of exceeding the water quality waiver of daily highest 12-hour average of TDG percent saturation of MASS1 long term time series output: medium flow season (1996)

Location	Project	River Mile	Baseline		Long Term #1		Long Term #2		Long Term #3	
			Days	%	Days	%	Days	%	Days	%
Spillway	LWG	SRM 107.5	42	25.1	0	0.0	0	0.0	0	0.0
> 120	LGS	SRM 70.1	55	32.9	41	24.6	1	0.6	1	0.6
	LMN	SRM 41.6	54	32.3	46	27.5	46	27.5	1	0.6
	IHR	SRM 9.5	16	9.6	13	7.8	13	7.8	13	7.8
	MCN	CRM 292.5	67	40.1	42	25.1	16	9.6	16	9.6
	JDA	CRM 215.75	30	18.0	8	4.8	8	4.8	8	4.8
	TDA	CRM 191.5	136	81.4	31	18.6	31	18.6	31	18.6
	BON	CRM 146.5	153	91.6	55	32.9	55	32.9	0	0.0
FMS	LWG	SRM 106.75	16	9.6	0	0.0	0	0.0	0	0.0
> 120	LGS	SRM 69.5	53	31.7	6	3.6	0	0.0	0	0.0
	LMN	SRM 40.75	41	24.6	23	13.8	9	5.4	0	0.0
	IHR	SRM 6.0	20	12.0	14	8.4	10	6.0	1	0.6
	MCN	CRM 290.5	51	30.5	37	22.2	12	7.2	11	6.6
	JDA	CRM 214.75	16	9.6	2	1.2	0	0.0	0	0.0
	TDA	CRM 189.0	37	22.2	14	8.4	7	4.2	7	4.2
	BON	CRM 140.5	71	42.5	33	19.8	32	19.2	0	0.0
Forebay	LGS	SRM 70.1	32	19.2	1	0.6	0	0.0	1	0.6
> 115	LMN	SRM 41.6	64	38.3	25	15.0	2	1.2	2	1.2
	IHR	SRM 9.5	58	34.7	35	21.0	28	16.8	5	3.0
	MCN	CRM 292.5	46	27.5	45	26.9	43	25.7	35	21.0
	JDA	CRM 215.75	37	22.2	28	16.8	7	4.2	7	4.2
	TDA	CRM 191.5	36	21.6	28	16.8	11	6.6	9	5.4
	BON	CRM 146.5	81	48.5	36	21.6	33	19.8	33	19.8
	TID	CRM 122.0	141	84.4	58	34.7	56	33.5	32	19.2
	TID	CRM 76.0	107	64.1	37	22.2	36	21.6	15	9.0

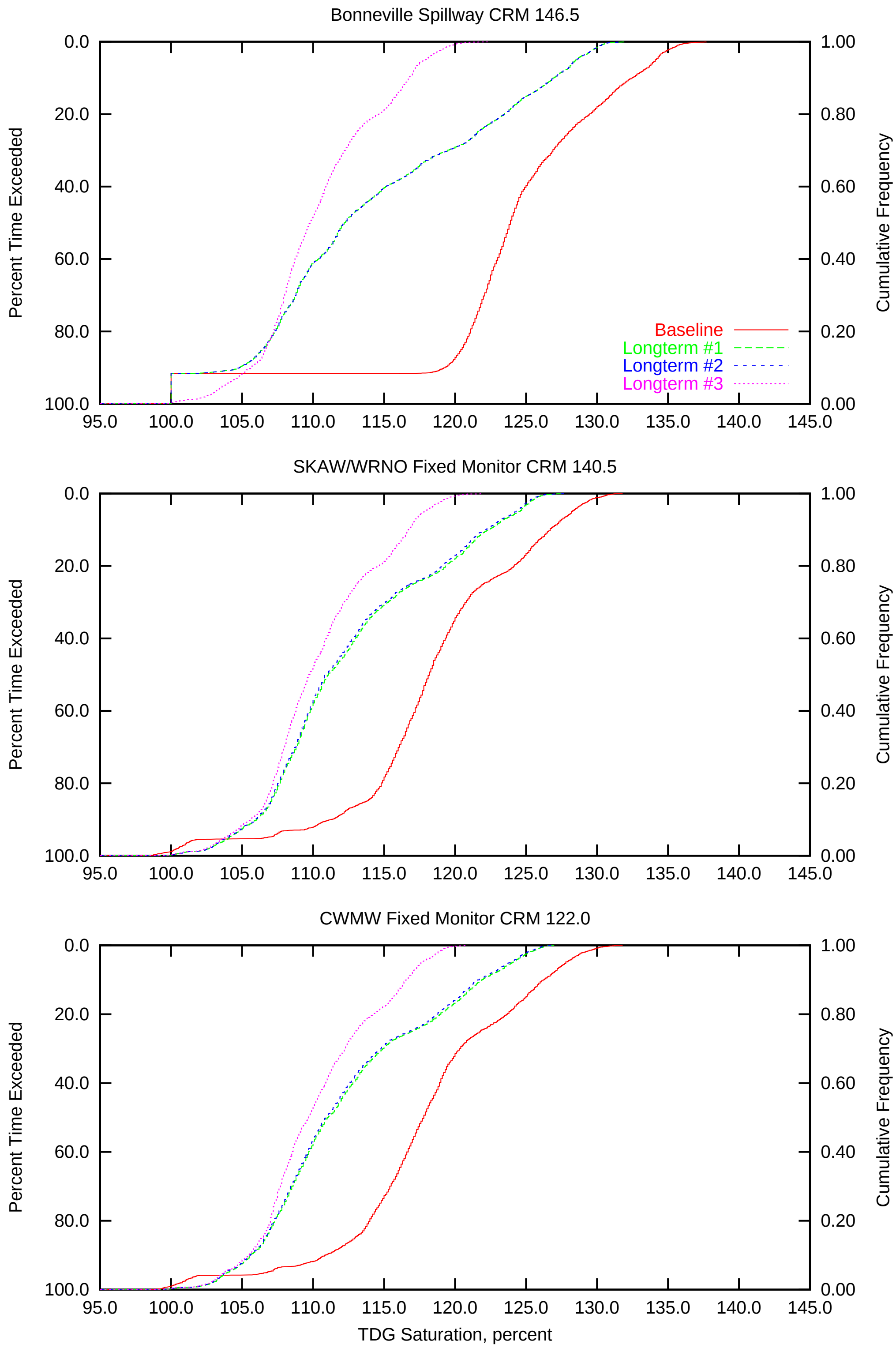

Figure 3.11: Comparision of simulated TDG saturation cumulative frequency distributions for locations in the tidal reach during a medium flow (1996) season.

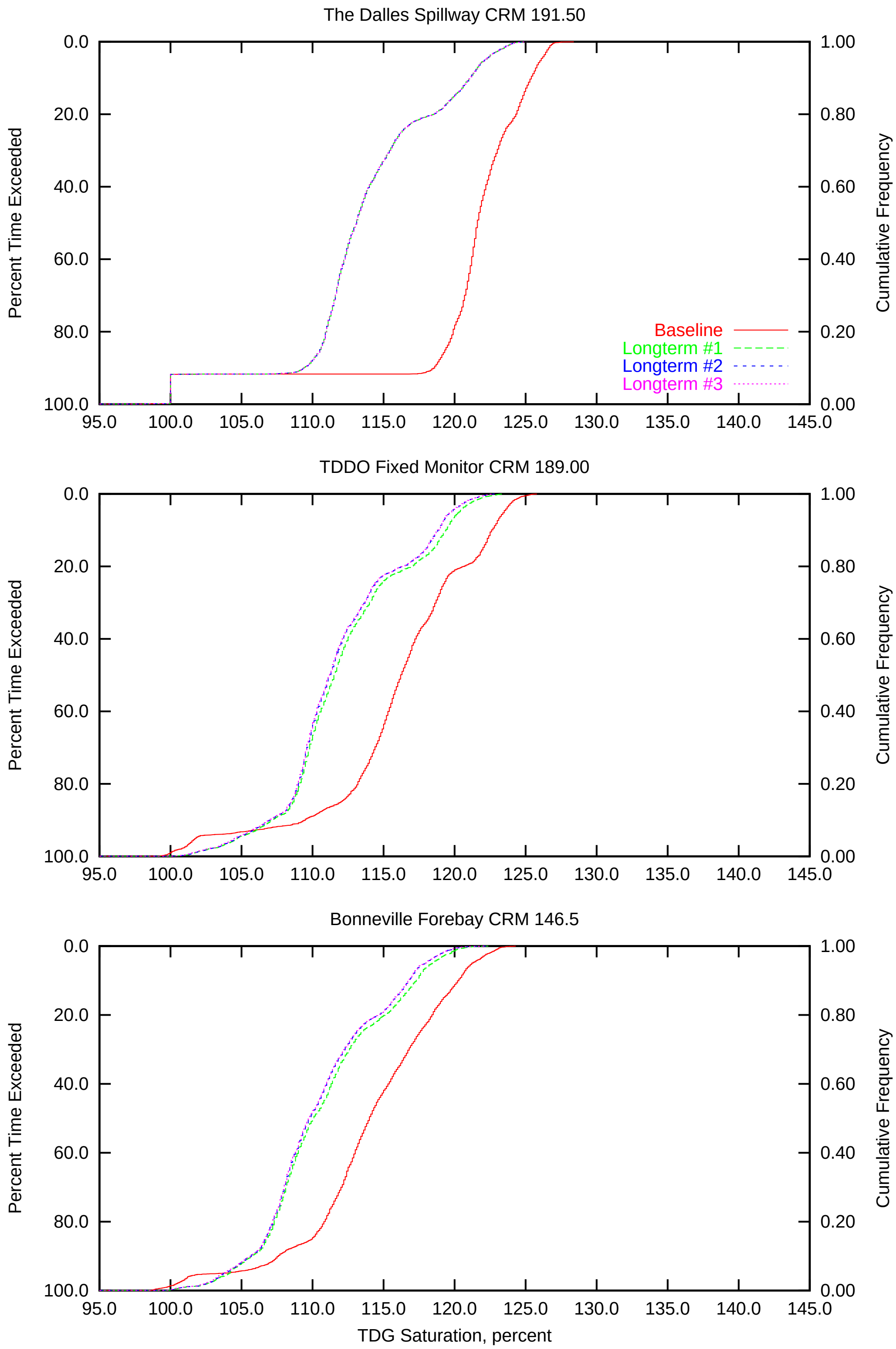

Figure 3.12: Comparision of simulated TDG saturation cumulative frequency distributions for locations in Bonneville pool during a medium flow (1996) season.

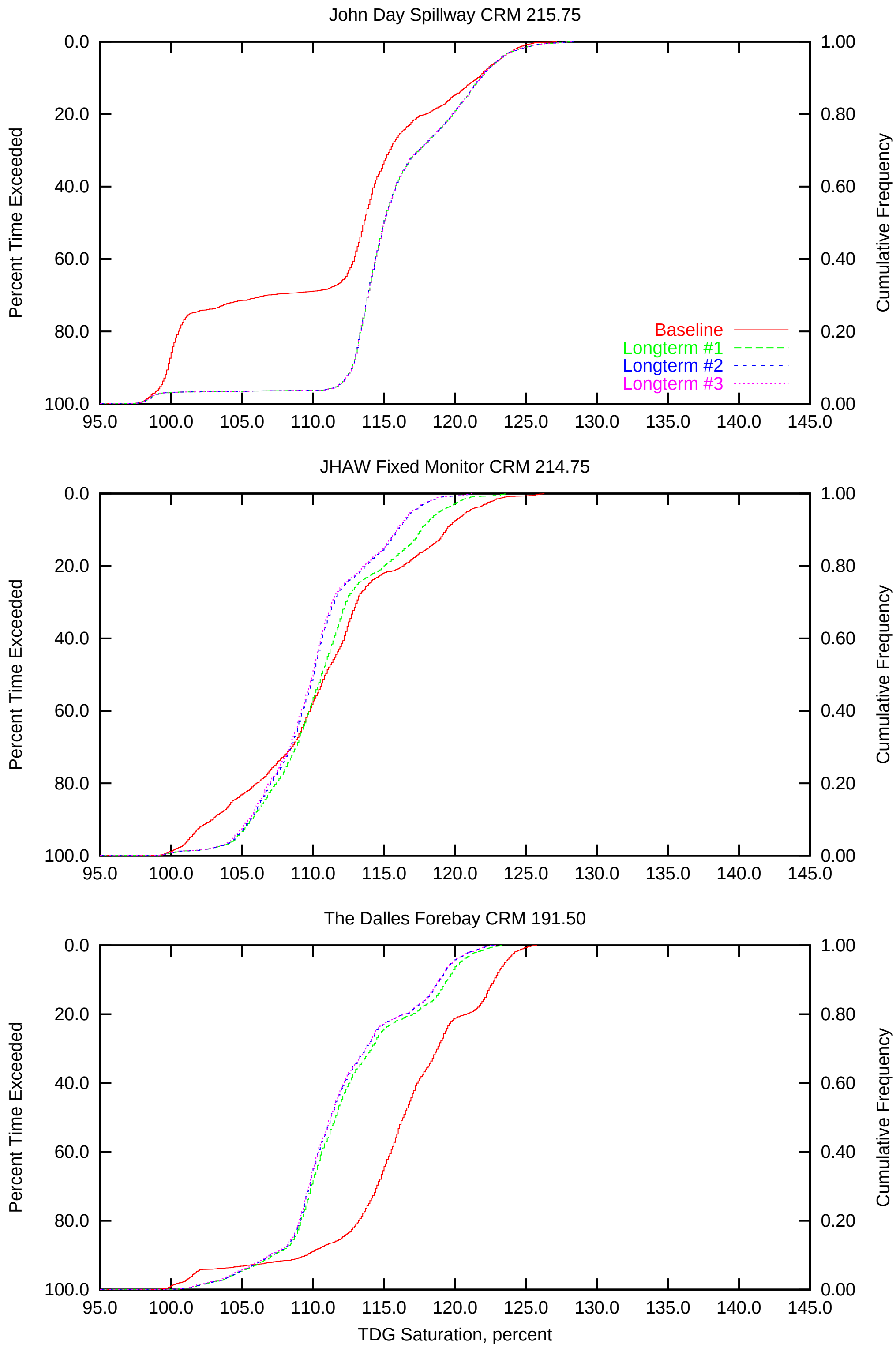

Figure 3.13: Comparision of simulated TDG saturation cumulative frequency distributions for locations in The Dalles pool during a medium flow (1996) season.

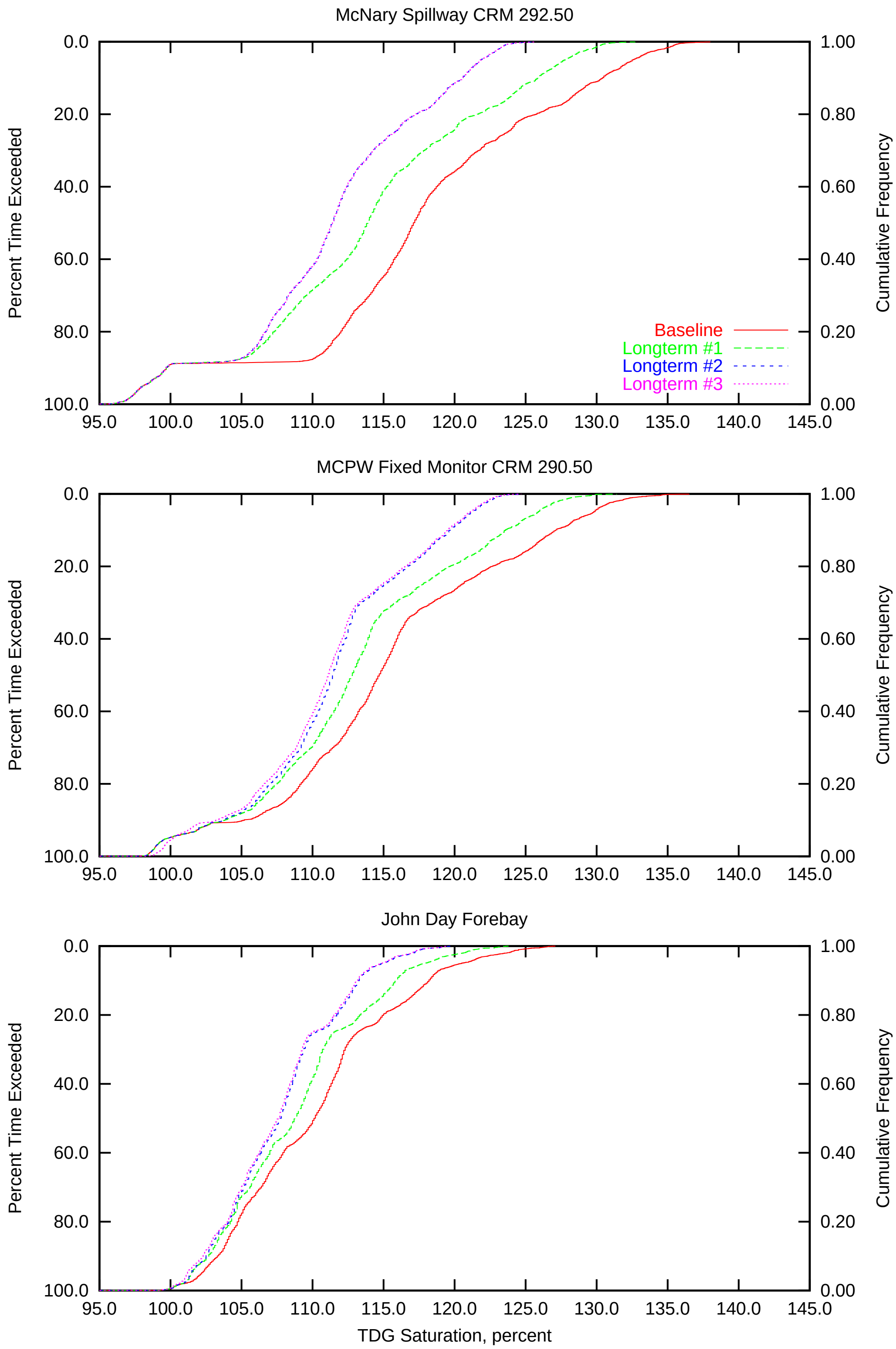

Figure 3.14: Comparision of simulated TDG saturation cumulative frequency distributions for locations in John Day pool during a medium flow (1996) season.

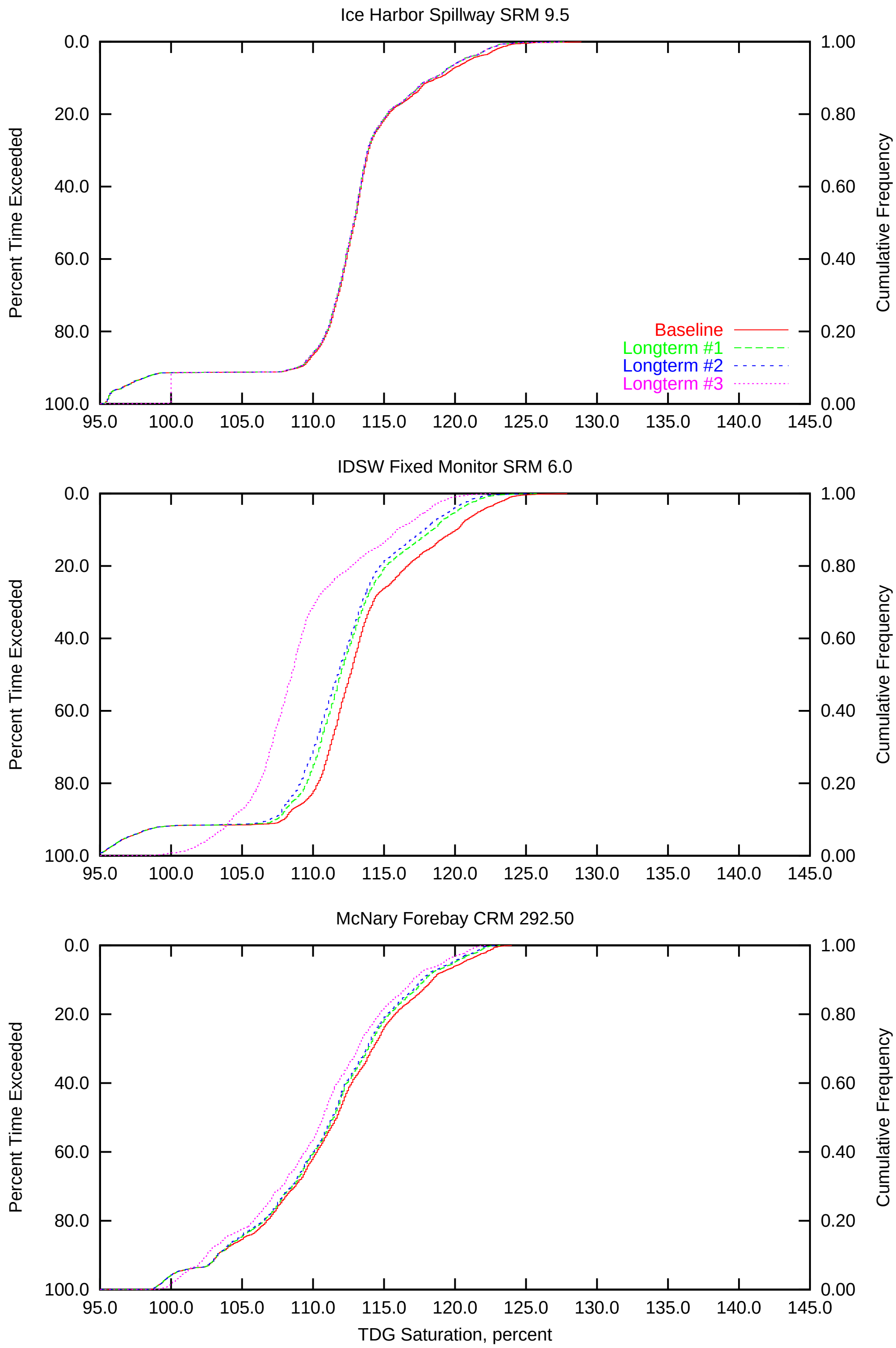

Figure 3.15: Comparision of simulated TDG saturation cumulative frequency distributions for locations in McNary pool during a medium flow (1996) season.

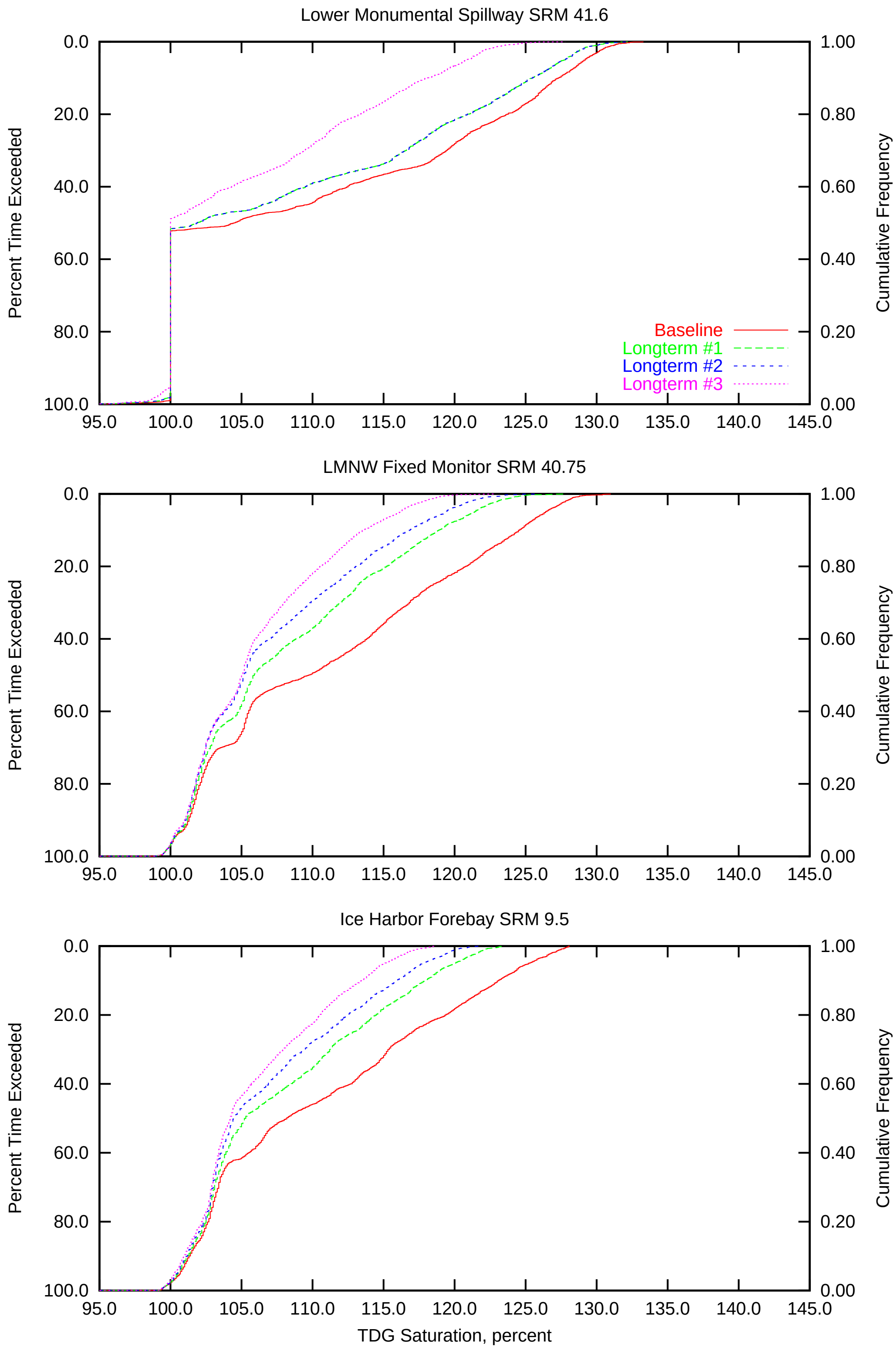

Figure 3.16: Comparision of simulated TDG saturation cumulative frequency distributions for locations in Ice Harbor pool during a medium flow (1996) season.

