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SYSTDG Manual

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Introduction

The purpose of the SYSTDG model is to provide support for spill management decisions throughout the Columbia River Basin. The model can be used to investigate the interaction of a large number of processes responsible for generating system TDG pressures. The prospective user will need to acquire an understanding of TDG properties and processes along with project characteristics to effectively apply this model and formulate balanced management strategies. (Add to this???) The influence of alternative spill management strategies can be quickly investigated in the model and more informed decisions are possible based upon the projected outcome of these alternatives. The quality control of the data obtained from the fixed monitoring system can be effectively screened through comparison with model projections based on historical responses to project operations and system conditions. The model and its formulation have known limitations that can be further defined through data analyses, comprehensive field studies, and improved data collection procedures. A living model will undergo a continual updating as new information is gained and system operation and structures evolve.

CHAPTER 1: Background and Theory behind SYSTDG:

In order to understand how SYSTDG model works, it is helpful to understand the background and scientific theory used to develop it. This chapter provides a brief overview of the background and scientific theory.

Background

Dissolved gas abatement measures and spill management plans are being considered at many projects throughout the Columbia River Basin as called for in the NMFS Biological Opinion. The Corps of Engineers and the Bureau of Reclamation, with assistance from Bonneville Power Administration (BPA), initiated a joint study to determine the most efficient and effective dissolved gas abatement measures at Chief Joseph and Grand Coulee dam. A system TDG model was developed (SYSTDG) in response to this gas abatement study with the purpose of assessing how the Columbia River system would best benefit from proposed gas abatement measures and operational schedules. The results of this modeling study can be found in the Chief Joseph Dam Columbia River, Washington Gas Abatement Study General Reevaluation Report (COE Seattle District, 2000). The concepts and application of the SYSTDG decision support tool were presented first to the action agencies and regional representatives in February of 2000 and to the Implementation Team in July of 2000. The need for a system model of Total Dissolved Gas was outlined in the 2000 Draft Biological Opinion to aid in planning spill management throughout the Columbia River Basin.

The baseline year of 1996 was used for model development since this was a high flow year including both forced and non-forced spill conditions. Gas production relationships at individual projects were based upon information representative of conditions used during the 1996 season and have been updated as project changes and specific TDG exchange studies have been conducted. ADD information on the SPECIFIC STUDIES???

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Scientific Theory

(Mike to describe this section in more detail???)
The system wide TDG pressures are determined by estimating the impacts of project operations on the releases to the Columbia River System. The project spill and powerhouse operations are treated separately when determining the impacts on project flows. The entrainment of powerhouse flows into the highly aerated spillway flows are also estimated at each project. Empirical equations relating spillway operations to the uptake in TDG pressure as defined by ΔP (TDG pressure minus barometric pressure) have been generated for each project. These relationships were developed from both near-field studies of spill and analyses of data from the fixed monitoring stations. The important independent variables in determining the TDG update in spill are the unit spillway discharges (kcfs/ft) and the tailwater channel depth of flows. In most cases, the empirical relationship takes the following form:

$$\Delta P = C_1 D_{tw}(1 - e^{-C_2 q_s}) + C_3 \qquad (1)$$

Where C_1, C_2, and C_3 are exchange coefficients, D_{tw} is the tailwater depth, q_s is the unit spillway discharge, and ΔP is the TDG pressure difference ($\Delta P = P_{tdg} - P_{atm}$). This equation results in an exponential response of TDG uptake to the unit spillway discharge with an upper limit dependent upon the depth of flow. This equation can also be a function of the type of spillway used (deflectored versus non-deflectored bays). The total dissolved gas pressure and saturation can be determined from the local barometric pressures ($P_{sp} = \Delta P + P_{atm}$, $Psat_{sp} = P_{sp}/P_{atm}*100$). The estimate of entrainment flow (Q_e) is based upon a linear function of the spillway discharge (Q_{sp}).

$$Q_e = C_1 Q_{sp} + C_2 \qquad (2)$$

The average flow-weighted TDG pressure (P_{avg}) is determined from the following relationship:

$$P_{avg} = \frac{(Q_{sp} + Q_e)P_{sp} + (Q_{ph} - Q_e)P_{ph}}{Q_{sp} + Q_{ph}} \qquad (3)$$

Where P_{ph} is the TDG pressure associated with powerhouse flows (typically equal to the forebay TDG pressure), P_{avg} is the flow weighted TDG pressure, and Q_{ph} is the powerhouse discharge.

The average TDG pressure routed through the lower pool to the next dam is calculated by using a lagranian hydrologic routing technique. The storage in the pool is determined from the pool stage storage relationship and the forebay pool elevation. The routing procedure treats hourly inflows as distinct control volumes that are routed through the pool in response to outflow volumes and change in reservoir storage. A dispersion coefficient is used to account for the non-uniformity in pool transport characteristics resulting in the attenuation of TDG fronts generated by project operation.

The influence of tributary inflows is treated in each pool. The Snake River provides the main tributary inflow to the McNary Pool.

The influence of the water temperature change on TDG pressure as based upon observations of river water temperatures can be applied to the arriving TDG characteristics at the next dam. The observed temperature difference between projects is used to estimate the change in TDG pressure associated with river flows. Generally, the water temperature at the tailwater FMS should be used to estimate the temperature at the dam. Erroneous or inconsistent temperature observations will result in the generation of unreliable pressure corrections. The equations governing the mass, pressure, temperature relationships are as follows:

The TDG exchange at the air-water interface is modeled as a first order process. The constant of proportionality is a function of the wind speed cubed or a constant exchange coefficient, which ever is largest. The equation for surface flux takes the following form:

$$\Delta P_{air/water}=C_1 * (P_{avg}-P_{atm})$$

$$C_1 = \max(C_{w1} * Wind^3, C_{w2})$$

CHAPTER 2: Overview of SYSTDG:

The following provides the SYSTDG user a brief overview of SYSTDG's ***capabilities***, ***limitations***, ***data acquisition*** and the three main components of the model, which are called ***Execute SYSTDG***; ***Model Input*** and ***Model Results***.

Capabilities

There are basically four main capabilities that SYSTDG has:
1. Real Time Spill Management Tool - SYSTDG can use to estimate the %TDG resulting from adjustments in gas caps for project operations:

- The Columbia River from Grand Coulee Dam to Bonneville Dam,
- The Snake River from Lower Granite Dam to the confluence with the Columbia River,
- The Clearwater from Dworshak Dam to its confluence with the Snake River.

2. Forecasting % TDG: The SYSTDG can forecast what % TDG will occur if various parameters are changed, such as the amount of spill, total flow, wind, water temperature, spill patterns, and other structural changes.

3.Tracks TDG across the Columbia River Basin: The SYSTDG worksheet determines an hourly ledger of TDG pressures approaching and leaving major main stem dams in the Columbia River Basin.

4.Contains Process Description: SYSTDG contains equations on TDG production, transport, and dispersion and dissipation.

SYSTDG estimates the TDG pressures resulting from project operations on the Columbia River from Grand Coulee Dam to Bonneville Dam, on the Snake River from Lower Granite Dam to the confluence with the Columbia River, and from Dworshak Dam on the Clearwater to its confluence with the Snake River. The model uses empirically derived equations to estimate the TDG exchange associated with spillway releases. The powerhouse operations are assumed to pass forebay TDG pressures. In some cases, a portion of the powerhouse flows encounter the highly aerated spillway releases and experience elevated TDG exchange rates. The entrainment of powerhouse flows will increase the effective discharge of the spillway and reduce the amount of powerhouse flow available for dilution during mixing zone development. The average flow weighted project TDG pressures are determined at each dam and are routed through the downstream river reach. The worksheet uses a simple hydrologic routing procedure to transport water from dam to dam that takes into account changing pool volumes and unsteady project flows. The influences of in pool heat exchange on TDG pressure can be accounted for through the application of the observed temperature differences between projects. The surface exchange of TDG pressures can also be estimated through a first order process where the exchange rate is based upon surface wind conditions.

Limitations

There are basically four main limitations that SYSTDG has:

1. Simulation of Heat budget – SYSTDG cannot be used to simulate the thermal budget of the Columbia River system.

2. Alternative water control measures - Cannot be used to directly simulate alternative water control measures or the hydrodynamic routing for system flows.

3. Have simple transport routines

4. Spatial resolution limited
   - TDG spillway releases is determined
   - Average flow-weighted TDG in project releases determined
   - No mixing zone calculations.

The SYSTDG workbook cannot be used to simulate the thermal budget of the Columbia River system. The direct simulation of the thermal budgets of the storage reservoir requires a more complex approach to account for the vertical thermal stratification in these impoundments. The influences of temperature can be accounted for in the workbook through temperature observations at the fixed monitoring stations. The model cannot be used to directly simulate alternative water control measures or the hydrodynamic routing for system flows. The workbook requires input data documenting hourly project flows and impoundment storage response. The workbook does simulate the mixing zone development that occurs below projects. The project releases are mixed and the flow weighted average TDG pressures are routed downstream. The hydrologic routing approximation of the open river reaches during periods of highly non-uniform discharges may result in a simplified estimate of river transport properties.

Data Acquisition and Management

There are several activities that must occur so that SYSTDG can be used easily: data acquisition from various websites; the storage of data in two databases; and filtering the data so erroneous data doesn't affect the model results. The following are discussions of each activity.

In order to use the SYSTDG spreadsheet in real-time mode additional files must be downloaded onto the user's computer within the same directory that the SYSTDG workbook has been saved in (C:\systdg). These additional files are used to download and store current weather, project operations, and water quality data into two Microsoft Access databases, FMSmaster.mdb and weatherklb.mdb, for later use in the SYSTDG spreadsheet.

The batch files getweatherdat.bat, and getweather8dat.bat are used to obtain current weather data from the Bureau of Reclamation's AgriMet ftp site ftp.usbr.gov while the file getweatherdatnoaa.bat is used to download recent National Weather Service weather data from the ftp site 205.156.51.200. The batch file getdat.bat is used to download up-to-date water quality and project operations information from the US Army Corps of Engineers' ftp site 137.161.202.92. Once this data is downloaded the files are saved onto the user's computer under the directory specified within the batch files. It is recommended that the Windows FTP client found on most computers under C:\WINNT\system32\FTP.EXE be used to execute these batch files.

The executable file loaddbv13.exe copies the project operation and water quality text files that have been stored onto the computer and loads them into the database FMSmaster.mdb. The executable file nwsextractV2.exe appends all National Weather Service text files into one comma delimited file called NWS.TXT that is later loaded in the database weatherklb.mdb using Microsoft Access macros.

The FMSmaster and weatherklb Databases

FMSmaster.mdb and weatherklb.mdb are the last two files that must be loaded onto the user's computer in order to use SYSTDG in real-time mode. Within the FMSmaster database (***Figure 1***) are 5 tables data, dataOld, test, test2, and weathersystdg. Also included in FMSmaster.mdb are numerous queries and macros designed to sort the data that loaddbv13.exe has inserted into the database, pulling out duplicate measurements and storing the finished product into the table data. The two tables data and systdgweather are used to store data and populate the SYSTDG spreadsheet when prompted, while the tables dataOld, test, and test2, are used by the database's macro. Within the table data are 18 columns which include STN (fixed monitoring station abbreviation), STN# (station number), Date/Time, Date, Time, Hour, Depth (ft), Temp (°C), BP (barometric pressure, mmHg), TDG (total dissolved gas pressure, mmHg), SAT (total dissolved gas saturation, %), Qspill (total spill, kcfs), Qgen (total generation megawatts), FBE (forebay elevation, ft), TWE (tailwater elevation, ft), and Gates (gates in operation).

Figure 1 - The "data" table in FMSmaster database

data : Table

STN	STN#	Year	DateTime	Date	Time	Hour	Depth	Temp	BP	TDG	SAT	QSpill	Qgen	QTot	FBE	TWE	GATES
ANQW	1280	2004	1/1/2004 1:00:00 AM	1/1/2004	1:00:00 AM	1							0				
ANQW	1280	2004	1/1/2004 2:00:00 AM	1/1/2004	2:00:00 AM	2							0				
ANQW	1280	2004	1/1/2004 3:00:00 AM	1/1/2004	3:00:00 AM	3							0				
ANQW	1280	2004	1/1/2004 4:00:00 AM	1/1/2004	4:00:00 AM	4							0				
ANQW	1280	2004	1/1/2004 5:00:00 AM	1/1/2004	5:00:00 AM	5							0				
ANQW	1280	2004	1/1/2004 6:00:00 AM	1/1/2004	6:00:00 AM	6							0				
ANQW	1280	2004	1/1/2004 7:00:00 AM	1/1/2004	7:00:00 AM	7							0				
ANQW	1280	2004	1/1/2004 8:00:00 AM	1/1/2004	8:00:00 AM	8							0				
ANQW	1280	2004	1/1/2004 9:00:00 AM	1/1/2004	9:00:00 AM	9							0				
ANQW	1280	2004	1/1/2004 10:00:00 AM	1/1/2004	10:00:00 AM	10							0				
ANQW	1280	2004	1/1/2004 11:00:00 AM	1/1/2004	11:00:00 AM	11							0				
ANQW	1280	2004	1/1/2004 12:00:00 PM	1/1/2004	12:00:00 PM	12							0				
ANQW	1280	2004	1/1/2004 1:00:00 PM	1/1/2004	1:00:00 PM	13							0				
ANQW	1280	2004	1/1/2004 2:00:00 PM	1/1/2004	2:00:00 PM	14							0				
ANQW	1280	2004	1/1/2004 3:00:00 PM	1/1/2004	3:00:00 PM	15							0				
ANQW	1280	2004	1/1/2004 4:00:00 PM	1/1/2004	4:00:00 PM	16							0				
ANQW	1280	2004	1/1/2004 5:00:00 PM	1/1/2004	5:00:00 PM	17							0				
ANQW	1280	2004	1/1/2004 6:00:00 PM	1/1/2004	6:00:00 PM	18							0				

Within the table systdgweather (see Figure 2) are 10 columns, which include Station (abbreviations listed as ***Appendix A***), Date/Time, Date, Month, Day, Year, Hour, Wsp (wind speed, m/s), AirTemp (°C), and DewPoint (°C). Note that the table systdgweather found within the FMSmaster.mdb database is linked to the systdgweather table found in the weatherklb.mdb database and is accessible only when both databases are available. Systdgweather is used to update wind data in each project's data sheet within the SYSTDG workbook when prompted. The weather station KTTD is mapped to the project data sheets bon and tid. The weather station KDLS is mapped to the project data sheets jda, tda, and mcn. The weather station KPSC is mapped to the project data sheets hnf, prd, hdp, ihr, and lmn. The weather station KEAT is mapped to the project data sheets wan, ris, and rrh. The weather station cjdw is mapped to the project data sheets chj and wel. The weather station gcdw is mapped to the project data sheet gcl. The weather station lbrw is mapped to the project data sheet lgs. The weather station silw is mapped to the project data sheet lwg. Lastly, the weather station deni is mapped to the project data sheets dwr and clw. (See the ***Appendix A-Abbreviations*** for details)

Figure 2 - The "systdgweather" linked table in FMSmaster

Microsoft Access - [systdgweather : Table]

File Edit View Insert Format Records Tools Window Help

Station	DateTime	Date	Month	Day	Year	Hour	Wsp	AirTemp	DewPoint
bndw	3/1/2004	3/1/2004	3	1	2004	0	18.1498235464096	6.7819447517395	5.81527762942844
bndw	3/1/2004 1:00:00 AM	3/1/2004	3	1	2004	1	19.3121275305748	6.49305617809296	5.66388924916585
bndw	3/1/2004 2:00:00 AM	3/1/2004	3	1	2004	2	22.4972882866859	6.48750030994415	5.45555591583252
bndw	3/1/2004 3:00:00 AM	3/1/2004	3	1	2004	3	24.0954566001892	6.44861173629761	5.4236110051473
bndw	3/1/2004 4:00:00 AM	3/1/2004	3	1	2004	4	21.9720155000687	6.52916634082794	5.35972224341498
bndw	3/1/2004 5:00:00 AM	3/1/2004	3	1	2004	5	26.5653514862061	6.5569441318512	5.18750031789144
bndw	3/1/2004 6:00:00 AM	3/1/2004	3	1	2004	6	14.2941035330296	6.5652779340744	5.09999963972304
bndw	3/1/2004 7:00:00 AM	3/1/2004	3	1	2004	7	17.490439414978	6.70972180366516	5.00416649712457
bndw	3/1/2004 8:00:00 AM	3/1/2004	3	1	2004	8	15.7581594586372	7.63749957084656	5.12916670905219
bndw	3/1/2004 9:00:00 AM	3/1/2004	3	1	2004	9	15.8810955286026	8.2277774810791	4.92500040266249
bndw	3/1/2004 10:00:00 AM	3/1/2004	3	1	2004	10	17.579847574234	9.79166650772095	4.87638791402181
bndw	3/1/2004 11:00:00 AM	3/1/2004	3	1	2004	11	22.6202249526978	10.3319444656372	4.98055617014567
bndw	3/1/2004 12:00:00 PM	3/1/2004	3	1	2004	12	24.1401594877243	10.5499997138977	4.64999993642171
bndw	3/1/2004 1:00:00 PM	3/1/2004	3	1	2004	13	16.6298878192902	12.7611107826233	3.73333348168267
bndw	3/1/2004 2:00:00 PM	3/1/2004	3	1	2004	14	10.1366320252419	12.973611831665	3.14722220102946

The database weatherklb.mdb contains 11 tables and multiple queries and macros that are used to update the database with the most current weather data available. The tables ***AgriMet Data***, ***Lewiston Weather Data***, ***National Weather Service Data***, and ***systdgweather*** store the meteorological data collected by various agencies. The tables ***all data template***, ***NWS data template***, ***NWS template***, ***NWS weather template***, ***weather template***, ***wu data template***, and ***wu weather template*** are used by the database's macros to load meteorological text files into the weatherklb database and organize this data, storing the finished product into the table ***systdgweathe***r (mentioned above). The two tables ***AgriMet Data*** and ***National Weather Service Data*** hold all data downloaded from the AgriMet and NWS ftp sites and include additional information such as wind gust, wind direction standard deviation, relative humidity, solar radiation, precipitation, wind run, cloud cover, visibility, and cloud height on a 15-min to hourly interval.

Filter Implementation

Mike…please add something that deal with the data filter. ???

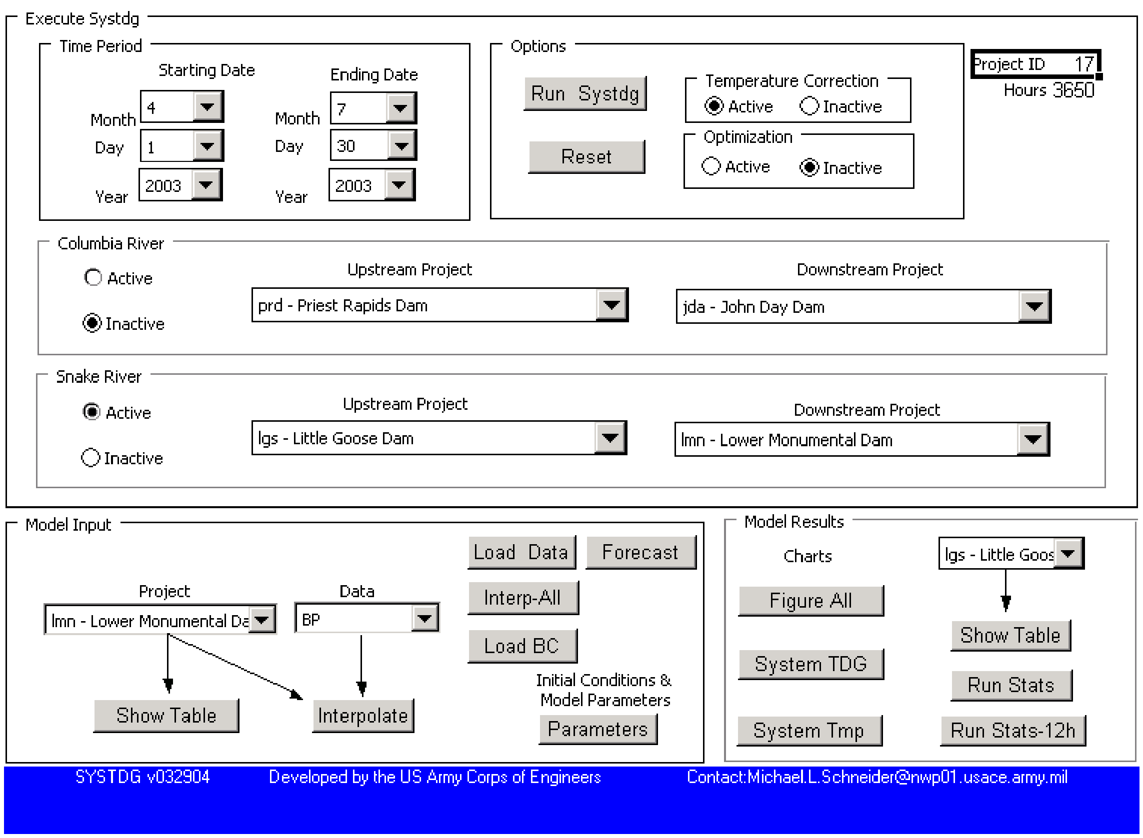
The Sub-Parts of SYSTDG:

The SYSTDG spreadsheet contains multiple workbooks containing a users interface, model components, model parameters, observed and calculated project operations and water quality data, daily summaries of project data, and figures depicting operations and water quality conditions.

There are three main parts to the SYSTDG model: Home Page Features and controls used to define the simulation; project data tables which contains the observed and calculated data; and the graphs and statistics for reviewing the model results.

The *Home* page contains basic model controls as shown in Figure 3. The three basic types of controls found on the *Home* page include *Execution*, *Model Input* and *Model Results.*

Figure 3 - Home Page controls



The following are descriptions of the sections on the home page.

Execute SYSTDG Section

On the home page of SYSTDG, there are controls for simulations of TDG pressure as a function of project operations. Under the ***Execute SYSTDG*** section there are the following controls:

- **River Reaches - Columbia River and Snake River -** The user can select whether or not to activate the Columbia River and, if activated, the upstream and downstream limits of the simulation. These reaches include the Columbia River from Grand Coulee Dam to river mile 122 below Bonneville Dam, the Snake River from the confluence of the Columbia River through Lower Granite pool and the Clearwater River from Dworshak Dam to the confluence with the Snake River (See ***Appendix A*** for abbreviations).

- **Hours** – The hours are a count of the cumulative number of hours included in the simulation. If the simulation has a start date of March 1st then the cumulative hours count will begin at 1. If the start date is later, then the cumulative hours count will begin at the number of hours for that date. A quickly changing count of the hours is an indication that the simulation is running.

- **Two Options** - Two execute options are available for the selected simulations. The first option entitled ***Temperature Correction*** will adjust the estimated TDG pressure based on the observed temperature changes from project to project. Caution should be exercised in selecting this feature especially when thermal stratification is present in the forebay of selected projects. The quality and representativeness of the temperature data varies over time and throughout the spill season. Temperature observations that do not accurately reflect conditions in the river will introduce a bias into the pressure estimates that may be erroneous. The second execution option entitled ***Optimization*** initiates a routine that develops a system spill management strategy. Add about if the optimization option has been activated the hourly spill discharge is also calculated. Mike to add to Optimization feature and ideas on management philosophy. ???

- **Project ID** – The project ID is the project identification number that SYSTDG has assigned each river reach. This is a programming technique to conveniently track the river reach that SYSTDG is working with. A quick change in the current project ID indicates that the simulation is running.

- **Run SYSTDG** – The ***Run SYSTDG*** button executes the model based on active river reach, starting date and ending date, and other options selected by the user. If need be, the program can be manually terminated by pressing the Esc key on the keyboard. As the program runs, noting the current project ID and cumulative hour of calculation as displayed in the upper right hand region of the Execute SYSTDG box indicates the progress of the simulation. A message window is presented when the current simulation is completed.

- **Reset** - The ***Reset*** button erases all boundary conditions and calculated values (the pink columns) in each of the project data tables. If by accident blue or orange columns have been *modified and saved* simply delete all data within those columns and select the ***Load Data*** button. This will re-fill cells with the correct observed data.

- **Snake River** - The user can select whether or not to activate the Snake River and, if activated, the upstream and downstream limits of the simulation.

- **Temperature Correction** - Takes into account the temperature change on TDG pressure observed during transport through the selected river reach**.**

- **Time Period** - Before the user runs SYSTDG the "Starting Date" and "Ending Date" must be selected by using the month, day, and year drop down tables

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Model Input Section

On the home page of SYSTDG, there are controls for data input and forecasting. Under the "Model Input" section there are the following controls:

- **Forecast** –The ***Forecast*** button assigns project-operating conditions into the future by assuming the most recent 24-hour operations are repeated. By selecting the ***Forecast*** button SYSTDG simply maps the last 24 hours of observed operating conditions through the end of the time interval selected. As a result, columns A through H of each project worksheet included in the selected river reach will have yesterdays data entered. This approach works well for all the projects except Bonneville, which has the new B2 corner collector. Columns J, K and I represent secondary sources, such as tributary inflows or the B2 corner collector. The data associated with the tributary inflows and the B2 corner collector are not automatically populated with the ***Forecast*** button. This is a needed future development that can be done once the CWMS data transition is complete. Until this development is completed, it is necessary to enter them manually. See ***Step 9 – Loading Secondary Source Data*** for details on how to do this.

- **Interpolate** – Interpolates data based on the users selections from the drop down tables "Project" and "Data". If you want to interpolate manually, there is a ***Interpolate*** button next to the ***Show Table*** control. . When using the ***Interpolate*** button, the user must select the ***Project*** and ***Parameter*** options from the drop down menus before clicking ***Interpolate***. This will prompt a linear interpolation between the specified data that has been selected. On the contrary, the user does not need to select from drop down menus before clicking on the ***Interp-All*** button. However, in choosing ***Interp-All*** every parameter in every project data sheet will be interpolated between and therefore takes longer to run. Data must be interpolated before a simulation can run successfully, not doing so will cause a run-time error within excel.

- **Interp-All** – Determines missing operations data (blue columns) by a linear interpolation from existing data

- **Load Data** – The ***Load Data*** control populates all project data table (the blue and orange columns) with current observed data, which is stored in the Microsoft Access database. The data found on the project data sheet can be entered manually or queried from a master database by selecting ***Load Data.*** Selecting the ***Load Data*** button will cause the most current data to be loaded into the project worksheets from the "data" and "systdgweather" tables found in the FMSmaster database. After selecting the ***Load Data*** control, one of two things may happen: Data will be added into the project worksheet or not. If data is being added to the worksheets, you will see the screen blinking and the "work" worksheet selected as the process occurs. At the end of this load you will see a box asking "Start Interpolation" Click OK. This box lets the user know that the data loading process was completed successfully.

- **Parameters** – The ***Parameters*** button routes the user to the project parameter ***Input Page.***

- **"Input" Page** - The input page includes model parameters such as pool storage coefficients, spillway TDG production coefficients, powerhouse entrainment coefficients, water surface exchange coefficients, powerhouse hydraulic capacity, and discharge-to-megawatt conversion factors (see Figure 4). The initial conditions that are stored in ***Input Page*** are used by the model to predict conditions downstream. The initial conditions can be manually changed to any date the user chooses by calculating a daily average observed forebay total dissolved gas and temperature for each project and replacing the values found in rows 4 and 5 on the ***Input Page*** (see Figure 4 below).

Figure 4 - Project Parameter Input Page

Project	GCL	CHJ	WEL	RRH	RIS	WAN	PRD	HNF	MCN	JDA	TDA	BON	TID	DWR	CLW	LWG	LGS	LMN	IHR	HDP
ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Initial Conditions																				
Temperature Initial (C)	4.2	4.2	4.7	5.2	5.5	6.0	6.2	6.2	8.0	8.0	6.5	6.4	5.6	4.8	4.0	7.0	7.7	8.1	8.3	8.3
TDG Pressure Initial (mmHg)	747.0	750.0	802.1	802.1	802.1	829.0	790.0	780.0	773.0	772.0	792.0	760.0	770.0	740.0	740.0	756.0	765.0	762.0	756.0	756.0
Pool Transport																				
Dispersion Coefficient	30	60	40	60	60	20	30	120	60	40	20	40	20	40	25	20	30	10	40	10
Effective Volume	1	1.2	1	1	1	1	1.2	1.2	0.85	1	1.2	1	1.1	1	1	0.8	0.9	0.8	0.8	1
Pool Storage																				
Stage Volume C1	0.215	0	0	0	0	0	0	0.048	0.178	0.879	0.053	0.075	0.005	0	0	0.045	0.037	0.044	0.037	0.022
Stage Volume C2	-473	-0.05	9.7	9	2.375	13.84	6.889	16	-94.9	-412	-6.56	3.92	10.84	0	0.006	-57.5	-36.7	-40.4	-24.4	-13.7
Stage Volume C3	3E+05	593.1	-7245	-5981	-1326	-7322	-3157	35.07	12783	50089	13.67	-18.7	102.5	0	25	18576	9023	9389	3967	2144
TDG Production Case 1																				
Entrainment E1	1.36	0	0	0	0	0.4	0	0	0	0	0	0	0	0	0	1	0.75	0.45	0	0
Entrainment E2	0	0	0	0	0	0	0	0	35	0	0	0	0	0	0	0	0	0	0	0
TDG Exchange P1	0	6.104	1041	5.763	965.9	12.2	7.196	0	1207	315.3	8.68	13.4	0	411.2	0	245.8	5.566	5.056	1053	0
TDG Exchange P2	0	-5.08	-313	-0.37	-743	67.11	-0.77	0	-395	-519	-507	1.6	0	-0.4	0	-0.14	-0.15	-0.21	-417	0
TDG Exchange P3	355.2	-0.48	-0.03	0	0	0	0	0	-0.04	-0.37	0	23.9	0	-140.2	0	0	0	0	-0.44	0
TDG Exchange P4	0	0	-743	0	0	0	0	0	-754		0	0	0	0	0	0	0	0	-755	0
TDG Production Case 2																				
Entrainment E1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.1	0	0
Entrainment E2	0	0	0	0	0	0	0	0	35	35	0	0	0	0	0	0	0	0	30	0
TDG Exchange P1	451	0	0	0	0	13.86	0	0	6.175	4.97	0	937	0	0	0	0	6.488	5.427	0.115	0
TDG Exchange P2	-0.03	0	0	0	0	60.57	0	0	-0.04	-0.23	1.02	-764	0	0	0	0	-0.28	-0.58	1.745	0

- **Load BC** –The ***Load BC*** control loads boundary conditions or observed forebay total pressure data (TDGfb column) into the table of the most upstream project selected. Note: the ***BC*** stands for **b**oundary **c**onditions. Before running a simulation, this button must be selected in order to load the observed forebay total pressure data into the TDGfb column of the most upstream project's data sheet.

Model Results Section

On the home page of SYSTDG, there are user controls to tabular or graphical summaries of observed and calculated conditions. Under the "Model Input" section there are the five controls:

1. **Figure All** – Routes the user to the "all-fig" time history chart of water quality and project operations
2. **Run Stats –** Runs the simulation statistics seen on the ***Stats-Obs and Calc*** page.
3. **Run Stats-12hr –** Runs the simulation statistics seen on the ***Stats-12hr*** page.
4. **System TDG -** Routes the user to the "sys TDG fig" time history chart of TDG levels.
5. **System Tmp -** Routes the user to the "sys Tmp fig" time history chart of temperature.
6. **Show Table** - Routes the user to the project tables. **Show Table** – Routes the user to the table or spreadsheet that is selected from the drop down menu ***Project***.

The following is a discussion of each.

Figure All Chart:

The ***all-fig*** chart displays time series plots of simulated and observed conditions at a selected project during March 1st through September 31st (Figure 5). The user has the ability to manipulate this plot by using the X-Axis Controls and Parameter/Project Controls located on either side of the graph. The X-Axis Controls, located on the left hand side of the graph gives the user multiple ways of modifying the x-axis. For instance, by selecting ***ALL*** the entire season (March through September) will be displayed on the x-axis. To select one month click on the desired month of ***MAR***, ***APR***, ***MAY***, ***JUN***, ***JUL***, ***AUG***, or ***SEP***. For any other time span the ***Start Date*** and ***End Date*** drop down menus should be used. When using the drop down ***Start Date*** and ***End Date*** menus you must hit the ***Plot*** button in order to see changes.

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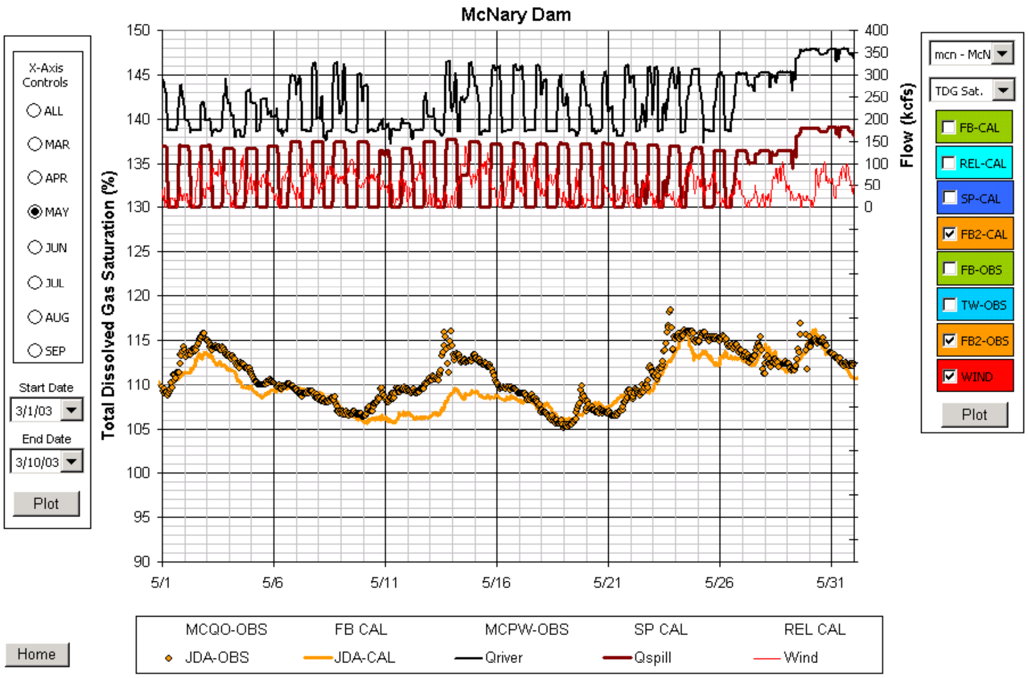
Figure 5 - Figure All Chart



The ***Parameter/Project Controls***, located on the right hand side of the graph, allow the user to choose the parameter, project, and contents to be displayed. Using the drop down menus the preferred project and parameter can be selected. The hourly calculated (Cal) and observed (Obs) properties in the forebay (FB), spillway (SP), average flow-weighted project release (REL), and downstream project forebay (FB2) locations can be displayed by selecting one or all of the boxes labeled FB-CAL, REL-CAL, SP-CAL, FB2-CAL, FB-OBS, TW-OBS, FB2-OBS, or WIND. Remember, the calculated workbook properties are labeled with the abbreviation (Cal) while the observed data from the fixed monitoring station are labeled (Obs). For example, the label REL-CAL refers to the calculated average flow-weighted release TDG property for a selected project. The label TW-OBS refers to the observed tailwater FMS property. Once ***Parameter/Project Controls*** have been selected the ***Plot*** button must be clicked for any changes to occur. The ***Home*** button located in the lower left hand corner of the chart will direct the user back to the Home page.