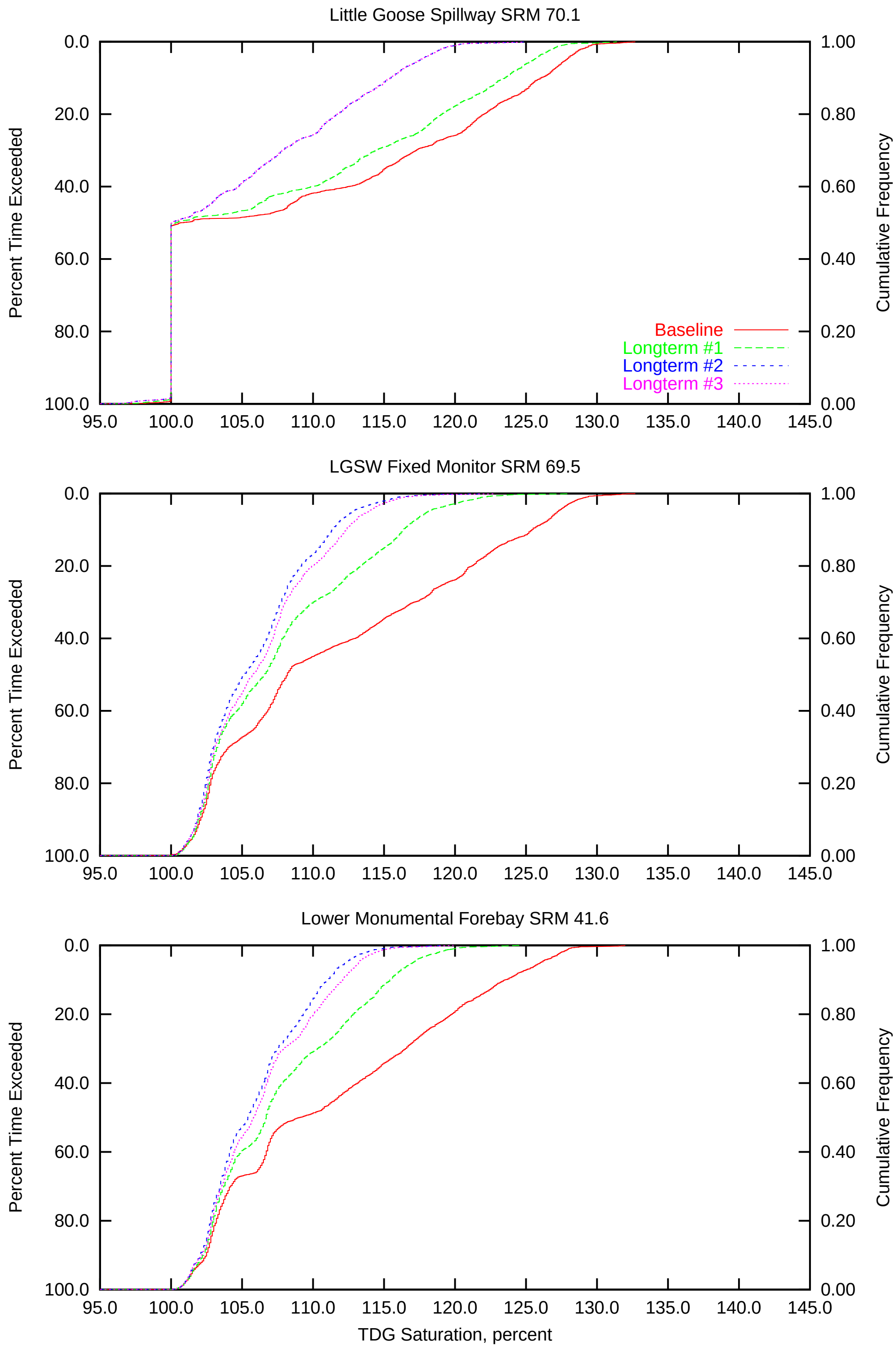

Figure 3.17: Comparision of simulated TDG saturation cumulative frequency distributions for locations in Lower Monumental pool during a medium flow (1996) season.

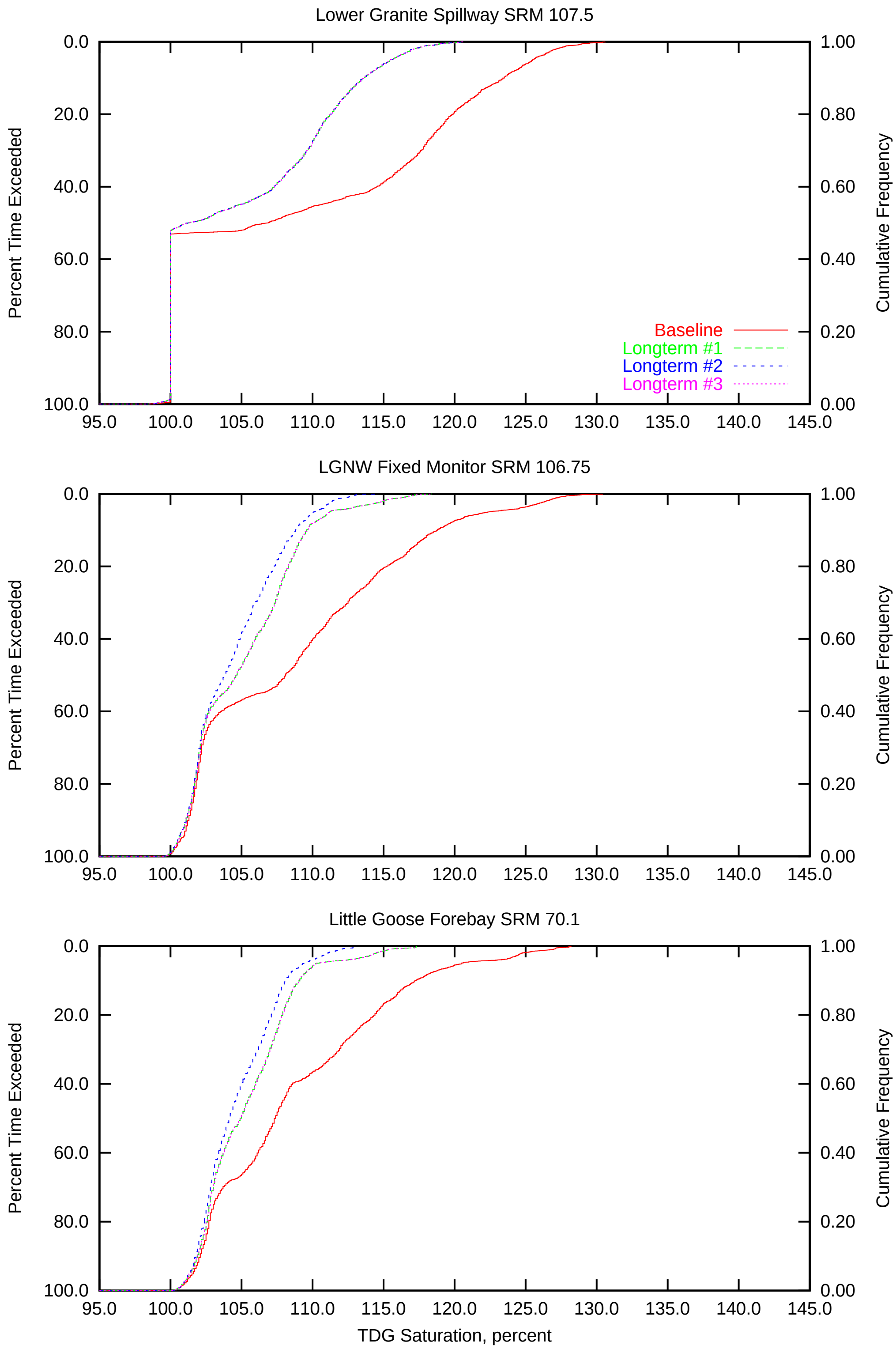

Figure 3.18: Comparision of simulated TDG saturation cumulative frequency distributions for locations in Little Goose pool during a medium flow (1996) season.

3.1.3 Alternative Spill Scenarios

Statistical plots and tables, similar to those prepared for the fast-track for the simulations, were prepared comparing the “Spill Cap”, “Spill Management” and #2 fast-track (Operations) scenarios. The full set of tables and graphs for all three simulation years can be found in the appendix C.

The “spill cap” scenario seems to accurately reflect the operation scheme in place during the high (1997) and medium (1996) flow years. It tended to increase the amount of spill during the low (1994) year.

Note that the “spill management” scenario ignores the importance of any operational goals other than meeting the spillway TDG saturation target. It does however, identify the extreme, and any corresponding benefit, to which this kind of management scheme can be taken. This scenario tends to even the spill over the season. It raised the TDG levels in the low flow season (1994), and tended to lower them in the medium/high (1996) and high (1997), while generally increasing spill in all three years. During the 1996 and 1997 seasons, all three of these scenarios produce the similar TDG levels at higher flows.

Analysis of the performance of spill management rules should be done following the selection of a preferred set of project structural alternatives. This analysis should use the MASS1 model and a longer period of hydrologic record to evaluate the risk of not meeting compliance criteria.

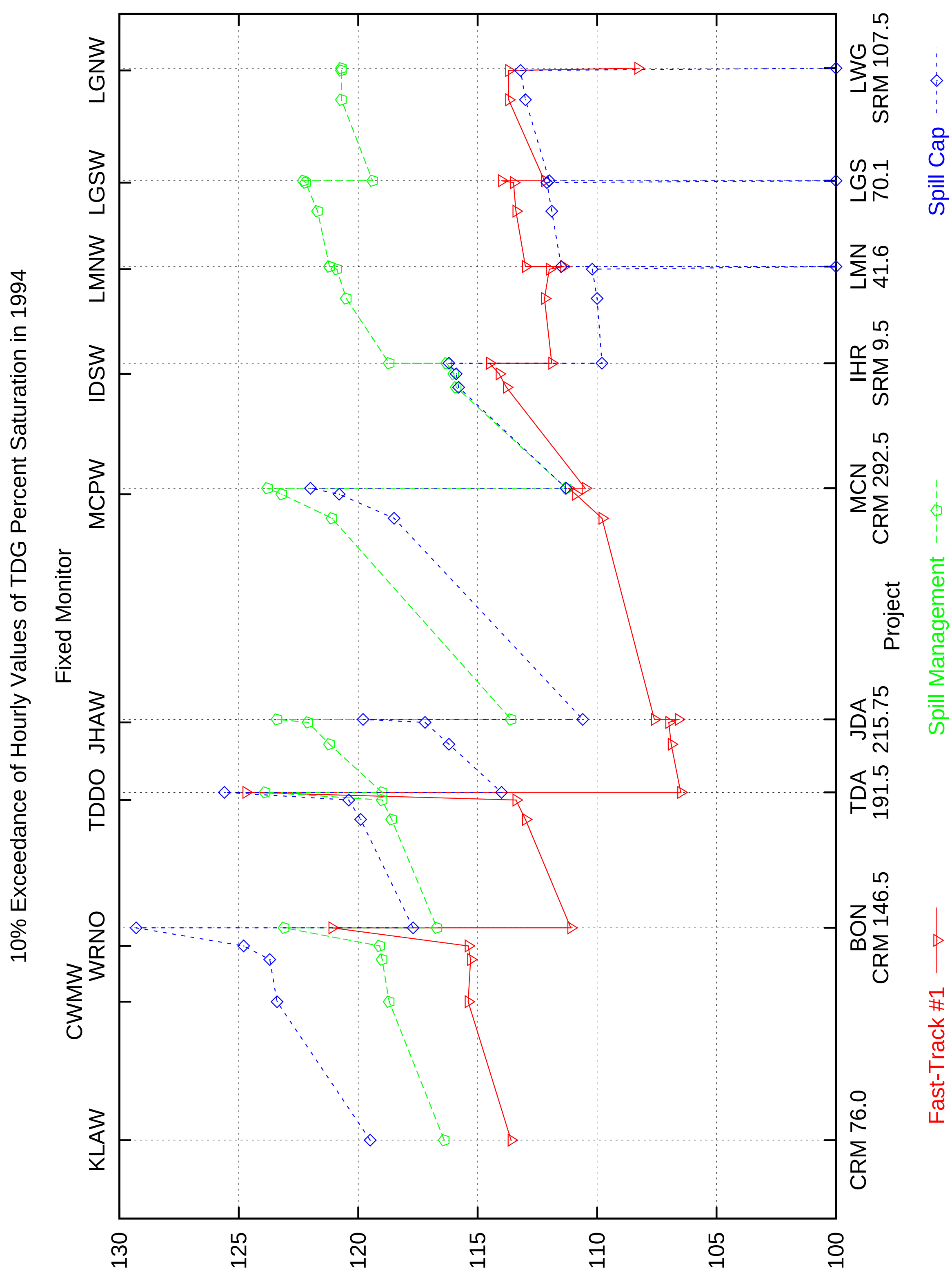

Figure 3.19: Comparison of the 10% exceedance of of TDG Percent Saturation of MASS1 time series output: Low Flow Season (1994)

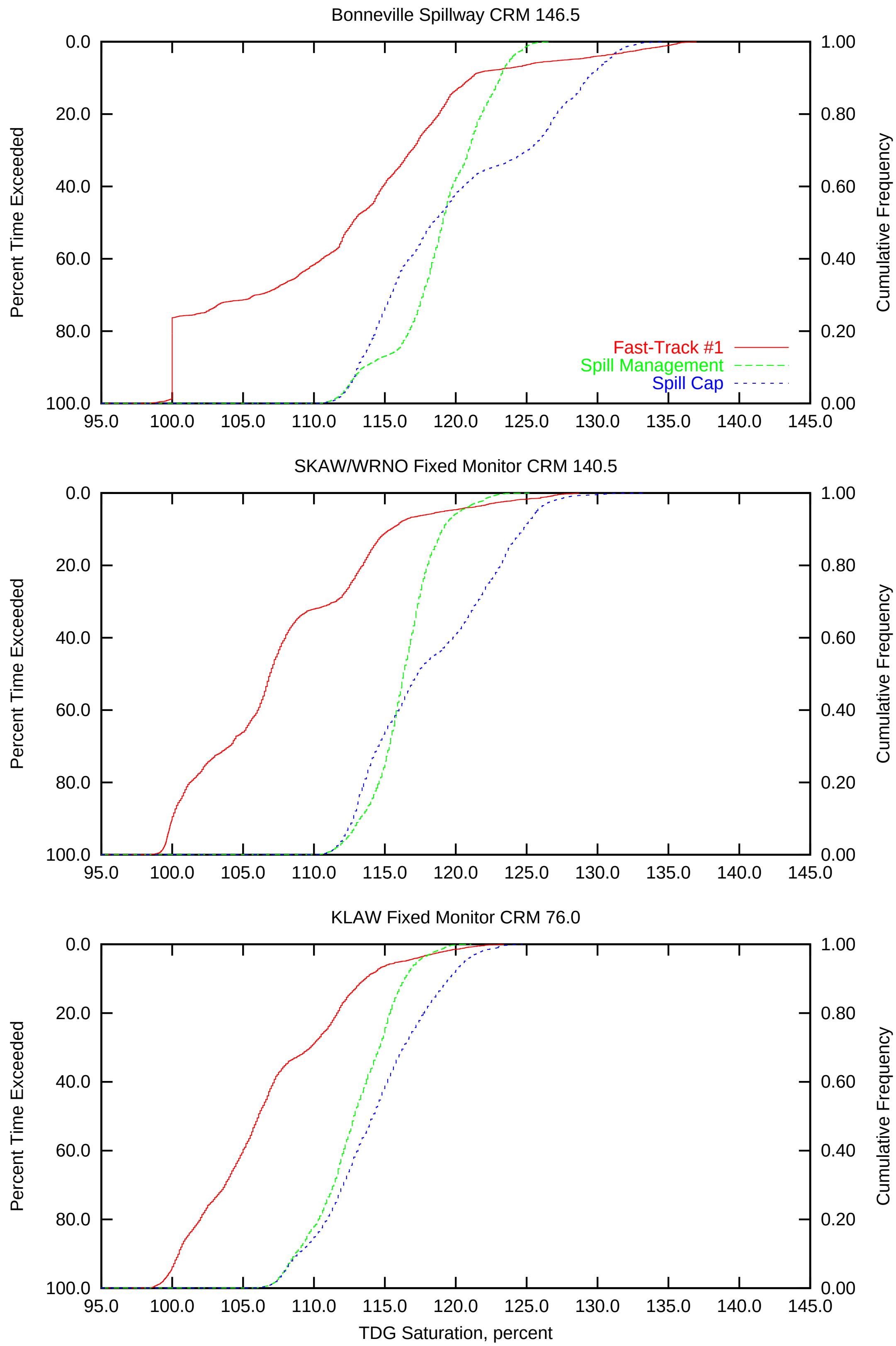

Figure 3.20: Comparision of simulated TDG saturation cumulative frequency distributions for locations in the tidal reach during a low flow (1994) season.

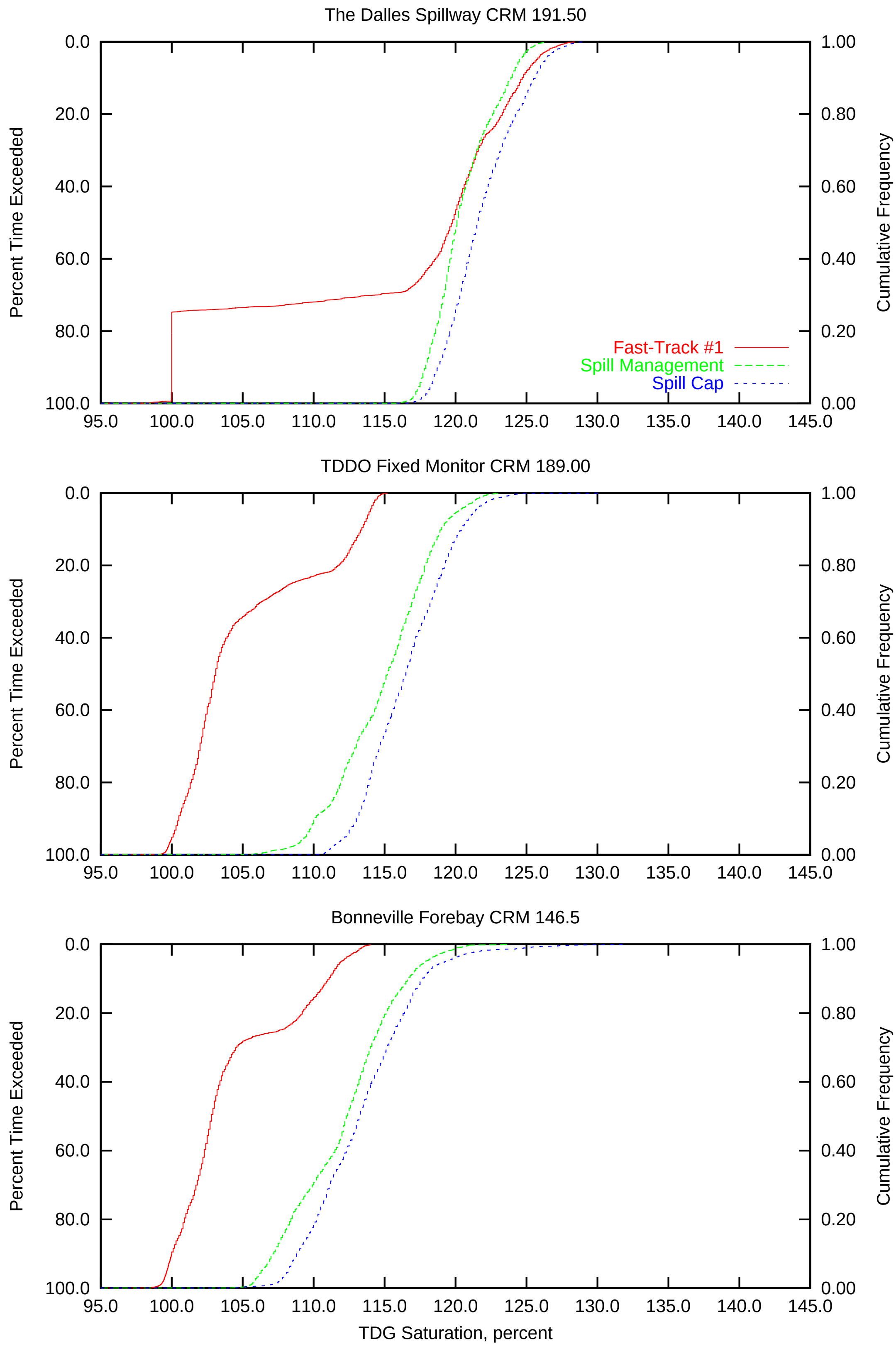

Figure 3.21: Comparision of simulated TDG saturation cumulative frequency distributions for locations in Bonneville pool during a low flow (1994) season.

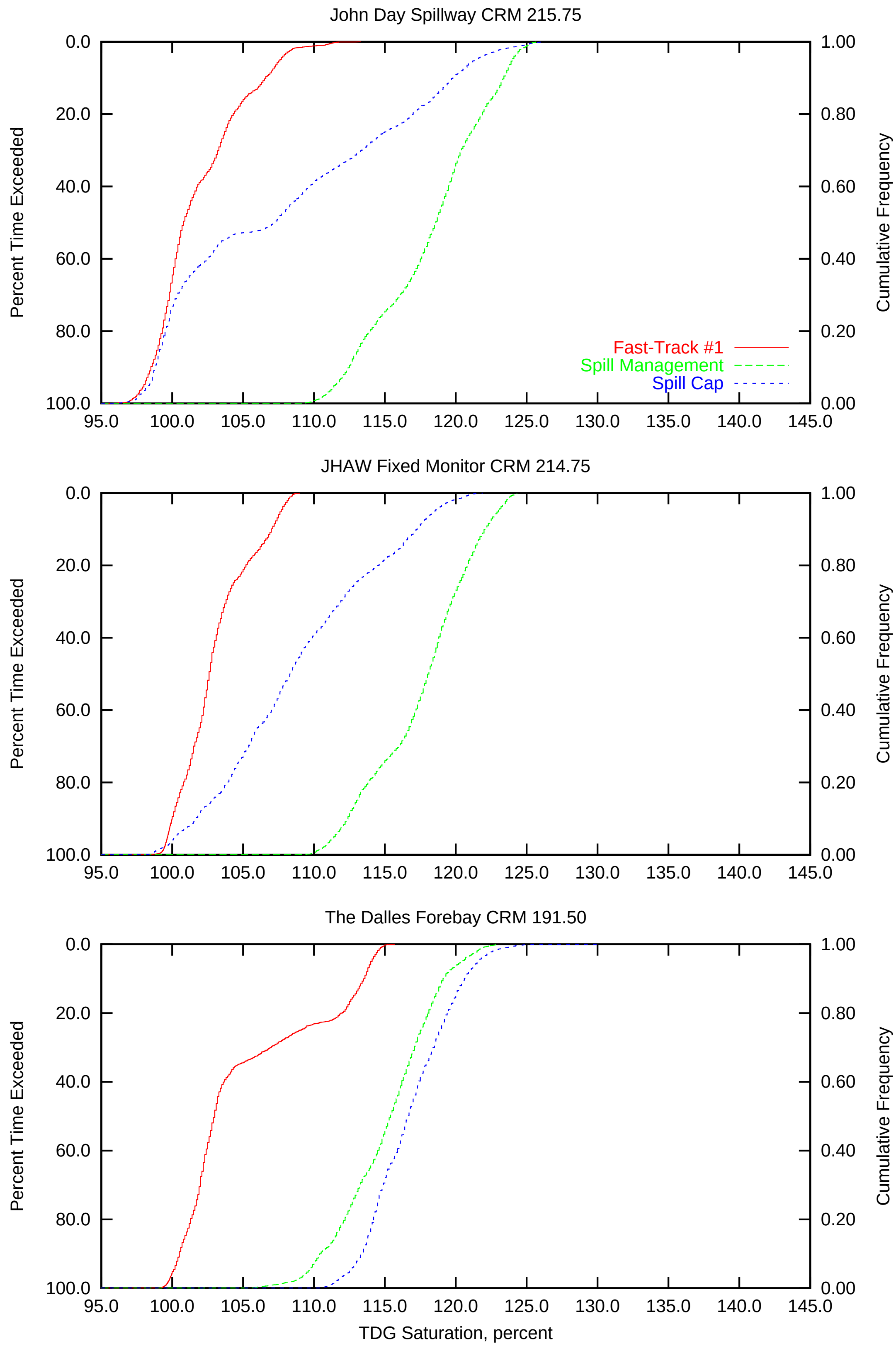

Figure 3.22: Comparision of simulated TDG saturation cumulative frequency distributions for locations in The Dalles pool during a low flow (1994) season.

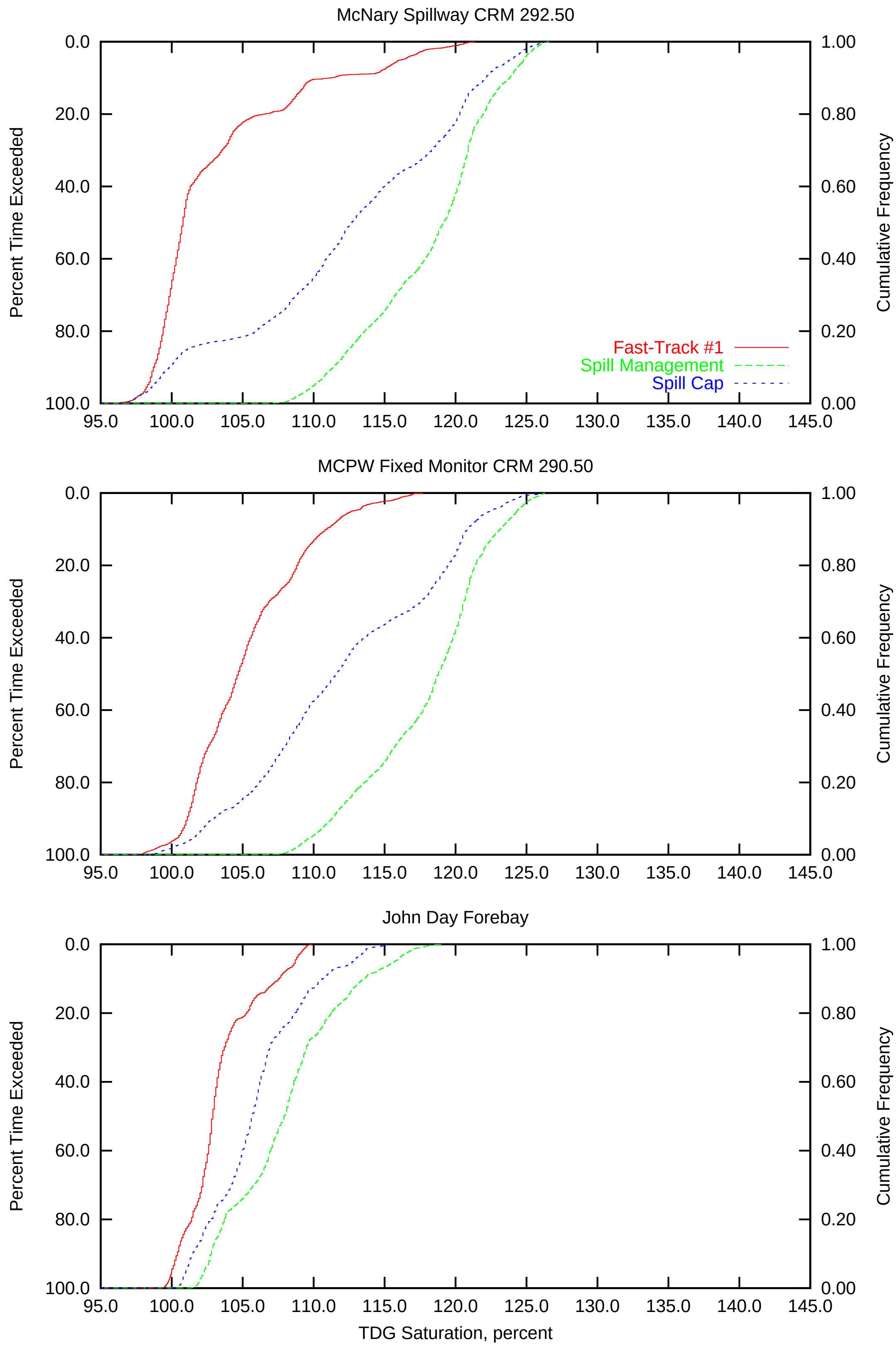

Figure 3.23: Comparision of simulated TDG saturation cumulative frequency distributions for locations in John Day pool during a low flow (1994) season.

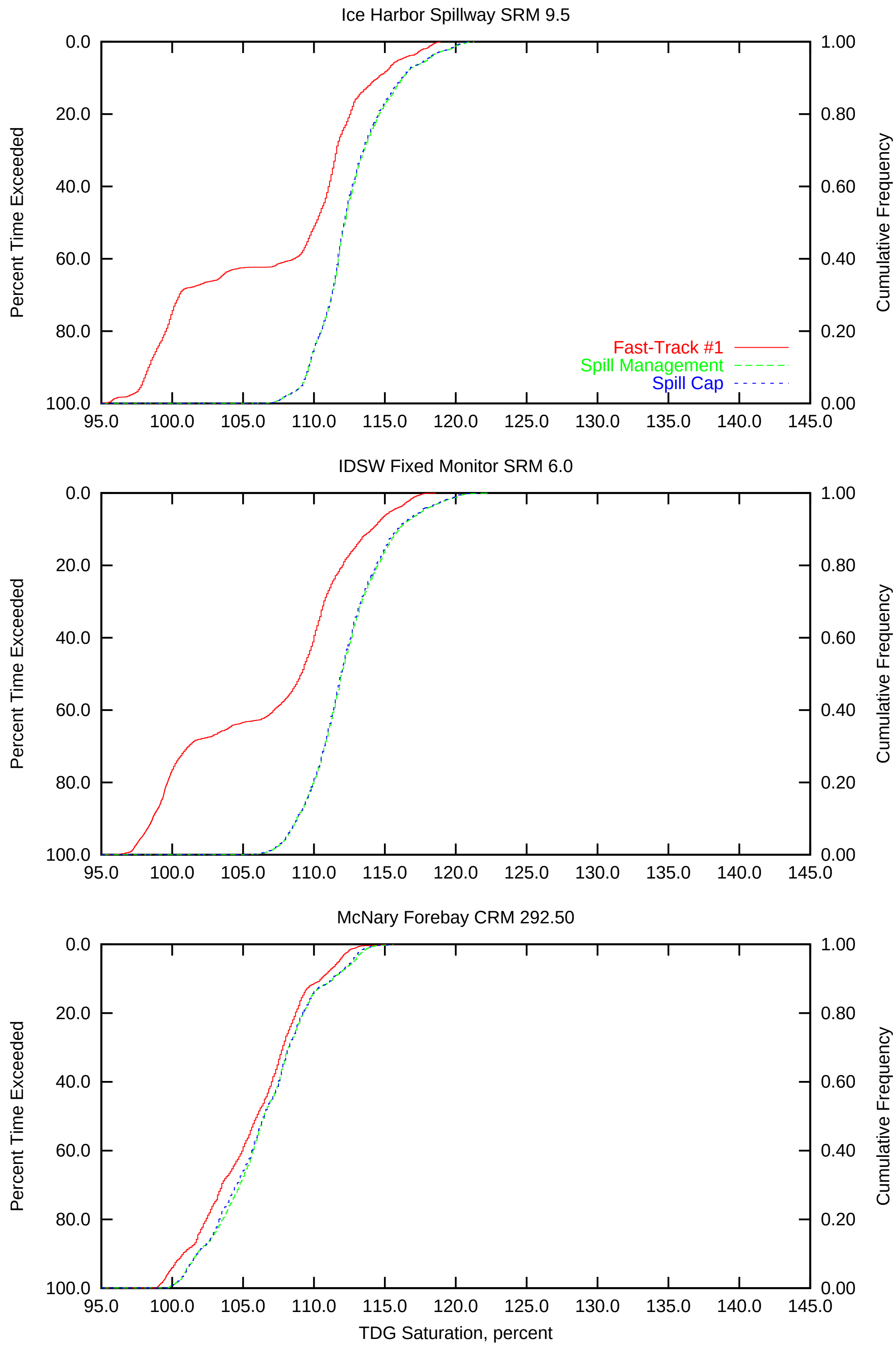

Figure 3.24: Comparision of simulated TDG saturation cumulative frequency distributions for locations in McNary pool during a low flow (1994) season.

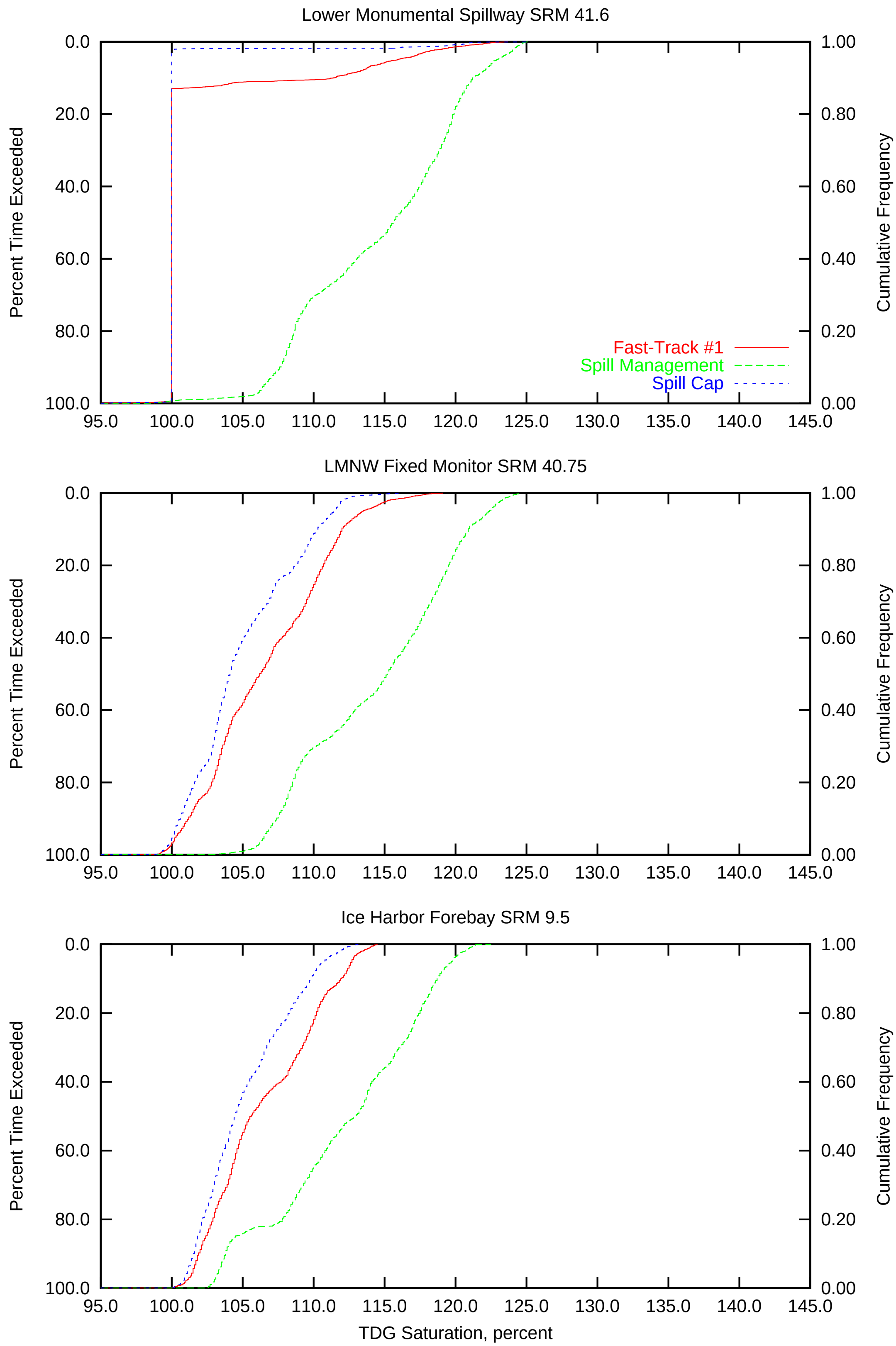

Figure 3.25: Comparision of simulated TDG saturation cumulative frequency distributions for locations in Ice Harbor pool during a low flow (1994) season.

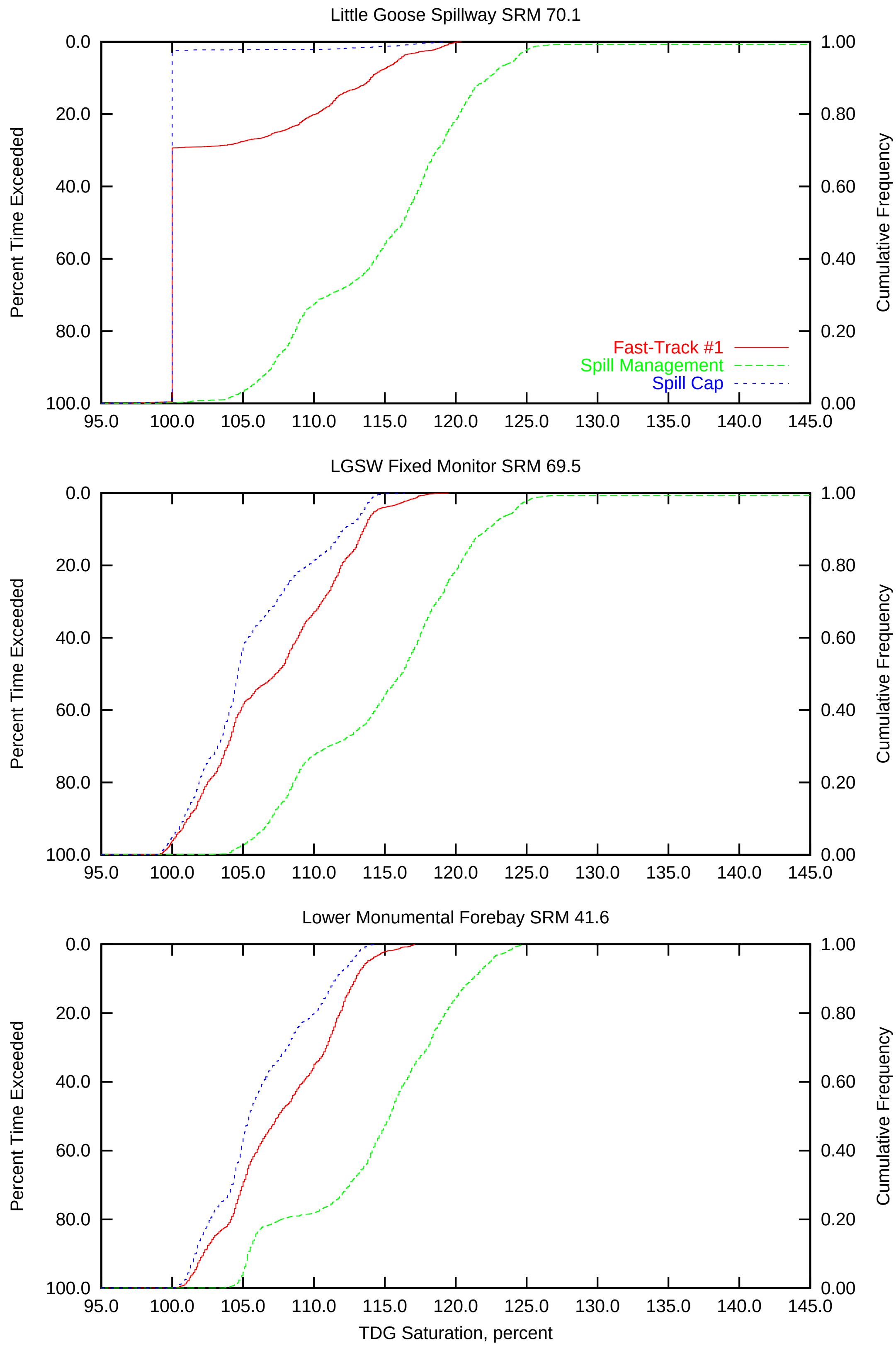

Figure 3.26: Comparision of simulated TDG saturation cumulative frequency distributions for locations in Lower Monumental pool during a low flow (1994) season.

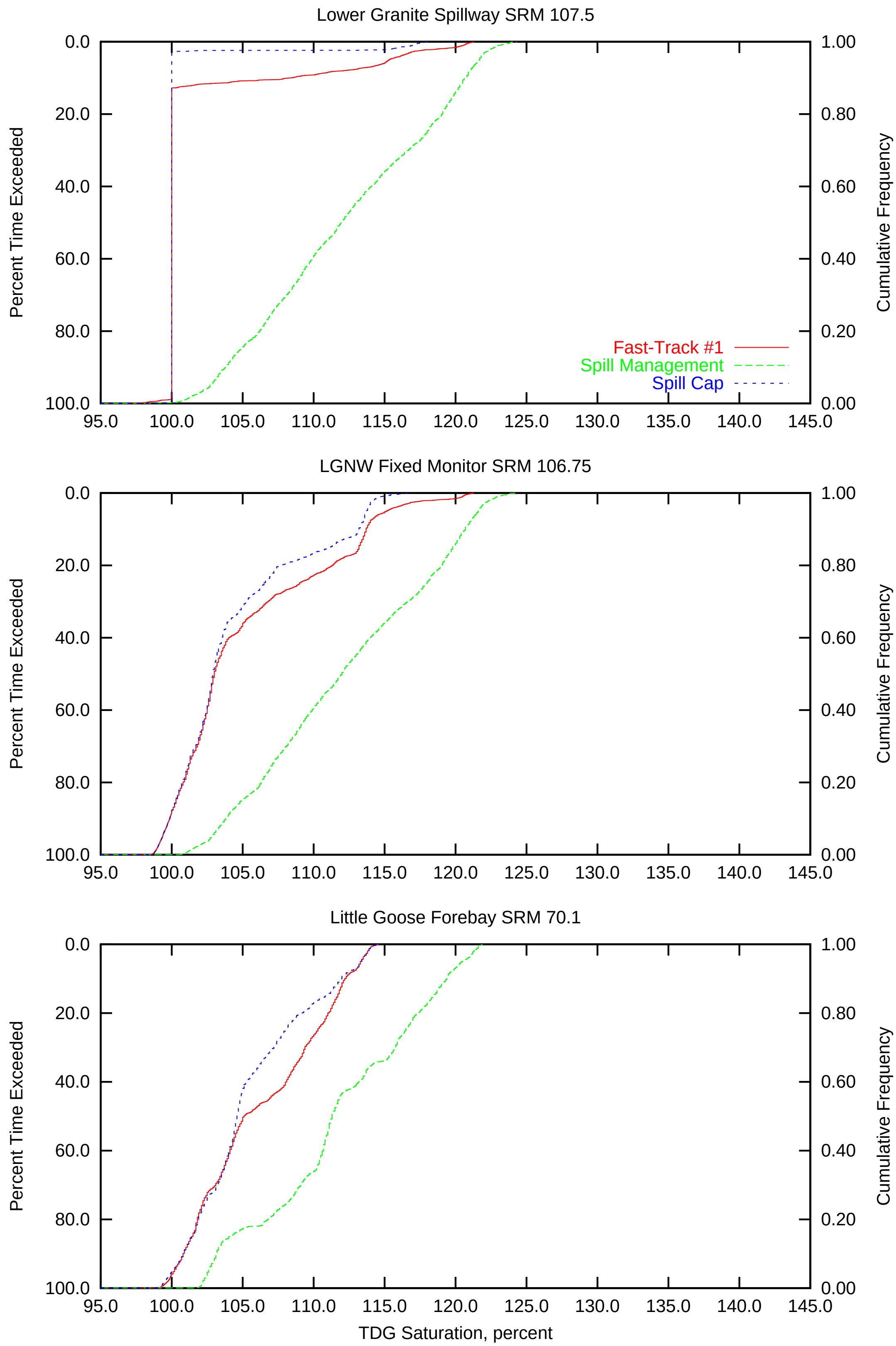

Figure 3.27: Comparision of simulated TDG saturation cumulative frequency distributions for locations in Little Goose pool during a low flow (1994) season.

3.2 Discussion of Two-Dimensional Simulations for Example Pools

Three of the fast-track scenarios were further analyzed using the hybrid 1D/2D model. The fast-track #1, #2, and #3 scenarios are compared to the Baseline. Scenario #4 was dropped from this stage of the analysis as it consisted mainly of raised tailrace alternatives which had various complications that eliminated them from further consideration. All three long-term scenarios were simulated. Results are shown only for the John Day pool on the Columbia River and for the Little Goose pool on the Snake River.

In the hybrid simulations, the upper end of each impoundment or reach was simulated using a two-dimensional, depth-averaged hydrodynamic model, MASS2. MASS2 is capable of simulating the lateral variation of stage, velocity, temperature, and TDG concentration in addition to the longitudinal variation, simulated by MASS1. Only the medium/high season (1996) was simulated using the same hydrologic conditions specified in Section 2.2.1.

In addition to the 1D/2D hybrid model, the baseline scenario was simulated for each full pool. This was done to further examine the effect of lateral dissolved gas variations on the analysis.

The main goal of these simulations was to investigate the lateral variation of TDG near the projects. Of particular interest was the project tailwater FMS location where water quality standards are typically enforced. The hybrid model was used to compare computed TDG gas levels at the actual FMS location, whereas the 1-D simulations compared a fully-mixed value at the FMS. This provides some indication if the FMS location was measuring gas levels from spill or powerhouse flow or a mixture of both. Simulated TDG levels from the hybrid model were also compared to the 1D simulations. This provided, at minimum, a cross check between the two approaches. It also provided a basis for comparison when examining several laterally spaced points: how do laterally varying gas levels at specific river mile compare to a cross section average? In addition, the hybrid model provided an spatial picture of gas levels, which could be used to quantify the extent of impacts on habitat.

Hybrid simulation results are presented in two ways: scenario to scenario comparison and comparison with the 1D simulations. A full complement of tables and figures is presented in Appendix D for Snake River pools and Appendix E for the Columbia River.

3.2.1 Columbia River, John Day Pool

The grids used during MASS2 calibration (Richmond et al., 1999) were shortened to include only about the upper 10 miles of each pool. A view of the John Day pool grid near McNary dam is shown in Figure 3.28 as an example.

The MASS2 model was driven by McNary project flows at the upstream end and a downstream stage. The spill and powerhouse flows at each project were the same as those used in the 1D simulations. Spill and powerhouse flow was distributed along the corresponding portions of the model grid after dividing the total spill using the scenario spill pattern. Appendix B shows how spill from individual bays was distributed for the the 2D pool simulations. The stage simulated by the 1D model was used for the downstream boundary stage in the 2D model.

The forebay TDG and temperature predicted in the 1D simulations were used as powerhouse water quality, and spillway temperature, boundary conditions in the 1D/2D model hybrid model for John Day (and other) pools. Spillway TDG concentrations for the 2D model were computed bay by bay using available production functions and/or algorithms presented in Appendix B.