There are several different data series that are graphed in All Fig. The following definitions define what the abbreviations mean:

- **FBcalc** - Calculated properties in the forebay equivalent to calculated powerhouse release properties
- **FB2calc** - Calculated properties in the next downstream forebay.
- **FBObs** - Observed forebay conditions, the orange forebay FMS columns found in the project data sheets
- **FB2Obs** - Observed forebay conditions for the next downstream project, the orange forebay FMS columns found in the project data sheets

- **RELcalc** - Calculated flow weighted properties of powerhouse and spillway flows (well mixed conditions)
- **SPcal** - Calculated properties in spillway flows only
- **TWObs** - Observed tailwater conditions, the orange tailwater FMS columns within the project data sheets
- **Wind** – The data entered into the wind column and plotted on the graphs are the observed wind speed for the reach of the river below the project.

The following descriptions will be useful in understanding the graphs.

Start and Ending Dates – On the left side of the worksheet, you will see the pull down tag with the dates, which you can use to select the dates that you would like to see the data for.

Station – On the upper right side of the worksheet, you will see the pull down menu with a project name under it. You can select which project you want to see graphed of by selecting it with this pull down menu.

Parameter - On the upper right side of the worksheet, you will see the drop down menu with a parameter name under it. Using this menu the user is able to select which parameter to graph. Your selection includes total dissolved gas saturation (TDGsat, %), temperature (Temp, C), and barometric pressure (BP, mmHg) and total pressure (TP, mmHg).

Run Stats Controls

The ***Run Stats*** button calculates daily statistics for projects within the river reach selected by the user. The user is then directed to the "Stats-Obs" worksheet. This routine is automatically executed when the ***Run SYSTDG*** button is clicked, however, can be run separately by clicking ***Run Stats***. The ***Run Stats*** control calculates daily statistics for projects within the river reach selected by the user. Once run, the user should will be able to view statistical results such as mean, min, max, and mean12 (the average of the highest 12 hourly observations in one day) which are calculated for ***Qspill*** - observed total spill (kcfs), ***Qspill2*** - calculated total spill (kcfs), ***Qtotal*** - observed total river (kcfs), ***FBTP*** - observed forebay total dissolved gas pressure (mm Hg), ***FBTDGSat*** - observed forebay total dissolved gas saturation (%), ***FBTemp*** - observed forebay temperature (C), ***FBBP*** - observed forebay barometric pressure (mm Hg), ***TWTP*** - observed tailwater total dissolved gas pressure (mm Hg), ***TWTDGSat*** - observed tailwater total dissolved gas saturation (%), ***TWTemp*** - observed tailwater temperature (C), ***TWBP*** - observed tailwater barometric pressure (mm Hg), ***FBcalTP*** - forebay calculated total dissolved gas pressure (mm Hg), ***FBcalTDGSat*** - forebay calculated total dissolved gas saturation (%), ***SPcalTP*** - calculated spillway total dissolved gas pressure (mm Hg), ***SPcalTDGSat*** - total dissolved gas saturation (%), ***RELcalTP*** - calculated release total dissolved gas pressure (mm Hg) and ***RELcalTDGSat*** - calculated release total dissolved gas saturation (%) for each project (See Figure 6).

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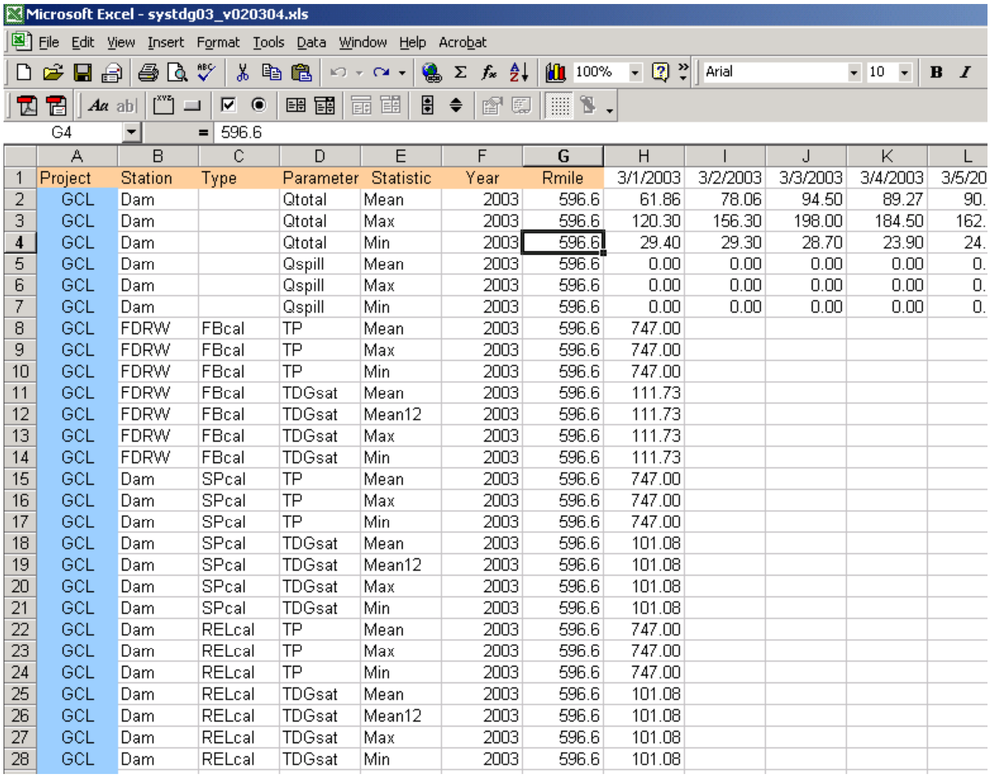
Figure 6 - Stats-Obs and Calc Page



	A	B	C	D	E	F	G	H	I	J	K	L
1	Project	Station	Type	Parameter	Statistic	Year	Rmile	3/1/2003	3/2/2003	3/3/2003	3/4/2003	3/5/20
2	GCL	Dam		Qtotal	Mean	2003	596.6	61.86	78.06	94.50	89.27	90.
3	GCL	Dam		Qtotal	Max	2003	596.6	120.30	156.30	198.00	184.50	162.
4	GCL	Dam		Qtotal	Min	2003	596.6	29.40	29.30	28.70	23.90	24.
5	GCL	Dam		Qspill	Mean	2003	596.6	0.00	0.00	0.00	0.00	0.
6	GCL	Dam		Qspill	Max	2003	596.6	0.00	0.00	0.00	0.00	0.
7	GCL	Dam		Qspill	Min	2003	596.6	0.00	0.00	0.00	0.00	0.
8	GCL	FDRW	FBcal	TP	Mean	2003	596.6	747.00				
9	GCL	FDRW	FBcal	TP	Max	2003	596.6	747.00				
10	GCL	FDRW	FBcal	TP	Min	2003	596.6	747.00				
11	GCL	FDRW	FBcal	TDGsat	Mean	2003	596.6	111.73				
12	GCL	FDRW	FBcal	TDGsat	Mean12	2003	596.6	111.73				
13	GCL	FDRW	FBcal	TDGsat	Max	2003	596.6	111.73				
14	GCL	FDRW	FBcal	TDGsat	Min	2003	596.6	111.73				
15	GCL	Dam	SPcal	TP	Mean	2003	596.6	747.00				
16	GCL	Dam	SPcal	TP	Max	2003	596.6	747.00				
17	GCL	Dam	SPcal	TP	Min	2003	596.6	747.00				
18	GCL	Dam	SPcal	TDGsat	Mean	2003	596.6	101.08				
19	GCL	Dam	SPcal	TDGsat	Mean12	2003	596.6	101.08				
20	GCL	Dam	SPcal	TDGsat	Max	2003	596.6	101.08				
21	GCL	Dam	SPcal	TDGsat	Min	2003	596.6	101.08				
22	GCL	Dam	RELcal	TP	Mean	2003	596.6	747.00				
23	GCL	Dam	RELcal	TP	Max	2003	596.6	747.00				
24	GCL	Dam	RELcal	TP	Min	2003	596.6	747.00				
25	GCL	Dam	RELcal	TDGsat	Mean	2003	596.6	101.08				
26	GCL	Dam	RELcal	TDGsat	Mean12	2003	596.6	101.08				
27	GCL	Dam	RELcal	TDGsat	Max	2003	596.6	101.08				
28	GCL	Dam	RELcal	TDGsat	Min	2003	596.6	101.08				

The following are the description of the Columns found in this worksheet:

Project - Project abbreviations, located in column A and given in greater detail in ***Appendix A-Abbreviations***.

Station - Column B describes where data is collected; at the dam (Dam), at the forebay fixed monitoring station (fixed monitoring station abbreviation shown in ***Appendix A-Abbreviations***), or at the tailwater fixed monitoring station (fixed monitoring station abbreviation shown in ***Appendix A-Abbreviations***)

Type – Column C informs the user of whether the statistics were derived by observed or calculated data. FB (forebay) or TW (tailwater) is observed data, while FBcalc, SPcalc, and RELcalc is calculated data (See "All Fig Worksheet definition for these terms.)

Parameter - Column D describes the parameters for which statistical analysis is available. Your selection includes total dissolved gas saturation (TDGsat, %), temperature (Temp, C), and barometric pressure (BP, mmHg total pressure (TP, mmHg),

Statistics - Column E describes the statistic used to analyze the data and includes min, max, mean, or mean12, which is the average of the highest 12 hourly observations in a day

Run Stats-12hr Control

The ***Run Stats-12hr*** button calculates daily 12-hour average TDG statistics for projects within the river reach selected by the user. The user is then directed to the "Stats-12h Calc" worksheet. When executed a chart of the averaged observed12-highest hourly total dissolved gas saturation observations is generated for each project's forebay and tailwater. Calculated values will turn red if any excursions are met.

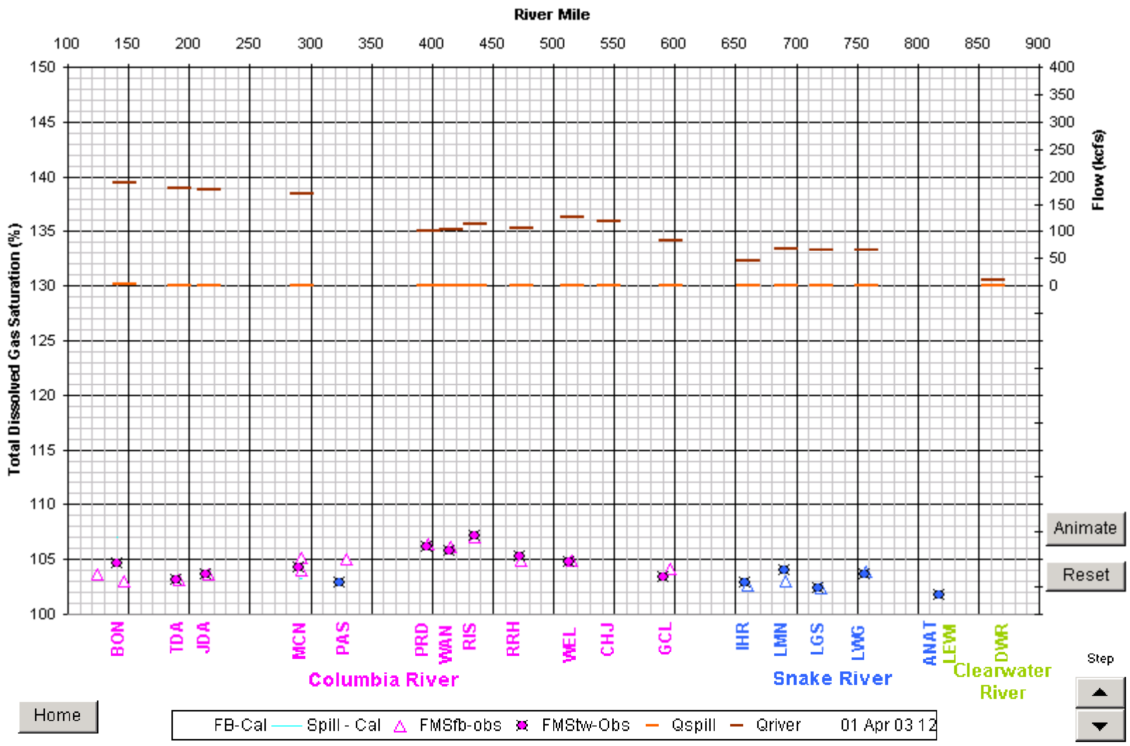
System TDG Control

System TDG Button - Routes the user to the chart "sys tdg-fig" which is a snapshot of total pressure throughout the Columbia and Snake River systems. This is a great way of seeing the actual observed conditions of the rivers in animation. Sys tdg fig graphs the TDG by river mile (**Rmile)** with the project abbreviations arranged according to their river mile locations. For station abbreviations meaning see ***Appendix A***. The ***sys temp fig*** produces the same kind of graph except for temperature.

"Sys tdg-fig" Chart - The sys tdg-fig chart allows the user to step through the spill season and view observed total dissolved gas saturations and spill at each project from Dworshak to Bonneville Dam.

System operations and TDG saturation can be viewed by selecting the ***System TDG*** button in the results section of the ***Home Page***. The upper half of this chart, shown in Figure 8, displays the hourly total and spill flow by project throughout the Columbia and Snake Rivers. The lower half of the chart shows the observed and calculated TDG saturation by project. The projects are located by river mile on the x-axis with the Clearwater River represented by green symbols, the Snake River represented by blue symbols, and the Columbia River represented by pink symbols. The triangles reflect observed data at the forebay FMS while the circles reflect conditions at the tailwater FMS. The day, month, year, and hour for the displayed data is listed in the lower right-hand side of the data legend. The time can be manually incremented one hour by selecting the ***up and down arrows*** located in the lower right hand corner of the figure. The data can be animated of played back continuously by selecting the ***Animate*** button on the chart. Depending on the speed of the user's computer processor the playback speed may be slow. To speed up the animation press the Esc key found on the keyboard once. To stop the animation processes press the Esc key twice. The ***Reset*** button returns the data display to March 1. The ***Home*** button located in the lower left hand corner of the chart will direct the user back to the Home page.

Figure 8 - System TDG Chart



System Tmp Control

System Tmp Button routes the user to the chart "sys tmp-fig" which is a snapshot of temperature throughout the Columbia and Snake River systems

"Sys tmp-fig" Chart allows the user to step through the spill season and view observed temperature and spill at each project from Dworshak to Bonneville Dam.

System operations and water temperatures can be viewed by selecting the ***System Tmp*** button in the results section of the ***Home Page***. The upper half of the chart, shown in Figure 9 displays the hourly total and spill flow by project throughout the Columbia and Snake Rivers. The lower half of the chart shows the observed and calculated water temperatures by project. The projects are located by river mile on the x-axis with the Clearwater River represented by green symbols, the Snake River represented by blue symbols, and the Columbia River represented by pink symbols. The triangles reflect observed data at the forebay FMS while the circles reflect conditions at the tailwater FMS. The day, month, year, and hour for the displayed data is listed in the lower right-hand side of the data legend. The time can be manually incremented one hour by selecting the ***up and down arrows*** located in the lower right hand corner of the figure. The data can be animated of played back continuously by selecting the ***Animate*** button on the chart. Depending on the speed of the user's computer processor the playback speed may be slow. To speed up the animation press the Esc key found on the keyboard once. To stop the animation processes press the Esc key twice.

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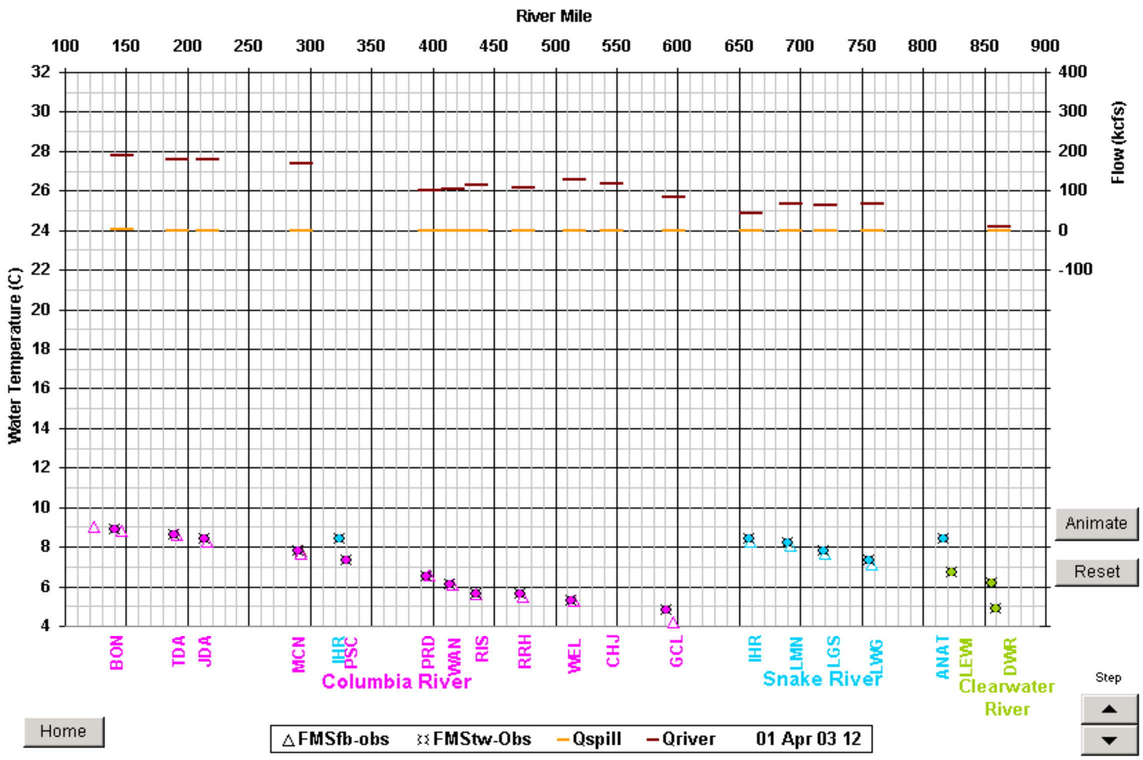
Figure 9 - System Tmp Chart



Show Table Control

The ***Show Table*** button routes the user to the table or spreadsheet that is selected from the drop down menu. The user can select a given project data sheet by using the drop down menu or by selecting the worksheet tab located on the bottom toolbar. Within each data table the user will find color-coded columns of information required to run the SYSTDG model (See Figure 10). Each column is defined and can be viewed by holding the cursor over one of the column headings (see Figure 7). See project data tables section for more information.

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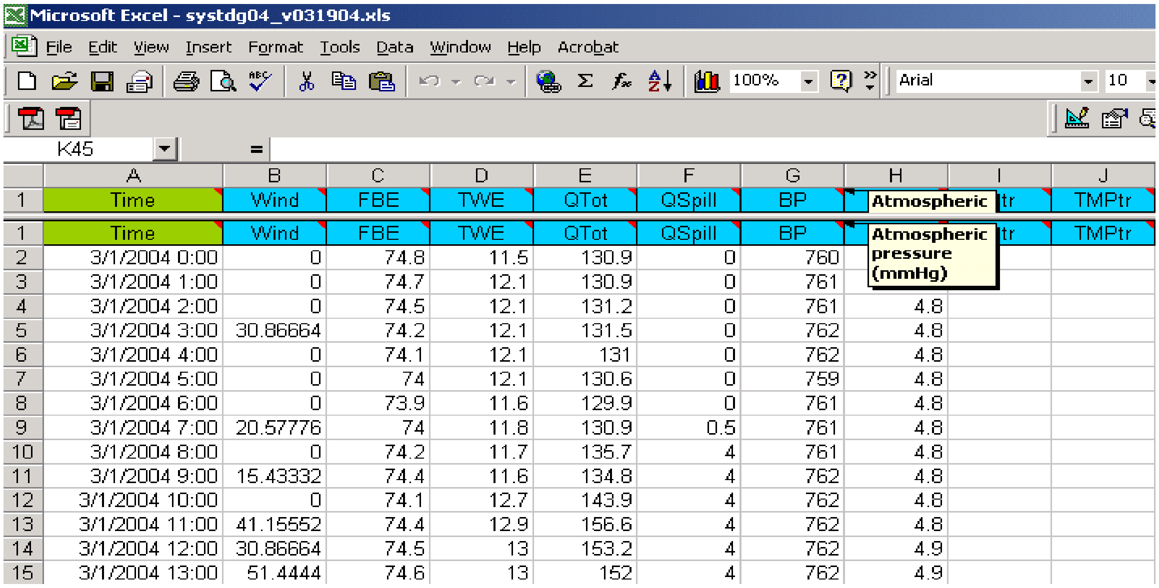
Figure 7 - Column Header Definitions



	A	B	C	D	E	F	G	H	I	J
1	Time	Wind	FBE	TWE	QTot	QSpill	BP	Atmospheric	tr	TMPtr
2	3/1/2004 0:00	0	74.8	11.5	130.9	0	760			
3	3/1/2004 1:00	0	74.7	12.1	130.9	0	761			
4	3/1/2004 2:00	0	74.5	12.1	131.2	0	761	4.8		
5	3/1/2004 3:00	30.86664	74.2	12.1	131.5	0	762	4.8		
6	3/1/2004 4:00	0	74.1	12.1	131	0	762	4.8		
7	3/1/2004 5:00	0	74	12.1	130.6	0	759	4.8		
8	3/1/2004 6:00	0	73.9	11.6	129.9	0	761	4.8		
9	3/1/2004 7:00	20.57776	74	11.8	130.9	0.5	761	4.8		
10	3/1/2004 8:00	0	74.2	11.7	135.7	4	761	4.8		
11	3/1/2004 9:00	15.43332	74.4	11.6	134.8	4	762	4.8		
12	3/1/2004 10:00	0	74.1	12.7	143.9	4	762	4.8		
13	3/1/2004 11:00	41.15552	74.4	12.9	156.6	4	762	4.8		
14	3/1/2004 12:00	30.86664	74.5	13	153.2	4	762	4.9		
15	3/1/2004 13:00	51.4444	74.6	13	152	4	762	4.9		

Project Data Tables

There are two ways to access the project data tables: The first way is from the home page of SYSTDG. At the bottom of the home page, there are worksheets for each project with data table. By clicking on the tabs that have the project abbreviation on it you can look at its data. For a complete list of project abbreviations see ***Appendix A-Abbreviations***. The second way is through the ***Show Table*** control discussed in the ***Show Table Control*** in the Model Results section.

Within each data table are color-coded columns of data for that project. Figure 10 is an example of the data table for Bonneville dam. By placing your cursor over the colored header of each column you will be given the type of data stored in that column. The following are the descriptions of what the colors mean and what kind of data are in the columns.

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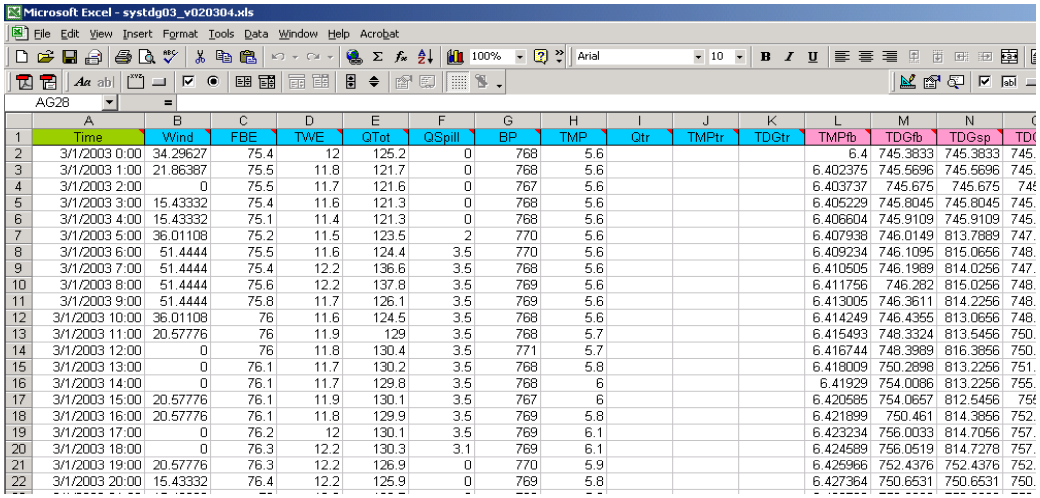
Figure 10 - Data Table for Bonneville Dam



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Time	Wind	FBE	TWE	QTot	QSpill	BP	TMP	Qtr	TMPtr	TDGtr	TMPfb	TDGfb	TDGsp	TD(
2	3/1/2003 0:00	34.29627	75.4	12	125.2	0	768	5.6				6.4	745.3833	745.3833	745.
3	3/1/2003 1:00	21.86387	75.5	11.8	121.7	0	768	5.6				6.402375	745.5696	745.5696	745.
4	3/1/2003 2:00	0	75.5	11.7	121.6	0	767	5.6				6.403737	745.675	745.675	745
5	3/1/2003 3:00	15.43332	75.4	11.6	121.3	0	768	5.6				6.405229	745.8045	745.8045	745.
6	3/1/2003 4:00	15.43332	75.1	11.4	121.3	0	768	5.6				6.406604	745.9109	745.9109	745.
7	3/1/2003 5:00	36.01108	75.2	11.5	123.5	2	770	5.6				6.407938	746.0149	813.7889	747.
8	3/1/2003 6:00	51.4444	75.5	11.6	124.4	3.5	770	5.6				6.409234	746.1095	815.0656	748.
9	3/1/2003 7:00	51.4444	75.4	12.2	136.6	3.5	768	5.6				6.410505	746.1989	814.0256	747.
10	3/1/2003 8:00	51.4444	75.6	12.2	137.8	3.5	769	5.6				6.411756	746.282	815.0256	748.
11	3/1/2003 9:00	51.4444	75.8	11.7	126.1	3.5	769	5.6				6.413005	746.3611	814.2256	748.
12	3/1/2003 10:00	36.01108	76	11.6	124.5	3.5	768	5.6				6.414249	746.4355	813.0656	748.
13	3/1/2003 11:00	20.57776	76	11.9	129	3.5	768	5.7				6.415493	748.3324	813.5456	750.
14	3/1/2003 12:00	0	76	11.8	130.4	3.5	771	5.7				6.416744	748.3989	816.3856	750.
15	3/1/2003 13:00	0	76.1	11.7	130.2	3.5	768	5.8				6.418009	750.2898	813.2256	751.
16	3/1/2003 14:00	0	76.1	11.7	129.8	3.5	768	6				6.41929	754.0086	813.2256	755.
17	3/1/2003 15:00	20.57776	76.1	11.9	130.1	3.5	767	6				6.420585	754.0657	812.5456	755
18	3/1/2003 16:00	20.57776	76.1	11.8	129.9	3.5	769	5.8				6.421899	750.461	814.3856	752.
19	3/1/2003 17:00	0	76.2	12	130.1	3.5	769	6.1				6.423234	756.0033	814.7056	757.
20	3/1/2003 18:00	0	76.3	12.2	130.3	3.1	769	6.1				6.424589	756.0519	814.7278	757.
21	3/1/2003 19:00	20.57776	76.3	12.2	126.9	0	770	5.9				6.425966	752.4376	752.4376	752.
22	3/1/2003 20:00	15.43332	76.4	12.2	125.9	0	769	5.8				6.427364	750.6531	750.6531	750.

<u>Blue Columns -</u> The blue columns include observed data that is used as input information to the model. These observed input data includes wind, forebay elevation (FBE), tailwater elevation (TWE), total river flow (Qtotal), total spill (Qsp), barometric pressure (BP), temperature, (TMP), total tributary flow (Qtr), tributary temperature (TMPtr), and tributary total dissolved gas pressure (TDGtr) data.

<u>Pink Columns -</u> The pink columns include calculated data that the model generates. The model generated data includes forebay temperature (TMPfb), forebay total dissolved gas pressure (TDGfb), spillway total dissolved gas pressure (TDGsp), release total dissolved gas pressure (TDGrel), forebay total dissolved gas saturation (PSATfb), spillway total dissolved gas saturation (PSATsp), release total dissolved gas saturation (PSATrel), and (Qsp-est).

<u>Orange Columns -</u> The orange columns include observed data that the model results can be compared against. These observed data used for comparison includes forebay and tailwater fixed monitoring station temperature, barometric pressure, total dissolved gas pressure, and total dissolved gas saturation data

The SYSTDG workbook calculates the hourly project forebay water temperature (C), forebay TDG pressure (mm Hg), forebay TDG saturation (%), spill TDG pressure (mm Hg), spill TDG saturation (%), release TDG pressure (mm Hg), release TDG saturation (%) and travel times (days). The release TDG properties are based upon the average flow-weighted project flows from the powerhouse and spillway. If the optimization option has been activated the hourly spill discharge is also calculated. The project data sheet calculated parameters are highlighted in pink. The calculated values can be erased prior to a workbook simulation by selecting the ***Reset*** button on the ***Home page***.

Columns T – AA, in orange, display the Fixed Monitoring Station observed water quality data. Abbreviations used to describe the Fixed Monitoring Stations can be found under the definitions section found at the beginning of the manual.

CHAPTER 3: Using SYSTDG

Using SYSTDG involves several different components: setting up SYSTDG on the computer, ensuring that it is downloading data properly, and being able to run simulations. This chapter provides information on how to set up SYSTDG on your computer, a step-by-step guidance on how to do simulations and the possible errors that a user may encounter.

Setting Up SYSTDG on Your Computer:

When setting SYSTDG up on your computer, there are several steps that are necessary: Ensure that your computer has the necessary resource requirements, the data acquisition scheduled tasks are operating and the macros are enabled. The following are discussions of these activities:

Resource Requirements

The SYSTDG model has been built around Microsoft Excel 97 with standard visual basic and optimization add-ins. The SYSTDG model will also run under the Excel 2000 release. In general, the decision support system should run on any personal computer with a Pentium 100 or faster processor with at least 64 MB of memory (RAM). The full system represented with seven months of data results in a spreadsheet size of approximately 32 MB. The execution time for the full system for seven months without optimization is generally on the order of 10 minutes on a 600 Mz Pentium III. The execution of the optimization components significantly increases run times. A simple user interface is provided allowing access to data input functions, model execution options, and model output tables and graphical summaries. The Excel platform also provides linkage to database and statistics applications and access to the Internet. The Excel platform is generally accessible to a wide range of users and can be easily modified to accommodate user specific tables, statistics, and charts. The macro security as found under the Tools feature of Excel, needs to be set to medium or low to allow the spreadsheet to execute the visual basic routines. Securities set to high will disable all macros within the workbook.

Establishing Scheduled Tasks

By using the Microsoft Scheduled Task program the required files mentioned above can be "scheduled" to run at any desired time and frequency. There are several ways to do this. ***Appendix B*** provides a detailed description of how to set up scheduled tasks using the wizard. If the user prefers a quick more direct approach, they can take the following steps. To schedule a task go to the ***Start*** button then ***Settings*** then ***Control Panel*** and double click on the ***Scheduled Tasks*** icon. On the toolbar select ***File*** then ***New Scheduled Task***. This should add a new task to the scheduled task list. Rename the task then double click on it to add information into the Run and Start In command lines (see Figure 11 and the list of commands below).

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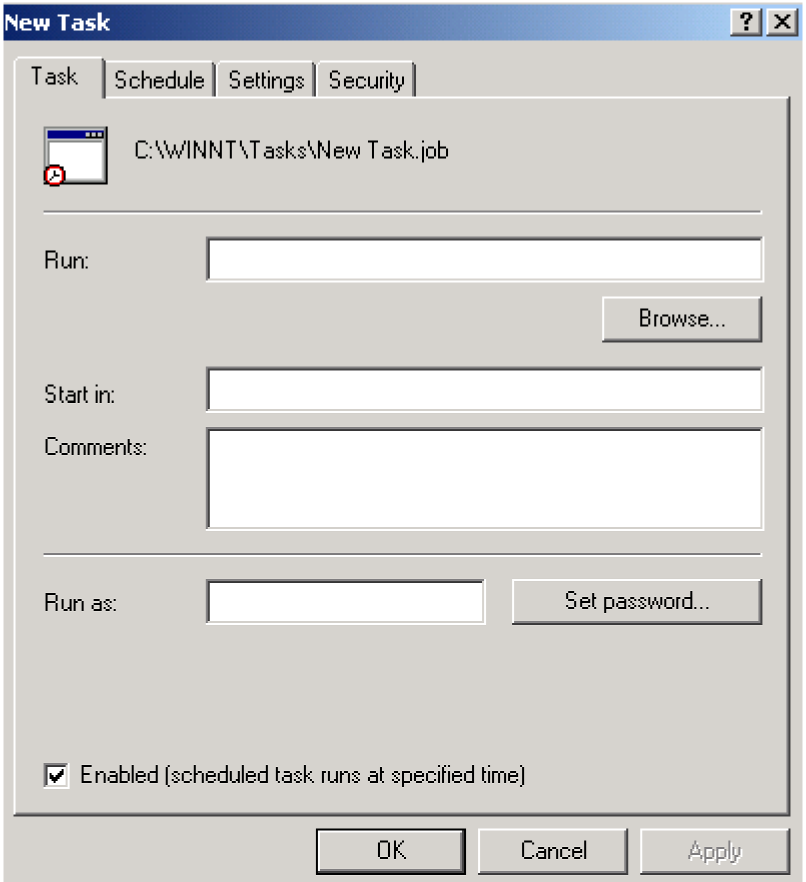
Figure 11 - A New Scheduled Task Properties window



The necessary commands required to successfully schedule each file are listed below.