Fast-Track Scenario Results

In the 2D portion of the hybrid simulations, the time series data were extracted at three points across the channel at the FMS location. One point was located near the actual FMS location, a second mid-channel, and a third on the opposite shore. In the John Day pool these points were located at about Columbia River Mile 291 and shown in the inset of Figure 3.28. Simulated time series from these locations were compared as CFD plot and are shown in Figure 3.30.

Simulated FMS time series from the 1D/2D hybrid model were compared with the 1D series. These time series were compared in a CFD plot shown in Figure 3.29. Table 3.3 presents the same information in a histogram table. For uniform spill patterns the 1D spillway TDG is comparable to the 2D FMS TDG. The fully-mixed 1D results near the FMS lie in between the lateral distribution of TDG simulated by the 2D model.

The 2D simulation results were also summarized in maps are area/volume tables. Figure 3.32 shows maps of the number of days TDG saturation exceeded 120% during the simulated season in the John Day pool. Table 3.4 shows the area and volume of the John Day pool that was included in the hybrid model, corresponding to the 25% exceedance TDG histogram. A histogram table showing the compensation depth associated with the 25% exceedance TDG level is presented in Table 3.5. Other spatial statistics are presented in such a manner in Appendix E.

The hybrid simulations highlight the benefits of a uniform spill pattern at McNary. For example, compare the Baseline and fast-track #1 scenarios in Figure 3.30. The nonuniform pattern currently used is apparent in the Baseline case at the FMS location, which is along the north shore.

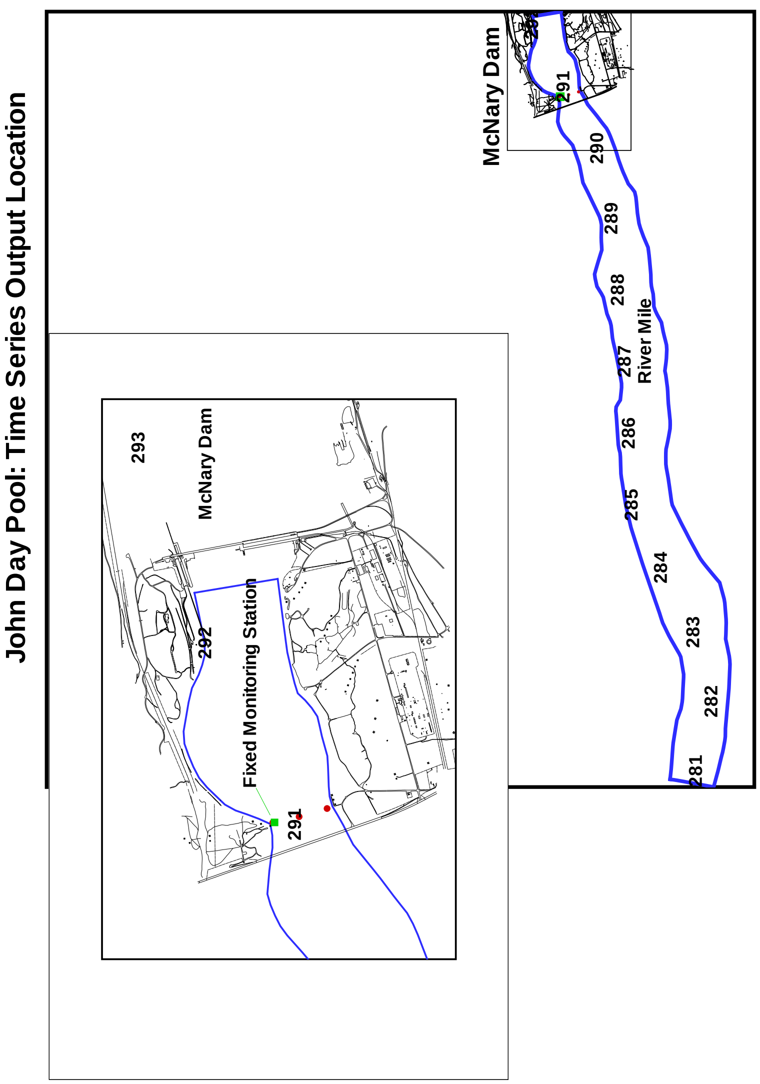

Figure 3.28: Grid and FMS locations for the area of John Day pool simulated in two dimensions with the one/two-dimensional hybrid model.

Table 3.3: Histogram table of TDG saturation percentage of MASS2 and MASS1 time series output for fast-track scenarios in John Day pool in a medium flow season (1996)

Location	TDG Range	Base Line		Fast-Track No.1		Fast-Track No.2		Fast-Track No.3	
		Days	%	Days	%	Days	%	Days	%
North FMS	less than 105	2	1.2	6	4.3	8	5.6	6	4.3
	105 - 110	4	2.8	28	18.8	31	20.6	33	21.9
	110 - 115	26	17.6	36	24.5	51	34.0	51	34.1
	115 - 120	42	28.5	32	21.3	25	16.9	25	16.6
	120 - 125	24	16.0	16	10.8	19	13.0	20	13.1
	125 - 130	18	12.2	18	12.0	15	9.8	15	9.9
	above 130	32	21.6	12	8.2	0	0.1	0	0.1
Mid-channel	less than 105	6	3.7	7	4.7	7	4.9	8	5.5
	105 - 110	24	16.4	27	17.9	32	21.8	40	26.7
	110 - 115	51	34.0	54	36.1	57	38.0	54	36.2
	115 - 120	27	17.9	19	12.6	20	13.7	17	11.3
	120 - 125	14	9.3	13	8.9	18	12.2	18	12.4
	125 - 130	19	12.6	17	11.6	14	9.3	12	7.8
	above 130	9	6.0	12	8.1	0	0.1	0	0.1
South	less than 105	10	7.0	10	7.0	11	7.1	11	7.3
	105 - 110	50	33.4	50	33.4	50	33.9	51	34.3
	110 - 115	58	39.0	58	38.9	58	38.8	59	39.3
	115 - 120	24	16.2	24	16.2	24	16.1	24	16.0
	120 - 125	6	4.3	6	4.3	6	4.1	5	3.1
	125 - 130	0	0.1	0	0.1	0	0.0	0	0.0
	above 130	0	0.0	0	0.0	0	0.0	0	0.0
1-D FMS	less than 105	2	1.6	6	3.8	6	3.8	6	3.9
	105 - 110	20	13.3	24	16.4	27	18.0	27	18.0
	110 - 115	47	31.6	49	33.1	62	41.4	64	43.1
	115 - 120	35	23.7	29	19.3	22	14.8	22	14.5
	120 - 125	18	12.0	16	10.9	21	14.3	21	14.1
	125 - 130	19	12.9	18	12.1	11	7.7	9	6.3
	above 130	7	4.9	7	4.4	0	0.1	0	0.0

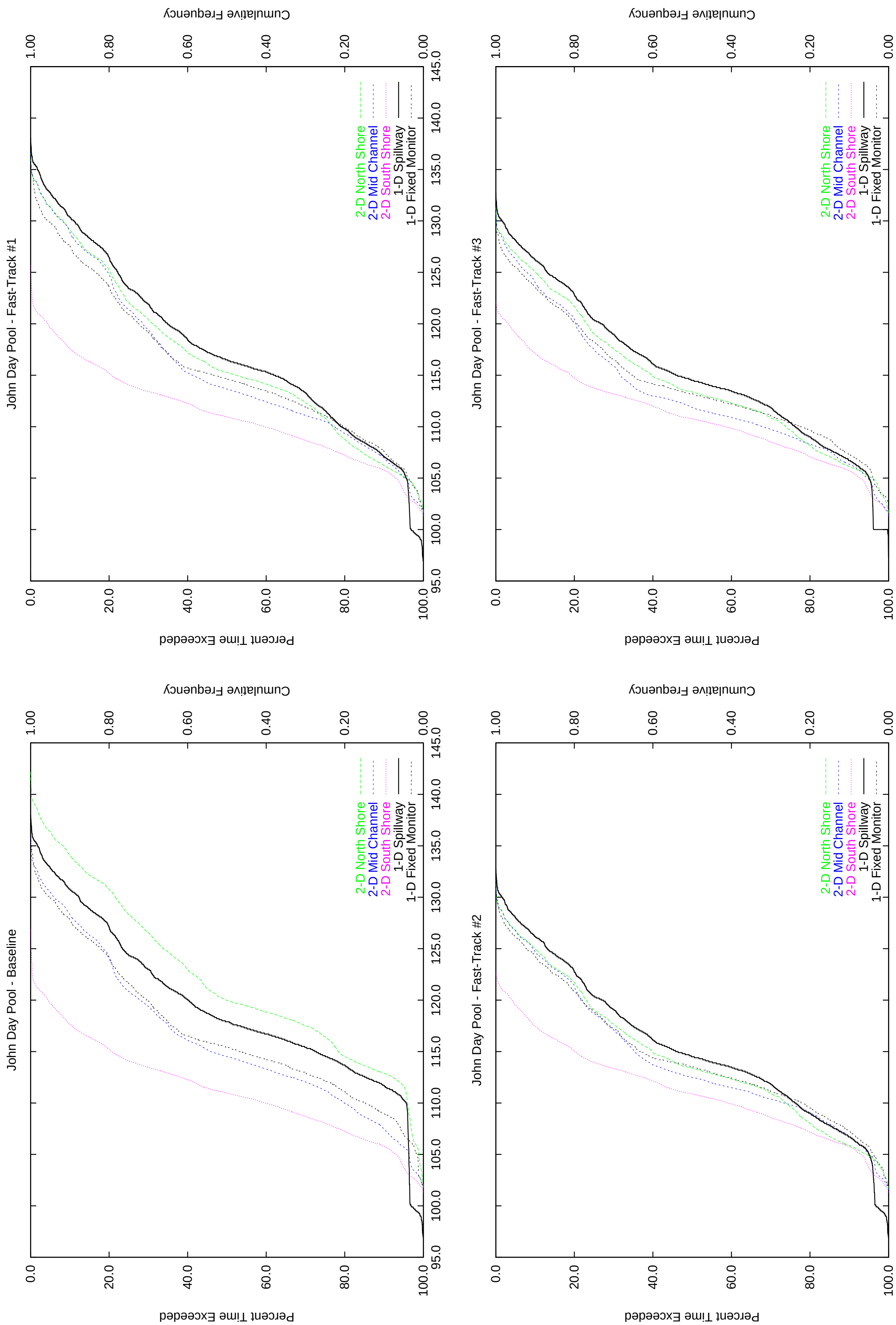

Figure 3.29: Cumulative frequency distributions TDG saturation simulated by the 1-D/2-D hybrid model for several points across the channel at the MCPW FMS location (CRM 291) John Day Pool during a medium/high flow (1996) season and each scenario compared with similar values from the 1-D simulations at the spillway and FMS location.

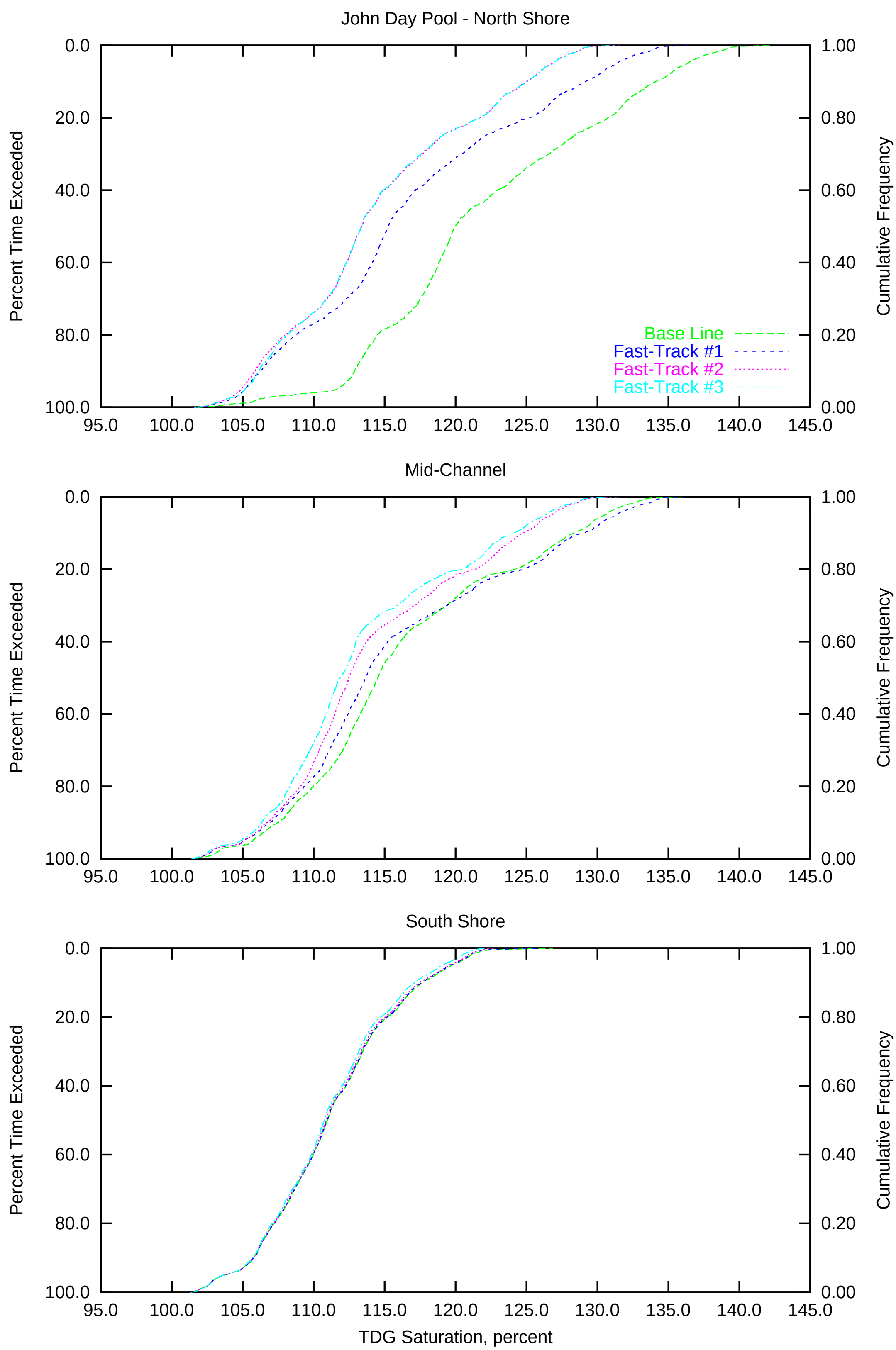

Figure 3.30: Comparision of simulated TDG saturation cumulative frequency distributions for several points across the channel at the MCPW FMS location (CRM 291) in the John Day Pool during a medium/high flow (1996) season.

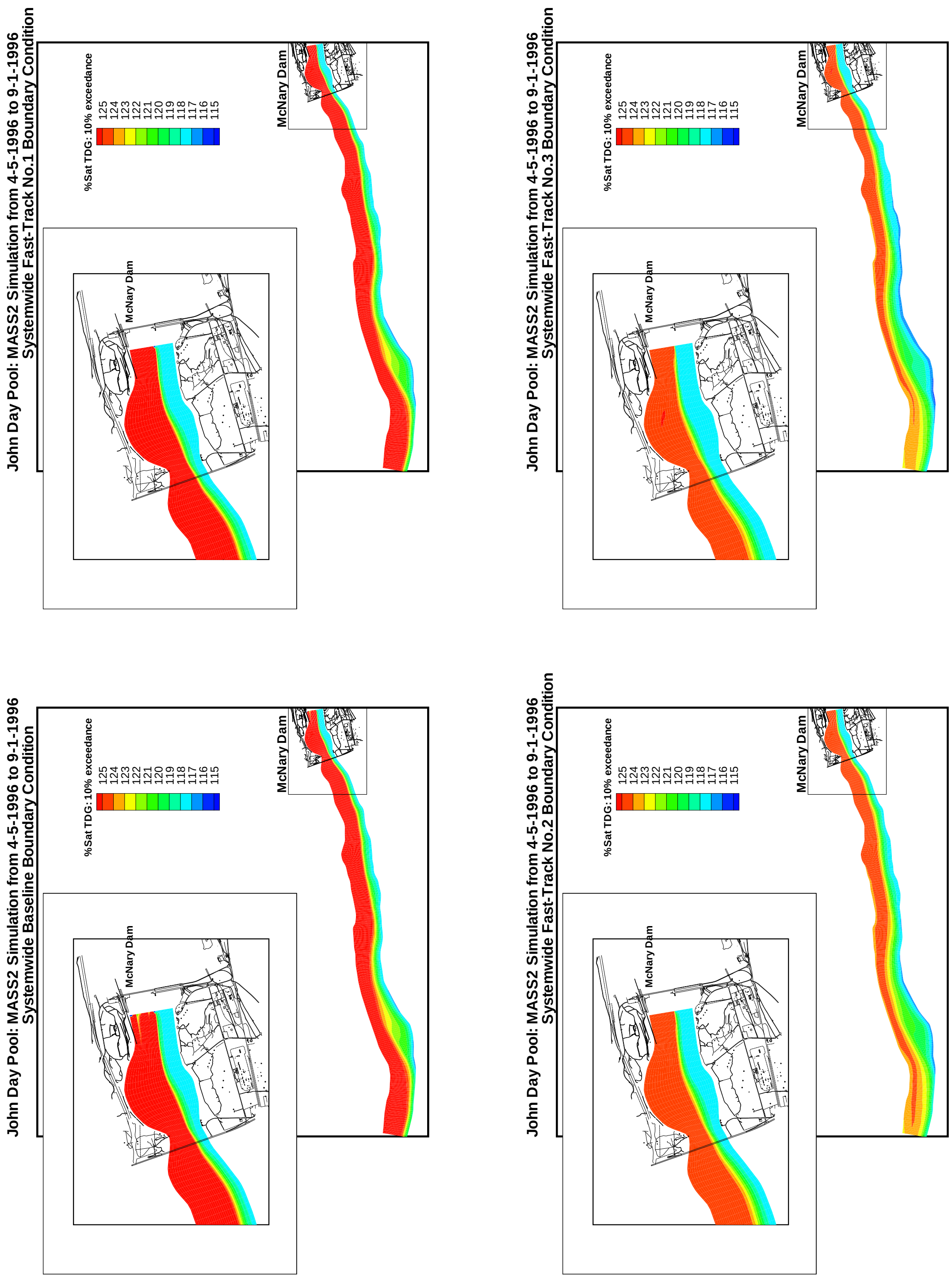

Figure 3.31: Areal comparison of TDG saturation exceeded 10% of a medium flow season (1996) for the fast-track scenarios in John Day Pool.

Table 3.4: Tabular histogram of TDG saturation exceeded 25% of the medium/high flow season (1996) over 2-D modeled area in John Day pool during the Fast-Track scenario simulations.

Baseline Medium/High Flow

Range of TDG Saturation Median (percent)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 105	0.0	0.0	0.0	0.0
105 - 110	0.0	0.0	0.0	0.0
110 - 115	830.4	18.0	12830.8	10.7
115 - 120	1577.2	34.1	46465.1	38.7
120 - 125	1820.6	39.4	55401.0	46.1
≥ 125	396.6	8.6	5515.1	4.6
Total	4624.8	100.0	120211.9	100.0

Fast-Track #1 Medium/High Flow

Range of TDG Saturation Median (percent)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 105	0.0	0.0	0.0	0.0
105 - 110	0.0	0.0	0.0	0.0
110 - 115	893.2	19.3	14308.7	11.9
115 - 120	1589.3	34.4	47108.6	39.2
120 - 125	2142.3	46.3	58786.8	48.9
≥ 125	0.0	0.0	0.0	0.0
Total	4624.8	100.0	120204.0	100.0

Fast-Track #2 Medium/High Flow

Range of TDG Saturation Median (percent)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 105	0.0	0.0	0.0	0.0
105 - 110	0.0	0.0	0.0	0.0
110 - 115	1170.1	25.3	19951.5	16.6
115 - 120	3454.7	74.7	100260.0	83.4
120 - 125	0.0	0.0	0.0	0.0
≥ 125	0.0	0.0	0.0	0.0
Total	4624.8	100.0	120211.5	100.0

Fast-Track #3 Medium/High Flow

Range of TDG Saturation Median (percent)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 105	0.0	0.0	0.0	0.0
105 - 110	0.0	0.0	0.0	0.0
110 - 115	1607.0	34.7	30898.9	25.7
115 - 120	3017.8	65.3	89314.9	74.3
120 - 125	0.0	0.0	0.0	0.0
≥ 125	0.0	0.0	0.0	0.0
Total	4624.8	100.0	120213.8	100.0

Table 3.5: Tabular histogram of TDG saturation exceeded 25% of the medium/high flow season (1996) over 2-D modeled area in John Day pool during the Fast-Track scenario simulations.

Baseline Medium/High Flow | Fast-Track #1 Medium/High Flow

Range of Compensation Depth Median (feet)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)	Range of Compensation Depth Median (feet)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 2	0.0	0.0	0.0	0.0	< 2	0.0	0.0	0.0	0.0
2 - 4	0.0	0.0	0.0	0.0	2 - 4	0.2	0.0	8.4	0.0
4 - 6	1758.0	38.0	36005.7	30.0	4 - 6	1777.1	38.4	36703.0	30.5
6 - 8	2104.0	45.5	70232.0	58.4	6 - 8	2847.4	61.6	83492.6	69.5
8 - 10	741.8	16.0	13585.8	11.3	8 - 10	0.0	0.0	0.0	0.0
≥ 10	20.9	0.5	388.5	0.3	≥ 10	0.0	0.0	0.0	0.0
Total	4624.8	100.0	120211.9	100.0	Total	4624.8	100.0	120204.0	100.0

Fast-Track #2 Medium/High Flow | Fast-Track #3 Medium/High Flow

Range of Compensation Depth Median (feet)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)	Range of Compensation Depth Median (feet)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 2	0.0	0.0	0.0	0.0	< 2	0.0	0.0	0.0	0.0
2 - 4	0.0	0.0	0.0	0.0	2 - 4	0.0	0.0	0.0	0.0
4 - 6	2489.6	53.8	61160.8	50.9	4 - 6	2953.5	63.9	77041.6	64.1
6 - 8	2135.2	46.2	59050.6	49.1	6 - 8	1671.3	36.1	43172.2	35.9
8 - 10	0.0	0.0	0.0	0.0	8 - 10	0.0	0.0	0.0	0.0
≥ 10	0.0	0.0	0.0	0.0	≥ 10	0.0	0.0	0.0	0.0
Total	4624.8	100.0	120211.5	100.0	Total	4624.8	100.0	120213.8	100.0

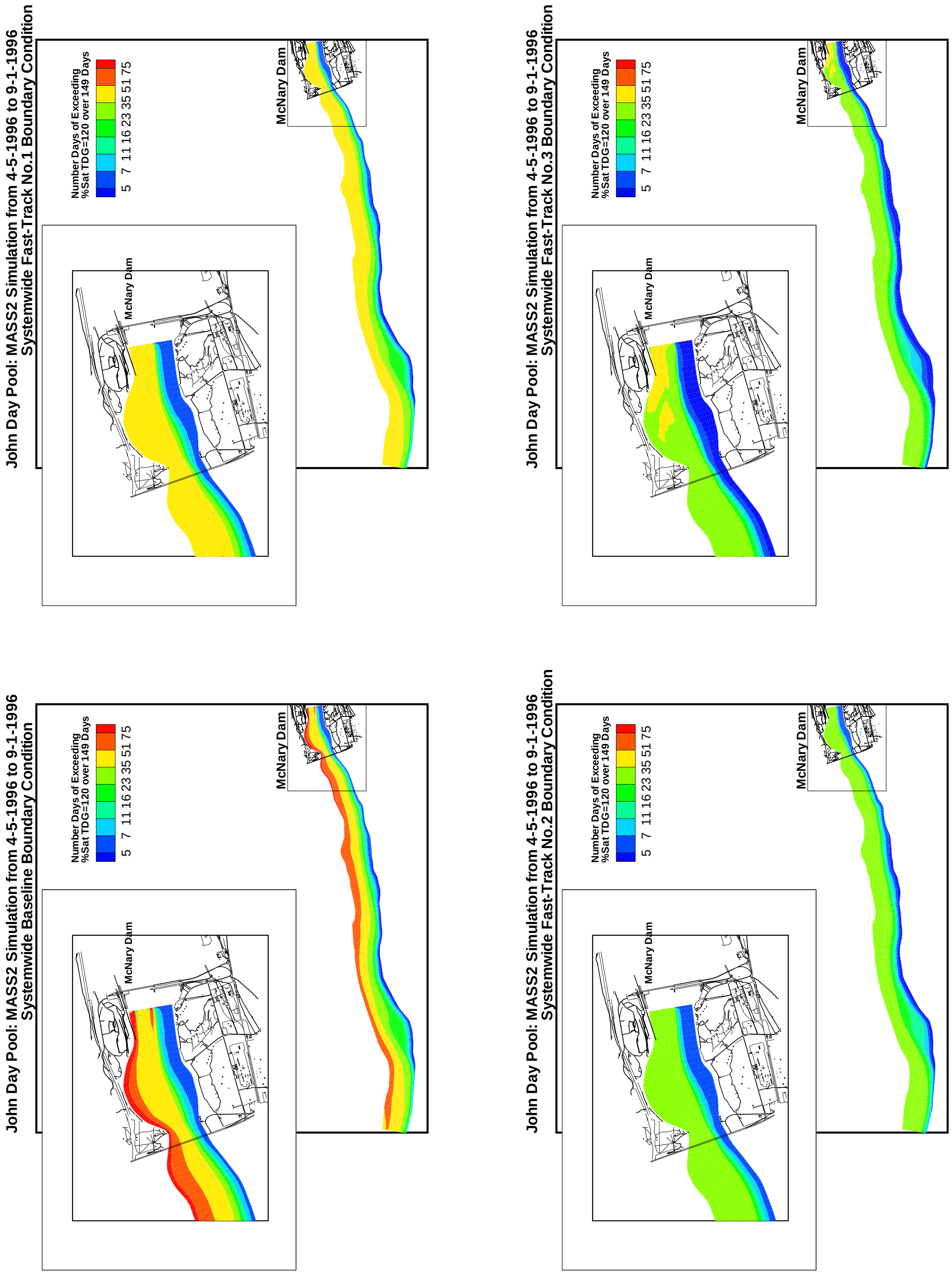

Figure 3.32: Areal comparison of days exceeding TDG saturation of 120% for fast-track scenarios in John Day Pool in a medium flow season (1996).