FTP AgriMet8day:
Run: C:\WINNT\system32\FTP.EXE -s:c:/systdg/getweather8daydat.bat s5ftp.usbr.gov
Start In: C:\winnt\system32
Comments: **(downloads AgriMet data from the past 8 days)**

AgriMet8day db:
Run: "C:\Program Files\Microsoft Office\Office\MSACCESS.EXE" "c:\systdg\weatherklb.mdb" /x macro8day
Start In: C:\systdg
Comments: **(loads AgriMet 8 day data into weatherklb database)**

FTP AgriMet:
Run: C:\WINNT\system32\FTP.EXE -s:c:/systdg/getweatherdat.bat s5ftp.usbr.gov
Start In: C:\winnt\system32
Comments: (downloads AgriMet data from the past 4 hours)

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AgriMet db:
Run: "C:\Program Files\Microsoft Office\Office\MSACCESS.EXE" "c:\systdg\weatherklb.mdb" /x macro2
Start In: C:\systdg
Comments: (loads AgriMet data into weatherklb database)

FTP NWS:
Run: C:\WINNT\system32\FTP.EXE -s:c:/systdg/getweatherdatnoaa.bat 205.156.51.200
Start In: C:\systdg
Comments: (downloads NWS data)

Loadnws (can be called NwsextractV2):
Run: C:\systdg\nwsextractV2.exe
Start In: C:\systdg
Comments: **(compiles NWS text files into one flat file called NWS.TXT)**

NWS db:
Run: "C:\Program Files\Microsoft Office\Office\MSACCESS.EXE" "c:\systdg\weatherklb.mdb" /x macroNWS
Start In: C:\systdg
Comments: (loads NWS data into weatherklb database, sorts, and organizes)

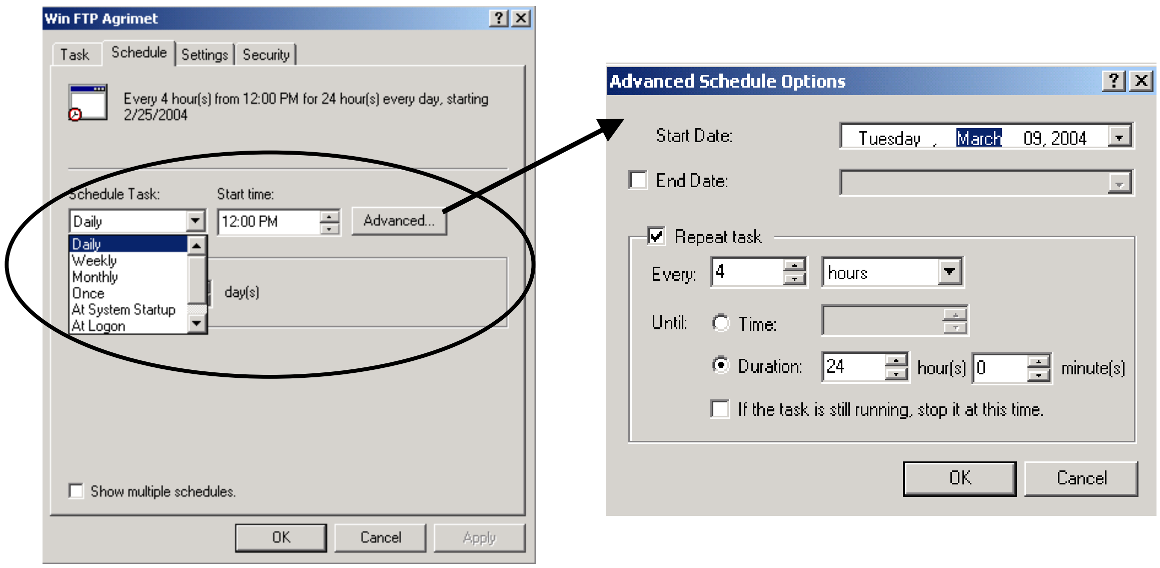
FT wq data:
Run: C:\WINNT\system32\FTP.EXE -s:c:/systdg/getdat.bat 137.161.202.92
Start In: C:\systdg
Comments: (downloads water quality and project ops data)

Loaddbv13:
Run: C:\systdg\loaddbv13.exe
Start In: C:\systdg
Comments: (loads water quality and project ops into FMSmaster database)

fmsmaster db:
Run: "C:\Program Files\Microsoft Office\Office\MSACCESS.EXE" "c:\systdg\fmsmaster.mdb" /x macro1
Start In: C:\systdg
Comments: (sorts and organizes data within FMSmaster database)

Once the Run, Start In and comments lines are completed for a given task select the Schedule tab to choose the desired time, frequency, and duration of that task (see Figure 12 below).

Figure 12 - Windows Scheduler, time interval selections



For the Northwestern Division, Corps of Engineers, Reservoir Control Center (RCC), it is suggested that scheduled tasks be set to run in the early morning hours because as files automatically open screens will pop up distracting the computer user. It is important to schedule the ftp downloads first, then the executable files, and finally the database macros, since programs cannot run simultaneously. The recommended schedule for running the tasks are shown on Table 1:

Table 1 - Recommended Times for Scheduled Tasks

AgriMet.db	5:45
AgriMet8day.db	5:15
Fmsmaster.db	6:30
FTP AgriMet	5:30
FTP AgriMet8day	5:00
FTP nws	4:00
FTP wqdata	6:00
Loaddbv13.exe	6:15
Nws.db	4:45
NwsextractV2	4:30

Click OK when complete. A window will open requesting a password be given. **You must type in the password you use to log on to your computer.** If you do not do so the scheduled tasks will not run. Note: If the scheduled tasks stop working for unknown reasons it is recommended that the user first try re-setting passwords associated with each task in order to correct the problem.

When automating the download, transfer, and storage of data via the Microsoft Scheduler you may run into run-time errors such as “Run-Time Error 53…File Not Found”. This usually occurs when there has been an interruption in the transfer of data, which causes one or more files used by the executable files, loaddbv11.exe or nwsextract.exe, to become unusable. To correct this problem, manually run the ftp task again, followed by the executable task, and then the database macro task.

Tip on compressing databases: If the SYSTDG user prefers to take a closer look at the tabular data in Access databases, then it is recommended that they compress the databases by selecting Tools, then Database Utilities, then Compact and Repair Database from the toolbar. This step will not speed up the loading of data into SYSTDG, but will make queries run faster.

Loading SYSTDG onto Your Computer:

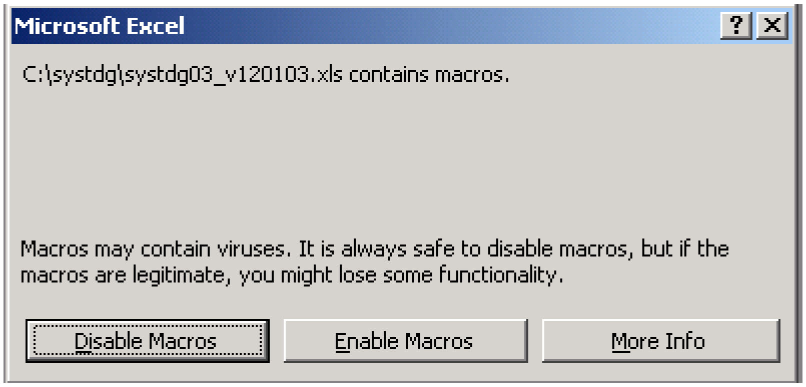
In order to load SYSTDG you must establish a systdg folder for it. It is recommended that you establish a folder on the C drive called systdg. It is possible to use a different drive than C, but programming changes to the FTP tasks, executable files, databases, and SYSTDG model would be necessary. Once you have the C:systdg folder established, copy all of the systdg files into it. At this point, you have everything you need to operate SYSTDG.

Tip on Using only a Copy: It is a good practice to save the original master SYSTDG Excel program and use a copy of the original so if copy gets corrupted, you always have the original.

Enabling Macros

Once SYSTDG???.xls is copied onto your computer, you can open it with Windows Explorer or from within Excel through the File/Open tool bar. A warning may appear during this loading procedure that indicates the workbook contains macros. This occurs because the security level on the Macros is set on high or medium. Select the ***Enable Macros*** option to complete the loading of the workbook (Figure 13). The macro security will need to be set to medium of low to allow the visual basic routines and macros to execute**.** This can be done by selecting ***Tools***, ***Macros***, then ***Security*** from the main toolbar at the top of the excel spreadsheet.

Figure 13 - Workbook contains macros Warning Message



The spreadsheet should open to display the users interface or worksheet entitled *Home.* If the spreadsheet does not automatically open up to the *Home Page*, simply click the *Home* tab located at the bottom of the excel spreadsheet. You are now able to perform a simulation. To begin, the following steps are typical ones during any simulation:

<u>Step by Step Approach to Using SYSTDG</u>

The following list of steps are a guide on how the SYSTDG user can use SYSTDG to assist in establishing spill gas caps on the Columbia and Snake Rivers. These steps are written from the perspective of how the SYSTDG user at the US Army Corps of Engineers, Reservoir Control Center (RCC) uses SYSTDG as a real time operations tool. There are many ways that SYSTDG can be used and the main two ways are hindcast simulations and forecast simulations. Hindcast simulations are when SYSTDG is used to replay historic conditions. Forecast simulations are when SYSTDG is used to predict future outcomes. The following provides guidance of when to perform a hindcast or a forecast.

Forecast Simulations

Forecasts involve the simulation of future river conditions to provide an estimate of what is likely to happen tomorrow or the upcoming week. The SYSTDG user will want to run a forecast simulation if they are interested in any of the following:

- See what TDG levels will be if the current gas caps remain unchanged
- See what TDG levels will be with different gas caps
- See what TDG levels will be with changes in total river flow.
- See what TDG levels will be with different environmental conditions such as a rise in water temperature due to solar radiation or change in wind speed.

For the SYSTDG user at RCC, most of the time it will be necessary to run a forecast simulation everyday during spill season when the gascap is limiting spill, which occurs when total river flows are high. The only exception is when the baseline hindcast simulation shows that all the gas caps are established at the needed levels. For more details on

Hindcast Simulations
A hindcast simulation involves replaying what has previously taken place and addresses the question what would have happened under a different operating policy. The SYSTDG user will want to run a hindcast simulation if they are interested in any of the following:

- Evaluate the accuracy of the TDG model
- See the effects of environmental changes on the TDG levels.
- Investigate the outcome of alternative operations such as
- Investigate different spill operations on the TDG levels.
- Identify anomalies or data outlier in observed data that may indicate a malfunction of monitoring equipment or an unusual project operation.
- Need to screen data.
- Desire to become familiar with different processes influencing the TDG production, transport, and dissipation throughout the Columbia River Basin
- Investigate how the current or past system conditions were generated

The following examples illustrate the utility of conducting hindcasts of system TDG conditions.

The TDG saturation in the forebay of a project fell over 8 percent in one day with no change in the upstream operation of neighboring projects. A hindcast can be conducted to investigate the likihood of such an occurrence. When forebay TDG levels decline at such a rapid rate without significant change in the operation of upstream projects, it is often cause by wind generated degassing events.

The use of SYSTDG simulation have consistently recommended operations at a project that have resulted in excursions of water quality standards at the forebay of the next downstream dam. An hindcast of conditions during the past two weeks indicate that model simulation consistently under-estimate the TDG conditions in the river reach of interest. This prediction bias was quantified and used to estimate a factor of safety used to set the spill levels in subsequent applications of the model.

The TDG levels at a forebay station which usually constrains the operation of the upstream project has been falling well below the 115% TDG criteria. The questions arises how much more water could have been spilled without exceeding the forebay water quality criteria at the downstream project. A series of hindcasts can be run with increasingly higher spill levels to determine the upper limit on spillway operations that result in TDG levels approaching the water quality criteria.

A hindcast of TDG levels immediately below a project are found to fall far below the observed TDG levels for a three-hour period the previous day. The difference between the observed and predicted tailwater TDG levels are small both before and after the three-hour discrepancy in TDG levels suggesting that the monitoring equipment is operating properly. The operating conditions of the spillway were examined in greater detail during the previous day revealing a short debris spill through a single bay was scheduled to maintain safe conditions at the project.

The following procedures are recommended in using the SYSTDG workbook as a simulation model for forecasting or hindcasting river conditions. The first seven steps are basically the same for both forecast and hind cast but the last eight steps can vary with which application the SYSTDG users are doing.

Step 1 – Check Data Acquisitions:

An integral component of the SYSTDG workbook is a real-time automated database containing hourly project operations, water quality, and meteorological data. It is recommended to the user to verify the proper functioning of the data acquisition and handling procedures. There are several ways of checking that the data acquisitions have occurred: 1.) Have the scheduled tasks run as scheduled; 2.) Is the data in FMSmaster and 3.) Is the data loaded into SYSTDG the same as that shown on the website. The following is a more detailed discussion of each:

1. Have the scheduled tasks run? The database assembly has been automated through the scheduling of tasks under the Windows operating system. The real time updating of the database can fail for a number of reasons. The most frequently encountered problems involve network availability, timed out raw data transfer processes, and missing data files. Three main functions need to be completed to successfully update the database: 1) data files downloaded to the local PC, 2) data QA/QC checked and imported into a database table, 3) database aggregation and assembly. The first step and a very important one, is to check whether the schedules tasks ran as programmed. Checking when the last run times were can do this. The last run time should be for the current day and the scheduled time. If you used the recommended times listed in ***Table 1***, then the scheduled tasks should have those times. Even if the last run time is for the current day and appropriate scheduled time, the data may not have been downloaded. There are several error messages or indictors that the SYSTDG user may receive or see that suggest that the scheduled tasks didn't run:

- A Run Time Error 53:
- A "running" in the scheduled task status column:
- A continuous running scheduled task and a Microsoft Jet database Engine Message:
- A "Could not start" message in the status column of the scheduled tasks.
- One day's worth of data is missing in SYSTDG worksheets but appear to exist in FMSmaster:

The section called Potential Errors When Running SYSTDG has more information on what these messages/indictors mean, what causes them, and what steps to take to correct them.

2. Is the data in FMSmaster? If the scheduled tasks ran and the data properly downloaded, it should appear in the FMSmaster database. Reviewing the

newest date/time designation of information in the table "DATA" will determine what information is available.

3. Is the data loaded into SYSTDG the same as that shown on the website? If the data was not properly downloaded, then the data in the project worksheets will not match the data from the websites that it was taken from. This will happen when the scheduled tasks have been missed for three days in a row and there is a one-day lag time in the data displayed in SYSTDG worksheets. Before using SYSTDG, it is recommended that the SYSTDG user check the water quality data in the worksheets against data listed at ***http://www.nwd-wc.usace.army.mil/report/total.html***. Wind data can be checked against data listed in the websites ***http://www.usbr.gov/pn/agrimet/*** and http://www-k12.atmos.washington.edu/k12/grayskies/nw_weather.html.

Step 2 - Select a Time Interval:

The second step in running SYSTDG is to select time interval. There are some general guidance concepts on selecting the length of the time interval and the following is a list of them:

General guidance on selecting the Length of The Time Interval:
There are several considerations that enter in setting the length of the time interval and the following outlines them:

- The time interval must be longer than the travel time for the river reach selected. This is important so that the initial conditions don't taint the simulation results. As a rough estimate, the time interval for the McNary to Camas reach would be 1 ½ weeks and 2 weeks for the Lower Granite to the confluence reach.
- A good rule of thumb is to have the time interval = travel time for that reach X 3
- The length of the travel time will be based on the river reach selected: short river reaches can use short time intervals, long river reaches can use long time intervals.
- The SYSTDG workbook can be ran using a period of just a few days or as long as months from March through September. The time period can ranges from March 1 through September 31.

The simulation time interval is the period between the start date and ending date. The following is a discussion of how to select the start and ending dates, and change them:

Selecting the Start date:
Using SYSTDG for real time operations in a forecasting mode, the time interval usually includes a start date of March 1 or when the gages are working (see Changing The Start Date Section.), which during 2004 was March 28^{th}.

The starting and ending month, day, and year can be selected in the dropdown menus on the ***Home Page*** (Figures 3 and Figure 14). It is easier if the start day remains constant throughout the year so that new the initial conditions do not have to be calculated and modified. But as described in the Changing The Start Date, there are reasons to consider changing the start day. If the SYSTDG user wants to change the start date, the following is a description of how to do it.

Reasons to Change The Start Date:
When setting the time interval, it is important to be aware of two factors that may influence the need to move the start date:

1. Delayed Start date of FMS: Many fixed monitoring stations are out of operations during the winter and are brought back on line sometime in March. Make sure to create a start date that is late enough in March when all fixed monitoring stations are operating. Failure to do so will result in the error message "Run Time Error '6' Overflow" when trying to run a simulation (see the ***Possible Errors Messages When Running SYSTDG*** section for more details).

2. Long Times for Simulations to run: The longer the simulation time period the longer it takes for SYSTDG to run. For instances, to run a two month simulation will take SYSTDG about three minutes. Although this is not a long time, it can seem like it when you are waiting for the simulation results.

Changing The Start Date and Initial Conditions:
If the SYSTDG user wants to change the start day, it will be necessary to go into the worksheet called ***Input Page*** and change the initial conditions for all of the projects. The initial conditions described in rows 4 (Temperature Initial (^oC)) and 5 (TDG Pressure Initial (mmHg)) are the only fields that the SYSTDG user will ever need to change. To obtain the new values to enter into rows 4 and 5 of the Input worksheet, the SYSTDG user needs to calculate a 24-hour average of the observed forebay temperature in ^oC and TDG pressure in mmHg for the day selected as the new start date. New initial conditions must be calculated for all projects listed in the Input worksheet. The observed forebay temperature (^oC) and TDG pressure (mmHg) can be found in columns T and V respectively in the project tables of SYSTDG.

If data is missing for any of the projects for the new start day, it is recommended that the SYSTDG user use the next closest day that data is available for. There are project worksheets that are missing all observed forebay temperature (^oC) and TDG pressure (mmHg) data such as the reach below Ice Harbor Dam at Snake River mile 0.0 called HDP. In the case of HDP, the SYSTDG user should use the observed temperatures and pressure from the Ice Harbor tailwater FMS gage.

Once the new initial temperatures and TDG pressures are entered, it is activated as part of the ***Load BC*** button.

Selecting The Ending Date:
The SYSTDG user will want to have the ending date far enough into the future so that the effects of the initial conditions are not seen. For real time forecasting, it is

recommended that the ending date is at least two days into the future. With hind casting, the ending date will need to be any time in the past for which data is available.

Step 3- Select a River Reach:

The third step in running SYSTDG is to select a river reach. The SYSTDG workbook can be run using just a single river reach or the complete system. You will need to decide whether you want to run a simulation for just the Columbia River or just the Snake River or both, and click the appropriate “active” or “inactive” radio buttons. When activated, an upstream and downstream project must be chosen.

There are several questions that the SYSTDG user would consider when selecting the reach.

1. Does the SYSTDG user have the time to run individual simulations to make up a large river reach instead of one simulation with a large river reach?
2. Does the SYSTDG user need to have the most accurate simulation?
3. How will the simulation results be used?

Selecting a large river reach: The drawback with simulating the entire river reach is that conditions are calculated when observed conditions could be used if simulating individual project reaches, From this perspective, selecting an entire river reach is not as accurate as single project reach.

Selecting a single project: If the SYSTDG user wants to model only one project, the river reach needs to start at one project upstream in order to capture the TDG levels coming to that reach. The SYSTDG user will want to do this to ensure the most accurate forecast.

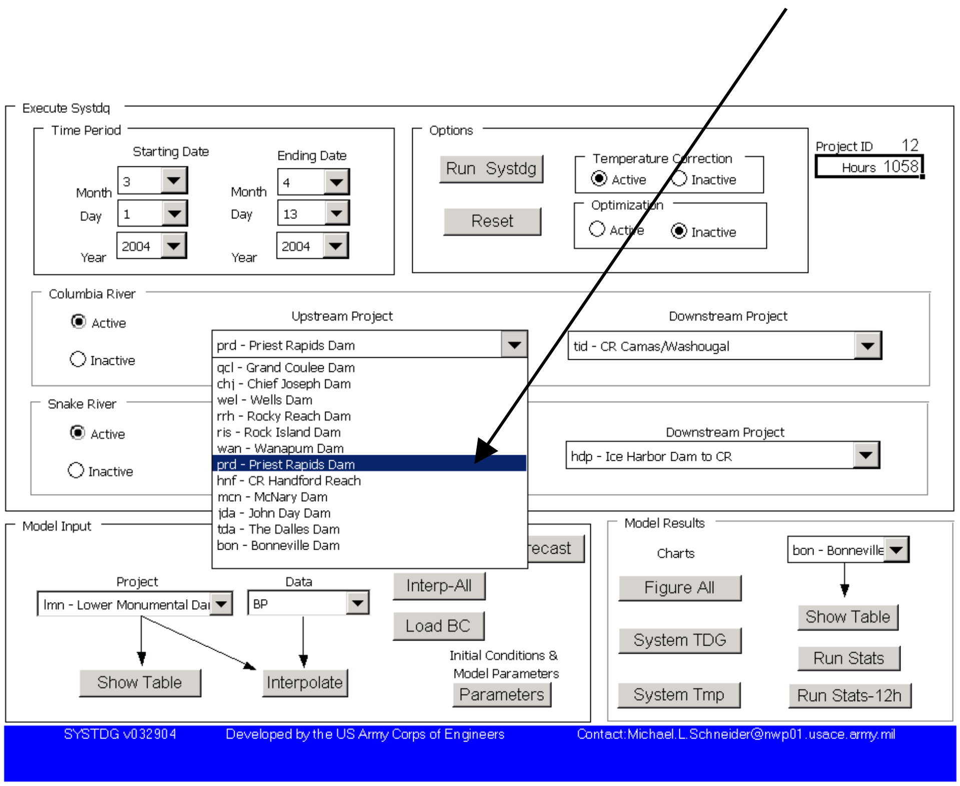
Selecting McNary: It is important to note that if you are doing a simulation for the McNary project, the Snake River from Ice Harbor down to HDP must be “activated” in order to capture the effects the Snake River produces. It is also important for the SYSTDG user to be aware that the Priest Rapids and Wanapum fixed monitoring station water quality data has at least a one day lag time before it appears on the public website (***http://www.nwd-wc.usace.army.mil/report/total.html***). The lag time can be up to four days depending on whether there is a holiday close to the weekend. This lag time is carried over into the SYSTDG worksheets and effects how accurately SYSTDG can predict McNary TDG levels. According to Mike Schneider, the effects are not as bad as you would think. Since the data for the amount spilled is available on a real time basis, SYSTDG predicts that well. This portion is 61% of the total flow of the upper Columbia River through Priest Rapids. It is the data associated with the 39% of the flow that has the one to four day lag time. The amount of error associated with using one to four day old data to represent the 39% of the total Upper Columbia River flow is unknown and needs to be evaluated. The amount of error can be established through hindcasting with SYSTDG. This is a future project for RCC to perform.

Selecting Dworshak: Since Dworshak is the beginning of the Snake River reach that SYSTDG simulates and there is no forebay gage, there are no boundary conditions that can be loaded in column M when ***Load BC*** is selected. The additional step of calculating the boundary conditions is described in ***Step 7 – Load Boundary Conditions***.

Recommendation: For forecasting or hind casting in real time operations, it is recommended that large river reaches be selected instead of small ones. This will minimize the number of simulations performed and save time. The results will be very close to that of individual simulations. For RCC, real time operations, Priest Rapids to Camas/Washougal is selected for the Columbia River. Lower Granite to the confluence below Ice Harbor (HDP) is selected for the Snake River.

Once the SYSTDG user has decided on the desired river reaches, then they may select the river reaches by choosing from drop down menus on the ***Home Page*** as shown on Figure 14.

Figure 14 River reach drop down menu on the *Home Page*



Step 4 - Select Options:

For most simulations, it is best to leave the ***Temperature Correction*** activated and the ***Optimization*** deactivated. For more information, see the two options section in the ***Execute SYSTDG section***.

Step 5 – Load Historical Data:

After completing the above three steps, click the ***Load Data*** button to begin loading data into the project spreadsheets. This step will provide project data up to the current date. If future data is needed, such as for a forecast, go to ***Step 8 – Load Future Project Data***. It is necessary to click the ***Load Data*** button only once while the SYSTDG model is open. Loading the data will take about 4 to 5 minutes or longer depending on how long the time interval is set for. If you get any error messages, it is recommended to manually run all of the schedule tasks again and click the ***Load Data*** button again. For more information, see the ***Load Data*** button section in the ***Model Input section***.

Step 6 – Interpolate Data:

SYSTDG is programmed to automatically interpolate data if the ***Load Data*** button is clicked. After the data is loaded, it will ask you "Start Interpolate?" with an OK button. It is recommended that you click the "OK" button so data is interpolated every time data is loaded. Interpolating is used to fill in missing data cells found in a project's data sheet. If the data is missing, SYSTDG will not run.

It will be necessary to manually run the interpolation when the SYSTDG user has only a few hourly values and needs the rest of the values to be calculated, such as in the case of having four forecasted flows that will ramp up, down or both. To manually interpolate data, first select the type of data that will be manually interpolated, which can be done using the pull down menu in the Model Input section of the ***Home*** page. Then select the project worksheet that needs the interpolation, which can be done using the pull down menu in the Model Input section of the ***Home*** page. Enter the values that you want interpolated into the project worksheet that was selected in the previous step. Select the ***Interpolate*** button. Check and see if you like the new hourly values. This is a great example where SYSTDG can quickly, easily and conveniently calculate the hourly values for new flows, spill, temperatures or wind when the SYSTDG user modifies the worksheets. Manually interpolation is also useful when you have a single change for a large number of cells.

Step 7 – Load Boundary Conditions:

The boundary conditions at projects selected as the upstream limits of the simulated river reaches are required in the form of the forebay total dissolved gas pressure (column M of the project page). This information is used to estimate the TDG pressure contained in powerhouse flows.

There are two ways that boundary conditions are loaded into SYSTDG: automatically and manually. The following is a discussion of each:

The automatic approach: The automatic approach is used on all projects except Dworshak. Automatically loading boundary conditions can be done by clicking the ***Load BC*** button. It is important to note that any time different river reaches are selected, the ***Load BC*** button must be clicked again. If running multiple simulations, it is important to remember not to click the "***Forecast***" button before the ***Load BC*** button. Doing so will erase the forecasted data.

The manual approach: The manual approach to loading boundary conditions is used on Dworshak because it is the beginning of the Snake River reach that SYSTDG simulates and there is no forebay TDG gage. Since there is no forebay total dissolved gas pressure data at Dworshak, there are no boundary conditions that can be loaded in column M when ***Load BC*** is selected. To address this issue it is necessary to calculate a reasonable estimate that can be used. A reasonable estimate of what forebay total dissolved gas pressure to use can be derived by looking at the response at the tailwater FMS during periods of comparable powerhouse operations without spillway discharges. However, the powerhouse at Dworshak can generate elevated TDG levels when units are run at inefficient gate settings. At normal operating conditions the TDG levels discharged by the turbines should be similar to what was present in the forebay.

With this understanding, select a daily average tailwater FMS total dissolved gas pressure found in column Z of the dwr worksheet (dwqi-bp observed FMS tailwater total dissolved gas saturation-mmHg). Select it during a period of comparable powerhouse operations without spillway discharges. Copy it into column M of the dwr worksheet for the forecasted period.

Step 8– Loading Future Project Data:

When the SYSTDG user wants to do a forecast, he will need to load project data into the project tables. Clicking the ***Forecast*** button will populate columns A through H of the worksheets for the projects in the selected reaches through the designated time interval. If the SYSTDG user desires to include the influences from secondary sources, it will be necessary to populate columns J, K and I as described in Step 9.

Step 9– Loading Secondary Source Data:

If the SYSTDG user wants to include secondary sources, such as tributary inflows or the B2 corner collector in SYSTDG, then columns J, K and I of the project worksheets will need to be populated manually. The secondary sources data are not automatically populated with the ***Forecast*** button. This is a needed future development that can be done once the CWMS data transition is complete. Secondary sources are represented in Columns J, K and I of the project tables. To populate columns J, K and I copy the last entry in columns and paste them down to the end of the time interval. **Be sure that column k does not progressively increase by 1, which occurs with certain copy functions of Excel.** If no data is entered into columns J, K and I then the SYSTDG user will need to go to CWMS database to get the needed data. . I will need to add more on this later???

Once the boundary conditions, project and secondary source data are loaded, there are several ways the SYSTDG user can choose to go. He can perform a baseline, forecast or long term hindcast simulation. Depending on what the SYSTDG user wants to do, he may want to skip some of the following steps. For instance, if the SYSTDG user is performing a long-term hindcast study, it is not necessary to do Step 11 – Perform Daily Forecast. For the RCC real time operations SYTDG user, the steps are written in the order needed to establish daily gas caps for the spill program.

Step 10– Perform Daily Baseline Simulation:

For the US Army Corps of Engineers, RCC SYSTDG user, it is recommended that a daily baseline simulation be the first simulation performed in the process of establishing daily gas caps. A baseline simulation is a simulation where there are no changes in conditions and yesterday's data is used as today and tomorrows data. In a sense, the baseline simulation is both a hindcast and forecast. It is a hindcast because it uses only historical data and it is a forecast because it projects yesterday's conditions as today and tomorrow's conditions. For the RCC SYSTDG user, a baseline simulation can do the following:

1. It is the best way to see what would happen if the gas caps were not changed.
2. It establishes baseline values that all subsequent forecast simulations can be compared against to see the effects of any change.
3. It will identify the low or high TDG areas in the system so that the SYSTDG user will know which gas caps needs to be changed in the forecast simulation.

At this point the SYSTDG user needs to decide if a forecast simulation is needed. If it is, then, go to continue to Step 11 – Perform Daily Forecast.

Step 11– Perform Daily Forecast:

For the US Army Corps of Engineers, RCC SYSTDG user, performing at least one daily forecast simulation will be typical for establishing daily gas caps. The RCC SYSTDG user can need to run many simulations as he attempts to identify the acceptable gas cap.

Depending on data availability and conditions, the SYSTDG user may need to modify one or more parameters. The parameters that can be modified are listed below with hyperlinks to more detailed information:

1. The spill level (Qspill), ***New Spill Values***
2. Total flow (Qtot), ***New Flow Values***
3. Wind (Wind), ***New Wind Values***
4. Water temperature (Tmp.), ***New Temperature Values***

This step of using SYSTDG is the most complex with the high potential for error because of the need to calculate or select new values for several parameters. The procedure to do this is still under development and the following is what is currently available. For additional information on how to obtain new values for each of these parameters, click on the hyperlinks listed above.

Obtain New Values for Spill:

Obtaining new spill amounts for 24 hours to enter the SYSTDG is more complex that what might appear to an uninformed user. In many cases, it is not possible to just enter the gas cap amount as the spill amount because all the projects have other factors that limit the spill amount. These factors include:

1. Minimum generation commitments;
2. Gas caps;
3. Percent of the river flow designated for spill,
4. Fish test,
5. BiOp spill requirements and other considerations, such as daytime/nighttime definitions; and daytime no spill
6. Spilling to a different flow than what is established in the BiOp such as the RSW plus 12 at Lower Granite.

At times, most of these factors may limit spill at a project. These limiting factors must be factored into the spill amounts equations. Because these factors vary from year to year, and from month to month, the equations for calculating spill will need to be modify as conditions vary.

Minimum generation commitments or the gas cap are the two primary limiting factors to the amount of spill at Lower Granite and Little Goose. The spill at Ice Harbor; Lower Monumental; McNary, John Day; and The Dalles have three or more factors on a regular basis that limit their spill such as percent of river flow; the gas cap, generator capacity, fish test and minimum generation commitments. Generic equations are provided that could be used after modification with the current spill season conditions.

Equations to calculate Spill:
The following equations for Lower Granite and Little Goose projects could be used with the assumption that the BiOp spill requirements remain established, and that no fish test will occur.

Lower Granite Equation: IF(e1>gas cap+11.5,gas cap,e1-11.5)
Little Goose Equation: IF(e1>gas cap+11.5,gas cap,e1-11.5)
Lower Monumental Equation: ???????
Ice Harbor Equation: ???
McNary Equation: ???
John Day Equation: ???
The Dalles: ???
Bonneville Equation: IF(e1>gas cap+30,gas cap,e1-30))

Note: If spill at Lower Granite were RSW plus 12kcfs then this equation would need to be modified to reflect this change.

The equations would be inserted into column F "Qspill" of the worksheets for the appropriate times as described by the 2000 Biological Opinion and other regional decisions. Use these equations with the understanding that e1 is the amount of total flow amount found in column E, cell 1; the 11.5 and 30 are the minimum generation commitments and the gas cap is the gas cap established daily through the spill priority list that RCC issues. The Corps, RCC changes the gas caps daily, so these equations would also be change daily.

Obtain New Values for Total Flow:

Obtaining new total flow amounts for simulations can be done two ways:

1. Using the River Forecast Center (RFC) ten day flow forecast or
2. Use the ***Forecast*** control in SYSTDG to copy the previous 24 hours data into the future.

Using the River Forecast Center (RFC) ten day flow forecast: If the SYSTDG user wants to use the RFC ten day flow forecast, they can find it at the Corps internal website at ***https://npr71.nwd-wc.usace.army.mil/rccweb/*** . The flow forecasts provide flow amounts for a ten-day period with each day estimating flows at 500; 1100; 1700 and 2300 hours. If these flows are used, it will be necessary to expand the four forecasted hours to have 24 hours of values. Entering the four forecasted hourly values into the SYSTDG worksheet and manually interpolate can do this. For more information on manually interpolating, see ***Step 6 – Interpolate Data***

Use the ***Forecast*** control in SYSTDG: Selecting the ***Forecast*** control in SYSTDG copies the previous 24 hours values, pasting them into the total flow column through the forecasted period. This is easier, quicker and in the opinion of the SYSTDG users at RCC, more accurate than using the RFC's ten-day forecast. We have found that using the ***Forecast*** control in SYSTDG to copy the previous 24 hours values actually provides values that are closer to the actual than the RFC ten day flow forecast. A more thorough analysis needs to be made on this issue to confirm that in fact, it is more accurate.

Obtain New Values for Wind:

There are several websites that provide daily updates on the wind forecasts that can be used for modeling TDG on the Columbia and Snake Rivers. For instance, ***http://www.wunderground.com/US/OR/Hood_River/KDLS.html*** provides wind speed in mph for the Columbia Gorge, which can be used as a good forecast for wind conditions below The Dalles. To use this wind speed data in SYSTDG, it is necessary to convert it to the units that SYSTDG uses, which are meters/second times 10. Here are the conversion factors the SYSTDG user will need:

wind speed and wind gust conversion:
mph to m/s
n * 0.44704

knots to mph
n * 1.150779448

knots to m/s
n * 0.5144444444

By using these conversion factors and the websites with wind forecasts, the SYSTDG user will have a daily average wind speed, which they can compare against the description of a "calm", "moderate", or "high" wind day. Mike Schneider and Kathryn Barko developed the following description of wind days based on their evaluation of 1995 to 2003 wind data:

Calm = 1 to 25 meter/second wind speed (less than 5.6 mph)
Moderate = 25 to 75 meter/second wind speed (between 5.6 and 16.8mph)
High = greater than 75 meters/second wind speed (greater than 16.8 mph)

Depending on which type of wind day the SYSTDG user needs for forecasting purposes, they can select between a set of 24-hour values of wind found in ***Appendix C***.

There are other reaches besides The Dalles that are substantially affected by wind, such as John Day and McNary. The Snake River project reaches are believed to also be affected but not to the same extent as The Dalles. It would be necessary to use hindcasting to evaluate which projects are most affected by wind. This future project is being considered.

<u>Obtain New Values for Water Temperature:</u>

Obtaining new water temperatures for simulations has not been fully developed yet. Mike Schneider and Kathryn Barko will be working on a way to use the information from ***http://137.161.65.209/weather/10_day.cgi*** focusing on the influence weather forecasts (i.e. air temperatures) have on water temperature changes. I will need to write more on this.???

So far, Mike Schneider and Kathryn Barko have developed the following description of water temperature days based on their evaluation of 1995 to 2003 water temperature data:

- Low temp. change day = if water temp. changes 0.1°C or less between any two hours
- Moderate temp. change day = if water temp. changes between 0.1°C and 0.4 °C between any two hours
- High temp. change day = if water temp. changes 0.4 °C between any two hours

Depending on which type of water temperature day the SYSTDG user needs for forecasting purposes, they can select between a set of 24-hour values of water temperature found in ***Appendix C***.

Once the SYSTDG user has calculated or selected the new values and entered them into the worksheets, then go to Step 12– Run SYSTDG.

Step 12– Run SYSTDG:

Once the SYSTDG user has made the changes to the project worksheets they desire and the simulation is ready to run, then select the ***Run SYSTDG*** button, which executes the model based on active river reach, starting date and ending date, and other options the user has selected. As the program runs, the SYSTDG user can watch the progress of the simulation, which is indicated by the current project ID and cumulative hour of calculation as displayed in the upper right hand region of the Execute SYSTDG box. The SYSTDG user can expect to see the current project ID to change from 12 (where it begins) to 1. The cumulative hour of calculation will change from 1(March 1st start date) to the current number of hours (same as the rows of data) that data is used in the simulation. A message window is presented when the current simulation is completed. If data is missing or one of the other user related mistakes occurred, the SYSTDG user will receive an error message. It is recommended that the SYSTDG user visit the section that discusses ***the possible error messages when running SYSTDG*** and take the necessary actions. If need be, the program can be manually terminated by pressing the Esc key on the keyboard.

Tip on Saving: The decision on whether to save the simulation will depend much on whether the SYSTDG user performs a hindcast or a forecast. Since hindcasts are typically studies, then **it will be important to save the** results of the simulation, which can be done by saving it under a different name. When the SYSTDG user performs a forecast simulation for real time operations, **it is best NOT to save any** of the simulations. It is better to start the SYSTDG model as a clean slate so that if the SYSTDG user forgets to select the Load BC button, that it doesn't use the boundary conditions from yesterday.

Step 13– Run Statistics for Simulation:

SYSTDG is programmed so that when a simulation is executed by selecting the ***Run Systdg*** button, several tables (Stats-Obs and Cal, Stats-12hObs, Stats-12hCal) of summary statistics are calculated for both observed and calculated parameters. The ***Run Stats*** and ***Run Stats-12h*** buttons can also be selected manually so that the statistics can be updated at anytime.

Step 14– Review Simulation Results:

There are three ways to review the simulation results: Graphically, statistically and tabular. These approaches are good for specific situations and their use is dependent on what the SYSTDG user is trying to achieve. There are situations when all three approaches may be helpful. The following is a description of the three approaches.

Graphical Simulation Review:
Viewing simulation results graphically is a good first quick approach to see what the results look like. The user is able to see the TDG levels, temperatures, etc… at a quick

glance and decide whether they need to be looked at with greater detail. If the SYSTDG user would like to view the simulation results graphically, they can use ***All Fig***, ***sys TDG Fig*** or ***sys tmp Fig***. By selecting one of these three buttons on the home page you will be directed to an interactive graph of system properties. These three charts show the observed and calculated values. For RCC real time operations, the All Fig is especially useful and is recommended as the first graph to view.

Statistical Simulation Review:
Viewing simulation results statistically provides greater detail along with a good overview of the high 12-hour average TDG levels and other details useful for comparisons between different model simulations and between observed and calculated results. The statistical results available are generated through the ***Run Stats*** **or** ***Run Stats-12hr*** **Buttons**, discussed in the ***Model Results Section*** of this manual. The statistical results are shown on the ***Stats-Obs. and Calc***; ***Stats-12hrObs*** and ***Stats-12hrCalc*** pages. Depending on what the SYSTDG user is trying to achieve, he will want to look at all three of these pages. The ***Stats-Obs. and Calc*** page seems to be most user-friendly because of its layout and types of information available at a glance.

For RCC real time operations, the ***Stats-Obs. and Calc*** page is recommended as the main source for statistical review. The ***Stats-12hrObs*** and ***Stats-12hrCalc*** pages are convenient if the SYSTDG does not have access to the 12 hour averages found at ***http://www.nwd-wc.usace.army.mil/ftppub/water_quality/12hr/html/***, which are considered the official high 12-hour average calculations that RCC uses for Clean Water Act compliance purposes.

Tabular Simulation Review:
Viewing simulation results in a tabular form is the best way of reviewing detailed simulation results. If the SYSTDG user looks at the graphical and statistical simulation results and the results look questionable or unusual, then he/she will want to review the numerical simulation results. To perform a tabular simulation review, the SYSTDG user will look at values in the orange, pink and blue columns on the project tables for the projects included in the simulation reach. Reviewing the values in these columns will be especially insightful if the graphical or statistical simulation results show unusual peaks, dips or trailing off. Since the pink columns are the calculated values the simulation generates, they should be of special interest in a tabular review.

Step 15 – Long Term Hindcast

I need to add how to do a long-term hindcast????

Possible Errors Messages When Running SYSTDG

The SYSTDG user should expect to receive error messages from time to time, due to potential malfunctions of the data downloading or various agencies' web posting, or mistakes the SYSTDG user makes. This is a normal part of using SYSTDG. **THE SYSTDG USER MUST NOT ATTEMPT TO MAKE PROGRAMMING CHANGES TO SYSTDG!!!! Doing so will change the copy of SYSTDG from the standard and potentially corrupt it.**

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The following are some of the common error messages that a SYSTDG user may receive, the cause and the action that prompts the messages:

1. **Run-Time error 5 "Invalid Procedure call or argument**": What caused this????

2. **Run-Time error 6 "Overflow":** This error is generated when the user tries running a simulation after setting the starting or ending date beyond the time span that data exists**.** To fix this error change the starting or ending date to encompass the time span that data is available.
3. **Run-Time error 11 "Division by Zero":** This error message is generated when the "run SYSTDG " button was clicked before the data is loaded or interpolated and the boundary conditions are set.
4. **Run-Time error 53 "File not found":** This usually occurs when there has been an error in the file download procedure that a FTP task has performed and one or more text files that loaddb12.exe or nwsextractV2.exe is trying to locate cannot be found. To fix this error manually run the FTP task again and then manually run the desired executable program followed by associated database macros. This is done by right finger clicking on the task and selecting "run". It is "safer" and more assuring to run all of the scheduled tasks although not necessary.
5. **Run-Time error 1004 "Unable to set the Name Property of the Series class":** This message occurs when zeros or blanks are found in the forebay elevation or tailwater elevation columns within the project data sheets. To fix this error find and delete zeros then click the ***Interp-All*** button found on the ***Home*** page.
6. **Run-Time error 1004 "Select method of series classed failed":** This error occurs when the –999 values found in rows 5138 of the project data sheets have been deleted. The –999 values should *not* be deleted! They are required placeholders that ensure data will plot correctly in the ***Fig-All*** chart.
7. **User Error: Data Filters Must Be Off!:** If the SYSTDG user uses the excel data filters on any of the project data sheets and then tries to graph this data within ***Fig-All***, several things may happen. SYSTDG will either not graph any of the data or it will graph the data incompletely. To fix this error turn off any filters that are active.
8. **User Error: Load BC Must be Clicked after Reset!:** Make sure to click ***Load BC*** after you have clicked the ***Reset*** button, found on the ***Home*** page. If boundary conditions are not re-entered before running a simulation the user will most likely see unrealistic plots of calculated data (***RELcal***, ***FBcal*** and ***FB2cal***) in the chart ***Fig-All*** and statistics that are not within normal ranges found on the ***Stats-Obs and Calc*** page**.**
9. **User Error: Both River Reaches Must Be Selected!:** This error occurs when the user tries to simulate conditions at McNary Dam but does not select both the Columbia River and Snake River reach just upstream. (Priest Rapids Dam to McNary Dam and Ice Harbor Dam to McNary Dam)
10. **Scheduled Tasks Error: A task continuous running and a Microsoft Message:** When the FMSmaster database scheduled task continues to run long

after it should have been completed and the SYSTDG user receives the message "The Microsoft Jet database Engine can not find the input table or query "data". This message will occur when files or data tables that the database macros are looking for are missing. Files or data tables that the macros may have deleted include NWS.txt; and "data" or "dataOld" tables in FMSmaster. Check to see if they exist. If they do not, then the actions you take will depend on what type of file is missing. If a text file is missing, rerun the scheduled tasks to generate the texts files. If the "data" or "dataOld" tables in FMSmaster are missing, reconstruct them. Typically, one of the two tables still exists. To reconstruct the missing table, copy the existing table (data or dataOld) and rename it to the name of the missing table. Then run the FMSmaster db schedule task again and see if it runs completely. It should.

11. **Scheduled Tasks Error: A task or all the scheduled tasks have a "could not start" Microsoft Message:** When the SYSTDG user's window password changes and the new password is not changed in the properties of each scheduled task, then the "could not start" message in the status column will appear. To correct this problem, go into each scheduled task properties and re-set the password.
12. **Scheduled Tasks Error: One day's worth of data is missing in SYSTDG worksheets but exist in FMSmaster:** When one or more scheduled tasks don't run for four of more days in a row, and the SYSTDG user doesn't manually runs the scheduled tasks until the fifth day a one-day lag time will be seen in the observed water quality and project operations data when it is loaded into SYSTDG. Within the FMSmaster database data will appear be up to date, but it will not be. The one-day lag time is the difference between how long the scheduled task was not working and the "four day spanned of available water quality data. These one-day lag times can add up to be a larger lag times when data is loaded into SYSTDG without the gap of data being corrected.
13. **Scheduled Tasks Error: A continuous "running" in the scheduled task status column:** When a schedule task continues to run long after it should have been completed, then there is a problem with how one of the ftp tasks ran. If this occurs, then run the ftp, the database and the executables associated with the ftp again. For instance, if the AgriMet8day db is found to continue running, then the ftp AgriMet8day did not run correctly. It will be necessary to run both of them again in the correct time sequence. If the loaddbv13.exe is continuing to run, then the ftp wq data did not run correctly. It will be necessary to run the ftp wq data; loaddbv13.exe and FMSmaster again. It is "safer" and more assuring to run all of the scheduled tasks although not necessary.
14. Barometric pressure data measured by the fixed monitoring stations at each project is, at times, incorrect. If this occurs BP can be calculated using the following equation:

$$\log_{10} BP = \log_{10} BP_o - \frac{h - h_o}{kT_a}$$

Where h and h_o equal the elevation in **meters** above sea level at the station in question and the reference station, respectively; BP and BP_o equal the pressure at the two stations in mmHg; k equals 67.4; and T_a

equals the average of the absolute air temperatures (273 + C) between the two stations. It is important to note that temperature has little effect on barometric pressure estimates and an absolute air temperature between the two stations of 20°C is sufficient for this calculation.

Example:

If the BP measured in the forebay of Chief Joseph Dam is known but not in the tailwater of Grand Coulee Dam the equation would look like so:

Chief Joseph Dam barometric pressure = 739 mmHg Chief Joseph Dam forebay elevation = 952.5 ft Grand Coulee Dam tailwater elevation = 959.8 ft

a. $\log_{10}BP_{gcl} = \log_{10}(739) - \frac{959.8\text{-}952.5}{67.4*(293*3.2808)}$

b. $\log_{10}BP_{gcl} = 2.868644 - \frac{7.3}{64{,}790.7}$

c. $BP_{gcl} = 738.8$ mmHg

CHAPTER 4: Examples of Running SYSTDG

As previously discussed, there are two ways of using SYSTDG – in a forecast or hindcast mode. This chapter provides examples of each. The first example is the hind cast example.

Successfully running a hind cast in SYSTDG

These are the steps that the SYSTDG user would take to run a hind cast:

1. Open Systdgxxxx.xls from the Windows Explorer or from within Excel through the File/Open tool bar.

2. Select the ***Enable Macros*** option to complete the loading of the workbook, directing the user to the ***Home Page***. (If the spreadsheet does not automatically open up to the ***Home Page***, click the ***Home*** tab located at the bottom of the excel spreadsheet.)

3. If data is not present in project data sheets click ***Load Data***, which is found under the Model Input section of the ***Home*** page. Note: an interpolation and statistical analysis of the data is automatically completed as well.

4. Click ***Load BC.*** (***Load BC*** or Load **b**oundary **c**onditions, loads the observed forebay total pressure data into the TDGfb column of the most upstream project's data sheet) Boundary conditions must be loaded before a successful simulation can be run.

5. Select a ***Starting Date*** and ***Ending Date*** under the Time Period section located on the ***Home Page.***

6. Next, select the upstream and downstream projects from the drop down menus located on the ***Home Page***.

7. ***Activate*** the ***Temperature Correction*** option while keeping the ***Optimization*** option ***Inactive***.

8. Go to the project data sheets and make any additional changes required to run the simulation. i.e. changing blue Qspill columns, orange FB-psat columns, etc…

9. Click the ***Run*** **Systdg** button, which will calculate statistics using data for the criteria (river reach and time span) that have been selected. Click ***OK*** when complete.

10. To view graphical results go to the ***All-Fig*** chart found either by clicking on the ***all-fig*** tab at the bottom of the spreadsheet or by choosing the ***Figure All*** button located on the ***Home*** page.

11. To view statistical results such as mean, mean12, min, and max go to the ***Stats-Obs and Calc*** tab located at the bottom of the spreadsheet. (When the ***Run Systdg*** button is clicked statistics are automatically calculated for the river reach and time span selected on the ***Home*** page. There is no need to click the ***Run Stats*** button at this time.)

Example A:

From May 11th through May 13th, 2003, excursions above the 115% criteria were measured at the Camas/Washougal fixed monitoring station. On May 11, 2003, the 12 highest hourly observations, averaged, were approximately 116.59%. May 12th observations were approximately 115.15% and May 13th observations were measured at about 116.11%. During this time spill discharges ranged from 73 kcfs to 154 kcfs. Figure 15 is a time series plot that portrays these historical conditions.

Figure 15 - Bonneville observed historical TDG conditions

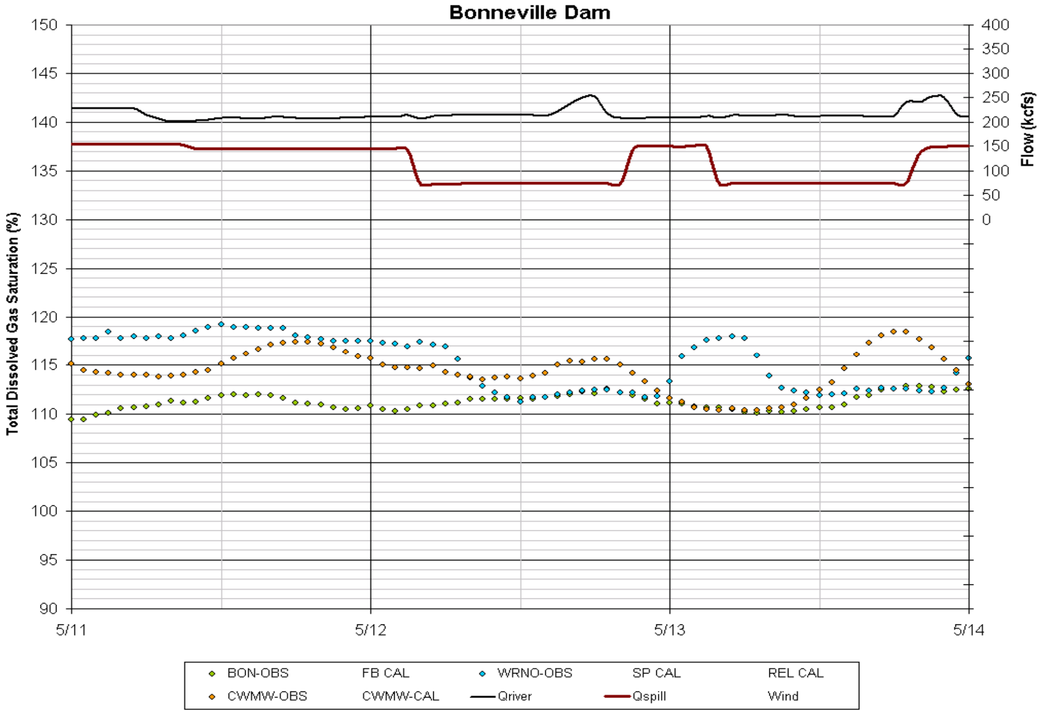


Figure 15 is a time series plot of observed (historical) total dissolved gas conditions measured at Bonneville forebay (green dotted line), Warrendale (blue dotted line), and Camas/Washougal (orange dotted line), May 11-13, 2003.

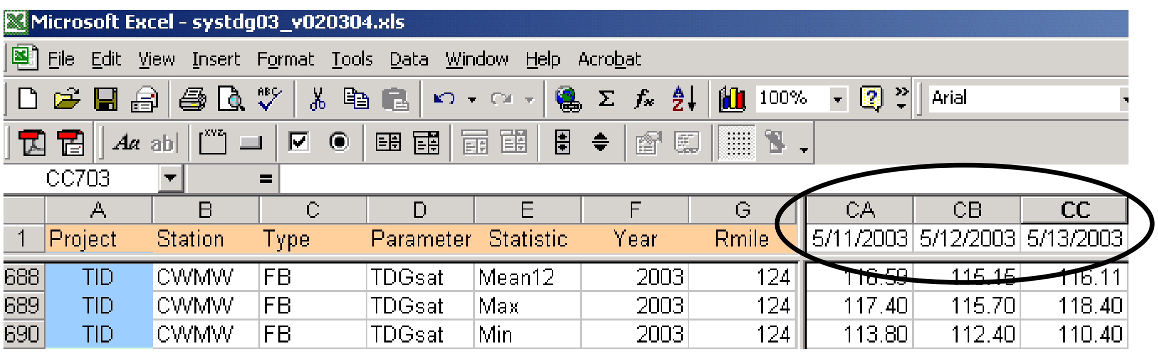
A simulation was run in order to determine whether lower spill discharges could have prevented excursions at the Camas/Washougal fixed monitoring site. The procedures used to investigate alternative spill management policies are described below:

a. Open systdg020304.xls from the Windows Explorer or from within Excel through the File/Open tool bar.
b. Select the ***Enable Macros*** option to complete the loading of the workbook, directing the user to the ***Home Page***. (If the spreadsheet does not automatically open up to the ***Home Page***, click the ***Home*** tab located at the bottom of the excel spreadsheet.)
c. Once on the ***Home Page***, click ***Load Data***.
d. Click ***Load BC.*** (***Load BC*** or Load **b**oundary **c**onditions, loads the observed forebay total pressure data into the TDGfb column of the most upstream project's data sheet)
e. Select a ***Starting Date*** and ***Ending Date*** under the Time Period section located on the ***Home Page.*** For this simulation select a starting date and ending date to encompass the month of May. (It is recommended that the ***Starting Date*** be changed to March 1st so that initial conditions found on the ***Input Sheet*** do not have to be modified.)

f. Next, select the upstream and downstream projects from the drop down menus located on the ***Home Page***. For this simulation click the Columbia River reach ***Active*** and select Bonneville Dam as the ***Upstream Project*** and tid- CR Camas/Washougal as the ***Downstream Project***. Keep the Snake River reach ***Inactive***. ***Activate*** the ***Temperature Correction*** option while keeping the ***Optimization*** option ***Inactive***.

g. Click the ***Run* SYSTDG** button, which will calculate statistics using observed (historical) data for the criteria (river reach and time span) that has been selected. This data can be viewed by selecting the ***Stats-Obs and Calc*** tab located on the ***Home Page.*** For observed statistics go to row 688 to view conditions at ***Project*** TID, for ***Station*** CWMW, ***Type*** FB, ***Parameter*** TDGsat, and ***Statistic*** Mean12. Move to the right until you find the columns ***5/11/2003*** through ***5/13/2003*** (columns CA, CB, and CC). See Figure 16 below.

Figure 16 - Camas/Washougal Observed conditions



	A	B	C	D	E	F	G	CA	CB	CC
1	Project	Station	Type	Parameter	Statistic	Year	Rmile	5/11/2003	5/12/2003	5/13/2003
688	TID	CWMW	FB	TDGsat	Mean12	2003	124	116.59	115.15	116.11
689	TID	CWMW	FB	TDGsat	Max	2003	124	117.40	115.70	118.40
690	TID	CWMW	FB	TDGsat	Min	2003	124	113.80	112.40	110.40

Figure 16 shows the observed conditions measured at Camas/Washougal, May 11-13, 2003

h. A comparison between observed conditions and calculated conditions using historical river data should be made in order to identify errors associated with calculating values in SYSTDG. Calculated conditions derived from historical data can be viewed by moving to row 661, columns CA, CB, and CC on the ***Stats-Obs and Calc*** page. Notice the mean12 calculated historical river conditions (Figure 17) and the mean12 observed historical river conditions (Figure 16) are not equal. (See both Figures 16 and 17 and Table 2 for comparisons)

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Figure 17 - Camas/Washougal Calculated Conditions

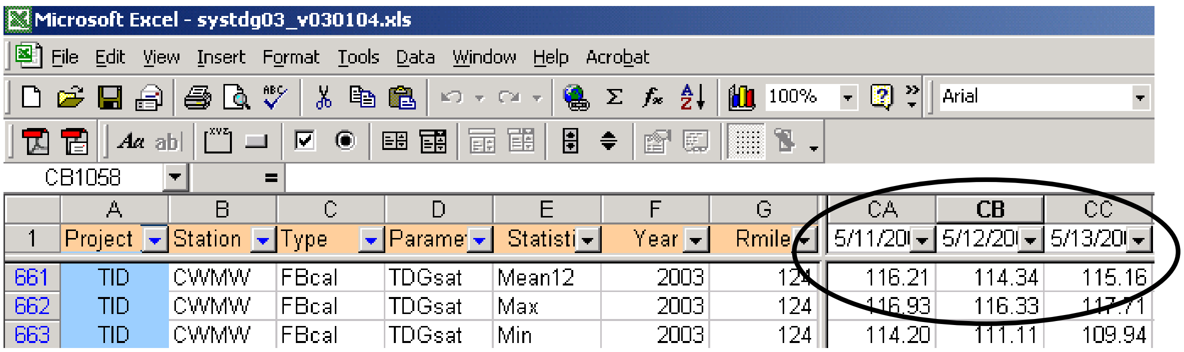

Figure 17 shows the calculated historical conditions measured at Camas/Washougal, May 11-13, 2003.

i. To decrease spill discharges from historical levels and possibly lower TDG saturations at CWMW go to the Bonneville data page by selecting the tab ***bon*** located at the bottom of the excel spreadsheet**.**
j. Once on the ***bon*** data sheet move down to row 1706 or May 11, 2003 0:00. Delete the cells under column F (Qspill) from rows 1706 through 1777 or May 11 through May 13.
k. In the fields that have been deleted manually type in a total spill discharge of 115 kcfs for May 11th and 13th and 127 kcfs for the 12th.
l. Go back to the ***Home Page*** by using the tabs at the bottom of the spreadsheet.
m. Click ***Run SYSTDG*** (As the program runs, the progress of the simulation is indicated by noting the current project ID and cumulative hour of calculation as displayed in the upper right hand region of the Execute SYSTDG box.)
n. A message window is presented when the current simulation is completed. Click ***OK***.
o. Go to the Stats-Obs and Calc worksheet, row 661 to view conditions at ***Project*** TID, for ***Station*** CWMW, ***Type*** FBcalc, ***Parameter*** TDGsat, and ***Statistic*** Mean12. Move to the right until you find the columns ***5/11/2003*** through ***5/13/2003*** (columns CA, CB, and CC). See Figure 18.

Figure 18 - Calculated Conditions After Decreasing Spill

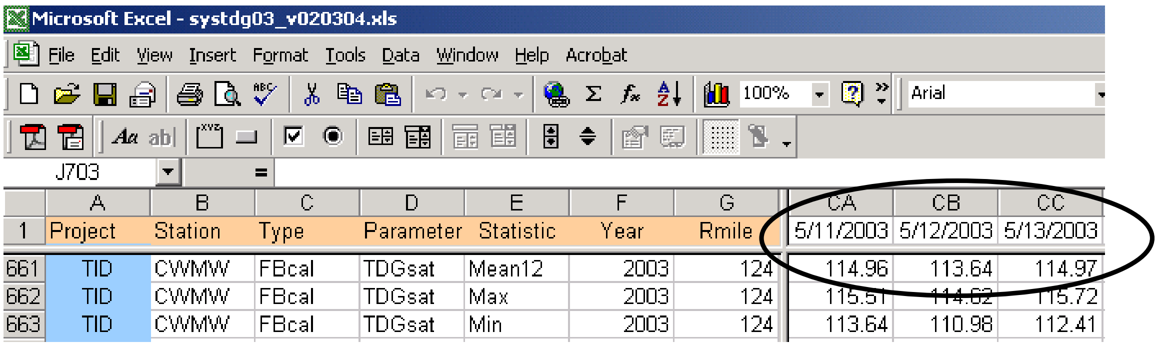

Figure 18 shows the calculated conditions measured at CWMW subsequent to decreasing total spill at Bonneville Dam, May 11-13, 2003.

Notice when spill discharges are decreased to 115 kcfs on the 11th and 13th and to 127 kcfs on the 12th mean12 total dissolved gas saturations at the Camas/Washougal fixed monitoring site fall below the state standard of 115%.

Table 2 - A comparison of observed and calculated data

	5/11/2003	5/12/2003	5/13/2003
Observed/Historical conditions (Figure 16)	116.59%	115.15%	116.11%
Hind cast/Calculated conditions (Figure 17)	116.21%	114.34%	115.16%
Calculated/Simulated conditions (Figure 18)	114.96%	113.64%	114.97%

Table 2 is a comparison of both observed and calculated data using historical and modified river conditions, May 11-13, 2003

p. To view a time series plot of both observed and calculated conditions during May 11-13, 2003 go to the ***all-fig*** chart by either clicking on the ***all-fig*** tab located at the bottom of the excel spreadsheet or by selecting the ***Figure All*** button within the Results Section of the ***Home Page***.

q. To view conditions during the month of May click the ***May*** button or select desired dates from the drop down menus ***Start Date*** and ***End Date*** within the ***X-Axis Controls*** found on the left hand side of the chart. Remember to hit the ***Plot*** button if you choose to use the ***Start Date*** and ***End Date*** drop down menus. (The ***Start Date*** and ***End Date*** drop down menus were used to create the plot seen below)

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r. Located on the right hand side of the chart ***all-fig*** are controls that can be used to display the desired project, parameter, and locations. For this simulation choose the project ***bon-Bonneville Dam*** and the parameter ***TDG Sat*** from the drop down menus. Click the orange buttons ***FB2-OBS*** and ***FB2-CALC*** to view a time series plot of observed and calculated conditions at the Camas/Washougal fixed monitoring site. (See Figure 19 below)

Figure 19 - Time series plot of conditions at CWMW

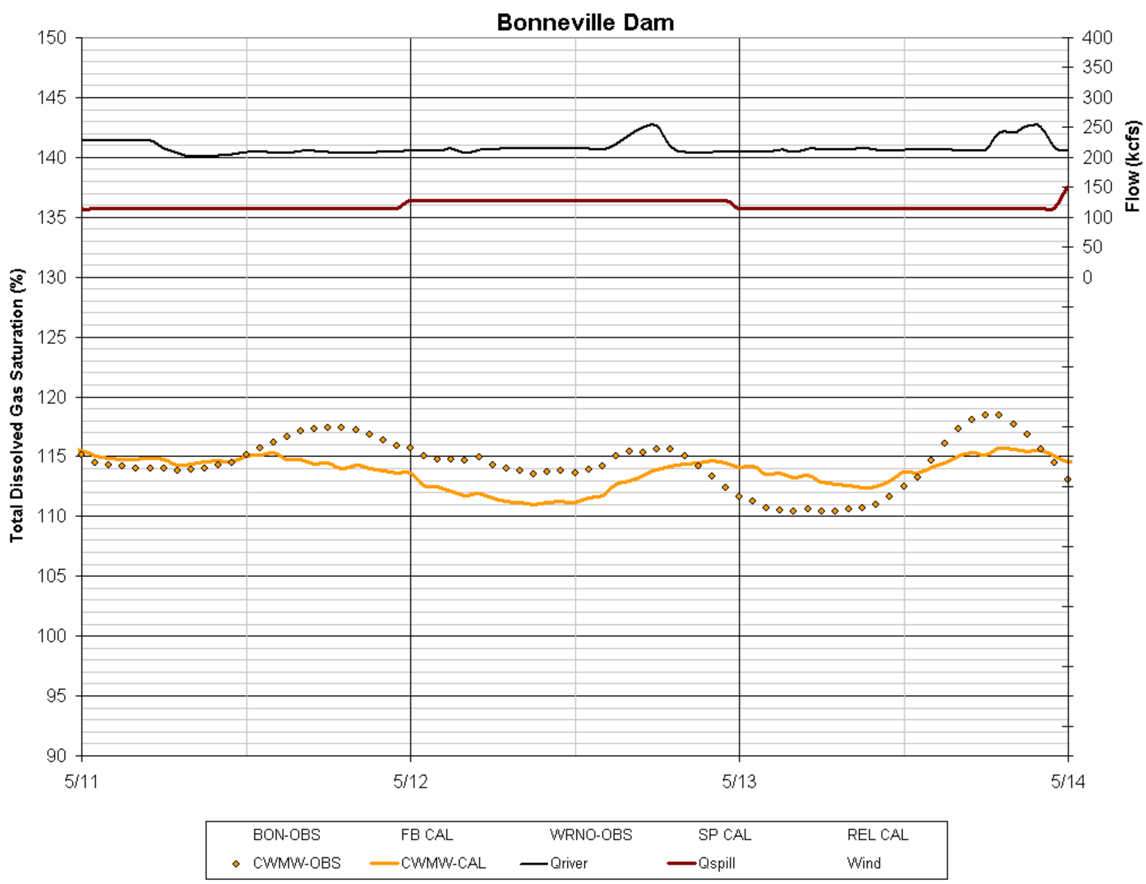

Figure 19 shows a time series plot of observed and calculated conditions at CWMW, May 11-13, 2003.

<u>Successfully running a forecast in SYSTDG</u>

These are the steps that the SYSTDG user would take to run a forecast:

1. Open Systdgxxxx.xls from the Windows Explorer or from within Excel through the File/Open tool bar.

2. Select the ***Enable Macros*** option to complete the loading of the workbook, directing the user to the ***Home Page***. (If the spreadsheet does not automatically

open up to the ***Home Page***, click the ***Home*** tab located at the bottom of the excel spreadsheet.)

3. Click ***Load Data***, which is found under the Model Input section of the ***Home*** page.

4. Select a ***Starting Date*** and ***Ending Date*** under the Time Period section located on the ***Home*** page.

5. Next, select the upstream and downstream projects from the drop down menus located on the ***Home*** page.

6. Change the total gas pressure initial conditions, found in rows 4 and 5 on the ***Input Sheet***, to the average observed forebay total dissolved gas and temperature conditions for the starting date measured at the upstream project that have been specified.

7. Click ***Load BC***. (***Load BC*** or Load **b**oundary **c**onditions, loads the observed forebay total pressure data into the TDGfb column of the most upstream project's data sheet) Boundary conditions must be loaded before a successful simulation can be run.

8. ***Activate*** the ***Temperature Correction*** option while keeping the ***Optimization*** option ***Inactive***.

9. Click ***Forecast*** (***Forecast*** simply maps the last 24 hours of observed operating conditions through the end of the time span selected.) **DO NOT SELECT LOAD BC AFTER A FORECAST HAS BEEN MADE. DOING SO WILL ERASE FORECASTED DATA**.

10. Go to the project data sheets and enter forecasted conditions.

11. ***Run SYSTDG***. Click ***OK*** when complete.

12. To view graphical results go to the ***All-Fig*** chart found either by clicking on the ***all-fig*** tab at the bottom of the spreadsheet or by choosing the ***Figure All*** button located on the ***Home*** page.

13. To view statistical results such as mean, mean12, min, and max go to the ***Stats-Obs and Calc*** tab located at the bottom of the spreadsheet. (When the ***Run SYSTDG*** button is clicked statistics are automatically calculated for the river reach and time span selected on the ***Home*** page.)

Example B:

Spring Creek Hatchery scheduled the release of 3.7 million Fall Chinook Monday, March 1, 2004. To aid passage, special operations of 50 kcfs will start at Bonneville

Dam between 0400 hours and 1600 hours Tuesday, March 2, 2004. These operations will continue for 96 hours while maintaining a minimum tailwater elevation of 12.7 feet. All turbine units will operate within their respective 1% efficiency ranges. A series of estimates of the Total Dissolved Gas saturation in the Columbia River were generated in response to spill operations at Bonneville Dam during the first week in March.

Three forecasts of the total dissolved gas saturation in the Columbia River were generated using the SYSTDG workbook (systdg04_030204.xls posted on CHL ftp server) assuming low, medium, and high projections of the total river flow at Bonneville Dam. These simulations generated estimates of the TDG saturation discharged by Bonneville dam downstream to the fixed monitoring station located at Camas/Washougal fixed monitoring station. The meteorological conditions (Wind speed, water temperature change) on March 1 were assumed to apply throughout the simulation period. The forebay TDG pressures (775-780 mm Hg or about 103%) and barometric pressures (761-769 mm Hg) observed on March 1st were assumed to be maintained throughout the simulation period.

The first forecast assumed a constant total river discharge of 130 kcfs beginning at 1200 hrs on March 2 through March 6, 2004 with a spill discharge of 50 kcfs. The results of this simulation are shown in Figure 20 for undiluted conditions in the spillway exit channel (SP CAL), well mixed conditions expected to correspond with observations at the Warrendale FMS (REL CAL), and the routed conditions expected at the Camas/Washougal FMS (CWMW-CAL). The TDG saturation is projected to increase about 2.8 percent from 103.6 to 106.4% at the Warrendale gage based on the highest 12 hourly observations on March 4. The resultant gain in TDG saturation at the Camas Washougal FMS was forecasted to be about the same as at the Warrendale gage because the temperature induced increase will just offset the losses from degassing at the water surface. The TDG saturation in the spillway exit channel will reach about 110.9 % of saturation and will quickly mix with powerhouse releases to moderate TDG levels observed at the redds near Hamilton Island.

Figure 20 - Forecasted conditions w/130 kcfs discharge

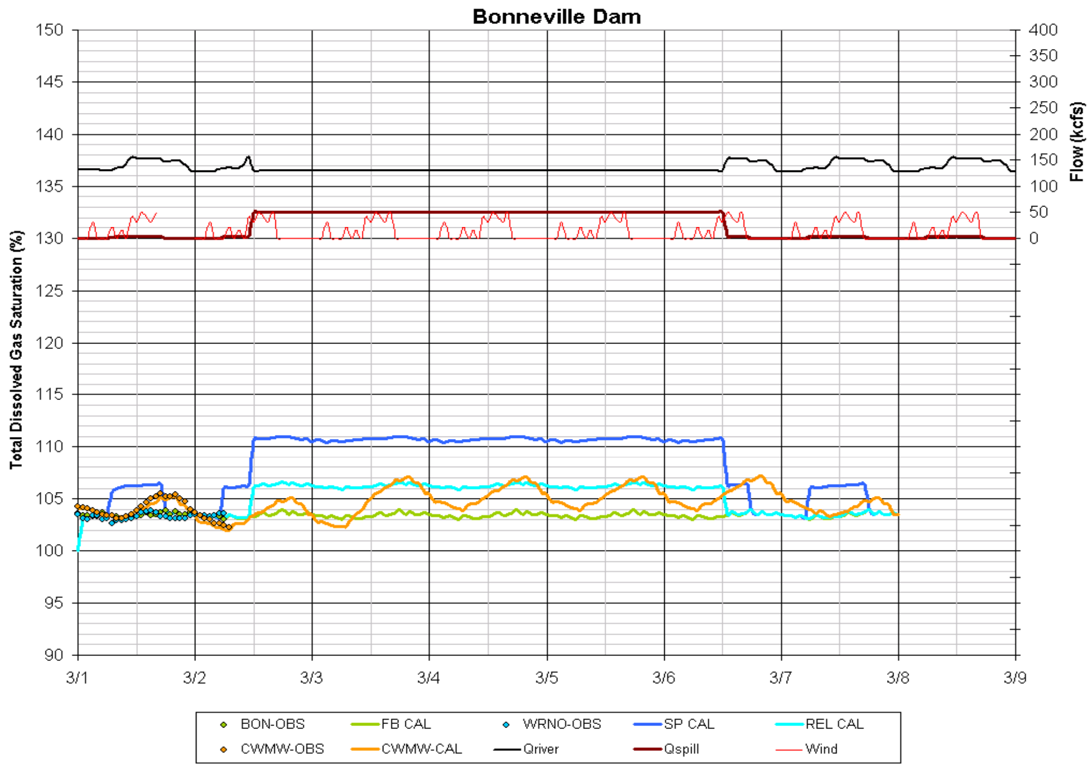

Figure 20 shows the forecasted conditions assuming a total river discharge of 130 kcfs, and a total spill of 50kcfs.