Long Term Scenario Results

The long-term scenarios were simulated using the same methodology as previously described for the fast-track cases. In long-term option #2 and #3 additional spillway bays are installed at McNary Dam. The 2D model grid was modified to include these spillways as shown in Figure 3.33. The simulation results are shown using the same type of time-series and spatial information as was used in the fast-track cases.

In general, the results show the benefit of installing additional spillway bays and the use of unifrom spill patterns. The spatial distribution of the TDG levels exceeded 10 % of the time shown in Figure 3.35 illustrate these benefits.

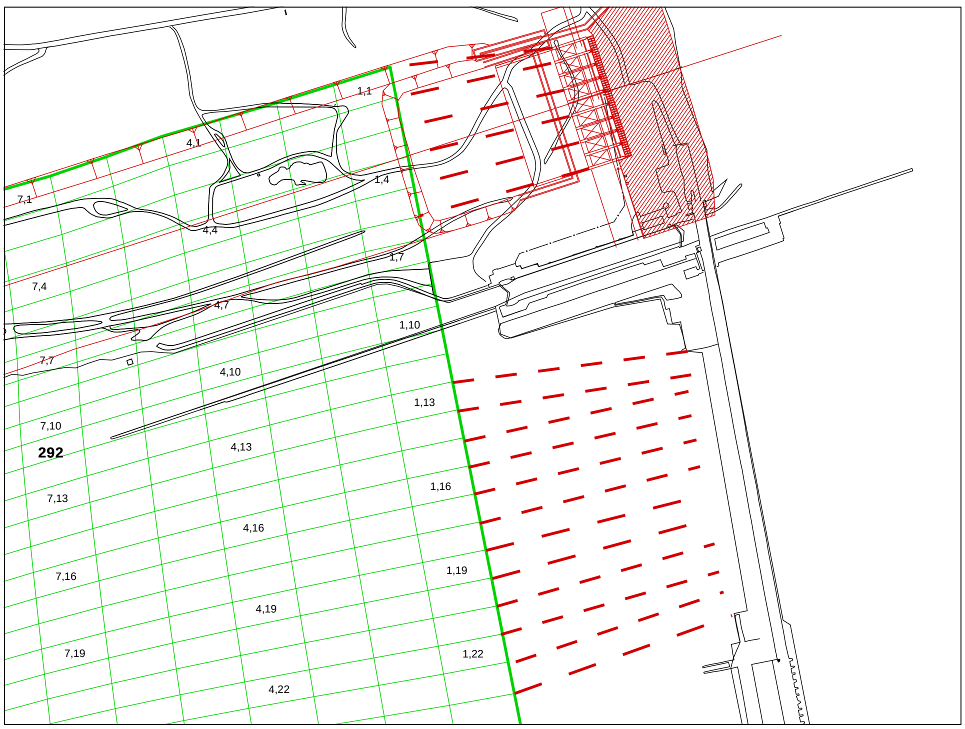

Figure 3.33: Model grid near McNary dam, with spill bay to grid mapping, used to simulate additional spill bays.

Table 3.6: Histogram table of TDG saturation percentage of MASS2 and MASS1 time series output for longterm scenarios in John Day pool in a medium flow season (1996)

Location	TDG Range	Base Line		Longterm No.1		Longterm No.2		Longterm No.3	
		Days	%	Days	%	Days	%	Days	%
North FMS	less than 105	2	1.2	8	5.6	5	3.4	6	4.2
	105 - 110	4	2.8	31	20.7	64	42.8	63	42.0
	110 - 115	26	17.6	51	34.0	77	51.8	77	51.8
	115 - 120	42	28.5	25	16.8	3	2.0	3	2.0
	120 - 125	24	16.0	19	13.1	0	0.0	0	0.0
	125 - 130	18	12.2	15	9.8	0	0.0	0	0.0
	above 130	32	21.6	0	0.1	0	0.0	0	0.0
Mid-channel	less than 105	6	3.7	7	4.9	7	4.8	10	6.4
	105 - 110	24	16.4	33	21.9	52	35.1	54	36.5
	110 - 115	51	34.0	57	38.0	52	35.1	48	32.3
	115 - 120	27	17.9	20	13.7	26	17.7	26	17.5
	120 - 125	14	9.3	18	12.1	11	7.4	11	7.3
	125 - 130	19	12.6	14	9.3	0	0.0	0	0.0
	above 130	9	6.0	0	0.1	0	0.0	0	0.0
South	less than 105	10	7.0	11	7.4	11	7.4	17	11.2
	105 - 110	50	33.4	51	34.5	52	34.8	57	38.3
	110 - 115	58	39.0	58	39.0	59	39.4	52	35.1
	115 - 120	24	16.2	24	16.0	24	15.9	22	14.8
	120 - 125	6	4.3	5	3.1	4	2.5	1	0.6
	125 - 130	0	0.1	0	0.0	0	0.0	0	0.0
	above 130	0	0.0	0	0.0	0	0.0	0	0.0
1-D FMS	less than 105	2	1.6	6	3.8	6	4.0	7	4.7
	105 - 110	20	13.3	27	18.1	37	24.8	40	27.0
	110 - 115	47	31.6	62	41.9	67	44.9	64	42.6
	115 - 120	35	23.7	22	14.5	32	21.7	33	22.0
	120 - 125	18	12.0	21	14.1	7	4.6	6	3.7
	125 - 130	19	12.9	11	7.5	0	0.0	0	0.0
	above 130	7	4.9	0	0.1	0	0.0	0	0.0

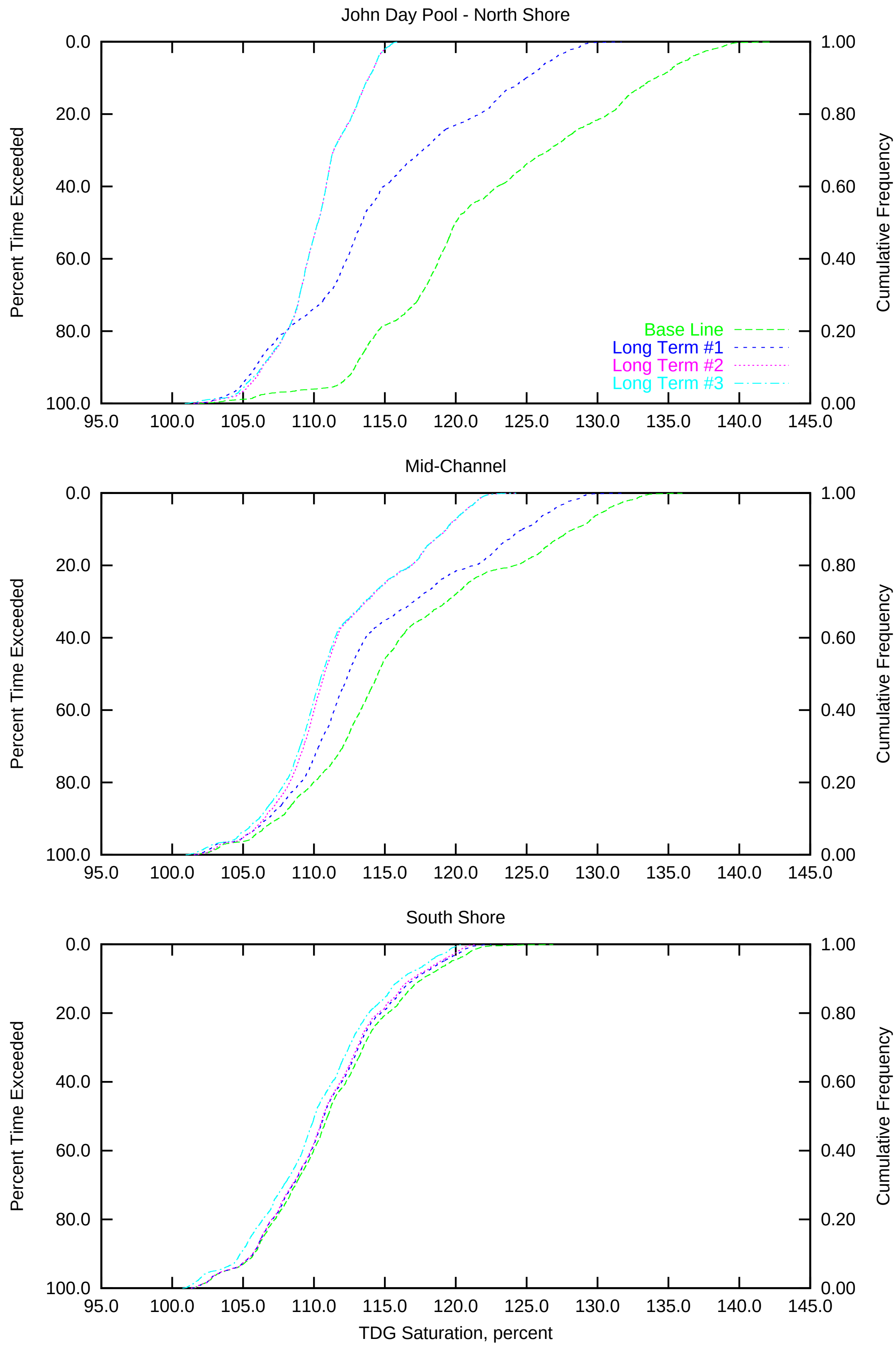

Figure 3.34: Comparision of simulated TDG saturation cumulative frequency distributions for several points across the channel at the MCPW FMS location (CRM 291) in the John Day Pool during a medium/high flow (1996) season.

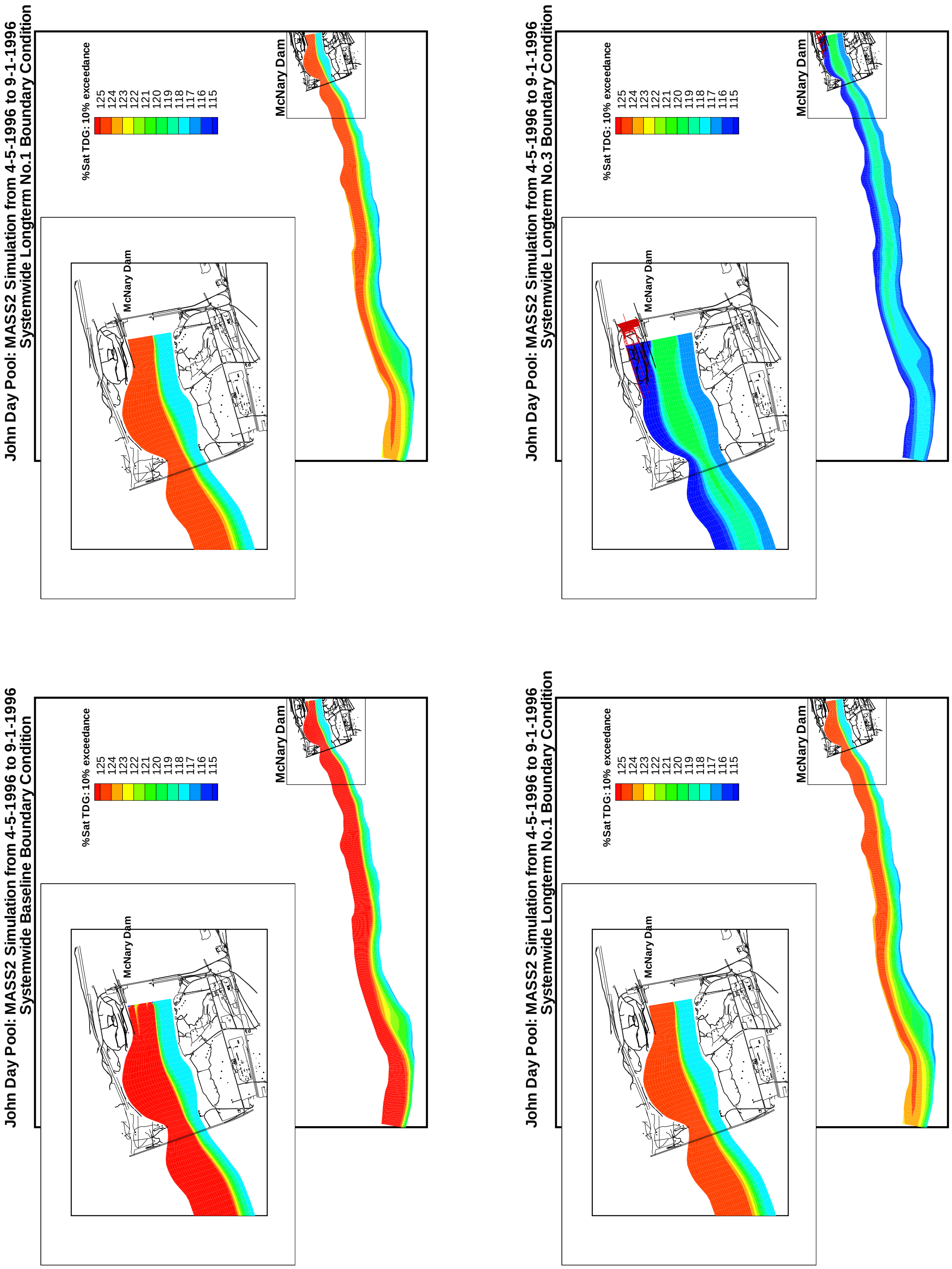

Figure 3.35: Areal comparison of TDG saturation exceeded 10% of a medium flow season (1996) for the long term scenarios in John Day Pool.

Table 3.7: Tabular histogram of TDG saturation exceeded 25% of the medium/high flow season (1996) over 2-D modeled area in John Day pool during the Long Term scenario simulations.

Baseline Medium/High Flow

Range of TDG Saturation Median (percent)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 105	0.0	0.0	0.0	0.0
105 - 110	0.0	0.0	0.0	0.0
110 - 115	830.4	18.0	12830.8	10.7
115 - 120	1577.2	34.1	46465.1	38.7
120 - 125	1820.6	39.4	55401.0	46.1
≥ 125	396.6	8.6	5515.1	4.6
Total	4624.8	100.0	120211.9	100.0

Long Term #1 Medium/High Flow

Range of TDG Saturation Median (percent)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 105	0.0	0.0	0.0	0.0
105 - 110	0.0	0.0	0.0	0.0
110 - 115	1268.8	27.4	22111.2	18.4
115 - 120	3356.0	72.6	98099.4	81.6
120 - 125	0.0	0.0	0.0	0.0
≥ 125	0.0	0.0	0.0	0.0
Total	4624.8	100.0	120210.6	100.0

Long Term #2 Medium/High Flow

Range of TDG Saturation Median (percent)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 105	0.0	0.0	0.0	0.0
105 - 110	0.0	0.0	0.0	0.0
110 - 115	4571.4	97.7	116724.9	96.6
115 - 120	105.5	2.3	4084.0	3.4
120 - 125	0.0	0.0	0.0	0.0
≥ 125	0.0	0.0	0.0	0.0
Total	4677.0	100.0	120808.9	100.0

Long Term #3 Medium/High Flow

Range of TDG Saturation Median (percent)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 105	0.0	0.0	0.0	0.0
105 - 110	0.0	0.0	0.0	0.0
110 - 115	4584.4	98.0	117148.6	97.0
115 - 120	92.6	2.0	3660.3	3.0
120 - 125	0.0	0.0	0.0	0.0
≥ 125	0.0	0.0	0.0	0.0
Total	4677.0	100.0	120808.9	100.0

Table 3.8: Tabular histogram of TDG saturation exceeded 25% of the medium/high flow season (1996) over 2-D modeled area in John Day pool during the Long Term scenario simulations.

Baseline Medium/High Flow

Range of Compensation Depth Median (feet)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 2	0.0	0.0	0.0	0.0
2 - 4	0.0	0.0	0.0	0.0
4 - 6	1758.0	38.0	36005.7	30.0
6 - 8	2104.0	45.5	70232.0	58.4
8 - 10	741.8	16.0	13585.8	11.3
≥ 10	20.9	0.5	388.5	0.3
Total	4624.8	100.0	120211.9	100.0

Long Term #1 Medium/High Flow

Range of Compensation Depth Median (feet)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 2	0.0	0.0	0.0	0.0
2 - 4	0.0	0.0	0.0	0.0
4 - 6	2524.3	54.6	62327.5	51.8
6 - 8	2100.5	45.4	57883.1	48.2
8 - 10	0.0	0.0	0.0	0.0
≥ 10	0.0	0.0	0.0	0.0
Total	4624.8	100.0	120210.6	100.0

Long Term #2 Medium/High Flow

Range of Compensation Depth Median (feet)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 2	0.0	0.0	0.0	0.0
2 - 4	153.9	3.3	1776.5	1.5
4 - 6	4523.1	96.7	119032.4	98.5
6 - 8	0.0	0.0	0.0	0.0
8 - 10	0.0	0.0	0.0	0.0
≥ 10	0.0	0.0	0.0	0.0
Total	4677.0	100.0	120808.9	100.0

Long Term #3 Medium/High Flow

Range of Compensation Depth Median (feet)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 2	0.0	0.0	0.0	0.0
2 - 4	155.0	3.3	1784.7	1.5
4 - 6	4522.0	96.7	119024.2	98.5
6 - 8	0.0	0.0	0.0	0.0
8 - 10	0.0	0.0	0.0	0.0
≥ 10	0.0	0.0	0.0	0.0
Total	4677.0	100.0	120808.9	100.0

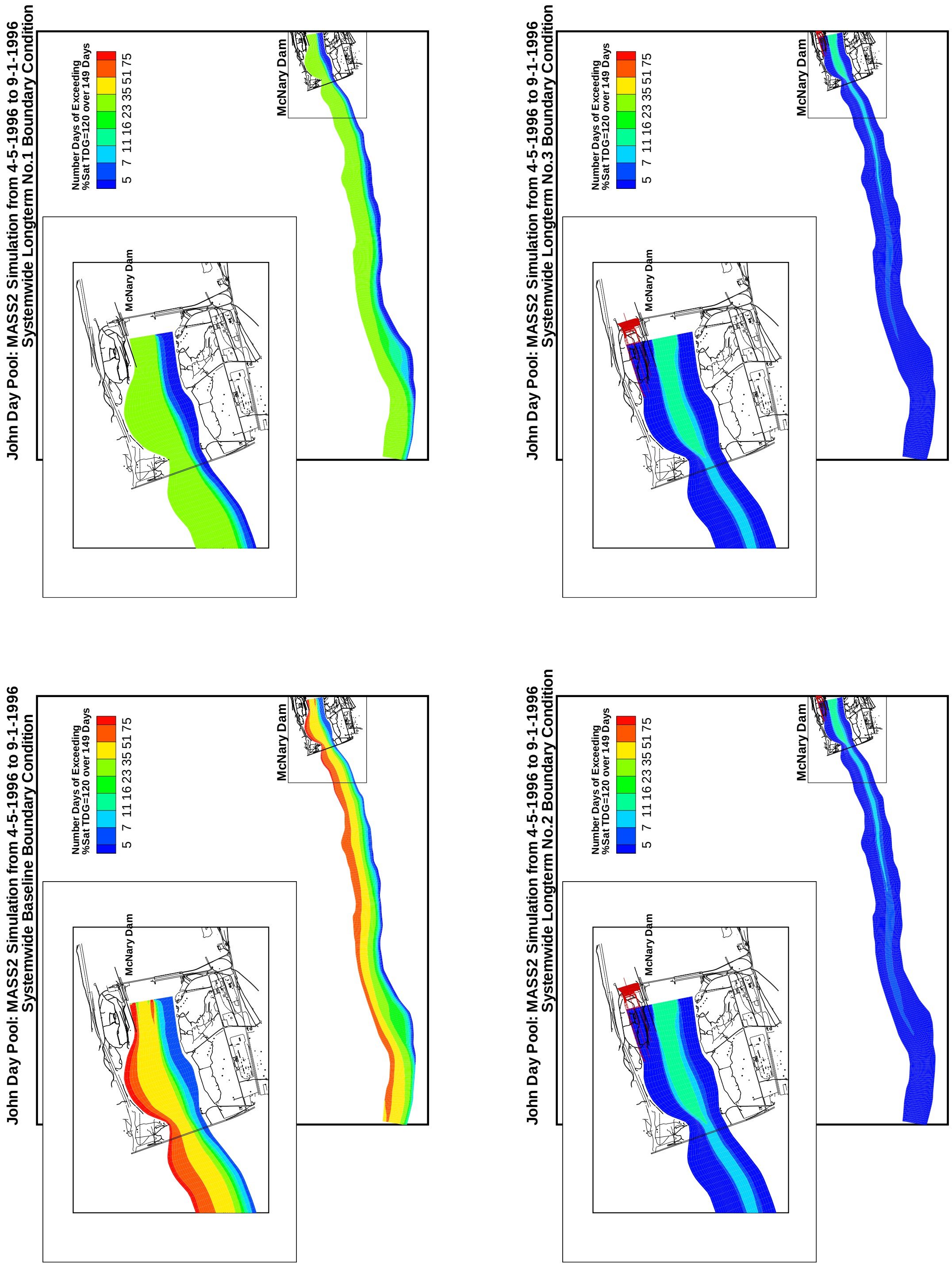

Figure 3.36: Areal comparison of days exceeding TDG saturation of 120% for long term scenarios in John Day Pool in a medium flow season (1996).

Full-pool Baseline Scenario

A full-pool simulation for the John Day pool was done for the baseline scenario and the medium-high flow (1996) hydrology. An example result from the simulation is shown in Figure 3.37. The lateral distribution of TDG becomes more uniform downstream and that leads to a relatively uniform exceedance distribution shown in the figure. Additional results are presented in Appendix E.

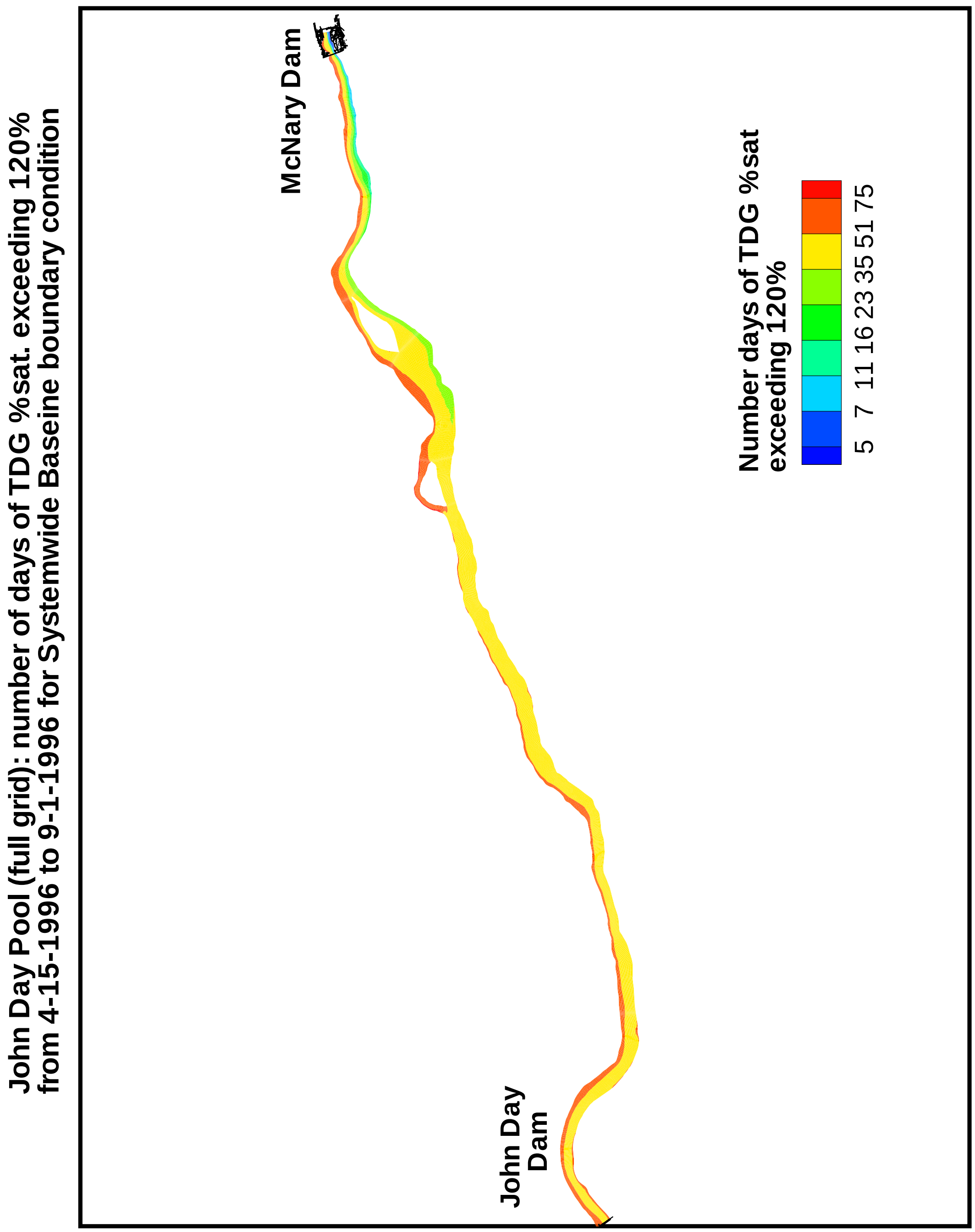

Figure 3.37: Number of days exceeding % TDG saturation of 120 % for baseline scenario in John Day pool (full grid) in a medium flow season (1996)

3.2.2 Snake River, Little Goose Pool

The area of the Little Goose pool downstream of Lower Monumental Dam simulated in the 1D/2D hybrid model is shown in Figure 3.38. This figure also shows the location of FMS monitor downsteeam on the north shore of the river.

The simulation methodology that was described for the John Day pool was also used for the Little Goose pool cases.

Fast-Track Scenario Results

Time series results in the form of CFD plots compare the 1D and 1D/2D hybrid results in Little Goose pool in Figure 3.39. The plot shows that the 1D spillway results are comparable to the 1D/2D hybrid at the FMS (north shore) when uniform spill patterns are used. However, in this case there is no benefit at the FMS location along the north shore from using uniform spill patterns (Figure 3.40).

Some of the fixed monitors are located such that they are monitoring gas levels as fully mixed flow, rather than spill alone, particularly downstream of The Dalles. In these cases, gas levels produced by the 1D model compare closely to those from the hybrid. Others are located such that they miss the spill gas levels. This section shows an example of situation in Little Goose pool, below Lower Granite dam. When the nonuniform spill pattern is used, in the Baseline and Fast-Track #2 scenarios, higher gas levels are seen mid-channel than on the north shore, where the FMS is as shown in Figure 3.42.

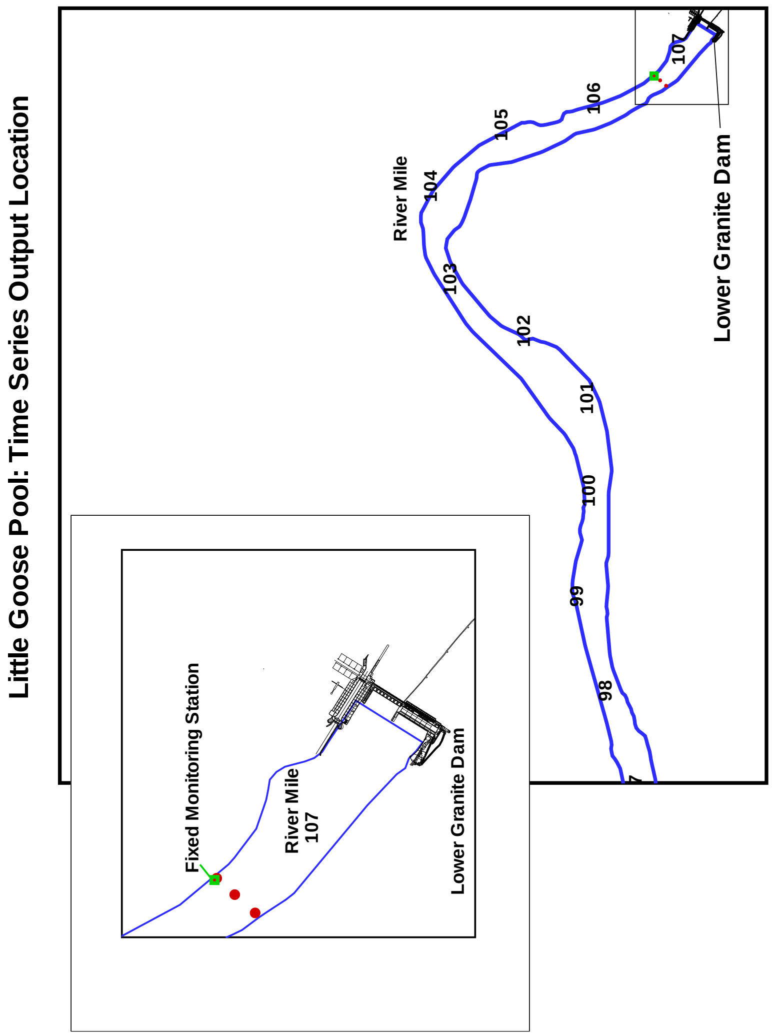

Figure 3.38: Grid and FMS locations for the area of Little Goose pool simulated in two dimensions with the one/two-dimensional hybrid model.

Table 3.9: Histogram table of TDG saturation percentage of MASS2 and MASS1 time series output for fast-track scenarios in Little Goose pool in a medium flow season (1996)

Location	TDG Range	Base Line		Fast-Track No.1		Fast-Track No.2		Fast-Track No.3	
		Days	%	Days	%	Days	%	Days	%
North FMS	less than 105	55	36.8	59	39.8	55	36.8	58	39.0
	105 - 110	27	18.3	14	9.2	27	18.3	15	10.4
	110 - 115	41	27.3	13	9.0	41	27.3	13	9.0
	115 - 120	22	14.6	33	22.1	22	14.6	33	22.1
	120 - 125	4	3.0	20	13.4	4	3.0	20	13.1
	125 - 130	0	0.0	9	6.2	0	0.0	9	6.1
	above 130	0	0.0	0	0.3	0	0.0	0	0.3
Mid-channel	less than 105	61	41.1	62	41.3	61	41.1	85	56.8
	105 - 110	14	9.5	15	9.9	14	9.5	36	23.9
	110 - 115	13	8.6	21	13.8	13	8.6	18	12.0
	115 - 120	22	15.0	26	17.2	22	15.0	4	2.9
	120 - 125	21	14.0	18	11.9	21	14.0	4	2.8
	125 - 130	13	8.4	8	5.6	13	8.4	2	1.7
	above 130	5	3.4	0	0.3	5	3.4	0	0.0
South	less than 105	115	77.2	115	77.2	115	77.2	130	87.1
	105 - 110	20	13.3	20	13.2	20	13.3	16	10.8
	110 - 115	4	2.9	5	3.5	4	2.9	3	2.1
	115 - 120	4	2.7	3	1.7	4	2.7	0	0.0
	120 - 125	6	3.9	3	1.9	6	3.9	0	0.0
	125 - 130	0	0.0	4	2.4	0	0.0	0	0.0
	above 130	0	0.0	0	0.0	0	0.0	0	0.0
1-D FMS	less than 105	61	40.7	62	41.4	61	40.7	66	44.0
	105 - 110	21	14.3	22	14.6	21	14.3	51	34.0
	110 - 115	33	22.1	32	21.8	33	22.1	26	17.2
	115 - 120	22	14.6	21	14.3	22	14.6	7	4.5
	120 - 125	6	4.4	6	4.1	6	4.4	0	0.3
	125 - 130	6	3.9	5	3.6	6	3.9	0	0.0
	above 130	0	0.1	0	0.1	0	0.1	0	0.0

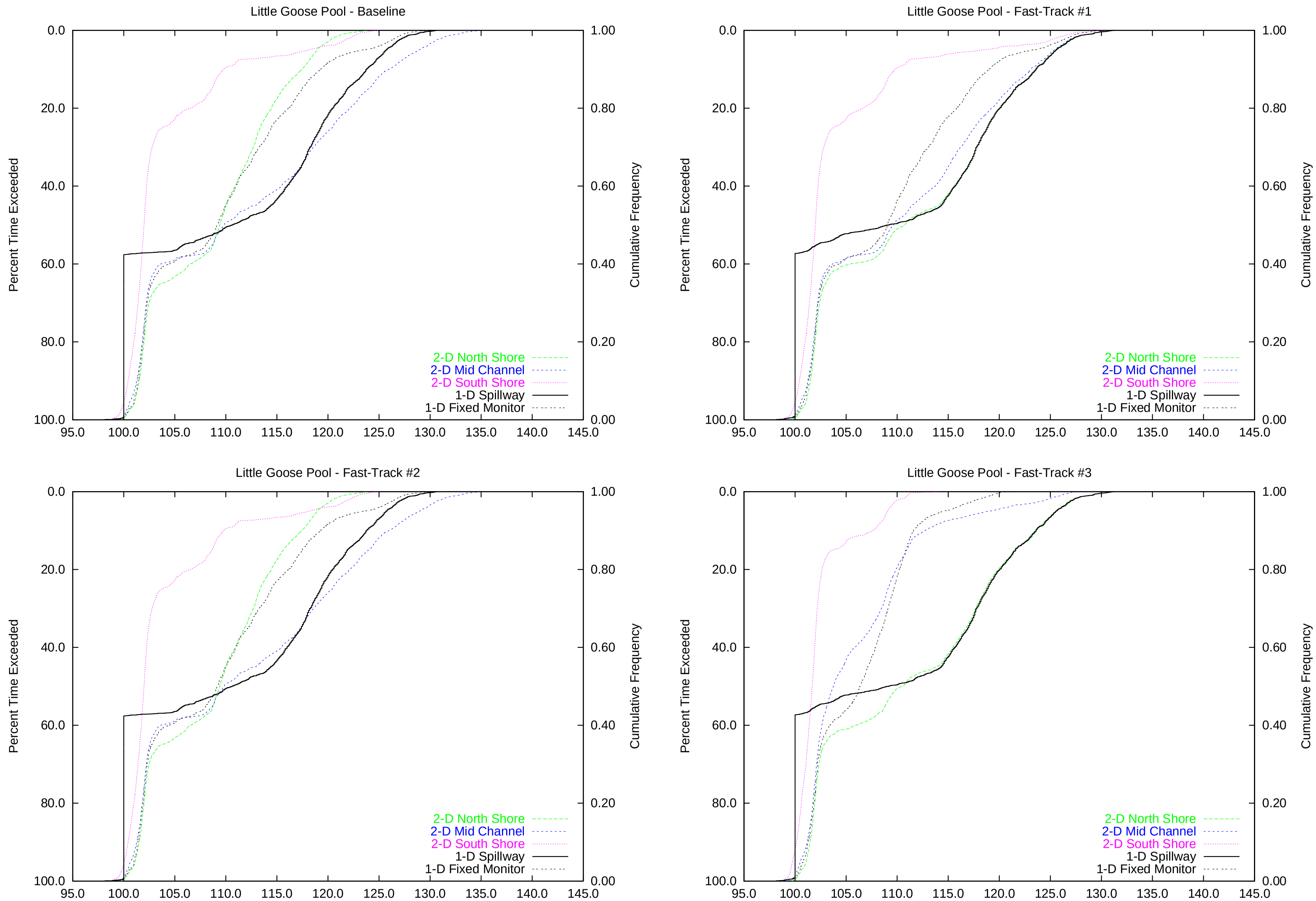

Figure 3.39: Cumulative frequency distributions TDG saturation simulated by the 1-D/2-D hybrid model for several points across the channel at the LGNW FMS location (SRM 107) Little Goose Pool during a medium/high flow (1996) season and each scenario compared with similar values from the 1-D simulations at the spillway and FMS location.

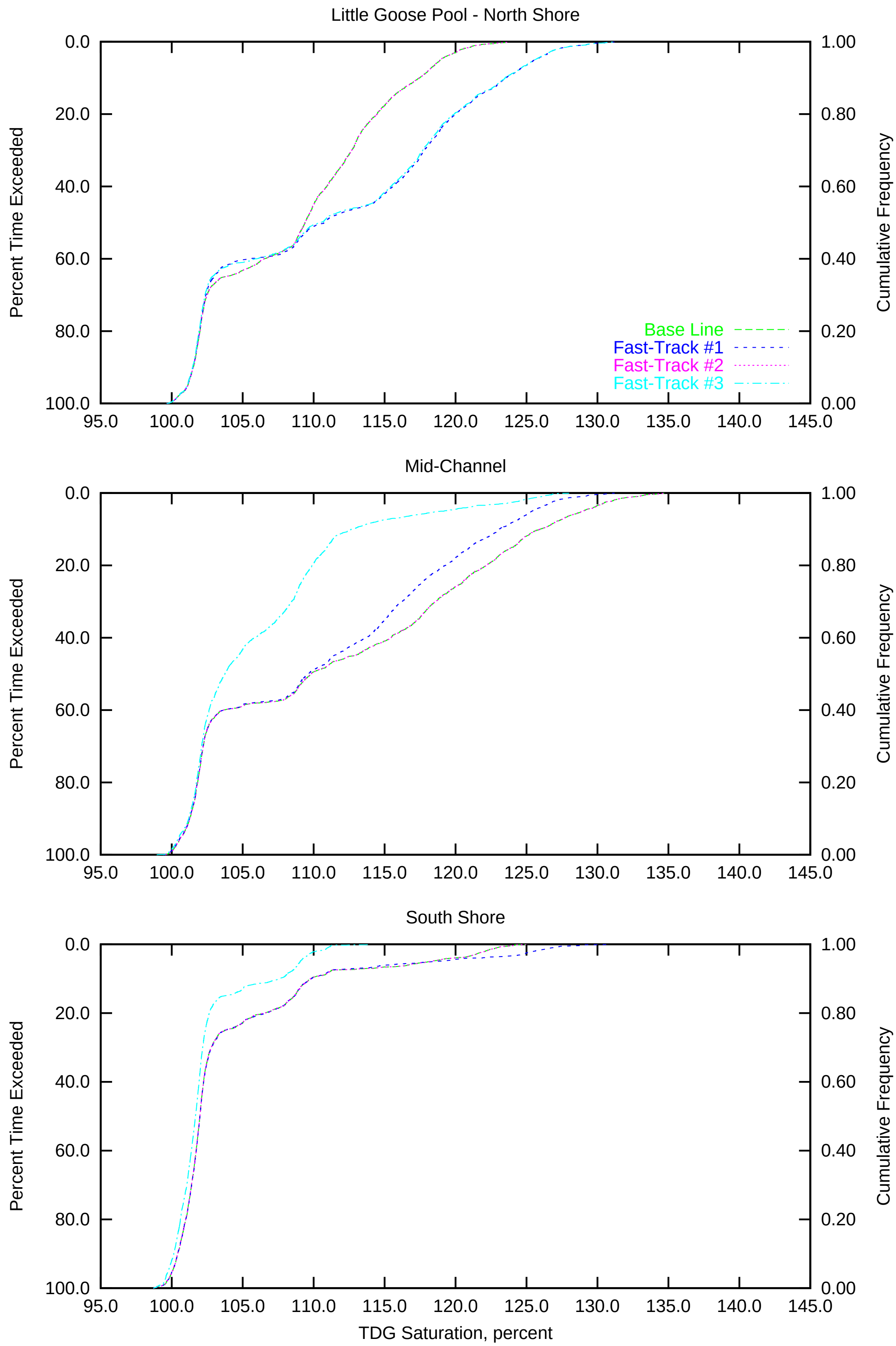

Figure 3.40: Comparision of simulated TDG saturation cumulative frequency distributions for several points across the channel at the LGNW FMS location (SRM 107) in the Little Goose Pool during a medium/high flow (1996) season.

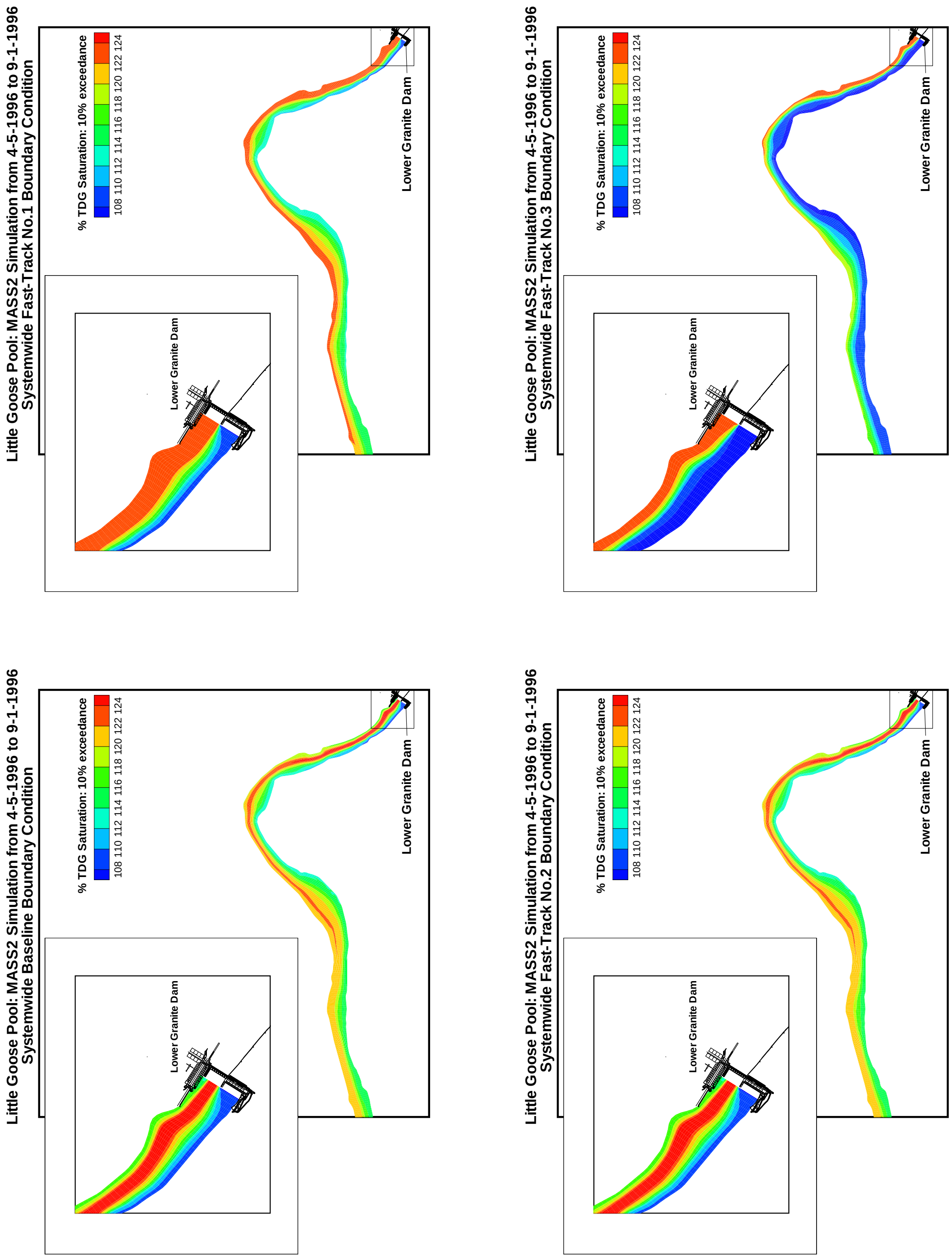

Figure 3.41: Areal comparison of TDG saturation exceeded 10% of a medium flow season (1996) for the fast-track scenarios in Little Goose Pool.

Table 3.10: Tabular histogram of TDG saturation exceeded 25% of the medium/high flow season (1996) over 2-D modeled area in Little Goose pool during the Fast-Track scenario simulations.

Baseline Medium/High Flow

Range of TDG Saturation Median (percent)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 105	25.1	1.4	449.7	0.9
105 - 110	383.4	20.7	7672.0	14.7
110 - 115	556.7	30.1	16186.8	31.1
115 - 120	851.0	46.0	26768.3	51.4
120 - 125	33.6	1.8	997.3	1.9
≥ 125	0.0	0.0	0.0	0.0
Total	1849.9	100.0	52074.1	100.0

Fast-Track #1 Medium/High Flow

Range of TDG Saturation Median (percent)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 105	24.4	1.3	432.4	0.8
105 - 110	426.4	23.0	8898.7	17.1
110 - 115	564.3	30.5	17618.3	33.8
115 - 120	834.8	45.1	25122.7	48.2
120 - 125	0.0	0.0	0.0	0.0
≥ 125	0.0	0.0	0.0	0.0
Total	1849.9	100.0	52072.1	100.0

Fast-Track #2 Medium/High Flow

Range of TDG Saturation Median (percent)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 105	25.1	1.4	449.7	0.9
105 - 110	383.4	20.7	7672.0	14.7
110 - 115	556.7	30.1	16186.8	31.1
115 - 120	851.0	46.0	26768.3	51.4
120 - 125	33.6	1.8	997.3	1.9
≥ 125	0.0	0.0	0.0	0.0
Total	1849.9	100.0	52074.1	100.0

Fast-Track #3 Medium/High Flow

Range of TDG Saturation Median (percent)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 105	583.4	31.5	12544.5	24.1
105 - 110	472.4	25.5	15458.2	29.7
110 - 115	606.9	32.8	19899.6	38.2
115 - 120	187.2	10.1	4171.3	8.0
120 - 125	0.0	0.0	0.0	0.0
≥ 125	0.0	0.0	0.0	0.0
Total	1849.9	100.0	52073.7	100.0

Table 3.11: Tabular histogram of TDG saturation exceeded 25% of the medium/high flow season (1996) over 2-D modeled area in Little Goose pool during the Fast-Track scenario simulations.