The second scenario was based on a total river discharge of 150 kcfs and a spill discharge of 50 kcfs (see Figure 21). The forecasted TDG saturation for this second scenario was very similar to the first scenario with a projected to increase about 2.5 percent from 103.6 to 106.1% at the Warrendale gage based on the highest 12 hourly observations on March 4. The resultant gain in TDG saturation at the Camas Washougal FMS was forecasted to be the same as at the Warrendale gage.

Figure 21 - Forecasted conditions w/ 150 kcfs discharge

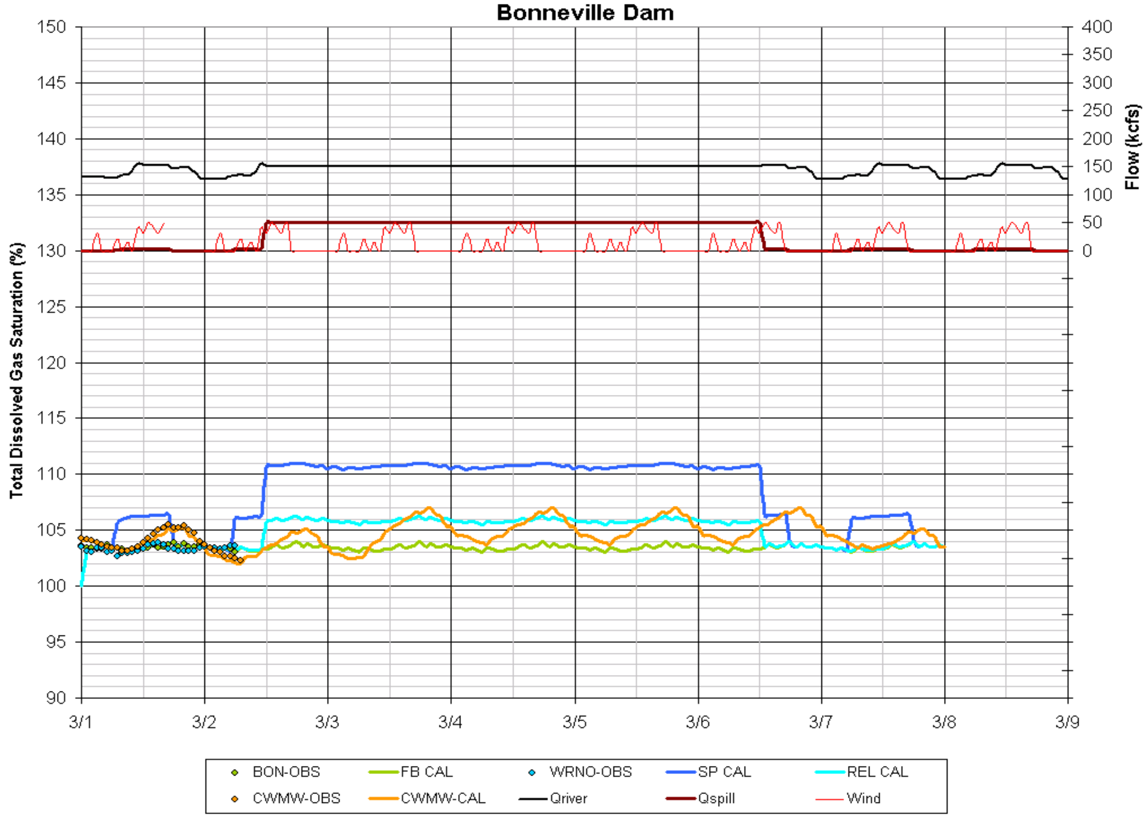

Figure 21 shows the forecasted conditions assuming a total river discharge of 150 kcfs, and a total spill of 50kcfs.

The third scenario assumed a total river discharge of 170 kcfs and a spill discharge of 50 kcfs (see Figure 22) resulted in even smaller impacts to the TDG saturation in the Columbia River due to the smaller ration of Bonneville spill to total river flow. The forecasted TDG saturation for this third scenario resulted in an increase of about 2.1 percent from 103.6 to 105.7% at the Warrendale gage based on the highest 12 hourly observations on March 4. The resultant gain in TDG saturation at the Camas Washougal FMS was forecasted to be about 2.4 percent and will be closely related to the meteorological conditions imposed on the Columbia River during the study period.

Figure 22 - Forecasted conditions w/170 kcfs discharge

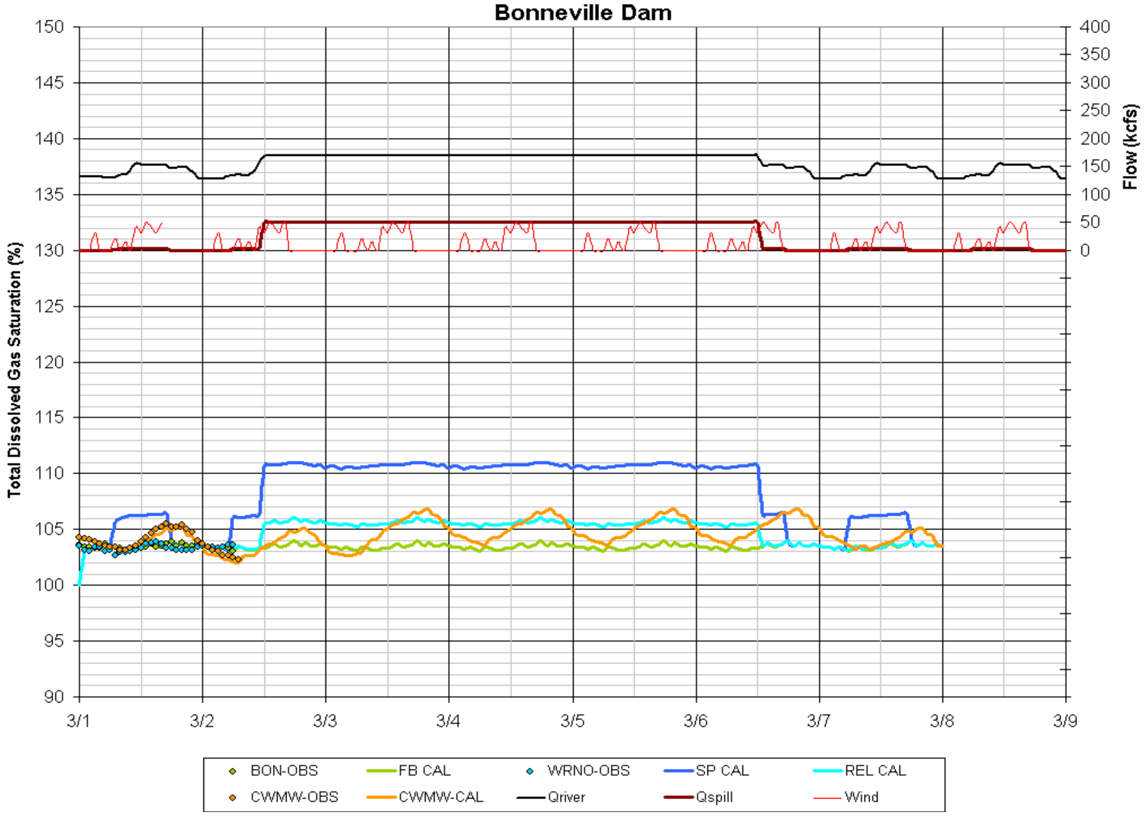

Figure 22 shows the forecasted conditions assuming a total river discharge of 170 kcfs, and a total spill of 50kcfs.

The TDG saturation in the Columbia River at designated compliance sampling locations will not exceed 110% of saturation during the proposed spill at Bonneville Dam associated with the Spring Creek release of juvenile Chinook. The TDG saturation at Warrendale FMS are forecasted to range from 105.7 to 106.4 % for total river flows ranging from 130 to 170 kcfs. The TDG saturation at the Camas/Washougal was forecasted to range from 106.0-106.3 % for the proposed river conditions. The TDG saturation in the exit spillway channel for a spill discharge of 50 kcfs was estimated to be about 110.9%. Theses forecast are based on assumed constant river flows, background TDG levels, and meteorological conditions. The actual river conditions will likely deviate from these forecasted conditions creating some difference between forecasted and observed river conditions. Future forecasts of TDG saturation should consider the uncertainty of other system processes such as wind, heat exchange, barometric pressure, and background TDG saturation.

Table 3 -Forecasted TDG Saturation for Case 1, 2, and 3

Case	Total River Flow(kcfs)	Spill Discharge (kcfs)	Estimated TDG Saturation Average of highest 12 hourly observations On March 4 (%)			
			BON	WRNO	CWMW	SPILL CALC
1	130	50	103.6	106.4	106.3	110.9
2	150	50	103.6	106.1	106.1	110.9
3	170	50	103.6	105.7	106	110.9

Table 3 shows the forecasted TDG saturation for case 1, 2, and 3 flow conditions in the Columbia River below Bonneville Dam, March 4, 2004

The procedures used to investigate forecasts of total dissolved gas saturation in the Columbia River are described below:

a. Open systdg04_020304.xls from the Windows Explorer or from within Excel through the File/Open tool bar.

b. Select the ***Enable Macros*** option to complete the loading of the workbook, directing the user to the ***Home Page***. (If the spreadsheet does not automatically open up to the ***Home Page***, click the ***Home*** tab located at the bottom of the excel spreadsheet.)

c. Select a ***Starting Date*** and ***Ending Date*** under the Time Period section located on the ***Home Page***. For this simulation select a starting date of 3/1/04 and ending date of 3/7/04.

d. Click ***Load BC***. (Load **b**oundary **c**onditions loads the observed forebay total pressure data into the TDGfb column of the Bonneville data sheet)

e. Click ***Interp-All***. Click ***OK*** when complete. (***Interp-All*** will prompt a linear interpolation between data, which will fill in any missing information within the project data sheets.)

f. Click *Forecast* (***Forecast*** simply maps the last 24 hours of observed operating conditions through the end of the time span selected.)

g. Change the TID temperature and total gas pressure initial conditions found on the ***Input Sheet*** under column N, row 4 and 5 to the average observed conditions measured at WRNO. (March 1, 2004 observed temperature conditions were approximately 4.8°C and total pressures were approximately 789)

h. ***Run SYSTDG***. For no spill conditions. Click ***OK*** when complete.

i. Go to the Bonneville data sheet. (The ***bon*** tab at the bottom of the spreadsheet)

j. Delete values in the blue ***Qtotal*** and ***Qspill*** columns (columns E and F) from 3/2/04 12:00 through 3/6/04 12:00. Type either 130, 150, or 170 kcfs into the empty Qtotal cells and 50 kcfs into the empty Qspill columns.

k. ***Run SYSTDG***. For forecasted river conditions. Click ***OK*** when complete.

l. To view graphical results go to the ***All-Fig*** chart found either by clicking on the ***all-fig*** tab at the bottom of the spreadsheet or by choosing the ***Figure All*** button located on the ***Home*** page.

m. To view statistical results such as mean, mean12, min, and max go to the ***Stats-Obs and Calc*** tab located at the bottom of the spreadsheet. (When the ***Run SYSTDG*** button was clicked statistics were automatically calculated for the river reach and time span selected on the ***Home*** page.)

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APPENDIX A - Abbreviations

The following is a list of station abbreviations used in the data tables or "systdgweather" tables.

Station Abbreviations within Data Tables

The following station abbreviations represent the fixed monitoring stations from which water quality data is collected.

ANQW - Observed forebay conditions for the Clearwater/Snake River confluence site (orange columns)

BON - The Bonneville Dam data table. Also observed forebay conditions (orange columns)

CCIW - Observed tailwater conditions at Bonneville Dam (orange columns)

CHJ - Chief Joseph Dam data table. Also observed forebay conditions (orange columns)

CHJW - Observed tailwater conditions at Chief Joseph Dam (orange columns)

CLW - Clearwater/Snake River confluence data table

CWMW - Observed downstream mixed river conditions at Camas/Washougal fixed monitoring station (RM 122.0)

DWR - The Dworshak Dam data table. Also observed forebay conditions (orange columns)

DWQI - Observed tailwater conditions at Dworshak Dam (orange columns)

FDRW - Observed forebay conditions at Grand Coulee Dam (orange columns)

GCGW - Observed tailwater conditions at Grand Coulee Dam (orange columns)

GCL - Grand Coulee Dam data table.

HDP - The reach below Ice Harbor Dam at Snake River mile 0.0

HNF - Observed tailwater conditions for the Hanford site (orange columns)

IHR - The Ice Harbor Dam data table. Also observed forebay conditions (orange columns)

IDSW - Observed tailwater conditions at Ice Harbor Dam (orange columns)

JDA - John Day Dam data table. Also observed forebay conditions (orange columns)

JHAW - Observed tailwater conditions at John Day Dam (orange columns)

LEWI - Observed tailwater conditions for the Clearwater/Snake River confluence site (orange columns)

LGNW - Observed tailwater conditions at Lower Granite Dam (orange columns)

LGS - The Little Goose Dam data table. Also observed forebay conditions (orange columns)

LGSW - Observed tailwater conditions at Little Goose Dam (orange columns)

LMN - The Lower Monumental Dam data table. Also observed forebay conditions (orange columns)

LMNW - Observed tailwater conditions at Lower Monumental Dam (orange columns)

LWG - The Lower Granite Dam data table. Also observed forebay conditions (orange columns)

MCN - McNary Dam data table

MCQO - Observed forebay conditions at McNary Dam, Oregon station (orange columns)

MCPW - Observed tailwater conditions at McNary Dam (orange columns)

MCQW - Observed forebay conditions at McNary Dam, Washington station (orange columns)

PAQW - Observed forebay conditions for the Hanford site (orange columns)

PEKI - Observed conditions at the Peck fixed monitoring site (orange columns)

PRD - Priest Rapids Dam data table. Also observed forebay conditions (orange columns)

PRXW - Observed tailwater conditions at Priest Rapids Dam (orange columns)

RIS - Rock Island Dam data table. Also observed forebay conditions (orange columns)

RIGW - Observed tailwater conditions at Rock Island Dam (orange columns)

RRDW - Observed tailwater conditions at Rocky Reach Dam (orange columns)

RRH - Rocky Reach Dam data table. Also observed forebay conditions (orange columns)

TDA - The Dalles Dam data table. Also observed forebay conditions (orange columns)

TDDO - Observed tailwater conditions at The Dalles Dam (orange columns)

TID - Project reference to the Camas/Washougal fixed monitoring station

WAN - Wanapum Dam data table. Also observed forebay conditions (orange columns)

WANW - Observed tailwater conditions at Wanapum Dam (orange columns)

WEL - Wells Dam data table. Also observed forebay conditions (orange columns)

WELW - Observed tailwater conditions at Wells Dam (orange columns)

WRNO - Observed tailwater conditions at Bonneville Dam (orange columns)

Station Abbreviations of "systdgweather" Table

The following station abbreviations represent the weather stations that weather data is taken from:

bndw - Bonneville Dam, WA
cjdw - Chief Joseph Dam, WA
deni - Dworshak-Dent Acres, ID
gcdw - Grand Coulee Dam, WA
KDLS - The Dalles Municipal Airport, OR
KEAT - Pangborn Memorial Airport, Wenatchee, WA
KPSC - Tri-Cities Airport, Pasco, WA
KTTD - Troutdale Airport, OR
lbrw - Lake Bryan-Rice Bar, WA
silw - Silcott Island, WA

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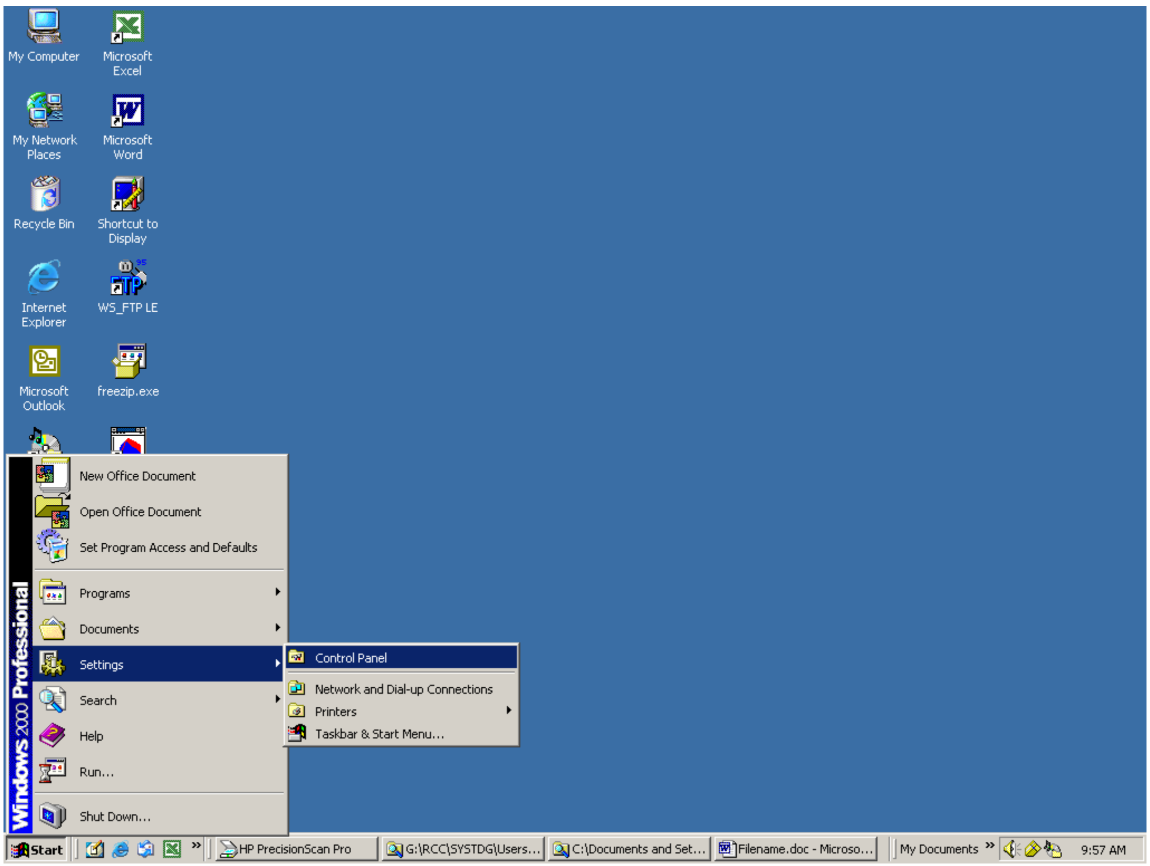
APPENDIX B: Step by Step guide on Setting Up Scheduled Tasks

This appendix provides a step-by-step guide on how to set up the Microsoft Scheduler, which is the program responsible for automatically downloading data files onto your computer and ultimately into the databases, FMSmaster.mdb and weatherklb.mdb.

The user begins by selecting the ***Start*** button from the main menu of the computer followed by the ***Settings*** button. Slide your mouse to the right in order to select the ***Control Panel*** button as shown in Figure 23.

Figure 23 - How to Get to Scheduled Tasked Menu



Once the user has selected the ***Control Panel***, the user should see the control panel main menu, shown in Figure 24.

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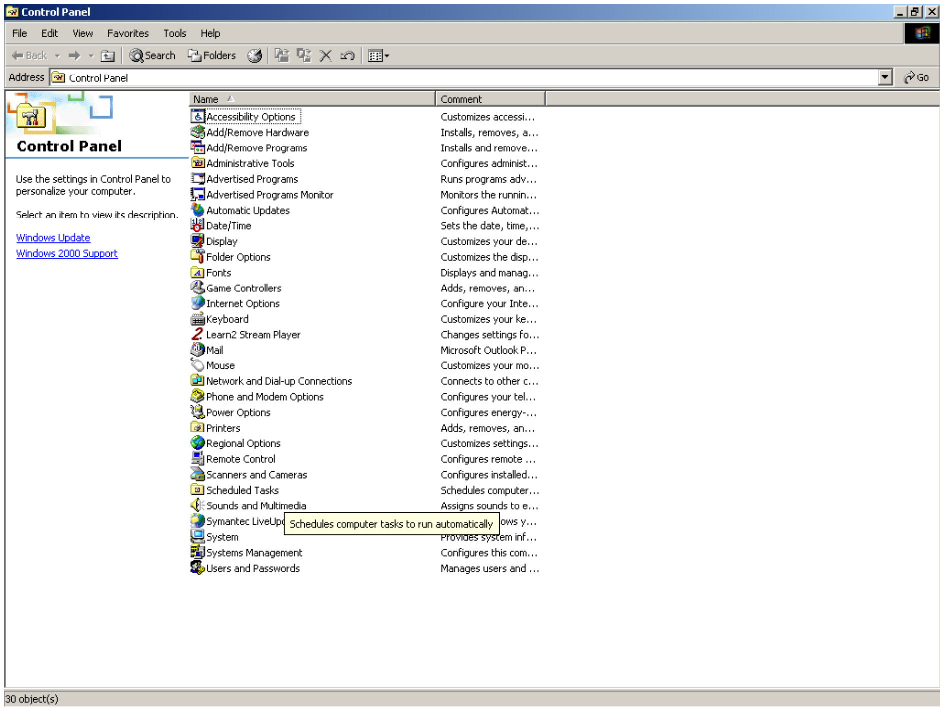
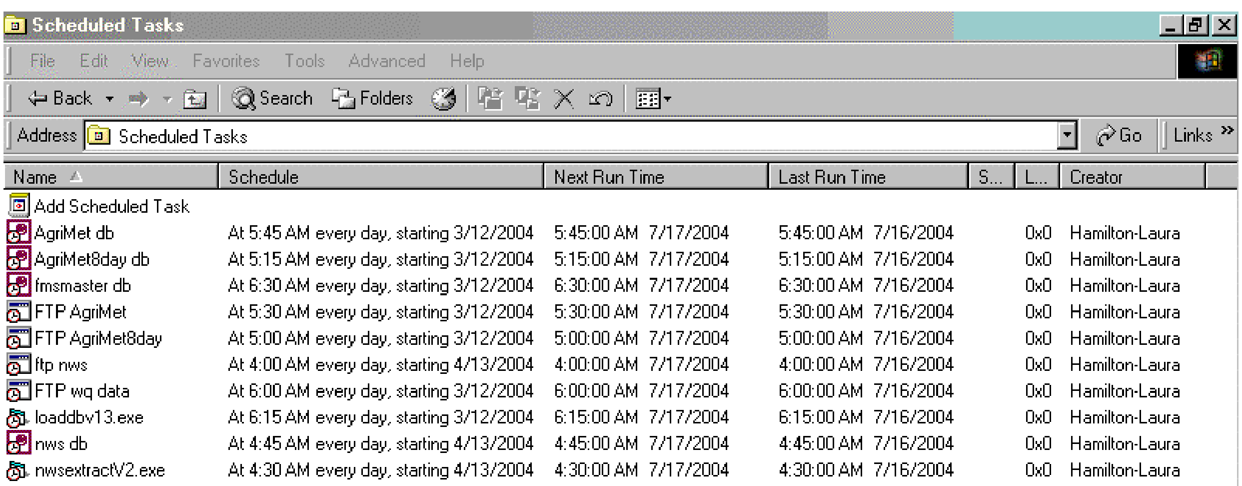
Figure 24 - Control Panel Main Menu



Next the user will need to select the ***Scheduled Task*** button from the control panel menu. The main menu of the Scheduled task will appear, see Figure 25.

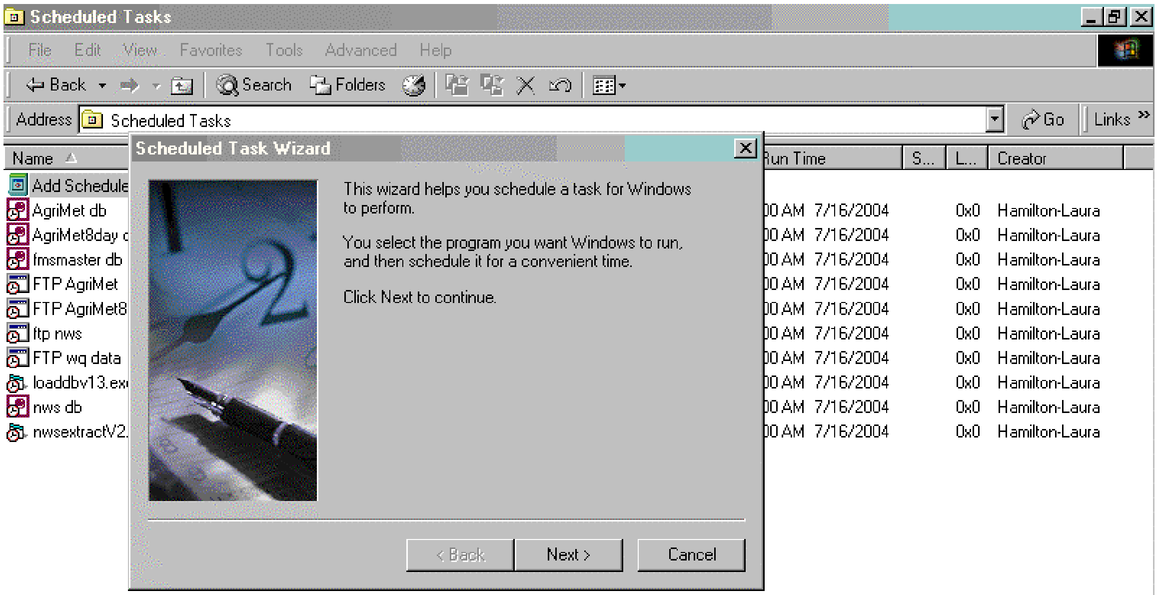
Figure 25 - Scheduled Tasks Main Screen



Select ***Add Scheduled Task*** from the scheduled tasks main menu, which is the first line on the menu as shown on Figure 25.

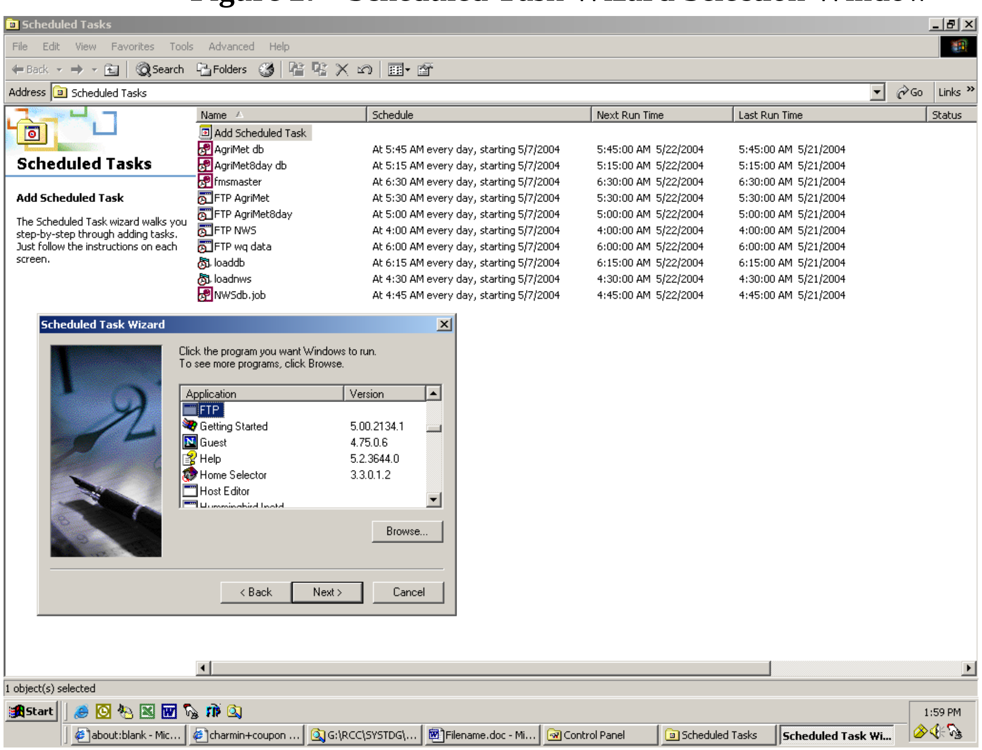
After the user clicks on ***Add Scheduled Task***, the Scheduled Task Wizard Displays screen will appear, which looks like Figure 26.

Figure 26 - Add Scheduled Tasks Wizard Screen



Select ***Next*** to continue. The user will next see a display screen that looks like Figure 27.

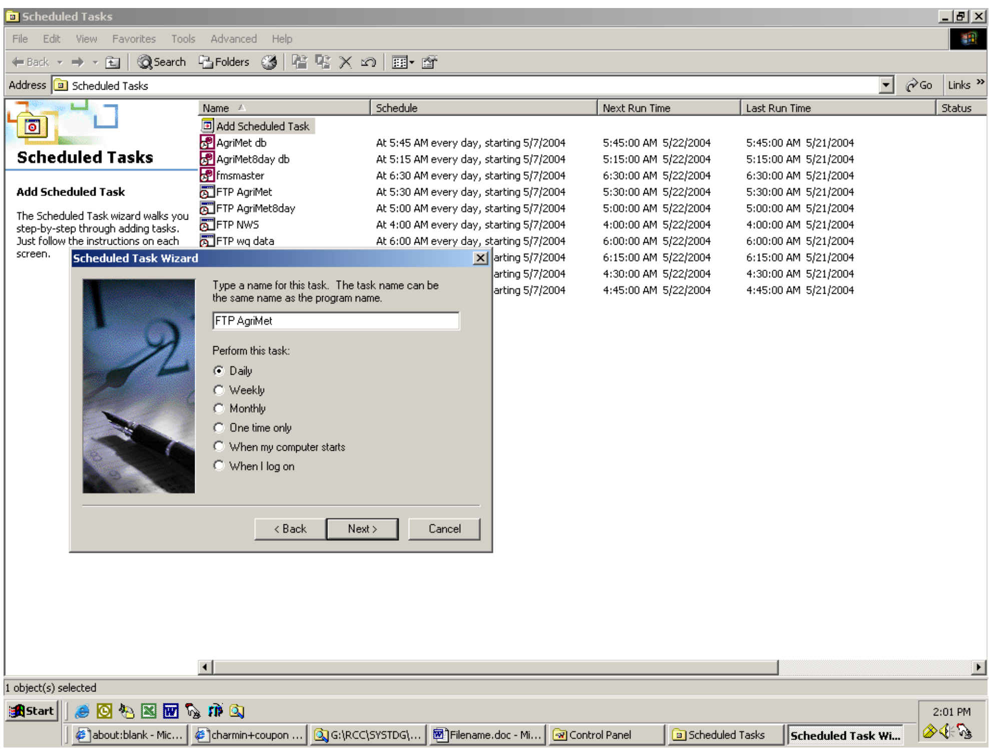
Figure 27 - Scheduled Task Wizard Selection Window



Scroll down the display screen using the slider bar until you find the FTP program ***FTP.exe***. Select ***Next***. Another window will appear that prompts you to name the task you are building. Type a name for your task and click Enter. A window similar to Figure 28 will appear.

If the program ***FTP.exe*** is not listed on the display screen select the ***Browse*** button and navigate to ***FTP.exe*** program stored (on most computers) in the folder C:\WINNT\system32. Select the ***FTP.exe*** program and click on the ***Open*** button. A window similar to Figure 28 will appear that shows the name ***displaying*** the name ***FTP.exe***. This name will need to be changed to the name of the task to be scheduled. The naming convention of the schedule tasks can be found in ***Chapter 3, Establishing Scheduled Tasks*** section. Next select to perform the task "Daily". This will set the task to run every day.

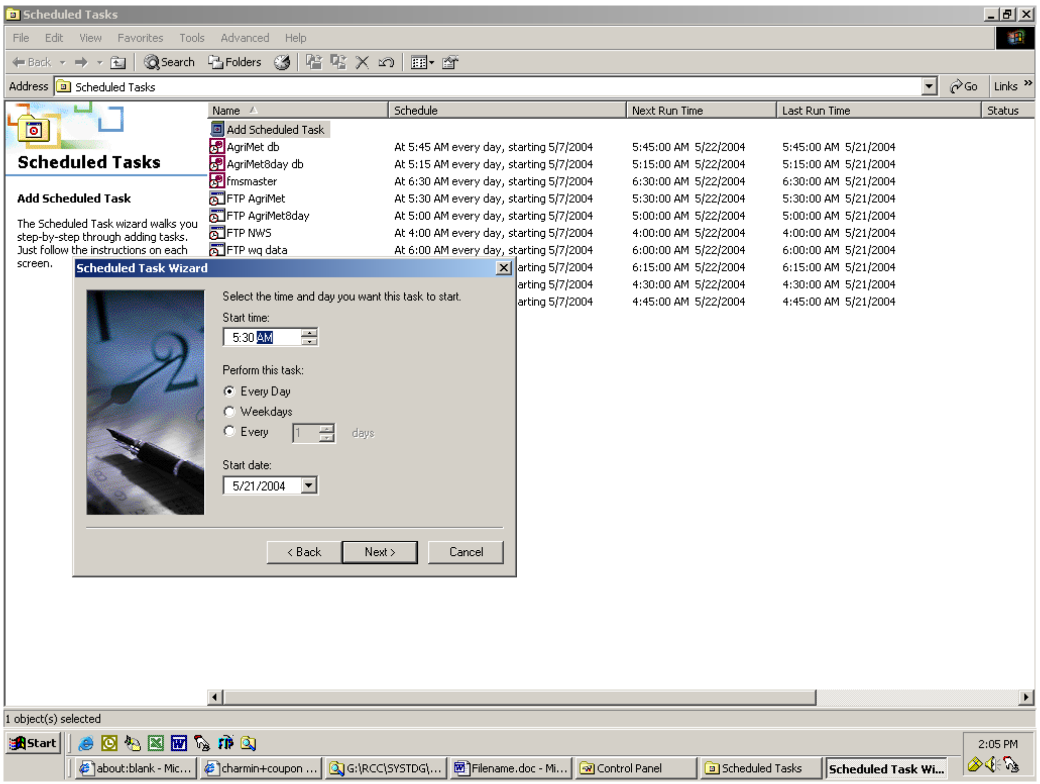
Figure 28 - Establishing Time of Scheduled Task



Select Next to continue. From the window seen in Figure 29 enter the ***Start Time*** that the user would desire the schedule task to run. For the recommended start times, see Table 1. The current date will be automatically entered as the start date. If the user wants a different start date, enter it now. Select the task to be performed "***Every Da"y*** so the scheduled task runs everyday. Then select ***Next***, which will prompt the window seen in Figure 30.