Baseline Medium/High Flow

Range of Compensation Depth Median (feet)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 2	32.0	1.7	622.8	1.2
2 - 4	601.9	32.5	13732.5	26.4
4 - 6	1142.2	61.7	35518.9	68.2
6 - 8	73.8	4.0	2199.8	4.2
8 - 10	0.0	0.0	0.0	0.0
≥ 10	0.0	0.0	0.0	0.0
Total	1849.9	100.0	52074.1	100.0

Fast-Track #1 Medium/High Flow

Range of Compensation Depth Median (feet)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 2	31.3	1.7	603.3	1.2
2 - 4	653.3	35.3	15098.9	29.0
4 - 6	988.0	53.4	32177.0	61.8
6 - 8	177.3	9.6	4192.9	8.1
8 - 10	0.0	0.0	0.0	0.0
≥ 10	0.0	0.0	0.0	0.0
Total	1849.9	100.0	52072.1	100.0

Fast-Track #2 Medium/High Flow

Range of Compensation Depth Median (feet)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 2	32.0	1.7	622.8	1.2
2 - 4	601.9	32.5	13732.5	26.4
4 - 6	1142.2	61.7	35518.9	68.2
6 - 8	73.8	4.0	2199.8	4.2
8 - 10	0.0	0.0	0.0	0.0
≥ 10	0.0	0.0	0.0	0.0
Total	1849.9	100.0	52074.1	100.0

Fast-Track #3 Medium/High Flow

Range of Compensation Depth Median (feet)	Simulated Area (acres)	Simulated Area (percent)	Season Average Simulated Volume (acre-feet)	Season Average Simulated Volume (percent)
< 2	685.2	37.0	15352.5	29.5
2 - 4	612.7	33.1	22301.5	42.8
4 - 6	495.4	26.8	13335.3	25.6
6 - 8	56.5	3.1	1084.4	2.1
8 - 10	0.0	0.0	0.0	0.0
≥ 10	0.0	0.0	0.0	0.0
Total	1849.9	100.0	52073.7	100.0

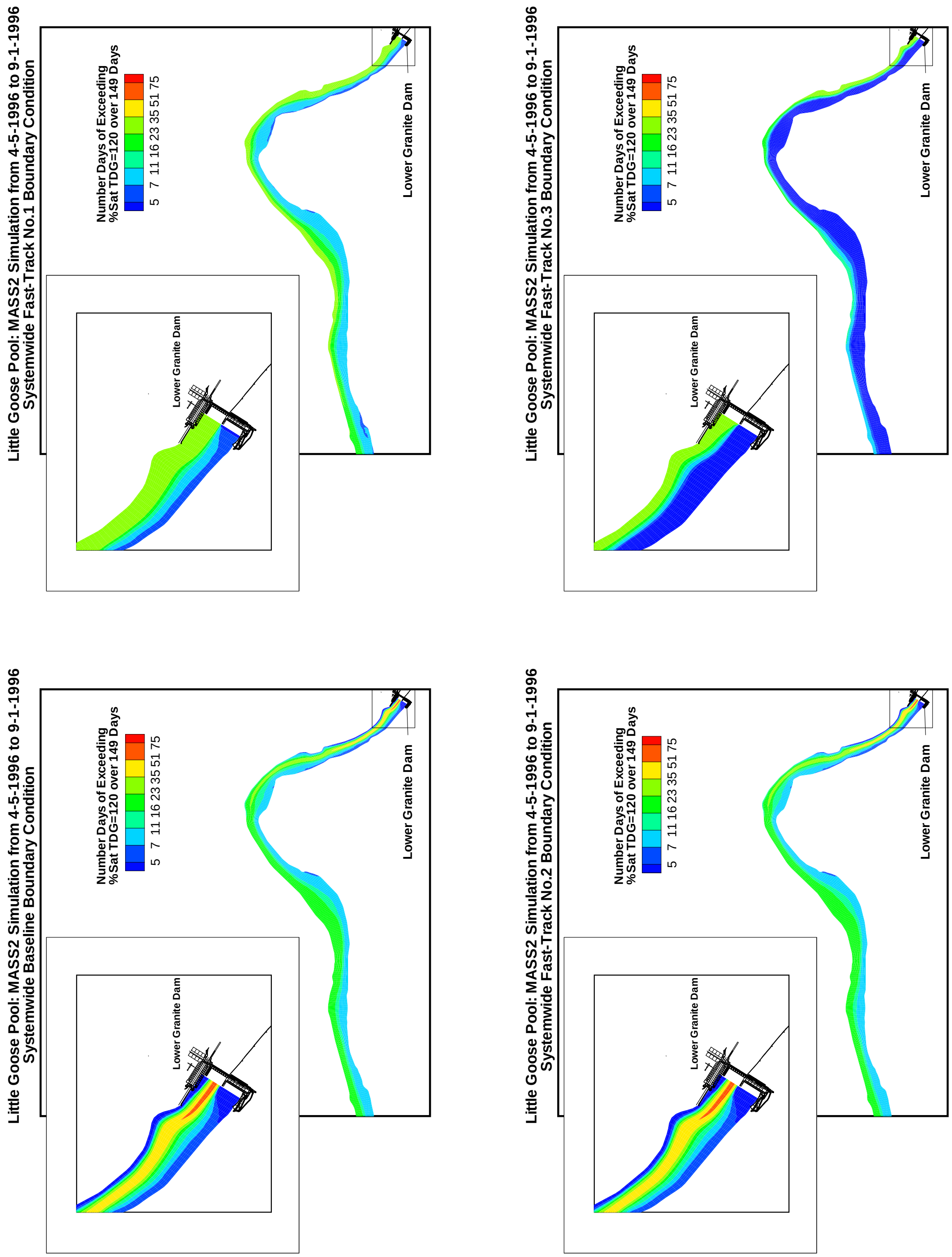

Figure 3.42: Areal comparison of days exceeding TDG saturation of 120% for fast-track scenarios in Little Goose Pool in a medium flow season (1996).

Long Term Scenario Results

The long-term scenarios were simulated using the same methodology as previously described for the fast-track cases. Additional spillway bays are included in all the long-term options at Lower Granite Dam. The 2D model grid was modified to include these spillways as shown in Figure 3.43. The simulation results are shown using the same type of time-series and spatial information as was used in the fast-track cases.

In general, the results show the benefit of installing additional spillway bays and the use of unifrom spill patterns. The altered flow patterns in the long-term scenario result in some increase of TDG at the FMS location for a band of exceedance as shown in Figure 3.44. The spatial distribution of the TDG levels exceeded 10 % of the time shown in Figure 3.45 illustrate these benefits.

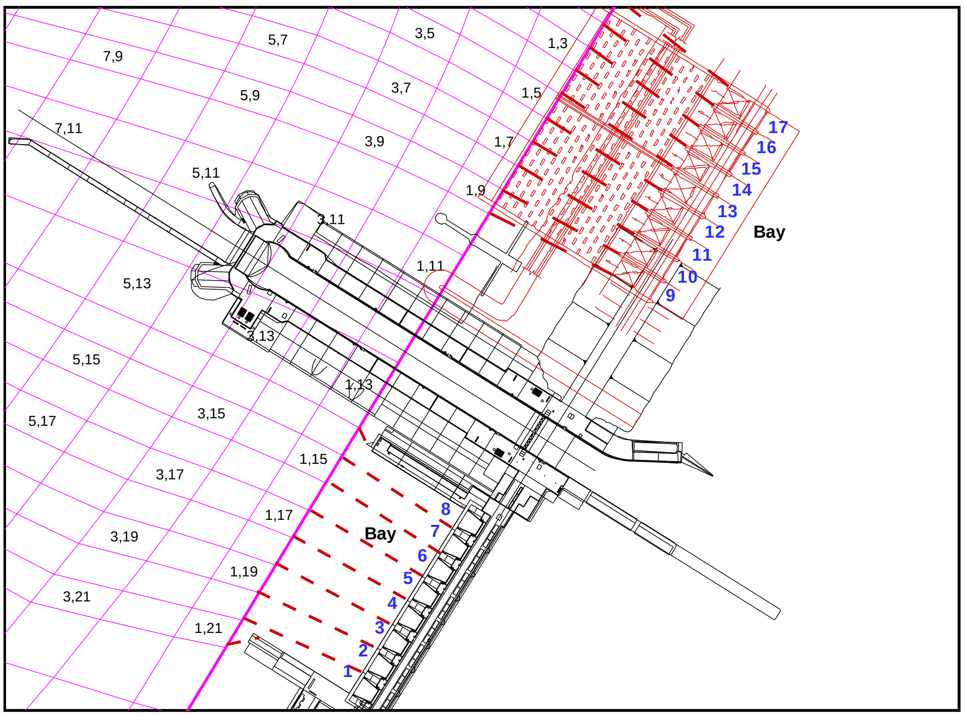

Figure 3.43: Location of additional spill bays added to Lower Granite dam in the long term alternative and spill bay to grid mapping.

Table 3.12: Histogram table of TDG saturation percentage of MASS2 and MASS1 time series output for longterm scenarios in Little Goose pool in a medium flow season (1996)

Location	TDG Range	Base Line		Longterm No.1		Longterm No.2		Longterm No.3	
		Days	%	Days	%	Days	%	Days	%
North FMS	less than 105	55	36.8	57	38.4	57	38.4	57	38.4
	105 - 110	27	18.2	14	9.5	15	10.1	15	10.1
	110 - 115	41	27.4	59	39.7	59	39.3	59	39.3
	115 - 120	22	14.6	18	12.4	18	12.2	18	12.2
	120 - 125	4	3.0	0	0.0	0	0.0	0	0.0
	125 - 130	0	0.0	0	0.0	0	0.0	0	0.0
	above 130	0	0.0	0	0.0	0	0.0	0	0.0
Mid-channel	less than 105	61	41.1	72	48.3	91	60.8	91	60.8
	105 - 110	14	9.5	52	34.6	47	31.7	47	31.7
	110 - 115	13	8.6	19	12.7	9	6.2	9	6.2
	115 - 120	22	15.0	6	4.4	2	1.3	2	1.3
	120 - 125	21	14.0	0	0.1	0	0.0	0	0.0
	125 - 130	13	8.4	0	0.0	0	0.0	0	0.0
	above 130	5	3.4	0	0.0	0	0.0	0	0.0
South	less than 105	115	77.2	127	85.1	130	87.1	130	87.1
	105 - 110	20	13.3	18	12.1	16	11.0	16	11.0
	110 - 115	4	2.9	4	2.7	3	1.9	3	1.9
	115 - 120	4	2.7	0	0.1	0	0.0	0	0.0
	120 - 125	6	3.9	0	0.0	0	0.0	0	0.0
	125 - 130	0	0.0	0	0.0	0	0.0	0	0.0
	above 130	0	0.0	0	0.0	0	0.0	0	0.0
1-D FMS	less than 105	61	40.7	69	46.1	79	52.8	66	44.6
	105 - 110	21	14.3	66	44.1	62	41.9	67	45.2
	110 - 115	33	22.1	13	8.5	8	5.3	13	9.0
	115 - 120	22	14.6	2	1.4	0	0.0	2	1.1
	120 - 125	6	4.4	0	0.0	0	0.0	0	0.0
	125 - 130	6	3.9	0	0.0	0	0.0	0	0.0
	above 130	0	0.1	0	0.0	0	0.0	0	0.0

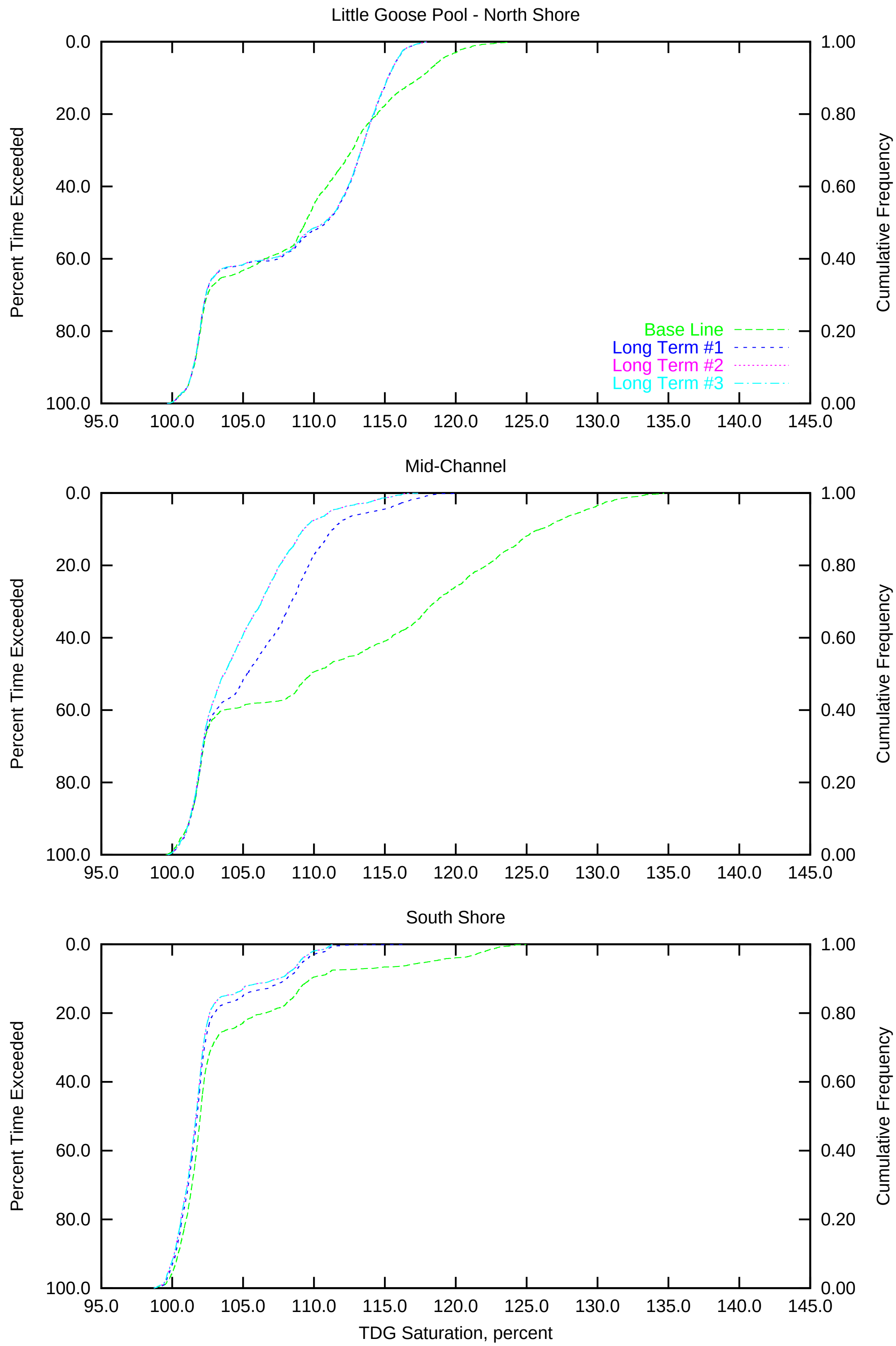

Figure 3.44: Comparision of simulated TDG saturation cumulative frequency distributions for several points across the channel at the LGNW FMS location (SRM 107) in the Little Goose Pool during a medium/high flow (1996) season.

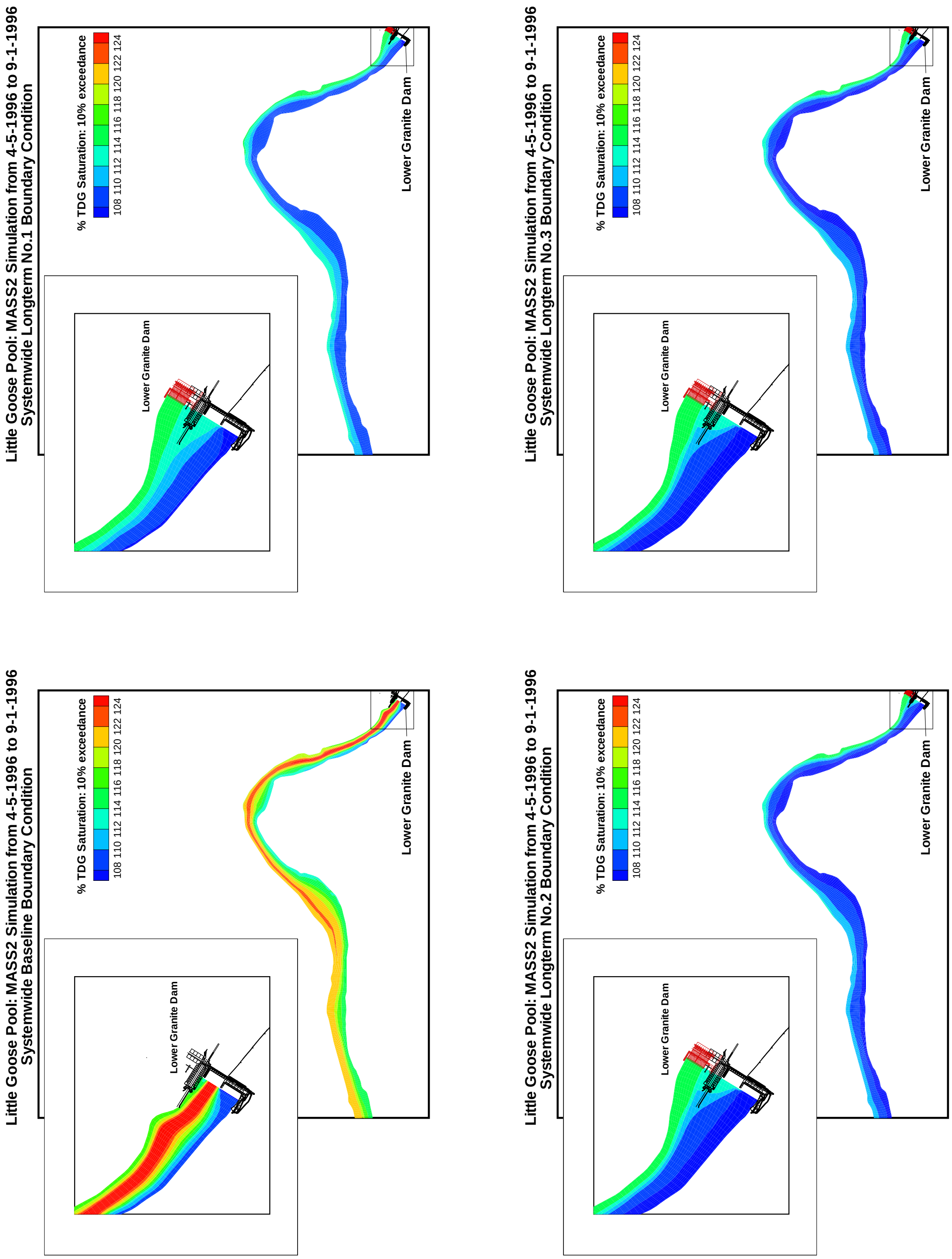

Figure 3.45: Areal comparison of TDG saturation exceeded 10% of a medium flow season (1996) for the long term scenarios in Little Goose Pool.

Table 3.13: Tabular histogram of TDG saturation exceeded 25% of the medium/high flow season (1996) over 2-D modeled area in Little Goose pool during the Long Term scenario simulations.

Baseline Medium/High Flow

Range of TDG Saturation Median (percent)	**Simulated Area (acres)**	**Simulated Area (percent)**	**Season Average Simulated Volume (acre-feet)**	**Season Average Simulated Volume (percent)**
< 105	25.1	1.4	449.7	0.9
105 - 110	383.4	20.7	7672.0	14.7
110 - 115	556.7	30.1	16186.8	31.1
115 - 120	851.0	46.0	26768.3	51.4
120 - 125	33.6	1.8	997.3	1.9
≥ 125	0.0	0.0	0.0	0.0
Total	1849.9	100.0	52074.1	100.0

Long Term #1 Medium/High Flow

Range of TDG Saturation Median (percent)	**Simulated Area (acres)**	**Simulated Area (percent)**	**Season Average Simulated Volume (acre-feet)**	**Season Average Simulated Volume (percent)**
< 105	405.9	21.6	7858.2	14.9
105 - 110	993.2	52.9	33318.9	63.3
110 - 115	478.6	25.5	11438.3	21.7
115 - 120	0.0	0.0	0.0	0.0
120 - 125	0.0	0.0	0.0	0.0
≥ 125	0.0	0.0	0.0	0.0
Total	1877.7	100.0	52615.4	100.0

Long Term #2 Medium/High Flow

Range of TDG Saturation Median (percent)	**Simulated Area (acres)**	**Simulated Area (percent)**	**Season Average Simulated Volume (acre-feet)**	**Season Average Simulated Volume (percent)**
< 105	724.3	38.6	16342.7	31.1
105 - 110	917.1	48.8	31440.7	59.8
110 - 115	236.4	12.6	4831.6	9.2
115 - 120	0.0	0.0	0.0	0.0
120 - 125	0.0	0.0	0.0	0.0
≥ 125	0.0	0.0	0.0	0.0
Total	1877.7	100.0	52615.0	100.0

Long Term #3 Medium/High Flow

Range of TDG Saturation Median (percent)	**Simulated Area (acres)**	**Simulated Area (percent)**	**Season Average Simulated Volume (acre-feet)**	**Season Average Simulated Volume (percent)**
< 105	724.3	38.6	16342.7	31.1
105 - 110	917.1	48.8	31440.7	59.8
110 - 115	236.4	12.6	4831.6	9.2
115 - 120	0.0	0.0	0.0	0.0
120 - 125	0.0	0.0	0.0	0.0
≥ 125	0.0	0.0	0.0	0.0
Total	1877.7	100.0	52615.0	100.0

Table 3.14: Tabular histogram of TDG saturation exceeded 25% of the medium/high flow season (1996) over 2-D modeled area in Little Goose pool during the Long Term scenario simulations.

Baseline Medium/High Flow					Long Term #1 Medium/High Flow				
Range of Compensation Depth Median	**Simulated Area**		**Season Average Simulated Volume**		**Range of Compensation Depth Median**	**Simulated Area**		**Season Average Simulated Volume**	
(feet)	**(acres)**	**(percent)**	**(acre-feet)**	**(percent)**	**(feet)**	**(acres)**	**(percent)**	**(acre-feet)**	**(percent)**
< 2	32.0	1.7	622.8	1.2	< 2	603.3	32.1	13234.1	25.2
2 - 4	601.9	32.5	13732.5	26.4	2 - 4	1162.0	61.9	37168.9	70.6
4 - 6	1142.2	61.7	35518.9	68.2	4 - 6	112.4	6.0	2212.5	4.2
6 - 8	73.8	4.0	2199.8	4.2	6 - 8	0.0	0.0	0.0	0.0
8 - 10	0.0	0.0	0.0	0.0	8 - 10	0.0	0.0	0.0	0.0
≥ 10	0.0	0.0	0.0	0.0	≥ 10	0.0	0.0	0.0	0.0
Total	1849.9	100.0	52074.1	100.0	Total	1877.7	100.0	52615.4	100.0

Long Term #2 Medium/High Flow					Long Term #3 Medium/High Flow				
Range of Compensation Depth Median	**Simulated Area**		**Season Average Simulated Volume**		**Range of Compensation Depth Median**	**Simulated Area**		**Season Average Simulated Volume**	
(feet)	**(acres)**	**(percent)**	**(acre-feet)**	**(percent)**	**(feet)**	**(acres)**	**(percent)**	**(acre-feet)**	**(percent)**
< 2	880.8	46.9	21333.0	40.5	< 2	880.8	46.9	21333.0	40.5
2 - 4	909.6	48.4	29586.9	56.2	2 - 4	909.6	48.4	29586.9	56.2
4 - 6	87.3	4.6	1695.0	3.2	4 - 6	87.3	4.6	1695.0	3.2
6 - 8	0.0	0.0	0.0	0.0	6 - 8	0.0	0.0	0.0	0.0
8 - 10	0.0	0.0	0.0	0.0	8 - 10	0.0	0.0	0.0	0.0
≥ 10	0.0	0.0	0.0	0.0	≥ 10	0.0	0.0	0.0	0.0
Total	1877.7	100.0	52615.0	100.0	Total	1877.7	100.0	52615.0	100.0

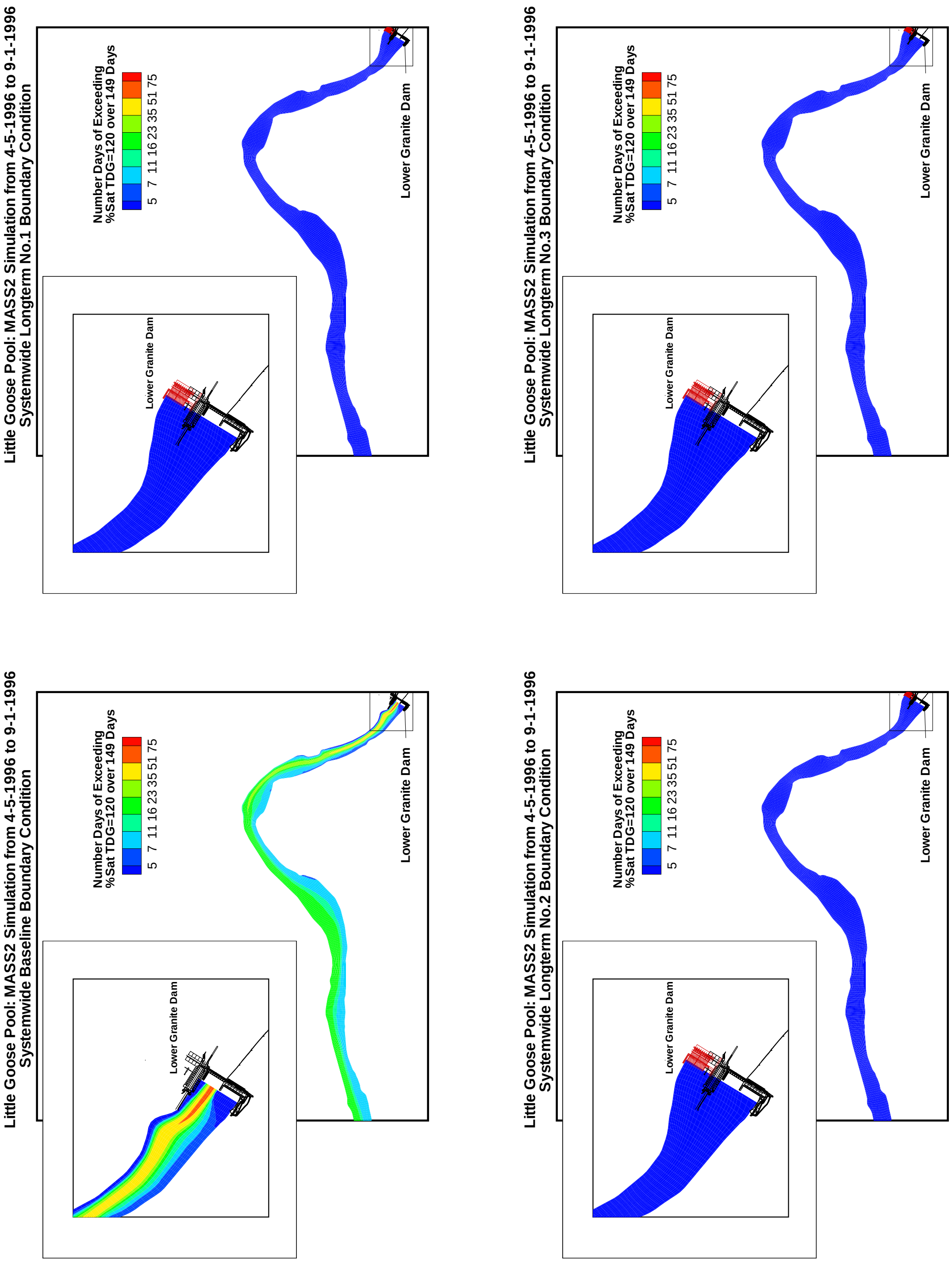

Figure 3.46: Areal comparison of days exceeding TDG saturation of 120% for long term scenarios in Little Goose Pool in a medium flow season (1996).