.

Figure 29 -Establishing the Time for the Scheduled Task



At this point the user needs to enter the name and password used to login onto the computer that is being used. For the Corps of Engineers, RCC users, the- user name will automatically appear in the user name area. If it doesn't, it should be entered as USACE_PORTLAND\LastName-FirstName. Make sure to confirm your password before clicking ***Next.***

Figure 30 - Establishing Password for the Scheduled Task

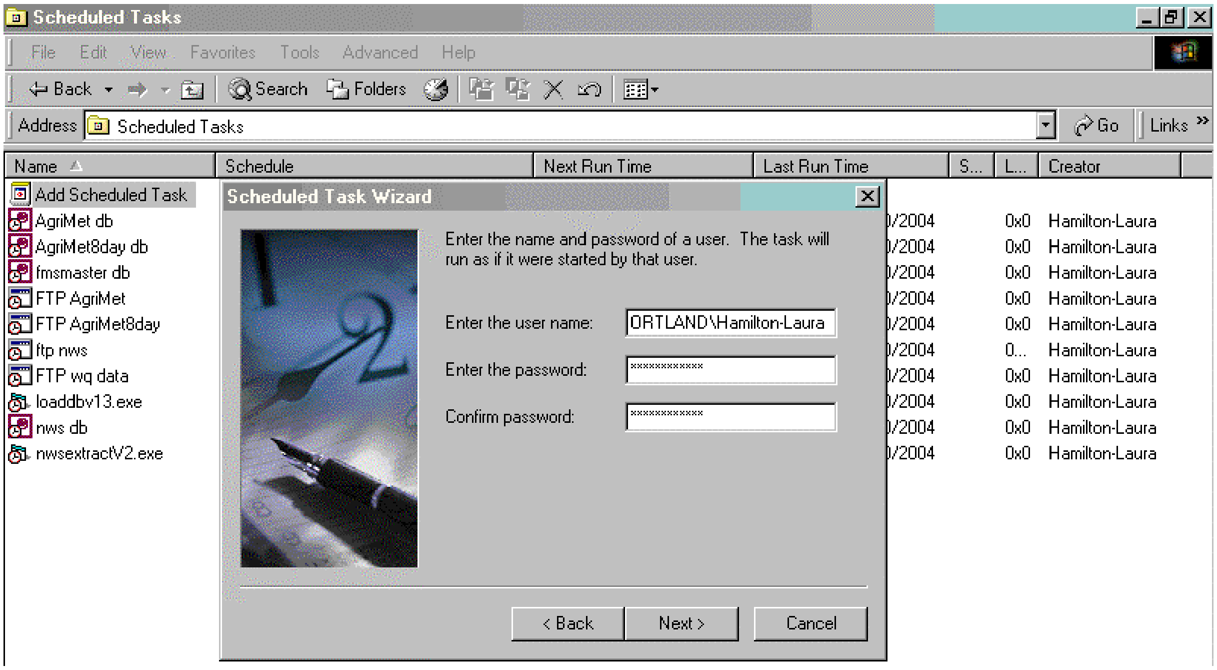


Figure 31 will appear to inform the user that the scheduled task has been successfully completed. Next check the box that will open advanced properties to this task once the Finish button is selected. Doing so will allow you to check the properties you have specified and change them if desired. Select ***Finish*** when complete.

Figure 31 - First Step To Scheduled Task Properties

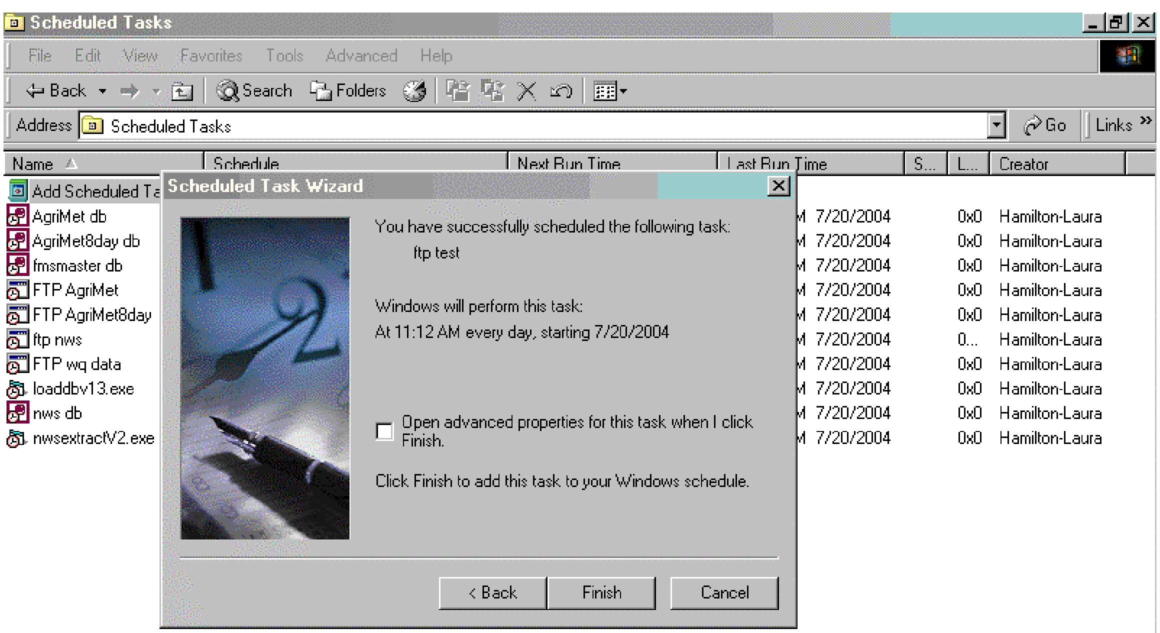
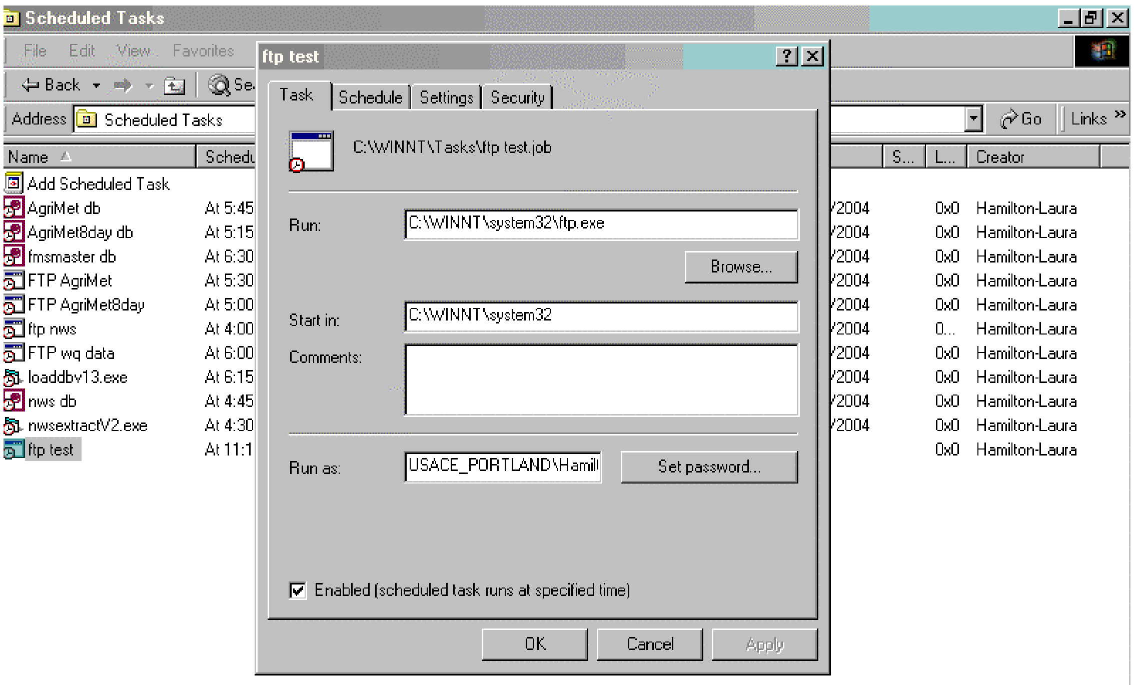


Figure 32 shows an example of what the properties of a scheduled task may look like. Notice how there is a line for ***Run*** and ***Start in***. The ***Run*** and ***Start In*** lines must be filled correctly for the scheduled task to run. ***Chapter 3, Establishing Scheduled Tasks*** section lists the appropriate ***Run*** and ***Start In*** commands needed to successfully run the required scheduled tasks.

Figure 32 - Final Step To Schedule Tasks Properties



Complete this process for the all the scheduled tasks listed below using the information listed in ***Chapter 3, Establishing Scheduled Tasks*** section.

FTPAgriMet
AgriMet db
FTP AgriMet8day
AgriMet8day db
FTP NWS
FTP WQ data
FMSmaster
NWS.db
Loaddbv13.exe
NwsextractV2

APPENDIX C: Forecasting Data for Environmental Conditions

Wind:
We need to provide wind data to use for calm; moderate and windy days.

Water Temperature
We need to provide wind data to use for calm; moderate and windy days.

APPENDIX D: Spillway Discharge Production of TDG Pressure

Introduction The total dissolved gas exchange associated with spillway operation at a dam is a process that couples both the hydrodynamic and mass exchange processes. The hydrodynamics are shaped by the structural characteristics of spillway, stilling basin, and tailwater channel as well as the operating conditions that define the spill pattern, turbine usage, and tailwater stage. The hydrodynamic conditions are influenced to a much smaller extent by the presence of entrained bubbles. The air entrainment will influence the density of the two-phase flow, and impose a vertical momentum component associated with the buoyancy in the entrained air. The entrained air content can result in a bulking of the tailwater elevation and influence the local pressure field. The transfer of atmospheric gasses occurs at the air-water interface, which is composed of the surface area of entrained air and at the water surface. The exchange of atmospheric gases is greatly accelerated when entrained air is exposed to elevated pressures because of the higher saturation concentrations. The pressure time history of entrained air will therefore be critical in determining the exchange of atmospheric gases during spill. The volume, bubble size, and flow path of entrained air will be dependent on the hydrodynamic conditions associated with project releases. The bubble size has been found to be a function of the velocity fluctuations and turbulent eddy length scale. The bubble size can also be influenced by the coalescence of bubbles during high air concentration conditions. The volume of air entrained is a function of the interaction of the spillway jet with the tailwater. The entrained bubble flow path will be dependent upon the development of the spillway jet in the stilling basin and associated secondary circulation patterns. The turbulence characteristics are important to the vertical distribution of bubbles and the determination of entrainment and de-entrainment rates.

Physical Processes The exchange of total dissolved gas is considered to be a first order process where the rate of change of atmospheric gases is directly proportional to the ambient concentration. The driving force in the transfer process is the difference between the TDG concentration in the water and the saturation concentration with the air. The saturation concentration in bubbly flow will be greater than that generated for non-bubbly flow where the saturation concentration is determined at the air-water interface. The flux of atmospheric gasses across the air-water interface is typically described by Equation 1.

$$J = k_l (C_s - C) \qquad (1)$$

Where k_l is the composite liquid film coefficient, C_s is the saturation concentration, and C is the ambient concentration in water.

The rate of change of concentration in a well mixed control volume can be estimated by multiplying the mass flux by the surface area and dividing by the volume over which transfer occurs as shown by the Equation 2:

$$\frac{dC}{dt} = k_l \frac{A}{V}(C_s - C) \qquad (2)$$

Where A is the surface area associated with the control volume and V is the volume of the water body over which transfer occurs.

This relationship shows the general dependencies of the mass transfer process. In cases where large volumes of air are entrained, the time rate of change of TDG concentrations can be quite large as the ratio of surface area to volume becomes large. The entrainment of air will also result in a significant increase in the saturation concentration of atmospheric gases thereby increasing the driving potential over which mass transfer takes place. Out side of the region of aerated flow during transport through the pools, the contact area is limited to the water surface and the ratio of the surface area to the water volume becomes small thereby limiting the change in TDG concentration. The turbulent mixing will influence the surface renewal rate and hence the magnitude of the exchange coefficient k_l.

The Equation 2 can be integrated provided the exchange coefficient, area, and volume are held constant over the time of flow. The initial TDG concentration at time=0 is defined as C_i and the final TDG concentration time=t_f is defined as C_f as shown in Equation 3. The resultant concentration C_f exponentially approaches the saturation

$$C_f = C_s(1 - e^{-k_l \frac{A}{V} t}) + C_i e^{-k_l \frac{A}{V} t} \qquad (3)$$

concentration for conditions where the term k_tAt/V is large. The final concentration becomes independent of the initial concentration under these conditions.

Modeling Total Dissolved Gas Transfer The TDG exchange process involves the coupled interaction of project hydrodynamics and mass transfer between the atmosphere and the water column. Mechanistic models of TDG transfer must simulate the two-phase flow (liquid and gas phases) conditions that govern the exchange process. Several mechanistic models have been developed to simulate the total dissolved gas exchange in spillway flows. Orlins and Gulliver (1998) solved the advection-diffusion equation for spillway flows at Wanapum Dam for different spillway deflector designs. Physical model data were used to develop the hydraulic descriptions of the flow conditions throughout the stilling basin and tailwater channel. The model results were also compared to observations of TDG pressure collected during field studies of the existing conditions. A second model developed by Johnson and Gulliver (1999), used the same mass transport relationships together with the hydraulic descriptions associated with plunging jets. This approach does not require the specific hydraulic information to be derived from a physical model but it can be applied to any hydraulic structure that has plunging jet flow. This model accounted for the TDG exchange occurring across the bubble-water interface and the water surface. This model was tuned to observations of TDG exchange at The Dalles Dam and was developed as part of the Dissolved Gas Abatement Study. This model successfully simulated the absorption and desorption exchange caused by the highly aerated flow during spillway operations.

The decision to use empirically derived equations of TDG exchange was based on the recognition that data was not available to support mechanistic models of the mass exchange process at all the projects in the study area. The greatest unknowns associated with the development of a mechanistic model of highly aerated flow conditions in a stilling basin revolve around the entrainment of air and the subsequent transport the bubbles. The surface area responsible for mass transfer will require estimates of the total volume and bubble size distribution of entrained air. In addition, the roughened water surface is thought to contribute to the net exchange of atmospheric gasses. The pressure time history of entrained air would also have to be accounted for to determine the driving potential for TDG mass exchange. A description of the highly complex and turbulent three-dimensional flow patterns in the stilling basin and adjoining tailwater channel would need to be defined for a wide range of operating conditions. The influence of turbulence on both the mass exchange coefficients and redistribution of buoyant air bubbles would also need to be quantified throughout a large channel reach and for a wide range of operating conditions. The flow conditions generated by spillway flow deflectors have been found to be sensitive to both the unit spillway discharge and submergence of the flow deflector. The presence of flow deflectors has significantly changed the rate of energy dissipation in the stilling basin and promotes the lateral entrainment of flow. These entrainment flows are often derived from powerhouse releases which reducing the available volume of water for dilution of spillway releases.

TDG Exchange Formulation The accumulated knowledge generated through observations of flow conditions during spill at study projects and in scale physical models, along with mass exchange data collected during site specific near-field TDG exchange studies and from the fixed monitoring stations, has lead to the development of a model for TDG exchange at dams throughout the study area. The general framework is based upon the observation that TDG exchange is an equilibrium process that is associated with highly aerated flow conditions that develop below the spillway. It recognizes that flow passing through the powerhouse is not generally exposed to entrained air under pressure and therefore does not experience a significant change in TDG pressure. It also recognizes that powerhouse releases can directly interact with the aerated flow conditions below the spillway and experience similar changes in TDG pressure that are found in spill.

The TDG exchange associated with spillway flows has also been found to be governed by certain processes. The TDG exchange in spill is initiated by the large volume of air entrained into spillway releases. This entrained air is exposed to elevated total pressures and the resulting elevated saturation concentrations. The exposure of the bubble to elevated saturation concentrations greatly accelerates the mass exchange between the bubble and water. The amount and trajectory of entrained air is greatly influenced by the structural configuration of the spillway and the energy associated with a given spill. The presence of spillway flow deflectors directs spill throughout the upper portion of the stilling basin thereby preventing the plunging of flow and transport of bubbles throughout the depth of the stilling basin. Spillway flow deflectors also greatly change the rate of energy dissipation in the stilling basin transferring greater energy and entrained air into the receiving tailwater channel. Generally, spill water experiences a rapid absorption of TDG pressure throughout the stilling basin region where the air content, depth of flow, flow velocity, and turbulence intensity are generally high. As the spillway flow move out into the tailwater channel, the net mass transfer reverses and component gases are stripped from the water column as entrained air rises and is vented back to the atmosphere. The region of rapid mass exchange is limited to the highly aerated flow conditions within 1000 ft of the spillway. In general, downstream of the aerated flow conditions the major changes to the TDG pressures occur primarily through the redistribution of TDG pressures through transport and mixing processes. The in-pool equilibrium process established at the water surface is chiefly responsible for changes to the total TDG loading in the river.

One of the more important observations regarding TDG exchange in spillway flow is the high rate of mass exchange that occurs below a spillway. The resultant TDG pressure generated during a spill is determined by physical conditions that develop below the spillway and is independent from the initial TDG content of this water in the forebay. The TDG exchange in spill is not a cumulative process where higher forebay TDG pressures will generate yet higher TDG pressures downstream in spillway flow. The TDG exchange in spill is an equilibrium process where the time history of entrained air below the spillway will determine the resultant TDG pressure exiting the vicinity of the dam. One consequence of this observation is that spilling water can result in a net reduction in the TDG loading in a system if forebay levels are above a certain value. This was a common occurrence at The Dalles Dam during the high flow periods during 1997 where the forebay TDG saturation exceeded 130 percent saturation. A second consequence the rapid rate of TDG exchange in spill flow is that the influence from upstream projects on TDG loading will be passed downstream only through powerhouse releases. If project operations call for spilling a high percentage of the total river flow, the contribution of TDG loading generated from upstream projects will be greatly diminished below this project.

Given the conceptual framework for TDG exchange described above, the average TDG pressures generated from the operation of a dam can be represented by the mass conservation statement shown in Equation 4:

$$P_{avg} = \frac{(Q_{sp} + Q_e)P_{sp} + (Q_{ph} - Q_e)P_{ph}}{Q_{sp} + Q_{ph}} \qquad (4)$$

Where:

Q_{sp} = Spillway Discharge (kcfs)
Q_{ph}= Powerhouse Discharge (kcfs)
Q_e = Entrainment of Powerhouse Discharge in Aerated Spill (kcfs)
$Q_{se} = Q_{sp} + Q_e$ = Effective Spillway Discharge (kcfs)
$Q_{tot} = Q_{sp} + Q_{ph}$ = Total River Flow (kcfs)
P_{ph} = TDG Pressure releases from the powerhouse (mm Hg)
P_{sp} = TDG Pressure associated with spillway flows (mm Hg)
P_{avg} = Average TDG Pressure associated with all project flows (mm Hg)

This conservation statement using TDG pressure assumes the water temperature of powerhouse and spillway flows are similar and that the heat exchange during passage through the dam and aerated flow region is minimal. It is recognized that projects have other water passage routes besides the powerhouse and spillway such as fish ladders, lock exchange, juvenile bypass systems, and other miscellaneous sources. These sources of water have generally been lumped into powerhouse flows and are not accounted for separately.

Equation 4 contains three unknowns: Q_e= Powerhouse Entrainment Discharge, P_{sp}=TDG pressure associated with spillway flows, P_{ph}=TDG pressure associated with powerhouse releases. The TDG pressure associated with the powerhouse release is generally assumed to be equivalent to the TDG pressure observed in the forebay. Numerous data sets support the conclusion that turbine passage does not change the TDG content in powerhouse releases. All of the near-field TDG exchange studies have deployed TDG instruments in the forebay of a project and directly below the powerhouse in the water recently discharge through the turbines. An example of this type of data is shown in Figure 1 during the 1998 post-deflector John Day Dam TDG exchange study (Schneider and Wilhelms, 1998). TDG instruments were deployed in the forebay of John Day Dam (station FB1P), and in the tailwater from below powerhouse draft tube deck (station DTD1P and DTD2P), near the fish outfall (FISHOUTP). The TDG pressure was logged on a 15-minute interval at each of these stations throughout the testing period. All four stations recorded the same TDG saturations throughout the testing period even during operating events calling for spilling nearly the entire river on February 11 and 12. The TDG pressure from the forebay and tailwater fixed monitoring stations should also be similar during period of no spill provided that these stations are sampling water with similar water temperatures. In cases, where a turbine aspirates air or air is injected into turbine to smooth out operation, the above assumption will not hold. The operation of Dworshak Dam during low turbine output can result in the generation of elevated TDG pressures.

Spillway TDG Exchange The TDG exchange associated with spillway flows has been found to be governed by the geometry of the spillway (standard or modified with flow deflector), unit spillway discharge, and depth of the tailwater channel. The independent variable used in determining the exchange of TDG pressure in spillway releases is the delta TDG pressure (ΔP) defined by the difference between the TDG pressure (P_{tdg}) and the local barometric pressure (P_{atm}) as listed in Equation 5. The selection of TDG pressure as expressed as the excess pressure above atmospheric pressure accounts for the variation in the barometric pressure as a component of the total pressure.

$$\Delta P = P_{tdg} - P_{atm} \qquad (5)$$

Restating the exchange of atmospheric gases in terms of mass concentrations introduces a second variable, water temperature, into the calculation. The added errors in calculating the TDG concentration as a function of temperature and TDG pressure were the main reasons for using pressure as the independent variable. The TDG concentration would also vary seasonally with the change in water temperature.

The TDG pressure is often summarized in terms of the percent saturation or supersaturation. The total dissolved gas saturation (S_{tdg})is determined by normalizing the TDG pressure by the local barometric pressure as expressed as a percentage. The delta pressure has always been found to be a positive value when spillway flows are sampled. The total dissolved gas saturation (S_{tdg}) is determined by Equation 6.

$$S_{tdg} = \frac{P_{tdg}}{P_{atm}} * 100 = \frac{(P_{atm} + \Delta P)}{P_{atm}} * 100 \qquad (6)$$

Unit Spillway Discharge The TDG exchange associated with spillway flows has been found to be a function of unit spillway discharge (q_s) and the tailwater channel depth (D_{tw}). The unit spillway discharge is a surrogate measure for the velocity, momentum, and exposure time of aerated flow associated with spillway discharge. The higher the unit spillway discharge the greater the TDG exchange during spillway flows. An example of the dependency between the delta TDG pressure and unit spillway discharge is shown in Figure 2 at Ice Harbor Dam. This figure shows two sets of tests involving a uniform spill pattern over 8 bays with flow deflectors. The two sets of tests were distinguished only by the presence of powerhouse releases. In both cases, the resultant spill TDG pressure was found to be an exponential function of the unit spillway discharge. The determination of a single representative unit discharge becomes problematic in the face of a non-uniform spill pattern. The flow-weighted specific discharge was found to be a better determinant of spillway TDG production in cases where the spill pattern is highly nonuniform. The flow-weighted unit discharge places greater weight on bays with the higher discharges. The following Equation 7 describes the determination of the specific discharge used in the estimation of TDG exchange relationships:

Depth of Flow The large amount of energy associated with spillway releases has the

$$q_s = \frac{\sum_{i=1}^{nb} Q_i^2}{\sum_{i=1}^{nb} Q_i} \qquad (7)$$

capacity to transport entrained air throughout the water column. In many cases, the

depth of flow is the limiting property in determining the extent of TDG exchange below a spillway. An example of the influence of the depth of flow on TDG exchange is shown in Figure 2 at Ice Harbor Dam. The only difference between the two sets of data in this figure was the presence of powerhouse flow. The events with powerhouse flow resulted in higher TDG pressure than comparable spill events without powerhouse releases at higher spillway flows. The observed tailwater elevation is also listed in Figure 2 for each test event. The tailwater elevation was about 5 ft higher during the events corresponding with powerhouse operation. The depth of flow in the tailwater channel was hypothesized to be more relevant to the exchange of TDG pressure than the depth of flow in the stilling basin because of the influence of the flow deflectors and resultant surface jet, and the high rate of mass exchange observed below the stilling basin. The average depth of flow downstream of the spilling basin was represented as the difference between the tailwater elevation as measured at the powerhouse tailwater gage, and the average tailwater channel elevation within 300 ft of the stilling basin. The tailwater channel reach within 300 ft of the stilling basin was selected because most of the TDG exchange (degassing) occurs in this region. A summary of project features including stilling basin elevation, deflector elevation, and tailwater channel elevation are listed in
Table 1.

The functional form of the relationship between the delta TDG pressure change and the prominent dependent variables unit spillway discharge and tailwater channel depth of flow, takes the same form as the exponential formulation shown in Equation 3. The delta TDG pressure was found to be a function of the product of the depth of flow and the exponential function of unit spillway discharge as shown in Equation 8.

$$\Delta P = C_1 D_{tw} (1 - e^{-c_2 q_s}) + C_3 \qquad (8)$$

The coefficients C_1, C_2, and C_3 were determined from a non-linear regression analyses. The product of C_1 and the tailwater Depth (D_{tw}) represents the effective saturation pressure in Equation 3 while the product of C_2 and the unit spillway discharge (q_s) reflects the combined contribution from the mass exchange coefficient, ratio of surface area to control volume, and time of exposure.

A second formulation used in this study relating the delta TDG pressure and independent variable involves a power series as shown in Equation 9.
This equation can also result in a linear dependency between the delta TDG pressure and either tailwater depth or unit spillway discharge. A linear dependency in the tailwater depth occurs when c_2=1 and c_3=0. A linear dependency between TDG pressure and unit spillway discharge occurs when c_2=0 and c_3=1.

$$\Delta P = c_1 D_{tw}^{c_2} q_s^{c_3} + c_4 \qquad (9)$$

Data Sources. TDG data were available on many of the projects from several sources: the fixed monitoring system, near field and spillway performance tests, and in-pool transport and dispersion tests. Operational data were obtained from each project detailing the individual spillway and turbine discharge on an interval ranging from 5 minutes to one hour. These sources of data are discussed below. With these data sources, the most appropriate analysis was selected for each project. Individual mathematical relationships were developed on a project-by-project basis.

Fixed Monitor Data. TDG data from the fixed monitoring system consisted of remotely-monitored total dissolved gas pressure, dissolved oxygen (DO), water temperature, and atmospheric pressure from a fixed location in the forebay and tailwater of each project. Data from the fixed monitors provide a continuous record of TDG throughout the season, capturing detailed temporal and extreme events. However, the fixed monitoring system provides only limited spatial resolution of TDG distribution. In some cases, the TDG observed in the tailwater at the fixed monitor location was not representative of average spillway conditions and misrepresented the TDG loading at a dam.

Spillway Performance Tests and Near-Field Studies. Spillway performance tests and near-field tailwater studies were conducted at several projects to more clearly define the relationship between spill operation and dissolved gas production. TDG, DO, and water temperature were monitored in the immediate tailrace region, just downstream of the project stilling basin. These observations provided a means to directly relate the local TDG saturation to spill operations and to define gas transfer in different regions of the tailrace area. Manual sampling of TDG pressures in spillway discharges from several bays was conducted downstream of the aerated flow regime at Lower Granite, Little Goose, Ice Harbor, and The Dalles (Wilhelms 1995); and John Day, Lower Monumental, and Bonneville Dams (Wilhelms, 1996). In the near-field studies, automated sampling of TDG pressures in spillway discharges during uniform and standard spill patterns were conducted with an array of instruments in the stilling basin and tailwater channel of all the projects in the study area with the exception of Lower Granite Dam. Automated sampling of TDG levels provide the opportunity to assess three-dimensional characteristics of the exchange of TDG immediately downstream of the stilling basin on a sampling interval ranging from 5 to 15 minutes. The integration of the distribution of flow and TDG pressure can yield estimates of the total mass loading associated with a given event. These tests were of short duration, generally lasting only several days, and therefore pertain to limited to the range of operations scheduled during testing.

<u>In-Pool Transport and Dispersion Studies</u>. During the 1996 spill season, in-pool transport and dispersion investigations were conducted to define the lateral mixing characteristics between hydropower and spillway releases. TDG levels, DO, and water temperature were measured at several lateral transects located over an entire pool length. These studies focused on the lateral and longitudinal distribution of TDG throughout a pool during a period lasting from a few days to a week. In-pool transport and mixing studies were conducted below Little Goose, Lower Monumental, Ice Harbor, John Day, The Dalles, and Bonneville Dams during the 1996 spill season). In most cases, a lateral transect of TDG instruments were located below the dam to establish the level of TDG entering the pool, with additional transects throughout the pool. These studies provided observations of the TDG saturation in project releases as they moved throughout an impoundment. However, only a limited range of operations was possible during the relatively short duration of these tests.

<u>Operational Data.</u> Operational data were obtained from each project detailing the spillway and powerhouse unit discharge on time intervals ranging from 5 minutes to one hour. The average hourly total spillway and generation releases, and forebay and

tailwater pool elevations were summarized in the DGAS database. The tailwater pool gage was generally located below the powerhouse of each dam. The tailwater elevation at the powerhouse was found to be within +-1 ft to the water elevation downstream of the stilling basin in most instances.

Table 1 Columbia and Snake River Project Features.

	Spillway Crest Elevation (ft)	Deflector Elevation (ft)	Stilling Basin Elevation (ft)	Tailwater Channel Elevation (ft)	Miniumum Operating Pool (ft)	Normal Tailwater Pool (ft)
Bonneville	24	14	-16	-30	70	20
The Dalles	121	na	55	58	155	80
John Day	210	148	114	125	257	162
McNary	291	256	228	235	335	267
Ice Harbor	391	338	304	327	437	344
Lower Monumental	483	434	392	400	537	441
Little Goose	581	532	466	500	633	539
Lower Granite	681	630	580	604	733	635

<u>Entrainment of Powerhouse Flow</u> The interaction of powerhouse flows and the highly aerated spillway releases can be considerable at many of the projects in the study area. Observations of the flow conditions downstream of projects where the powerhouse is adjacent to the spillway often indicates a strong lateral current directed toward the spillway. The presence of Bradford and Cascade Islands at Bonneville Dam eliminates the potential entrainment of powerhouse flow into aerated spillway releases. The clearest example of the influence of the entrainment of powerhouse on TDG exchange was documented during the near-field TDG exchange study at Little Goose Dam. The study at Little Goose Dam was conducted during February of 1998 when the ambient TDG saturation in the Snake River ranged from 101-103 %. The test plan called for adult and juvenile spill of up to 60 kcfs with the powerhouse discharging either 60 kcfs or not operating. The cross sectional average TDG pressure in the Snake River below Little Goose Dam was determined from seven separate sampling stations located across the river from the tailwater fixed monitoring station. The project operations and resultant TDG saturation are summarized in Figure 3 where the

observations from the forebay and tailwater fixed monitoring stations are shown as LGS and LGSW, the cross sectional average TDG saturation at the tailwater FMS is labeled T5avg, and the flow-weighted average TDG saturation assuming no entrainment of powerhouse flow is labeled FWA (flow weighted average). The TDG saturation estimated by assuming that powerhouse releases were available to dilute spillway flows during this test (FWA) were significantly less than estimates derived from averaging information from the seven sampling stations at the tailwater FMS (T5avg). This study demonstrated that nearly all of the powerhouse flows from Little Goose Dam were entrained and acquired TDG pressures similar to those in spillway flows during this study. The circulation patterns below the dam during the test clearly supported the TDG data indicating high rates of entrainment of powerhouse flows into the stilling basin.

The entrainment of powerhouse flow was modeled as a simple linear function of spillway discharge. The relationship shown in Equation 10 was used to estimate the entrainment discharge for each project. The coefficients c_1 and c_2 are project specific constants. The entrainment of powerhouse flow was assumed to be exposed to the same conditions that spillway releases encounter and hence achieve the same TDG pressures.

$$Q_e = c_1 Q_{sp} + c_2 \qquad (10)$$

Data Interpretation The objective of this analysis was to develop mathematical relationships between observed TDG and operational parameters, such as discharge, spill pattern, and tailwater channel depth. These relationships were derived with observations from the fixed monitoring system, and spillway performance tests. However, before the analysis could be conducted, the monitored data had to be evaluated to determine its reliability for this kind of analysis. For example, the monitored TDG data from the fixed stations provide a basis for defining the effects of spillway operation on dissolved gas levels in the river below a dam, but the following limitations should be noted:

a. The fixed monitors sample water near-shore, which may not reflect average TDG levels of the spill. The monitor sites were, in general, located on the spillway side of the river to measure the effects of spillway operation. However, with a non-uniform spill distribution and geometry across the gates of the spillway, the monitor may be more representative of the spillbays closest to the shore. Outside spillbays, without flow deflectors, can create elevated TDG levels downstream from these bays compared to adjacent deflectored bays. A spill pattern that dictates higher unit discharges on these outside bays can further elevate the TDG levels downstream of these bays relative to the releases originating from the deflectored interior bays.

b. Depending upon the lateral mixing characteristics, the fixed monitor(s) downstream of a project may be measuring spillway releases that have been diluted with hydropower releases. The tailwater monitors below The Dalles and Bonneville Dam are located in regions where substantial mixing has occurred between generation and spillway discharges. Under most conditions, the TDG saturation of generation releases is less than the TDG level associated with spillway releases. The TDG at the tailwater monitors will be a function of the discharge and level of TDG from both generation and spillway releases. Obviously, if there is no spill, then the monitored TDG levels will reflect the TDG saturation released by the hydropower facility.

c. Passage of generation flows through a power plant does not significantly change the TDG levels associated with this water. However, there can be a significant near-field entrainment of powerhouse flow by spillway releases at some projects, especially if flow deflectors are present. Observed data suggest that, under these conditions, some portion of the powerhouse discharges will be subjected to the same processes that cause absorption of TDG by spillway releases. In these cases, the TDG levels measured immediately downstream of a spillway will be associated with the spillway release plus some component of the powerhouse discharge.

The observations of tailwater TDG pressure need to be paired up with project operations to conduct an evaluation of the data. A set of filters or criteria were established to select correctly-paired data for inclusion in this analysis The travel time for project releases from the dam to the tailwater FMS was typically less than 2 hours and steady-state tailwater stage conditions were usually reached within this time period. Thus, the data records were filtered to include data pairs corresponding with constant operations of duration greater than 2 hours to exclude data corresponding with unsteady flow conditions. This filtering criteria eliminated data associated with changing operation and retailed only a single observation for constant operating conditions equal to 3 hours in duration. Manual and automated inspection for obviously inaccurate observations were conducted. An automated search for values above or below expected extremes identified potential erroneous and inaccurate data in the database. These data were inspected and, if appropriate, excised from the database. Comparison of measurements from forebay and tailwater instruments during non-spill periods was one validation of the accuracy of observed data. During the non-spill periods, downstream measurements should approach the forebay concentration when only the hydropower project is releasing water. Inspection of the data was conducted to identify errors, when this condition was not met. Comparison of measurements from redundant tailwater TDG monitors, if available. TDG tailwater data was rejected when measurements of two instruments at the same site varied by more than 3 percent saturation.