Full-pool Baseline Scenario

A full-pool simulation for the Little Goose pool was done for the baseline scenario and the medium-high flow (1996) hydrology. An example result from the simulation is shown in Figure 3.47. The lateral distribution of TDG becomes more uniform downstream and that leads to a relatively uniform exceedance distribution shown in the figure. Additional results are presented in Appendix D.

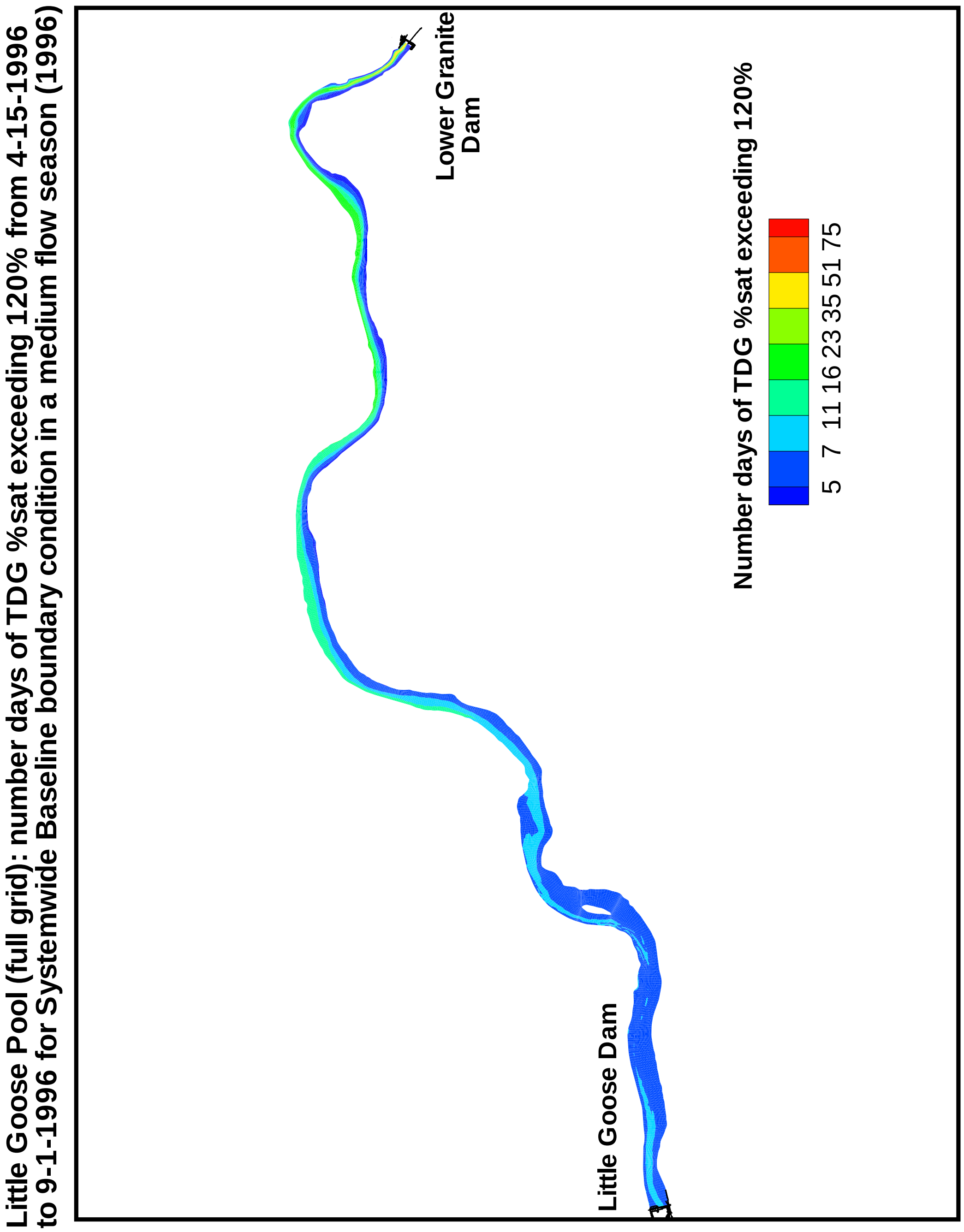

Figure 3.47: Number of days exceeding % TDG Saturation of % 120 for baseline scenario in Little Goose Pool (full grid) in a medium flow season (1996)

4 Conclusions and Recommendations

Application of the MASS1 and MASS2 numerical models for hydrodynamics and dissolved gas transport has produced a broad range of metrics that have been used to compare the performance of different gas abatement alternatives. The alternatives analyzed were primarily structural modidfications to the dams, but operational changes such the use of unifrom spill patterns were also included. A limited set of simulations looked at the effects of different spill management rules.

The overall performance and ranking of the various gas abatement scenarios can be summarized in terms of the numbers of days that water quality criteria are exceeded. The criteria selected was the waiver standard based on the highest 12 hourly values in a single calendar day exceeding 120% at the tailwater and 115% satuaration at the downstream foreabay monitor locations, respectively. The rankings were based on simulation results from MASS1 at the tailwater (Tables 4.1 and 4.4) and at the downstream forebay (Tables 4.3 and 4.6). The same ranking was also calculated from the 1D/2D hybrid MASS2 results at the tailwater monitor location (Tables 4.2 and 4.5).

The tables quantitatively show that as additional gas abatement measures are implemented at a project, or series of projects, the number of days exceeding the water quality standard decreases. The fully-mixed 1D MASS1 results at a given project tailwater and next forebary reflect both changes at the project spillway and upstream changes. The 1D/2D MASS2 results are not fully-mixed (in most cases) and only reflect changes to the project gas production and/or spill pattern. For example, the unmixed ranking of LMN (Table 4.2) changes very little between the various fast-track alternatives, but the fully-mixed tailwater (Table 4.1) shows a consistent decrease because of upstream improvements. This is driven primarily from implmenting upstream divider walls.

Selection of alternatives for implementation and the associated implementation order depends on many factors. These factors include water quality criteria, fish passage, construction costs,

Table 4.1: Ranking of simulated fast-track system-wide gas abatement scenarios using days the fully-mixed (1-D) gas saturation at the FMS exceeding the water quality waiver (> 120%) in the medium/high flow year (1996).

	Days exceeding 120% at tailwater FMS (Rank)									
Project	**Baseline**		**Fast-Track #1**		**Fast-Track #2**		**Fast-Track #3**		**Fast-track #4**	
LWG	16	(5)	14	(3)	16	(4)	1	(2)	0	(1)
LGS	53	(4.5)	53	(4.5)	39	(3)	8	(2)	0	(1)
LMN	41	(4.5)	41	(4.5)	37	(3)	23	(2)	3	(1)
IHR	20	(5)	19	(4)	18	(3)	15	(2)	12	(1)
MCN	51	(5)	43	(4)	37	(3)	36	(1.5)	36	(1.5)
JDA	16	(5)	14	(4)	9	(3)	4	(1.5)	4	(1.5)
TDA	37	(4.5)	37	(4.5)	36	(3)	15	(1.5)	15	(1.5)
BON	71	(5)	70	(4)	56	(3)	46	(2)	34	(1)
Total		(38.5)		(32.5)		(25)		(14.5)		(9.5)
Scenario Rank		**5**		**4**		**3**		**2**		**1**

Table 4.2: Ranking of simulated fast-track system-wide gas abatement scenarios using days the unmixed (1-D/2-D hybrid) gas saturation at the FMS exceeding the water quality waiver (> 120%) in the medium/high flow year (1996).

	Days exceeding 120% at tailwater FMS (Rank)							
Project	**Baseline**		**Fast-Track #1**		**Fast-Track #2**		**Fast-Track #3**	
LWG	7	(1.5)	38	(3.5)	7	(1.5)	38	(3.5)
LGS	42	(3.5)	42	(3.5)	34	(1)	35	(2)
LMN	58	(3.5)	58	(3.5)	57	(2)	56	(1)
IHR	14	(2.5)	14	(2.5)	14	(2.5)	14	(2.5)
MCN	85	(4)	54	(3)	38	(2)	37	(1)
JDA	41	(3.5)	24	(1.5)	41	(3.5)	21	(1.5)
TDA	33	(3.5)	33	(3.5)	29	(2)	3	(1)
BON	78	(4)	74	(3)	63	(2)	60	(1)
Total		(26.0)		(24.0)		(16.5)		(13.5)
Scenario Rank		**4**		**3**		**2**		**1**

Table 4.3: Ranking of simulated fast-track system-wide gas abatement scenarios using days the fully-mixed (1-D) gas saturation at the the project forebay, or downstream FMS, exceeding the water quality waiver (> 115%) in the medium/high flow year (1996).

	Days exceeding 115% in forebay (Rank)									
Project	**Baseline**		**Fast-Track #1**		**Fast-Track #2**		**Fast-Track #3**		**Fast-Track #4**	
LGS	32	(3.5)	33	(5)	32	(3.5)	8	(2)	0	(1)
LMN	64	(5)	62	(4)	58	(3)	36	(2)	11	(1)
IHR	58	(5)	56	(4)	49	(3)	38	(2)	25	(1)
MCN	46	(3.5)	46	(3.5)	46	(3.5)	46	(3.5)	44	(1)
JDA	37	(4)	35	(3)	39	(5)	27	(2)	26	(1)
TDA	36	(5)	35	(4)	34	(3)	29	(2.5)	29	(1.5)
BON	81	(5)	73	(3)	76	(4)	35	(1.5)	35	(1.5)
CWMW	141	(5)	130	(4)	82	(3)	70	(2)	58	(1)
Total		(36)		(30.5)		(28)		(17.5)		(9)
Scenario Rank		**5**		**4**		**3**		**2**		**1**

Table 4.4: Ranking of simulated long term system-wide gas abatement scenarios using days the fully-mixed (1-D) gas saturation at the FMS exceeding the water quality waiver (> 120%) in the medium/high flow year (1996).

	Days Exceeding 120% at tailwater FMS (Rank)							
Project	**Baseline**		**Long Term #1**		**Long Term #2**		**Long Term #3**	
LWG	16	(4)	0	(2)	0	(2)	0	(2)
LGS	53	(4)	0	(1.5)	6	(2)	0	(1.5)
LMN	41	(4)	3	(1)	23	(3)	9	(2)
IHR	20	(4)	12	(2)	14	(3)	10	(1)
MCN	51	(4)	36	(2)	37	(3)	12	(1)
JDA	16	(4)	4	(3)	2	(2)	0	(1)
TDA	37	(4)	15	(3)	14	(2)	7	(1)
BON	71	(4)	34	(3)	33	(2)	32	(1)
Total		(36)		(17.5)		(19)		(10.5)
Scenario Rank		**4**		**2**		**3**		**1**

Table 4.5: Ranking of simulated fast-track system-wide gas abatement scenarios using days the unmixed (1-D/2-D hybrid) gas saturation at the FMS exceeding the water quality waiver (> 120%) in the medium/high flow year (1996).

	Days exceeding 120% at tailwater FMS (Rank)							
Project	**Baseline**		**Long Term #1**		**Long Term #2**		**Long Term #3**	
LWG	7	(4)	0	(2)	0	(2)	0	(2)
LGS	42	(4)	35	(3)	0	(1.5)	0	(1.5)
LMN	58	(4)	42	(2.5)	42	(2.5)	0	(1)
IHR	14	(4)	13	(3)	12	(2)	11	(1)
MCN	85	(4)	38	(3)	0	(1.5)	0	(1.5)
JDA	41	(4)	4	(2)	4	(2)	4	(2)
TDA	33	(4)	3	(3)	0	(1.5)	0	(1.5)
BON	78	(4)	40	(2.5)	40	(2.5)	0	(1)
Total		(32)		(21)		(15.5)		(11.5)
Scenario Rank		**4**		**3**		**2**		**1**

Table 4.6: Ranking of simulated long term system-wide gas abatement scenarios using days the fully-mixed (1-D) gas saturation at the the project forebay, or downstream FMS, exceeding the water quality waiver (> 115%) in the medium/high flow year (1996).

	Days Exceeding 115% at forebay (Rank)							
Project	Baseline		Long Term #1		Long Term #2		Long Term #3	
LGS	32	(4)	0	(2)	0	(2)	0	(2)
LMN	64	(4)	0	(1.5)	6	(3)	0	(1.5)
IHR	58	(4)	3	(1)	23	(3)	9	(2)
MCN	46	(4)	12	(2)	14	(3)	10	(1)
JDA	37	(3.5)	36	(2)	37	(3.5)	12	(1)
TDA	36	(4)	4	(3)	2	(2)	0	(1)
BON	81	(4)	15	(3)	14	(2)	7	(1)
CWMW	141	(4)	34	(3)	33	(2)	32	(1)
Total		(35.5)		(17.5)		(21.5)		(10.5)
Scenario Rank		**4**		**2**		**3**		**1**

dam safety, navigation, operation and maintenane costs, and construction scheduling. The results show that the Snake and Columbia are not strongly coupled and alternatives could be selected independently, provided that gas abatement is the primary criteria. Furthermore, if peak TDG concentrations are used as the principle criteria, the selection could be based only on the performance in an individual reservoir. Care should also be taken in choosing points of performance assessment, in particular, at the current set of fixed monitor locations. For example, the benefits of installing deflectors at The Dalles will vary depending on if one uses peak concentrations immediately downstream of the spillway or the more fully-mixed concentrations that occur at the current downstream fixed monitor.

If additional scenarios must be analyzed, they should first be done with the MASS1 model. Selection of project alternatives to be combined in new scenarios can be based on the spillway location results from the existing simulations. One potential new scenario could be developed by defining a system deflector case that modifies the existing fast-track #2 scenario by adding deflectors at The Dalles and uniform spill at John Day.

Further investigations could also be performed which look at the operation of the system once the physical modifications have been performed. These would be similar to those presented in Section 2.2.5, which evaluate some rule sets whereby project spill is determined. The MASS1 model should be used to analyze of the performance of spill management, rules and because it runs quickly (about 2 hour for a season long simulation) it can be coupled with optimization routines to examine tradeoffs between spill, power, and other operational criteria. The analysis should use a longer period of hydrologic record to evaluate the risk of not meeting compliance or other operational criteria over a broad range of hydrologic conditions.

The following items are recommended for additional study or for application of the models to other water management problems:

- The MASS2 model and near-field data should be used together to study TDG transport processes in the project tailwater region.‘

- Inverse modeling methods using the MASS2 model, fixed monitoring data, and near-field data could be used to improve the gas production equations
- The MASS1 model can be used for real-time in-season operations control to manage TDG in the river system

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A Glossary

A.1 Acronyms and Abbreviations

1D	one-dimensional (cross-section averaged, in this context)
2D	two-demensional (depth averaged, in this context)
CFD	cumulative frequency distribution
cfs	cubic feet per second, a unit of flow
CRM	Columbia River Mile
DGAS	Dissolved Gas Abatement Study
DGBT	dynamic gas bubble trauma model
FFDRWG	Fish Facilities Design Review Working Group
FINS	Fish-Individual Numerical Simulator
FMS	fixed monitoring station (see Section A.4)
GBT	gas bubble trauma disease
kcfs	1000 cubic feet per second, a unit of flow
MASS1	modular aquatic simulation system 1-dimensional
MASS2	modular aquatic simulation system 2-dimensional
mm Hg	millimeters of mecury, a unit of pressure
NMFS	National Marine Fisheries Service
SRM	Snake River Mile
TDG	total dissolved gas
USACE	U.S. Army Corps of Engineers

A.2 Symbols

q_s	spill per spill bay, cfs or kcfs
ΔP	excess TDG pressure, mm Hg

A.3 Project Codes

In this document, individual dams are often referred to by a three-letter code for brevity. Table A.1 lists the codes for several of the Snake and Columbia River projects.

Table A.1: Codes used for selected Snake and Columbia river projects.

River	Project	River Mile	Code
Columbia	Bonneville	146.1	BON
	The Dalles	191.5	TDA
	John Day	215.6	JDA
	McNary	292.6	MCN
	Priest Rapids	397.1	PRD
	Wanapum	415.8	WAN
	Rock Island	453.8	RIS
	Rocky Reach	473.7	RRH
	Wells	515.6	WEL
	Chief Joseph	545.1	CHJ
	Grand Coulee	596.6	GCL
Snake	Ice Harbor	9.5	IHR
	Lower Monumental	41.6	LMN
	Little Goose	70.3	LGS
	Lower Granite	107.5	LWG
	Hells Canyon	247.0	HCD
	Brownlee	285.0	BRN

A.4 Dissolved Gas Monitoring Network

Several references to “fixed monitors” are made in this document. For the purposes of this document, a fixed monitor is one of the water quality monitors deployed as part of the dissolved gas monitoring network, a map of which is shown in Figure A.1[1]. For brevity, these monitors are referred to by their code name. Figure A.1 also shows the code names.

Typically, there are two monitors installed at each of the projects. One monitors water quality in the projects forebay, and is usually given the same code name as the project (see Section A.3) – the project forebay monitor. The other monitor is usually located just downstream of the project, on the spillway side (there are several exceptions, though) – the project tailwater monitor. This monitor is usually where state water quality standards, or waivers to those standards, are applied.

[1]This figure was obtained from the Corps Water Management Division, URL: http://www.nwd-wc.usace.army.mil/report/pdf/gasmap.pdf.

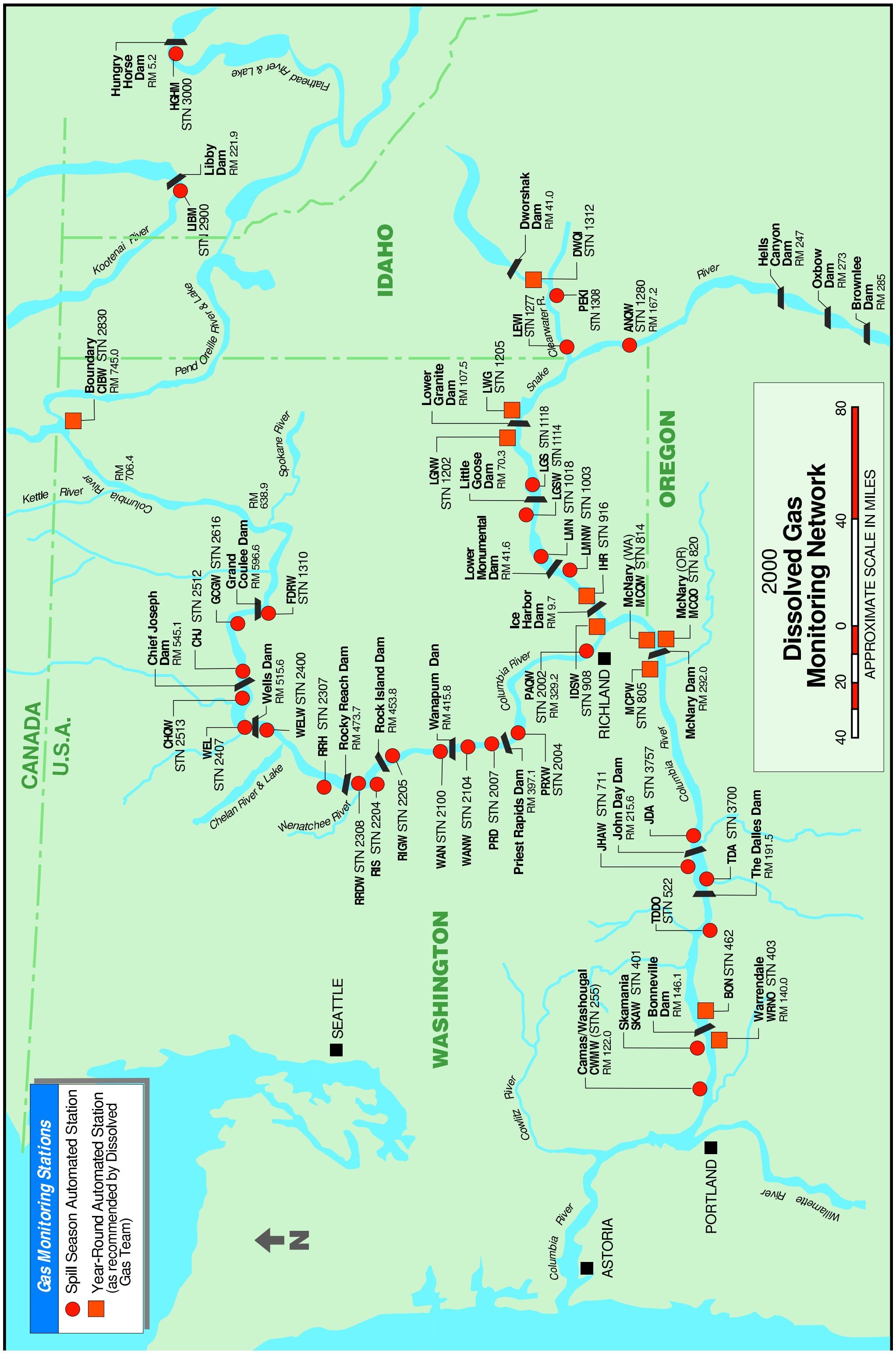

Figure A.1: Dissolved gas monitoring network. Each of the monitors has been given a three or four letter code name. The codes are used in this document when referring to a fixed monitor.

B Model Setup and Optimization

This appendix has been prepared as a separate document.
(model_config.pdf)

C Complete One-Dimensional Simulation Results

This appendix has been prepared as a separate document.
(complete_results_1d.pdf)

D Complete Simulation Results for Snake River Pools

This appendix has been prepared as a separate document.
(complete_results_snake.pdf)

E Complete Simulation Results for Columbia River Pools

This appendix has been prepared as a separate document.
(complete_results_colum.pdf)

F Verification of MASS1 for Lower Columbia/Snake Temperature and Total Dissolved Gas Simulation

This appendix has been prepared as a separate document.
(lower_col_mass1.pdf)

G Companion Documents

- *Selection of Representative Hydrographs for Dissolved Gas Simulations of Lower Snake and Lower Columbia Rivers* (`POR.pdf`)
- *Fish Individual-based Numerical Simulator (FINS) Model* (`FINS.pdf`)