Lower Granite Dam

<u>TDG Exchange</u> The spillway operation at Lower Granite Dam often results in the highest increase in the total dissolved gas loading within the study area. This fact is mainly caused by the low ambient TDG conditions approaching the dam. During 1997, the forebay TDG pressure was generally about 800 mm Hg (107 %) and the tailwater TDG pressure during peak forced spill events exceeded 1000 mm Hg (133 %). The resultant TDG levels transported to Little Goose Dam often reached maximum levels of 950 mm Hg (127 %) or a net 150 mm Hg (20 %) increase in the average TDG pressure as a result of spillway operations. The absence of detailed near-field data below Lower Granite Dam caused the description of project TDG exchange to be based solely on

observations from the fixed monitoring station. The seasonally low and relatively constant background TDG pressures in the forebay of Lower Granite Dam provided a unique opportunity to quantify the impacts of spill operation at Lower Granite Dam on TDG conditions in the Lower Snake River.

The TDG exchange properties at Lower Granite Dam were explored through the evaluation of data from the tailwater fixed monitoring station. The data collected during the 1997 spill season was filtered to include only events associated with a constant spill operation of 3 hours. The data filtering resulted in a total of 98 independent observations as summarized in Table 2. The delta TDG pressure ranged from 61.4 to 266.9 mm Hg for these events. The unit spillway discharge ranged from 3.1 to 26.4 kcfs/bay and the tailwater depth ranged from 48.7 to 55.5 ft.

Table 2. Statistical Summary of Regression Variables

	Delta Pressure ΔP (mm Hg)	Unit Spillway Discharge q_s (kcfs/bay)	Tailwater Depth D_{tw} (ft)
Number	98	98	98
Minimum	61.4	3.1	48.7
Maximum	266.9	26.4	55.5
Average	166.3	9.4	52.4
Standard Deviation	46.0	4.2	1.4

<u>Regression</u> The TDG production during spillway releases from Lower Granite Dam as defined by $\Delta P=P_{tw}-P_{bar}$, was found to be proportional to the product of tailwater depth and an exponential function of the specific discharge as shown in Equation 11. Both of the coefficients determined by the non-linear regression analysis were significant to the 99 percent confidence interval as shown in Table 3. This formulation explained much of the variability in the data with an r-squared of 0.93 and a standard error of 11.60 mm Hg. This relationship indicates that the upper limit for TDG exchange for large unit spillway discharge is influenced by the

tailwater depth below Lower Granite Dam. As the total river flow increases, the tailwater stage will increase and higher TDG pressures will be generated for the same spill operation. The storage in Little Goose pool can also influence the tailwater conditions below Lower Granite Dam. This equation also implies that increasing the unit spillway discharge will result in higher TDG pressures. The unit spillway discharge can be very high for debris spill at Lower Granite Dam resulting in high TDG pressures for relatively low total spillway discharges. The spill pattern at Lower Granite Spillway has also changed during the study period to accommodate the operation of the surface bypass system. Other structural changes to the spillway at Lower Granite Dam such as the raised spillway weir will also effect the spill pattern and resultant TDG exchange through changes to the average unit spillway discharge.

$$\Delta P = 5.307\, D_{tw}\ (1 - e^{-0.1059 q_s}) \qquad (11)$$

Where:

ΔP = $P_{tw} - P_{bar}$
P_{tw} = Total Dissolved Gas Pressure at the tailwater FMS (mm/Hg)
q_s = Flow weighted unit spillbay discharge (kcfs/bay)
D_{tw} = Tailwater channel depth (ft) (E_{tw}-E_{ch})
E_{tw} = Elevation of the tailwater (ft)
E_{ch} = Average elevation of the tailwater channel (585 ft)
P_{bar} = Barometric Pressure at the tailwater fixed monitoring station (mm Hg)

Table 3. Statistical summary of nonlinear regression at Lower Granite Dam, 1997 spill season.

$\Delta P_{tw}=c_1*D_{tw}*(1-\exp(c_2*q_s))$
Number of observations n=98
r^2=0.93
Std. Error=11.60 mm Hg

Coefficient	Estimate from Regression	Standard Error	t-statistic	Probability
c_1	5.307	0.151	35.17	<0.0001
c_2	-0.106	0.0056	-19.02	<0.0001

The unit spillway discharge was plotted against the observed and calculated tailwater TDG pressure difference in Figure 4. The exponential relationship between the TDG pressure and specific discharge is evident in this figure as the TDG pressure approached an upper limit as the specific discharge becomes large. Much of the variability in the TDG pressure for a constant unit discharge can be accounted for by the variation in the tailwater channel depth.

Most of the variability in the TDG production can be accounted for by the specific discharge. The specific discharge is a surrogate measure for the velocity, momentum, and exposure time of aerated flow associated with spillway discharge. The three-dimensional response surface for Equation 11 is shown in Figure 5 along with the observed data. The TDG pressure increases for a constant unit spillway discharge as the tailwater channel depth increases. However, the influence of the tailwater depth is small as evidenced by the small slope in the response surface for a constant unit discharge. The tailwater channel depth is a function of the total river flow and the pool elevation of the lower reservoir. This relationship couples the operation of the powerhouse at Lower Granite Dam and the storage management in Little Goose pool to the TDG production in spillway releases from the Lower Granite spillway.

The response function as defined in Equation 11 was used to hind cast the TDG production observed during the 1997 spill season. The hourly project operation and TDG pressure at the Lower Granite fixed monitoring stations for the month of June 1997 are show in Figure 6 along with the estimates of TDG saturation based on Equation 11. In general, the estimated TDG pressure was generally within 10 mm Hg of the observed tailwater TDG saturation. The tailwater TDG instrument malfunctioned during June 7-10 resulting in the large difference between observed and calculated values. The TDG production relationship could be used to screen data coming from the fixed monitoring system for the purpose of assuring the quality of information used for real time management decision-making. The occurrence of atypical spill patterns, measurement error, and dilution with powerhouse releases probably accounts for much of the estimation error shown during this period.

Entrainment of Powerhouse Discharge This formulation defined by Equation 11 does not account for the added mass of TDG associated with entrainment of powerhouse releases into the aerated flow regime below a spillway. The observations of surface flow patterns below Lower Granite Dam have demonstrated the vigorous interaction that occurs between spillway and powerhouse releases. A recirculation cell has been observed to form directly below the Lower Granite powerhouse which draws water back towards the powerhouse and promotes the lateral entrainment of powerhouse flows into the stilling basin.

The importance of the entrainment of powerhouse flows into the bubbly flow in the stilling basin was demonstrated by routing Lower Granite releases through the Little Goose pool for the historic conditions observed during 1997. The average TDG pressure generated by Lower Granite Dam operations were estimated by using a flow-weighted average of powerhouse and spillway flows. The TDG content of spillway flows were determined from Equation 11 while the TDG pressure associated with powerhouse releases were set to the observed forebay TDG pressure. A simple hydrologic routing of project releases was performed to estimate the TDG pressure arriving at Little Goose Dam. The results from this analysis are shown in Figure 7 where the observed hourly TDG pressure at Little Goose Dam (LGS-obs) is shown as the pink circles while the estimated TDG pressure in the forebay of Little Goose Dam (LGS-cal) is shown as a pink line. The difference between the estimated and observed TDG pressure was as is large as 80 mm Hg. The largest prediction errors tended to be associated with operating conditions resulting in a smaller percent of the river spilled. The simulation of TDG exchange was repeated using a simple linear relationship between spillway discharge and the estimated entrainment of powerhouse flow. The entrainment of powerhouse flow was assumed to equal 75 percent of the total spillway discharge as limited by available powerhouse releases. The entrained powerhouse flows were assumed to be exposed to the same conditions as spillway releases and experience comparable TDG uptake. The results from this formulation for TDG exchange at Lower Granite Dam are shown in Figure 8. The estimated TDG pressure in the Little Goose forebay much more closely predicted the observed TDG pressure throughout the month of June. The average prediction error was small for the simulation shown in Figure 8 with the peak TDG pressures well represented. The short travel time through Little Goose pool during this evaluation will lesson the influence of changing water temperatures and TDG exchange across the water surface on TDG pressure. As a consequence of this evaluation, the effective spillway flow (actual+entrainment) was estimated to be about 175 percent of the rated spillway release. The effective spillway discharge at Lower Granite Dam can be calculated as Qse=1.75Qs provided that the powerhouse flows exceed the entrainment discharge.

Little Goose Dam

TDG Exchange A near-field TDG exchange investigation was conducted at Little Goose Dam during February 20-22, 1998 as described in Schneider and Wilhelms (1998). The study consisted of sampling TDG pressures below the spillway during spillway discharges ranging from 20 to 60 kcfs with and without powerhouse flows. Two different spill patterns were investigated during this study: Adult and Juvenile Spill Patterns. The study findings indicated that the TDG production was directly related to the unit spillway discharge, spill pattern, and powerhouse flow. The resultant average TDG saturation in Little Goose project flows ranged from 110 to 127 percent during the study for unit spillway discharges ranging from 2.5 to 10 kcfs/bay. The operation of all 8 bays (Adult Pattern) was found to increase the TDG exchange when compared to the Juvenile Pattern (only bays with flow deflectors) at similar unit spillway flows by as much as 5 percent saturation. The presence of ambient TDG pressures associated with powerhouse releases were not observed downstream of the highly aerated flow regime associated with Little Goose spill implying considerable lateral interaction of project releases. In the case of the adult spill pattern at a discharge of 40 and 60 kcfs, the addition of a powerhouse flow of 60 kcfs with forebay TDG saturation of 101 percent did not change the average TDG saturation below Little Goose Dam of 123 and 126 %, respectively.

Regression The TDG exchange at Little Goose Dam was further explored through the evaluation of data from the fixed monitoring station. This evaluation provided a wider range of operating conditions in terms of spillway discharge and tailwater elevation than observed during the near-field test. The regression equation was based on data collected during the 1997 spill season for spill using the juvenile spill pattern (spill was limited to the six internal spill bays). The filtered data resulted in a total of 190 independent observations as listed in

Table 4. The delta TDG pressure ranged from 79.6 to 218.8 mm Hg for these events. The unit spillway discharge ranged from 1.8 to 21.6 kcfs/bay and the tailwater depth ranged from 36.3 to 42.1 ft.

Table 4. Statistical Summary of Regression Variables			
	Delta Pressure ΔP (mm Hg)	Unit Spillway Discharge q_s (kcfs/bay)	Tailwater Depth D_{tw} (ft)
Number	190	190	190
Minimum	79.6	1.8	36.3
Maximum	218.8	21.6	42.1
Average	158.4	9.5	39.0
Standard Deviation	29.0	3.5	1.3

The TDG production during spillway releases using the Juvenile spill pattern from Little Goose Dam as defined by $\Delta P = P_{tw} - P_{bar}$, was found to be proportional to the product of tailwater depth and an exponential function of the unit spillway discharge as shown in Equation 12. Both of the coefficients determined by the non-linear regression analysis were significant to the 99 percent confidence interval as shown in Table 5. This formulation explained much of the variability in the data with an r-squared of 0.84 and a standard error of 11.65 mm Hg. Several data points were responsible for the poorer correlation coefficient for this data set compared to the other projects.

$$\Delta P = 5.566\, D_{tw}\ (1 - e^{-0.150 q_s}) \qquad (12)$$

Where:

ΔP = $P_{tw} - P_{bar}$
P_{tw} = Total Dissolved Gas Pressure at the tailwater FMS (mm Hg)
q_s = Flow weighted unit spill bay discharge (kcfs/bay)
D_{tw} = Tailwater channel depth (ft) (E_{tw}-E_{ch})
E_{tw} = Elevation of the tailwater (ft)

E_{ch} = Average elevation of the tailwater channel (500 ft)
P_{bar} = Barometric Pressure at the tailwater fixed monitoring station (mm Hg)

Table 5. Statistical summary of nonlinear regression at Little Goose Dam, juvenile spill pattern, 1997 spill season.
$\Delta P_{tw}=c_1*D_{tw}*(1-\exp(c_2*q_s))$
Number of observations n=190
$r^2=0.84$
Std. Error=11.65 mm Hg

Coefficient	Estimate from Regression	Standard Error	t-statistic	Probability
c_1	5.566	0.0996	55.91	<0.0001
c_2	-0.150	0.0060	24.91	<0.0001

The unit spillway discharge was plotted against the observed and calculated tailwater delta TDG pressure in Figure 9. The exponential relationship between the TDG pressure and specific discharge is evident in this figure as the TDG pressure approached an upper limit as the specific discharge becomes large. Much of the variability in the TDG pressure for a constant unit discharge can be accounted for by the variation in the tailwater channel depth. The degree of TDG exchange will approach a threshold value only for a constant tailwater depth using this formulation. Since the tailwater depth will continue to increase for higher river flows during forced spill conditions, the limit for TDG exchange will also continue to increase.

Most of the variability in the TDG production can be accounted for by the unit spillway discharge. The specific discharge is a surrogate measure for the velocity, momentum, and exposure time of aerated flow associated with spillway discharge. The three-dimensional response surface for Equation 12 is shown in Figure 10 along with the filtered observed FMS data. The TDG pressure increases for a constant unit spillway discharge as the tailwater channel depth increases. However, the influence of the tailwater depth is small as evidenced by the small slope in the response surface for a constant unit discharge. The tailwater channel depth is a function of the total river flow and the pool elevation of the lower reservoir. This relationship couples the operation of the powerhouse at Little Goose Dam and the storage management in Lower Monumental pool to the TDG production in spillway releases from the Little Goose spillway.

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The response function as defined in Equation 12 was used to hind cast the TDG production observed during the 1997 spill season. The hourly project operation and TDG saturation at the Little Goose Dam fixed monitoring stations (LGS-forebay, LGSW-tailwater) for the month of May, 1997 are show in Figure 11 along with the estimates of tailwater TDG saturation (TDGest) based on Equation 12. In general, the estimated TDG saturation was generally within 1 percentage point of the observed tailwater TDG saturation during the Juvenile spill events. The scheduling of the adult spill pattern is indicated by the positive discharge through bay 8 (Qs8). In general, the tailwater TDG pressure dropped below 120 percent only during juvenile spill events of 40 kcfs or less. The tailwater TDG saturation exceeded 130 percent during juvenile spill releases approaching 100 kcfs. Large differences between the observed and calculated TDG saturations were observed prior to May 10. These differences were most likely due to instrument malfunction during this period.

The operations of all spill bays in the adult spill pattern with a constant operation of 3 hours were identified during the 1997 spill season for Little Goose Dam. This data filtering resulted in a total of only 35 independent hourly observations. The delta TDG pressure was found to range from 65.6 to 276.6 mm Hg as listed in Table 6. The range in unit spillway discharge was from 1.9 to 13.2 kcfs/bay and the tailwater depth ranged from 38.5 to 41.7 ft.

Table 6. Statistical Summary of Regression Variables

	Delta Pressure ΔP (mm Hg)	Unit Spillway Discharge q_s (kcfs/bay)	Tailwater Depth D_{tw} (ft)
Number	35	35	35
Minimum	65.6	1.9	38.5
Maximum	276.6	13.2	41.7
Average	222.4	7.9	40.2
Standard Deviation	42.0	2.8	0.8

The functional relationship for the TDG production of the adult spill pattern (all eight bays) was similar to the equation determined for spill bays with flow deflectors at Little Goose Dam as shown in Equation 13. All of the coefficients determined by the non-linear regression analysis were significant to the 99 percent confidence interval as shown in Table 7. This formulation contained a much higher standard error (19.5 mm Hg) than found in other production relationships with an r-squared of 0.79. The observed and calculated delta TDG pressures were plotted against the unit spillway discharge at Little Goose Dam in Figure 12.

$$\Delta P = 6.488\, D_{tw}\ (1 - e^{-0.280 q_s}) \qquad (13)$$

Table 7. Statistical summary of nonlinear regression at Little Goose Dam, juvenile spill pattern, 1997 spill season.
$\Delta P_{tw}=c_1 * D_{tw} * (1-\exp(c_2 * q_s))$
Number of observations n=35
$r^2=0.79$
Std. Error=19.51mm Hg

Coefficient	Estimate from Regression	Standard Error	t-statistic	Probability
c_1	6.488	0.2197	29.5268	<0.0001
c_2	0.2796	0.0319	8.7538	<0.0001

Entrainment of Powerhouse Discharge   The determination of the fate of powerhouse flow was documented during the TDG exchange study conducted at Little Goose Dam (Schneider and Wilhelms, 1998). The entrainment of powerhouse flows into the bubbly flow in the stilling basin is significant below Little Goose Dam and has been estimated to be a function of the spillway discharge. The effective spillway flow (actual+entrainment) has been greater than 200 percent of the rated spillway release. The effective spillway discharge at Little Goose Dam can be estimated as Qe=1.0Qs provided that the powerhouse flows exceed the entrainment discharge.

This functional form for the entrainment discharge was applied to observed data during the 1997 spill season at Little Goose Dam. The average TDG pressure generated by Little Goose Dam operations were estimated by using a flow-weighted average of powerhouse and spillway flows. The TDG content of spillway flows were determined from Equation 13 and while the TDG pressure associated with powerhouse releases was set to the observed forebay TDG pressure. A simple hydrologic routing of project releases was performed to estimate the TDG pressure arriving at Lower Monumental Dam. No entrainment of powerhouse flows were assumed for the first scenario. The results from this analysis are shown in Figure 13 where the observed hourly TDG pressure in the forebay of Lower Monumental Dam (LMN-obs) are shown as pink circles while the estimated TDG pressure in the forebay of Lower Monumental Dam (LMN-cal) are shown as a pink line. The difference between the estimated and observed TDG pressure was as is large as 50 mm Hg and was consistently less than observed conditions throughout the month of June. The simulation of TDG exchange and transport was repeated using a simple linear relationship between spillway discharge and the estimated entrainment of powerhouse flow. The entrainment of powerhouse flow was assumed to equal to the spillway discharge as limited by available powerhouse releases. The entrained powerhouse flows were assumed to be exposed to the same conditions as spillway releases and experience comparable TDG uptake. The results from the simulation with entrainment is shown in Figure 14. The calculated TDG pressure much more closely approximates the observed TDG pressures in the forebay of Lower Monumental Dam. This evaluation agrees closely with the finding from the near-field TDG study which indicated a significant component of powerhouse releases are exposed to aerated flow conditions and TDG exchange processes.

<u>Lower Monumental Dam</u>

A TDG exchange field investigation was conducted at Lower Monumental Dam during August 21-22, 1996 with the study summarized in Schneider and Wilhelms (1997). The study consisted of sampling TDG pressures below the spillway during spillway discharges ranging from 10 to 50 kcfs. Two different spill patterns were investigated during this study: Adult and Juvenile Spill Patterns. The study findings indicated that the TDG production was directly related to the unit spillway discharge. The TDG saturation ranged from 105 to 121 percent during the study for unit spillway discharges ranging from 1.3 to 8.4 kcfs/bay. The influence of the operation of spill bays without flow deflectors was found to increase the TDG exchange for comparable unit spill discharges by as much as 9 percent saturation. The relatively small total river flows and associated range in tailwater elevations resulted in test spill conditions corresponding with tailwater elevations ranging from 438.6 to 439.9 ft.

An evaluation of data from the tailwater fixed monitoring station during 1997 provided an opportunity to study the TDG exchange of spillway flows at Lower Monumental Dam under a wider range of operating conditions. The spillway events were identified by the applied spill pattern and separate evaluations were conducted for these types of events. The data associated with spill over bays with flow deflectors with a constant operation of 3 hours were identified. This data filtering resulted in a total of 68 independent hourly observations. The delta TDG pressure was found to range from 101.9 to 238.7 mm Hg as listed in Table 8. The range in unit spillway discharge was from 2.1 to 24.1 kcfs/bay and the tailwater depth ranged from 42.7 to 48.1 ft.

Table 8. Statistical Summary of Regression Variables

	Delta Pressure ΔP (mm Hg)	Unit Spillway Discharge q_s (kcfs/bay)	Tailwater Depth D_{tw} (ft)
Number	68	68	68
Minimum	101.9	2.1	42.7
Maximum	238.7	24.1	48.1
Average	205.1	13.3	44.6
Standard Deviation	25.6	4.8	1.1

<u>Regression</u> The functional relationship between TDG production and project operation at Lower Monumental Dam was similar to Little Goose Dam. The TDG pressure in excess of the local barometric as defined by $\Delta P = P_{tw} - P_{bar}$, was found to be proportional to the product of tailwater depth and an exponential function of the specific discharge as shown in Equation 14. All of the coefficients determined by the non-linear regression analysis were significant to the 99 percent confidence interval as shown in Table 9.

This formulation explained much of the variability in the estimated dependent variable with an r-squared of 0.96 and a standard error of 5.4 mm Hg.

$$\Delta P = 5.056\, D_{tw}\ (1 - e^{-0.210 q_s}) \qquad (14)$$

Where:

ΔP = $P_{tw} - P_{bar}$
P_{tw} = Total Dissolved Gas Pressure at the tailwater FMS (mm Hg)
q_s = Flow weighted unit spill bay discharge (kcfs/bay)
D_{tw} = Tailwater channel depth (ft) (E_{tw}-E_{ch})
E_{tw} = Elevation of the tailwater (ft)
E_{ch} = Average elevation of the tailwater channel (400 ft)
P_{bar} = Barometric Pressure at the tailwater fixed monitoring station (mm Hg)

Table 9. Statistical summary of nonlinear regression at Lower Monumental Dam, juvenile spill pattern, 1997 spill season.
$\Delta P_{tw}=c_1*D_{tw}*(1-\exp(c_2*q_s))$
Number of observations n=68
$r^2=0.96$
Std. Error=5.4 mm Hg

	Coefficient	Estimate from Regression	Standard Error	t-statistic	Probability
Deflectored bays	c_1	5.056	0.0306	165.3989	<0.0001
	c_2	-0.21	0.0060	35.8829	<0.0001

The unit spillway discharge was plotted against the observed and calculated tailwater TDG pressure above the local barometric pressure as shown in Figure 15. The exponential relationship between the TDG pressure and specific discharge is evident in this figure as the TDG pressure approached an upper limit as the specific discharge becomes large. Much of the variability in the TDG pressure for a constant unit discharge can be accounted for by the variation in the tailwater channel depth.

Most of the variability in the TDG production can be accounted for by the specific discharge. The specific discharge is a surrogate measure for the velocity, momentum, and exposure time of aerated flow associated with spillway discharge. The three-dimensional response surface for Equation 14 is shown in Figure 16 along with the observed data. The TDG pressure increases for a constant unit spillway discharge as the tailwater channel depth increases. However, the influence of the tailwater depth is small as evidenced by the small slope in the response surface for a constant unit discharge. The tailwater channel depth is a function of the total river flow and the pool elevation of the lower reservoir. This relationship couples the operation of the powerhouse at Lower Monumental Dam and the storage management in Ice Harbor pool to the TDG production in spillway releases from the Lower Monumental spillway.

The response function as defined in Equation 14 was used to hind cast the TDG production observed during the 1997 spill season. The hourly project operation and TDG saturation at the Lower Monumental Dam fixed monitoring stations (LMN-forebay, LMNW-tailwater) for the month of May, 1997 are show in Figure 17 along with the estimates of TDG saturation based on Equation 14. In general, the estimated tailwater TDG saturation (LMNW-cal) was generally within 1 percentage point of the observed tailwater TDG saturation. Spillway releases greater than 40 kcfs generally produced tailwater TDG saturation greater than 120 percent during this period. Forced spillway releases of 120 kcfs generated tailwater TDG saturation in excess of 132 percent. The usage of the adult spill pattern in Figure 17 is indicated by the operation of spill bay 1 (QS1-red).

The operations of all spill bays in the adult spill pattern with a constant operation of 3 hours were identified during the 1997 spill season. This data filtering resulted in a total of only 34 independent hourly observations. The delta TDG pressure was found to range from 134.5 to 267.5 mm Hg as listed in Table 10. The range in unit spillway discharge was from 2.2 to 12.5 kcfs/bay and the tailwater depth ranged from 43.5 to 46.6 ft.

Table 10. Statistical Summary of Regression Variables

	Delta Pressure	Unit Spillway Discharg	Tailwater Depth

	ΔP (mm Hg)	e q_s (kcfs/bay)	D_{tw} (ft)
Number	34	34	34
Minimum	134.5	2.2	43.5
Maximum	267.5	12.5	46.6
Average	237.1	7.5	45.1
Standard Deviation	23.8	2.5	0.8

The functional relationship for the TDG production of the adult spill pattern (Equation 15) was similar to the equation determined for spill bays with flow deflectors at Lower Monumental Dam. All of the coefficients determined by the non-linear regression analysis were significant to the 99 percent confidence interval as shown in Table 11. This formulation contained a much higher standard error (15.9 mm Hg) than found in other production relationships with an r-squared of 0.57. The observed and calculated delta TDG pressures were plotted against the unit spillway discharge in Figure 18.

$$\Delta P = 5.427\, D_{tw}\, (1 - e^{-0.580 q_s}) \qquad (15)$$

Table 11. Statistical summary of nonlinear regression at Lower Monumental Dam, adult spill pattern, 1997 spill season.
$\Delta P_{tw}=c_1 * D_{tw} * (1-\exp(c_2 * q_s))$
Number of observations n=34
r^2=0.57
Std. Error=15.9 mm Hg

Non-deflectored bays	c_1	5.427	0.0853	63.5939	<0.0001
	c_2	-0.58	0.0769	7.5959	<0.0001

<u>Entrainment of Powerhouse Discharge</u> Estimates of the entrainment of powerhouse flows into spillway discharge were not available from this the near-field study because of the limited amount of powerhouse discharge. Visual observations of surface flow patterns below the powerhouse suggested that all powerhouse releases (14.5-19.2 kcfs) were being directed into the stilling basin. Since direct determination of the entrainment of powerhouse flows into the highly aerated conditions below Little Goose

Dam were not practical, it was assumed that the entrainment characteristics of Lower Monumental Dam were similar to Ice Harbor Dam. The estimates of the entrainment of powerhouse flows were estimated to average 30 kcfs and to be independent of the total spillway discharge.

Ice Harbor Dam

TDG Exchange The installation of spillway flow deflectors at Ice Harbor Dam were completed in a staged schedule over 3 years. The first four deflectors were completed during the winter of 1996-97 followed by four more deflectors the following winter. The end bay deflectors were completed during the winter of 1998-99. Type II flow deflectors were installed in spill bays 2-9 at elevation 338 ft at Ice Harbor Dam. The flow deflectors significantly changed the TDG exchange properties and spill management from Ice Harbor Dam. A detailed post flow deflector near-field study of TDG exchange below Ice Harbor Dam was conducted during March 5-9, 1998 as described by Wilhelms and Schneider (1998). The study consisted of sampling TDG pressures below the stilling basin during spillway discharges ranging from 15 to 75 kcfs with and without powerhouse flows. Several different spill patterns were investigated during this study: uniform bays 2-9, and standard spill pattern. The study findings indicated that the TDG production was directly related to the unit spillway discharge. The TDG saturation was found to be an exponential function of unit spillway discharge with 110 percent saturation associated with a unit spillway discharge of 3 kcfs/bay and 115 percent saturation generated for a unit spillway discharge of 8 kcfs/bay for the uniform spill pattern. The data did support the additional influence of the tailwater depth of flow on the TDG exchange characteristics. The addition of flow deflector significantly reduced the absorption of TDG in the stilling basin reducing the peak TDG pressures just downstream of the stilling basin end sill from 170 to 135 percent saturation.

The evaluation of data from the tailwater fixed monitoring station during 1998 provided the opportunity to study the TDG exchange of spillway flows under a wider range of operating conditions. The spillway operation at Ice Harbor Dam was found to generate significantly lower TDG pressures during lower total river flow conditions in comparison to the other Snake River projects. The unit spillway discharge was plotted against the tailwater TDG saturation in Figure 19 for the filtered data during the 1998 spill season at Ice Harbor Dam. Two distinct linearly related groupings of points can be seen in this figure that roughly correspond with low and high total river flow conditions. The lower limit of this data cluster corresponds with lower total river flows and low tailwater stage. The corresponding spill capacity for a 120% tailwater waiver standard can be as high as 100 kcfs based on the lower limit in this data cluster. The upper limit of this data cluster corresponds with the highest total river flows experienced during 1998. The spill capacity for a TDG saturation of 120% in spillway releases into the tailwater channel could be as low as 70 kcfs. During the forced spill conditions at Ice Harbor Dam (15 kcfs/bay discharges) the TDG pressures generated at Ice Harbor Dam were significantly higher (10-20 mm Hg) than at upstream projects on the Snake River.

A second interesting feature of the relationship between unit spillway discharge and tailwater TDG saturation is the large variance in TDG saturation with unit spillway discharges of 4.5 and 9.0 kcfs/bay. These two spill levels correspond with the daytime and nighttime spillway capacities scheduled during much of the voluntary spring spill season. The data corresponding with a unit discharge of 9.0 kcfs/bay +/- 0.2 kcfs/bay were extracted from the body of the data and plotted against the tailwater stage, initial forebay saturation, and water temperature. The tailwater stage was found to be highly correlated with this subset of data for a constant unit spillway discharge. A linear regression between TDG saturation and tailwater stage resulted in a correlation coefficient of 0.76, and a slope of 0.8 percent saturation per foot. This relationship suggests a 8 percent increase in TDG saturation should result from a 10 feet increase in depth of the tailwater channel

<u>Regression</u> A nonlinear regression was performed on the data from the 1998 spill season. The dependent variable was TDG pressure above the barometric pressure at the tailwater FMS. The two independent variables were tailwater depth and average unit spillway discharge. To prevent the incorporation of redundant data pairs during the same extended operation, only data with a constant operation for three hours were included in the analysis, resulting in a sample set of 233 observations. The tailwater depth ranged from 19.4 ft to 34.5 ft which corresponded with total river flows from 29.7

kcfs to 243 kcfs as listed in Table 12. The unit spillway discharge ranged from 1.8 to 14.9 kcfs/bay and the delta pressure ranged from 79.3 to 239.0 mm Hg.

Table 12. Statistical Summary of Regression Variables

	Delta Pressure ΔP (mm Hg)	Unit Spillway Discharge q_s (kcfs/bay)	Tailwater Depth D_{tw} (ft)
Number	234.0	234.0	234.0
Minimum	79.3	1.8	19.4
Maximum	239.0	14.9	34.5
Average	132.9	6.5	25.6
Standard Deviation	23.5	2.3	3.0

The change in TDG pressure as defined by $\Delta P = P_{tw} - P_{bar}$ below Ice Harbor Dam during spillway operations was found to be proportional to the product of tailwater depth and the specific discharge as shown in Equation 16. The regression equation was based on data collected during the 1998 spill season. All of the coefficients determined by the non-linear regression analysis were significant to the 99 percent confidence interval as shown in Table 13. This formulation explained much of the variability in the estimated dependent variable with an r-squared of 0.90 and a standard error of 7.63 mm Hg. The constant coefficient of 84.57 forces a minimum TDG saturation of 112 percent at an atmospheric pressure of 755 mm Hg.

$$\Delta P = 0.014\, D_{tw}^{2.097} q_s^{0.772} + 84.57 \qquad (16)$$

Where:

ΔP = $P_{tw} - P_{bar}$
P_{tw} = Total Dissolved Gas Pressure at the tailwater FMS (mm Hg)
q_s = Flow weighted unit spill bay discharge (kcfs/bay)
D_{tw} = Tailwater channel depth (ft) (E_{tw}-E_{ch})
E_{tw} = Elevation of the tailwater (ft)
E_{ch} = Average elevation of the tailwater channel (320 ft)
P_{bar} = Barometric Pressure at the tailwater fixed monitoring station (mm Hg)

Table 13. Statistical summary of nonlinear regression for Ice Harbor Dam,
1998 spill season.
□$P = c_1 * Dtw^{c2} qs^{c3} + c_4$
Number of observations n=233
r^2=0.90
Std. Error= 7.63 mm Hg

Coefficient	Estimate from Regression	Standard Error	t-statistic	Probability
c_1	0.0140	0.0471	1.98	0.0486
c_2	2.097	0.0652	11.66	<0.0001
c_3	0.772	0.1356	11.99	<0.0001
c_4	84.57	3.62	24.04	<0.0001

This relationship implies both the depth of flow and specific discharge are important factors in determining the level of TDG exchanged during spillway releases. The response surface for TDG pressure above atmospheric pressure as a function of both unit discharge and tailwater stage is shown in Figure 20. The depth of the channel will influence the pressure time history of entrained air with larger depths resulting in a greater potential for the exchange of TDG. The specific discharge or discharge per spill bay reflects the amount of energy available during spillway releases, which will establish the turbulence and the potential to entrain air in the stilling basin. The level of forebay TDG saturation was not an important parameter. Water temperature was not a significant variable in the exchange relationship at Ice Harbor Dam.

Equation 16 was highly significant in explaining the variance in the TDG pressure at the tailwater FMS. The regression model was used to hind cast the observed tailwater TDG saturation below Ice Harbor Dam for the 1998 spill season. The results are shown in Figure 21 for the month of May 1998. The calculated TDG saturation closely tracked the diurnal variation in tailwater TDG saturation during May with a tendency to slightly over-estimate the observed conditions during the conditions during the beginning of the month. Even with this robust relationship, caution and judgement must be applied, when using this equation outside the ranges of discharge and tailwater depth from which is was derived. The average, absolute, and root mean square error in TDG saturation computed using all of the observed data with spillway discharge during the months of April through July of 1998 were -0.3, 1.3, and 2.1 percent respectfully. The calculation of the error of estimate of the tailwater TDG pressure did not take into account the lagged time of response between operational changes and arrival of water at the tailwater FMS.

The management of project operations with regard to TDG, must take into account the level of spillway discharge, spill pattern, and tailwater stage. The spill capacity resulting in 120 percent TDG saturation below Ice Harbor Dam will be a direct function of both the total river flow which is the determinant of tailwater stage and unit spillway discharge.

Entrainment of Powerhouse Discharge The entrainment of powerhouse the highly aerated flow conditions below Ice Harbor Dam was estimated from data collected during the 1998 spillway TDG exchange study. The powerhouse entrainment discharge was estimated for each flow conditions by applying a simple mass balance statement of powerhouse and spillway project flows. The estimates of the entrainment of powerhouse flows were found to range from 26.4 to 38.5 kcfs average and average about 30 kcfs. The powerhouse entrainment discharge was not found to vary as a function of the total spillway discharge.

McNary Dam

TDG Exchange A TDG exchange field investigation was conducted at McNary Dam during February 11-13, 1996 with the study summarized in Wilhelms and Schneider (1997). The study consisted of sampling TDG pressures below the spillway during spillway discharges ranging from 50 to 285 kcfs. Two different spill patterns were investigated during this study: Standard, and Uniform Spill Patterns. The study findings indicated that the TDG production was directly related to the unit spillway discharge. The TDG saturation ranged from 108 to 135 percent during the study for unit spillway discharges ranging from 2 to 17 kcfs/bay. The influence of the operation of spill bays without flow deflectors was found to increase the TDG exchange for comparable unit spill discharges. The relatively small total river flows and associated range in tailwater elevations resulted in test spill conditions corresponding with tailwater elevations ranging from 265.5 to 269.0 ft.

Regression The TDG production during spillway releases from McNary Dam as defined by $\Delta P = P_{tw} - P_{bar}$, was found to be power function of tailwater depth and the specific discharge as shown in Equation 17. The form of this functional relationship was similar to the equation developed at Ice Harbor Dam. The regression equation was based on data collected during the 1997 spill season. The data filtering resulted in 172 observations. The delta TDG pressure ranged from 81.9 mm Hg to a maximum value of 307.6 mm Hg as listed in Table 14. The range in unit spillway discharge ranged from 2.0 kcfs/bay to 21.9 kcfs/bay and the tailwater depth ranged from 30.8 to 40.5 ft.

Table 14. Statistical Summary of Regression Variables

	Delta Pressure ΔP (mm Hg)	Unit Spillway Discharge q_s (kcfs/bay)	Tailwater Depth D_{tw} (ft)
Number	173	173	173
Minimum	81.9	2.0	30.8
Maximum	307.6	21.9	40.5
Average	191.6	11.7	35.0
Standard Deviation	53.0	5.4	2.2

The unit spillway discharge was plotted against the observed and calculated tailwater TDG pressure difference in Figure 22. The near linear relationship between the TDG pressure and unit discharge is evident in this figure as the TDG pressure continues to increase as the specific unit discharge becomes large. Much of the variability in the TDG pressure for a constant unit discharge can be accounted for by the variation in the tailwater channel depth. All of the coefficients determined by the non-linear regression analysis were significant to the 99 percent confidence interval as shown in Table 15. This formulation explained much of the variability in the data with an r-squared of 0.97 and a standard error of 9.25 mm Hg.

$$\Delta P = D_{tw}^{0.647} q_s^{0.969} + 82.14 \qquad (17)$$

Where:

ΔP = $P_{tw} - P_{bar}$
P_{tw} = Total Dissolved Gas Pressure at the tailwater FMS (mm Hg)
q_s = unit spill bay discharge (kcfs/bay)
D_{tw} = Tailwater channel depth (ft) (E_{tw}-E_{ch})
E_{tw} = Elevation of the tailwater (ft)
E_{ch} = Average elevation of the tailwater channel (235 ft)
P_{bar} = Barometric Pressure at the tailwater fixed monitoring station (mm Hg)

Table 15. Statistical summary of nonlinear regression McNary Dam,
1997 spill season.
$\Delta P = D_{tw}^{c1} q_s^{c2} + c_3$
Number of observations n=173
r^2=0.97
Std. Error=9.26 mm Hg

Coefficient	Estimate from Regression	Standard Error	t-statistic	Probability
c_1	0.647	0.0693	12.71	<0.0001
c_2	0.969	0.0762	9.35	<0.0001
c_3	82.14	5.89	14.08	<0.0001

A review of the regression coefficients in Equation 17 reveals that the TDG exchange is relatively insensitive to the variation in the depth of flow below McNary Dam. The response surface for TDG pressure above atmospheric pressure as a function of both unit spillway discharge and tailwater stage is shown in Figure 23.

The response function as defined in Equation 17 was used to hind cast the TDG production observed during the 1997 spill season. The hourly project operation and TDG saturation at the McNary fixed monitoring stations for the month of June, 1998 are show in Figure 24 along with the estimates of TDG saturation based on Equation 3. In general, the estimated TDG saturation was generally within 1 percentage point of the observed tailwater TDG saturation. The maximum daily spillway discharge remained constant during much of the month of June with little variation in the production of TDG saturation. The forebay TDG level varied considerably during this period with little or no influence on the result TDG pressures. These observations are supported by observations at other projects that suggest the initial TDG pressure of spillway releases have little influence on the resultant pressure. The occurrence of atypical spill patterns, measurement error, and dilution with powerhouse releases probably accounts for much of the estimation error shown during this period.

The TDG performance of the spill bays without flow deflectors was needed to derive the TDG exchange from the exiting spillway. Spill bays 1, 2, 21, and 22 do not have flow deflectors and are typically operated by raising only the upper leaf of the split leaf vertical gates. This operation results in a jet that plunges into the stilling basin as a fully aerated nap. It should be noted that bay 22 is not typically operated due to absence of a dedicated gate hoist.

The results from the near-field TDG exchange test were used to estimate the TDG exchange characteristics of standard spill bays. The TDG production resulting from uniform spill flows bays 3-20 (bay with flow deflectors) was subtracted from the TDG response for the standard spill pattern. The difference in the delta TDG pressure generated between these curves was divided by the discharge from the spill bays 1, 2, and 21 to arrive at the response relation listed in Equation 18. A linear relationship between the unit spillway discharge and delta TDG pressure was estimated for these end bays at McNary Dam. The non-deflectored bay generated TDG saturation about 10 percent greater on average than deflectored bays.

$$\Delta P = 11.35qs + 143.1 \tag{18}$$

<u>Powerhouse Entrainment</u> Estimates of the entrainment of powerhouse flows into spillway discharge were not available from this study because of the limited amount of powerhouse discharge and the absence of flow distribution information. Since direct determination of the entrainment of powerhouse flows into the highly aerated conditions below McNary Dam were not practical, it was assumed for this study that the entrainment characteristics of McNary Dam were similar to John Day Dam. The

estimates of the entrainment of powerhouse flows was estimated to average 35 kcfs at McNary Dam and to be independent of the total spillway discharge.

John Day Dam

TDG Exchange The installation of spillway flow deflectors at John Day Dam were completed during the winter of 1997-8. A type II flow deflector was installed in spill bays 2-19 at elevation 148 ft at John Day Dam. The flow deflectors significantly changed the TDG exchange properties of releases from John Day Dam. A detailed near-field study of TDG exchange below John Day Dam was conducted during February 10-12, 1998 as described by Schneider and Wilhelms (1998). The study consisted of sampling TDG pressures below the stilling basin during spillway discharges ranging from 36 to 246 kcfs. Several different spill patterns were investigated during this study: uniform bays 2-19, uniform bays 1-20, provisional standard spill pattern, and uniform bays 10-19. The study findings indicated that the TDG production was directly related to the unit spillway discharge. The TDG saturation was found to be an exponential function of unit spillway discharge with 115 percent saturation associated with a unit spillway discharge of 4 kcfs/bay and 120 percent saturation generated for a unit spillway discharge of 9 kcfs/bay for the uniform spill pattern. The main limitation of this TDG exchange study was the small range in tailwater elevations (158.4 to 161.3 ft).

The influence of standard operating conditions on TDG exchange was further investigated through analyzing the TDG exchange indicated by the fixed monitoring station during the 1998-spill season. These conditions involved the newly adopted spill pattern, a wider range in tailwater elevation, and forced and voluntary spill discharges. The observed TDG data at the John Day tailwater FMS were used to generate a description of TDG exchange. The filtering of this data resulted in a total of 51 observations as summarized in Table 16. The observed ΔP ranged from 108 mm Hg to

184.0 mm Hg for these 51 events. The unit spillway discharge was found to range from 4.3 to 9.4 kcfs/bay and the tailwater depth was found to range from 33.6 to 42.4 ft.

Table 16. Statistical Summary of Regression Variables			
	Delta Pressure ΔP (mm Hg)	Unit Spillway Discharge q_s (kcfs/bay)	Tailwater Depth D_{tw} (ft)
Number	52.0	52.0	52.0
Minimum	108.0	4.3	33.6
Maximum	184.0	9.4	42.4
Average	152.7	7.1	38.7
Standard Deviation	16.7	1.2	1.9

The functional relationship between TDG production and project operation at John Day Dam was similar to those relationships derived for the upper Snake River projects. The delta TDG pressure as defined by $\Delta P = P_{tw} - P_{bar}$, was found to be proportional to the product of tailwater depth and an exponential function of the specific discharge as shown in Equation 19. Both of the coefficients determined by the non-linear regression analysis were significant to the 99 percent confidence interval as shown in Table 17. This formulation explained much of the variability in the data with an r-squared of 0.84 and a standard error of 6.8 mm Hg.

$$\Delta P = 4.969\, D_{tw}\,(1 - e^{-0.2278 q_s}) \qquad (19)$$

Where:

ΔP = $P_{tw} - P_{bar}$
P_{tw} = Total Dissolved Gas Pressure at the tailwater FMS (mm Hg)
q_s = unit spill bay discharge (kcfs/bay)
D_{tw} = Tailwater channel depth (ft) (E_{tw}-E_{ch})
E_{tw} = Elevation of the tailwater (ft)
E_{ch} = Average elevation of the tailwater channel (125 ft)
P_{bar} = Barometric Pressure at the tailwater fixed monitoring station (mm Hg)

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Table 17. Statistical summary of nonlinear regression John Day Dam, 1998 spill season (bays 2-19 with flow deflectors). $\Delta P_{tw}=c_1*D_{tw}*(1-\exp(c_2*q_s))$ Number of observations n=51 $r^2=0.84$ Std. Error= 6.78mm Hg				
Coefficient	Estimate from Regression	Standard Error	t-statistic	Probability
c_1	4.969	0.192	25.908	<0.0001
c_2	-0.2278	0.0221	10.3069	<0.0001

The unit spillway discharge was plotted against the observed and calculated tailwater TDG pressure above the local barometric pressure as shown in Figure 25. The exponential relationship between the TDG pressure and specific discharge is not as clearly defined at John Day Dam as other projects with this functional form. Much of the variability in the TDG pressure for a constant unit discharge can be accounted for by the variation in the tailwater channel depth. Equation 19 can be solved directly for the unit specific discharge assuming a delta P of 150 mm Hg (120 percent saturation) and a tailwater depth of 35 ft. The resultant unit spillway discharge of about 9 kcfs/bay is the solution to this equation. This unit spillway discharge was similar to the spillway capacity determined during the near-field TDG exchange study.

The three-dimensional response surface for Equation 19 is shown in Figure 26 along with the observed data. The TDG pressure increases for a constant unit spillway discharge as the tailwater channel depth increases. The influence of the tailwater depth is significant as evidenced by the slope in the response surface for a constant unit discharge. The upper limit in delta TDG pressure will continue to increase with increasing tailwater elevation. The TDG response during voluntary spill conditions will be different than a comparable spill discharge at a much higher total river flow.

The tailwater TDG saturation as approximated by Equation 19 was used to hind cast the TDG production observed during the 1998 spill season below John Day Dam. The hourly project operation and TDG saturation at the John Day Dam tailwater fixed monitoring stations (JHAW) for the months of May and June, 1998 are show in Figure 27 along with estimates of the tailwater TDG saturation (JHAW-est). In general, the estimated average TDG saturation was generally within 7 mm Hg of the observed tailwater TDG pressure. The operating conditions during May of 1998 depict both forced and voluntary spill conditions. The spill discharges were as high as 230 kcfs for total river flows over 400 kcfs resulting in tailwater TDG saturation of about 126 %. The nighttime only spill operations during the last two weeks of June imply voluntary spill conditions. Note the range in TDG response for the constant nighttime spill operations during this period. The nighttime spill on June 21 corresponded with elevated total river flows and high tailwater conditions resulted in TDG saturation exceeding 121 percent. A comparable spill two days later during much lower total river flow and tailwater stage conditions resulted in TDG saturations of only 119 percent.

John Day Dam has two spill bays without flow deflectors. The TDG response of these two bays were estimated using tailwater TDG pressures observed prior to the installation of the 18 flow deflectors during the 1996 and 1997 spill seasons. A total of 1137 hourly observations were pooled from the 1996 and 1997 spill seasons. The presence of 2 flow deflectors located in bays 18 and 19 during the 1997 spill season were not thought to influence the TDG response at the tailwater fixed monitoring station below John Day Dam. The range in the delta pressure for these events ranged from 84 to 324 mm Hg as shown in Table 18. The unit spillway discharge ranged from 1.8 to 15.3 kcfs/bay and the tailwater depth ranged from 35.6 to 46.7 ft during this sample period.

Table 18. Statistical Summary of Regression Variables

	Delta Pressure ΔP (mm Hg)	Unit Spillway Discharge q_s (kcfs/bay)	Tailwater Depth D_{tw} (ft)
Number	1137.0	1137.0	1137.0
Minimum	84.0	1.8	35.6
Maximum	324.0	15.3	46.7

Average	223.0	5.8	41.1
Standard Deviation	64.6	3.0	2.3

The delta pressure of a standard spill bay at John Day Dam was determined to be a function of the unit spillway discharge. The functional form of this relationship is shown in Equation 20 where a threshold delta pressure of 315.3 mm Hg is approached for large unit spillway discharges as shown in Figure 28. The maximum TDG saturation generated by this relationship approaches 141 percent for a barometric pressure of 760 mm Hg. . All of the coefficients determined by the non-linear regression analysis were significant to the 99 percent confidence interval as shown in Table 19. This formulation explained much of the variability in the data with an r-squared of 0.94 and a standard error of 15.9 mm Hg. The TDG exchange for a known spill pattern using bays with and without flow deflectors can be estimated by using both Equation 19 and 20. The average TDG pressure associated with a spill discharge would be determined by calculating a flow weighted average of the individual spill bay responses.

$$\Delta P = 315.29 - 519.09\, e^{-0.365 q_s} \qquad (20)$$

Table 19. Statistical summary of nonlinear regression John Day Dam,
1996-1997 spill season.
$\Delta P_{tw}=c_1-c_2*\exp(c_3*q_s)$
Number of observations n=1137
r^2=0.94
Std. Error=15.95mm Hg

Coefficient	Estimate from Regression	Standard Error	t-statistic	Probability
c_1	315.29	1.647	191.46	<0.0001
c_2	-519.09	10.3867	-49.975	<0.0001
c_3	-0.3649	0.0084	-43.38	<0.001

Powerhouse Entrainment The entrainment of powerhouse the highly aerated flow conditions below John Day Dam was estimated from data collected during the 1998 spillway TDG exchange study (Schneider and Wilhelms, 1998). The average TDG pressure of project and spillway releases were used with a simple mass balance statement of project flows were used to provide estimates of the effective spillway discharge and entrainment of powerhouse flows. The estimates of the entrainment of powerhouse flows were found to range from 5 to 60 kcfs average and average about 35 kcfs. The powerhouse entrainment discharge was not found to vary as a function of the total spillway discharge.

The Dalles Dam

Regression A TDG exchange field investigation was conducted below The Dalles Dam during August 28 and 29, 1996 with the study summarized in Schneider and Wilhelms (1996). The study consisted of sampling TDG pressures below the spillway during spillway discharges ranging from 50 to 200 kcfs. Three different spill patterns were investigated during this study: Adult, Juvenile, and Uniform Spill Patterns. The study findings indicated that the TDG production was weakly related to the unit spillway discharge. The TDG saturation ranged from 119 to 124 percent during the study for unit spillway discharges ranging from 2 to 14 kcfs/bay. The influence of the spill pattern was found to be accounted for by representing the total spillway discharge as defined by unit spill bay discharge. The main limitation of this TDG exchange study was the small range in tailwater elevation (75.7 to 78.3 ft).

The high river flows and spillway discharges during 1997 generally fell outside of the range of conditions scheduled during the 1996 spillway performance test. The application of the TDG production relationship determined during the 1996 near-field study did not replicate TDG conditions observed below The Dalles Dam during the 1997 spill season. The observed TDG data at The Dalles Dam from the forebay and tailwater FMS were used to generated an alternative description of TDG exchange. The TDG pressures observed at the forebay FMS were assumed to represent the conditions discharged from the powerhouse. The TDG pressures observed at the tailwater FMS were assumed to reflect the average TDG pressures in the Columbia River. The TDG properties of spillway discharge were estimated by performing a simple mass balance of project releases. The hourly data was filtered to retain only those data having constant project operations for a duration of 6 hours. This criterion was selected to allow steady-state conditions to develop at the tailwater fixed monitoring station located 3 miles downstream of the project. This criterion also allowed the inclusion of a single data for each extended event. This data filtering resulted in a total of 87 observations a summarized in Table 20. The estimated ΔP ranged from 143.3 mm Hg to 203.6 mm Hg for these 87 events. The unit spillway discharge was found to range from 4.3 to 19.0 kcfs/bay and the tailwater depth was found to range from 8.3 to 23.3 ft.

Table 20. Statistical Summary of Regression Variables

	Delta Pressure ΔP (mm Hg)	Unit Spillway Discharge q_s (kcfs/bay)	Tailwater Depth D_{tw} (ft)
Number	87.0	87.0	87.0
Minimum	143.3	4.3	8.3
Maximum	206.6	19.0	23.3
Average	178.4	9.6	14.5
Standard Deviation	14.1	3.6	3.6

The spillway releases from The Dalles Dam as defined by $\Delta P = P_{tw} - P_{bar}$, was found to be proportional to the product of tailwater depth and the specific discharge as shown in Equation 21. The regression equation was based on data collected during the 1997 spill season. The data filtering resulted in a total of 87 independent observations. The unit spillway discharge was plotted against the estimated and calculated tailwater delta TDG pressure in Figure 29. The form of the relationship shown in Equation 21 implies the TDG exchange for small spillway discharge will exceed 120 percent as was observed during the 1996 near-field investigation. All of the coefficients determined by the non-linear regression analysis were significant to the 99 percent confidence interval as shown in Table 21. This formulation explained much of the variability in the estimated dependent variable with an r-squared of 0.735 and a standard error of 7.3 mm Hg.

$$\Delta P = D_{tw}^{1.02} q_s^{0.33} + 145.9 \qquad (21)$$

Where:

ΔP = $P_{tw} - P_{bar}$
P_{tw} = Total Dissolved Gas Pressure at the tailwater FMS (mm Hg)
q_s = unit spill bay discharge (kcfs/bay)
D_{tw} = Tailwater channel depth (ft) (E_{tw}-E_{ch})
E_{tw} = Elevation of the tailwater (ft)
E_{ch} = Average elevation of the tailwater channel (68 ft)
P_{bar} = Barometric Pressure at the tailwater fixed monitoring station (mm Hg)

Table 21. Statistical summary of nonlinear regression The Dalles Dam,
1997 spill season.
$\Delta P = D_{tw}^{c1} q_s^{c2} + c_3$
Number of observations n=87
r^2=0.735
Std. Error= 7.34 mm Hg

Coefficient	Estimate from Regression	Standard Error	t-statistic	Probability
c_1	1.02	0.12	2.69	<0.0086
c_2	0.33	0.12	8.72	<0.0001
c_3	145.9	2.21	66.11	<0.0001

The dual dependency of the delta pressure change on tailwater depth and unit spill bay discharge is shown in Figure 30. This equation also indicates that the depth of flow accounts for most of the variability in the increase in TDG pressure associated with spillway discharges. The increase in TDG pressure was found to be a linear function of the depth of flow for a constant unit spillway discharge. The tailwater channel depth is a function of the total river flow and the pool elevation of the lower reservoir. This relationship couples the operation of the powerhouse at The Dalles Dam and the storage management in Bonneville pool to the TDG production in spillway releases from the The Dalles spillway.

The response function as defined in Equation 21 was used to hind cast the TDG production observed during the 1997 spill season. The hourly project operation and TDG saturation at The Dalles tailwater fixed monitoring stations (TDDO)for the month of June, 1997 are show in Figure 31 along with the estimates of the flow-weighted TDG saturation (TW-psat-est) released from The Dalles Dam based on Equation 21 and observations of TDG pressures in the forebay. In general, the estimated average TDG saturation was generally within 7 mm Hg of the observed tailwater TDG pressure. The maximum daily spillway discharge and percent of river spilled varied greatly during June of 1997 with spill discharges as high as 480 kcfs. The forebay TDG pressure often were higher than the tailwater TDG pressures implying a net reduction in TDG conditions in the Columbia River as a result of the operation of The Dalles Dam. The second half of June found the TDG pressures below The Dalles Dam larger than observed at the forebay station implying a net increase in TDG conditions in the Columbia River as a result of the operation of The Dalles Dam. The conditions during the latter half of June in 1997 reflect conditions more typical of voluntary spill conditions where spill at The Dalles Dam contributes to higher TDG loading in the Columbia River.

<u>Powerhouse Entrainment</u> The entrainment of powerhouse water into the aerated spilling basin was assumed to be zero at The Dalles Dam. The powerhouse is located a considerable distance from the spillway. The standard spillway design efficiently dissipates energy in the stilling basin which minimizes the potential to entrain flow laterally. The extent of aerated flow generally does not extend downstream of the shallow shelf below the stilling basin. The TDG exchange was not found to large near the downstream limits of the shallow tailwater shelf below the spillway (Wilhelms and Schneider, 1996).

<u>Bonneville Dam</u>

A description of total dissolved gas exchange at Bonneville Dam is needed to evaluate dissolved gas abatement alternatives and develop a system model of total dissolved gas properties. Structural alternatives to be evaluated under the fast-track project currently include operational adjustments, the addition of up to six new deflectors (bays 1,2,3,16 ,17and 18) and the provisional modifications to the existing 13 spillway flow deflectors. A description to describe TDG exchange is required to evaluate the various structural and operational alternatives. The following document presents the finding of a two total dissolved gas exchange studies conducted below Bonneville Dam and the TDG production relationships that were derived from this body of work. The first study was conducted during February 1-4, 2000 and involved measuring TDG pressures and velocities below the Bonneville Spillway. The objective of this investigation was to describe the TDG exchange processes associated with non-deflected bays, deflected bays, and a combination of deflectored and non-deflected bays as dictated by the standard spill patterns. The second test was conducted during May 7 – June 7 and involved measuring TDG pressures near the exit of the Bonneville spillway channel. The objective of this test was to investigate the role of tailwater elevation changes on the exchange of TDG associated with spillway releases during standard operating conditions.

The total dissolved gas pressures and flow distributions were measured near the exit of the Bonneville Spillway channel during the first week in February (Schneider and Carroll, 2000). A total of eleven TDG instruments were deployed across the channel at fixed locations and logged TDG pressure, water temperature, DO, and instrument depth on a fifteen minute interval. The velocity field was also measured near this array of instruments using an Acoustic Doppler Current Profiler. The TDG pressures were then integrated with the velocity field to estimate the TDG loading produced during spillway operations.

The test conditions involved spillway flows over non-deflected bays, deflected bays, and a combination of both deflectored and non-deflected bays. A total of five spill levels corresponding with gates setting of 1, 2, 3, 4, and 5 dogs were investigated for 4 different spill patterns. The first day of testing utilized only non-deflected bays 2, 3, 16, and 17 (day 1). The spill pattern for the second day of testing involved only deflected bays 8-15 with spill flow uniformly distributed (day 2). The third day of testing involved a uniform pattern over deflected bays 9-15, and non-deflected bays 16-17 (day

3). The spill pattern tested on the fourth day involved the standard 1997 spill pattern (day 4).

The non-deflected bays generated the highest TDG saturation for gate setting(s) up through 3 dogs as shown in Figure 32. The steady-state TDG saturation at nine sampling stations on transect T3 located at the mouth of the spillway channel are shown in this figure. The stations were labeled L1-L9 from south to north along this transect. The flow weighted TDG saturation on this transect is labeled T3avg. During the 2-dog setting, the non-deflected bays generated an average TDG saturation of 132 percent or about 12 percent greater than the comparable flows during day 2. The TDG saturation associated with non-deflected bays remained constant for gate setting of 2 dogs and higher.

The TDG saturation response to the unit spillway discharge over only deflected bays was nearly linear for gate settings of 1 through 4 dogs. This relationship was nearly identical to similar conditions measured during the initial Bonneville spillway performance test (Wilhelms and Schneider, 1997). The TDG saturation at 2 dogs was observed to be about 120 percent on all eleven instruments located across the spillway exit channel. Larger lateral gradients in TDG pressure were observed for higher discharges over the deflected bays as shown in Figure 33. The TDG pressures generated with deflectored spillway releases were observed to be greater than conditions for non-deflectored bays for spillway flows of 4 dogs and higher.

A flow-weighted specific spillway discharge was determined for the standard spill pattern because of the non-uniform distribution of flow. This representation of unit spillway discharge places more importance on flows from bays with larger discharges. The spill patterns during the five test conditions on day 4 are shown in Figure 34. The initial discharge of 50 kcfs on day 4 had a flow-weighted discharge of over 6 kcfs/bay due to the gap-toothed pattern where a highly non-uniform flow distribution was used. The high percentage of flow over the non-deflected bays resulted in nearly a constant TDG saturation for the first three test conditions. The slope of the TDG saturation and unit discharge curve approached conditions observed during the uniform patterns on day 3 during spill over both deflectored and non-deflected bays. The TDG saturation associated with the standard spill pattern was 125 percent and higher for all the test conditions.

Empirical relationships were derived for non-deflectored and deflected bay spill conditions. These regression equations were then applied to the individual bays used in the mixed bay spill patterns on the third and fourth day of the test to determine if these properties were additive. An exponential equation was fitted to the five flow conditions observed on the first day (non-deflected bays only). The following equation expresses the increase in TDG pressure over barometric pressure as a function of the unit discharge. Equation 22 is applicable only to non-deflected bays 1, 2, 3, 16, and 17 at the Bonneville spillway.

$$\Delta P = 255.58 - 1031.58 e^{-0.639 q_s} \qquad (22)$$

Where:

$\Delta P = P_{tdg} - P_{bar}$ (mmHg)
q_s = unit spillway discharge (kcfs/bay)
$q_s > 3.0$ kcfs/bay

A third order polynomial was fit to the five test conditions associated with the uniform spill over deflected bays. A third order polynomial was chosen because of the rapid change in slope of the curve at the higher discharges. Equation 23 expresses the increase in TDG pressure over barometric pressure as a function of the unit discharge. This equation only applies to the deflected bays 4-14 at the Bonneville spillway. This equation is not appropriate for unit discharges less than 3 kcfs/bay.

$$\Delta P = -0.0567 q_s^3 + 0.421 q_s^2 + 27.823 q_s - 37.067 \qquad (23)$$

Where:

$\Delta P = P_{tdg} - P_{bar}$ (mmHg)
q_s = unit spillway discharge (kcfs/bay)
$q_s > 3.0$ kcfs/bay

Equations 1 and 2 were applied to the individual spill bay discharges observed during the third and fourth day of testing during the first week in February. The resulting pressures were then multiplied by the ratio of spill bay discharge to total spillway discharge and summed to determine the flow-weighted pressure change. The barometric pressure was then applied to calculate the TDG saturation. The individual station saturations (L1T3B-L9T3B), cross sectional average saturation (T3avg), and forecasted aggregate saturation (T3avg-est) are shown in Figure 34 for the standard spill pattern. The forecast of the TDG saturation associated with the standard pattern followed the general trend in the data. The forecasted TDG saturation over-estimated the observed average conditions for the higher gate settings. The forecasted value falls within the range of observed values of TDG saturation downstream of the highly aerated flow regime.

The two-equation flow-weighted average formulation was also applied to the operations data gathered during the supplement TDG test conducted below Bonneville from May 7 – June 7. Equations 1 and 2 were applied to the observed spill bay discharge and average TDG saturation for spillway releases was determined using a flow-weighted approach. The average spillway TDG saturation was plotted with project operations, forebay FMS TDG saturation, tailwater FMS TDG saturation, and auxiliary station TDG saturation as shown in Figure 35. The average TDG saturation released from Bonneville Dam was estimated using the formulation presented above for the spillway contribution. The TDG loadings associated with powerhouse releases were estimated by the product of powerhouse discharge and forebay FMS TDG saturation. The estimated loading from the spillway was determined by the product of the spillway discharge and estimated spillway TDG saturation. The flow weighted average TDG saturation released from Bonneville Dam is shown in Figure 35 under the heading of TDG-tw-est. The estimated average TDG saturation closely followed the observed data at the tailwater fixed monitoring stations during most of the study period. The TDG distribution at the tailwater FMS is often not uniform and therefore cannot be used as a rigorous validation of this formulation. However, this comparison does lend additional credence to the formulation cited above.

Powerhouse Entrainment The entrainment of powerhouse flow was assumed to be zero at Bonneville Dam because of the physical barriers created by Bradford and Cascade Islands. The TDG exchange was not found to extend below the spillway channel during near-field investigations.

Dissolved Gas Abatement Alternatives The equations presented for each project reflect the TDG exchange with and without flow deflectors as a function of the unit spill bay discharge and tailwater depth of flow. These equations can be applied to individual bays and averaged over the spillway as weighted by the flow distribution. The additive property of individual bays was demonstrated through the application of the TDG performance of deflectored and non-deflectored bays to the standard spill pattern.

Spill Pattern Modification The TDG production for standard spill bays were found to be considerably greater than spill bays with flow deflectors. Many of the projects utilize spill patterns that call for considerable spill through bays without flow deflectors or utilize a spill pattern that is highly non-uniform. In these instances, the application of a spill pattern that minimizes the unit spill bay discharge over bays with flow deflectors will result in lower rates of TDG exchange. The benefits of applying this operational policy on TDG exchange can be investigated using the TDG exchange equations presented in this Appendix.

Additional Spillway Deflectors The design and construction of additional flow deflectors on spill bays that have not been modified, is current being considered throughout the study area with the exception of Ice Harbor and Lower Granite Dams. The addition of flow deflectors on unmodified spill bays will increase the deflected spillway capacity from 10% at John Day Dam to 28 % at Bonneville Dam. This added spillway capacity in bays with flow deflectors would reduce the unit spillway discharge and replace the high rates of TDG exchange associated with spill at standard bays. The benefits of structurally adding flow deflectors at a project can be estimated by using the appropriate TDG exchange relationship developed at each project. This approach assumes that the TDG exchange associated with bay with added flow deflectors will perform similarly to the existing bays with flow deflectors.

Spillway Powerhouse Training Wall The lateral entrainment of powerhouse flow into the highly aerated spillway flow can be a significant source for higher TDG loading of the Snake and Columbia River. The amount of TDG loading added through this entrainment process will be dependent upon the initial TDG pressure of powerhouse flows. A training wall could be added between the powerhouse and spillway to effectively eliminate the entrainment of powerhouse flows into the stilling basin. Preliminary designs of a training wall at Ice Harbor Dam were investigated in the 1:55 general model. The effectiveness of this structural alternative will be a function of the TDG content of powerhouse flows. The low ambient TDG pressures passed by the Lower Granite powerhouse coupled with the high entrainment rates, makes this an attractive TDG abatement alternative at this project. The specification of no powerhouse entrainment can by applied at selective project to estimate the benefits of this measure in reducing system TDG loadings. This approach assumes that the exclusion of lateral entrainment flow will not significantly change the net TDG exchange associated with spill. The finding from several field studies investigating various spill patterns tend to support this assumption.

Raised Tailrace Channel The potential for achieving TDG abatement by passing bubbly flow through a shallow tailwater channel has been demonstrated at Ice Harbor Dam. Flow deflector installation at Ice Harbor Dam began after the 1996 spill season and was completed prior to the 1999 spill season. Prior to the addition of flow deflectors, forced spill conditions at Ice Harbor Dam generated TDG saturations greater than 140 percent for a unit spillway discharge of 7 kcfs/bay. The post-deflector TDG exchange associated with 7 kcfs/bay has been observed to be as low as 115 percent or 25% less than pre-deflector conditions. Spill operations at Ice Harbor Dam generate the lowest TDG pressures in the study area for comparable unit spill bay discharges. The low rates of exchange can be attributed to the redirection of spill by flow deflectors in the stilling basin and the highly aerated flow conditions delivered to a shallow tailwater channel. The observations of TDG exchange at Ice Harbor Dam are used as the basis for predicting the TDG exchange at other projects with deflectors and a proposed raised tailrace channel.

An empirical model of total dissolved gas exchange in an open channel was presented in a memorandum entitled "Ice Harbor Raised Tailrace Total Dissolved Gas Exchange" (Schneider and Wilhelms, 1998). The same calculation procedure is applied to the other projects in the study area. The basis for these estimates are observations regarding the degassing of spillway flows downstream of the stilling basin as measured at The Dalles and Ice Harbor Dams. Observations of TDG pressure as a function of distance from the stilling basin have consistently demonstrated an exponential decay implying a first order exchange process. The exchange of TDG pressure in the tailrace channel has been described by Equation 24.

$$\frac{P_f - P_i}{P_{eq} - P_i} = (1 - e^{-k_l a t}) \qquad (24)$$

Where P_f, Pi, and P_{eq} are the dissolved gas pressures (or difference in pressure from atmospheric conditions) at the downstream (final) location, at the stilling basin end sill (initial), and equilibrium TDG pressure, respectively; $k_l a$ is the overall gas transfer coefficient (k_l is the liquid film mass transfer coefficient and a is the specific air concentration), and t is the retention time, which was determined by dividing the product of depth and distance from the end sill by the specific discharge.

The gas transfer coefficient was determined as a function of the specific discharge q_s and tailwater depth TW_{depth} at Ice Harbor and The Dalles Dams as shown in Equation 25.

$$k_L a = \min\left[\left(\frac{20}{TW_{depth}}\right)^{1.3} (q_s * 0.0014 + 0.0013), 0.012 \right] \qquad (25)$$

Where:

q_s = unit spill bay discharge (kcfs/bay)
TW_{depth} = Tailwater Depth (ft)

The final TDG pressure can be determined from Equation 24 given the initial TDG pressure, the equilibrium TDG pressure, the gas transfer coefficient, and the time of travel from the starting point to the ending point. The reduction in TDG pressures associated with a raised tailwater channel were determined by calculating the difference between the reduction in TDG pressure under existing and proposed conditions (□P=P_f-P_{f*} where P_f is the TDG pressure at distance "x" below the stilling basin under the base conditions and P_{f*} is the TDG pressure at a distance "x" below the stilling basin under the proposed conditions). The proposed conditions involve the elevation and length "x" of the proposed raised tailwater channel. The □P is subtracted from the base condition at equilibrium to arrive at estimates of the TDG pressure associated with spillway flow over a raised tailrace channel.

The initial TDG pressure exiting the stilling basin with flow deflectors can be estimated by the relationship observed at Ice Harbor Dam. The delta TDG pressure was found to be a linear function of the unit spillway discharge as shown in Equation 26.

$$P_{i-} P_{atm} = 29.785 q_s - 5.70 \qquad (26)$$

The average retention time (T_{ret}) of the spillway flow over the length of the impacted reach (L_{sp}) below the stilling basin is determined from Equation 27. The discharge per foot is determined by dividing the unit spill bay discharge by the spill bay width W_{sp}.

$$T_{ret} = (TW_{depth} * L_{sp})/(q_s * 1000/Wsp) \qquad (27)$$

The equilibrium TDG pressure P_{eq} for the base conditions can be determined using Equation 24. This pressure corresponds to the conditions a specified distance (length of the proposed raised tailrace channel) downstream for the stilling basin end sill.

The equations 25-27 can be solved for the proposed conditions associated with the raised tailrace channel. The equilibrium TDG conditions are estimated using the production relationship of Ice Harbor Dam (Equation 16) . Equation 24 can then be solved for the provisional final TDG pressure associated with the raised tailrace channel. The reduction in TDG exchange associated with the raised tailwater channel can be calculated by subtracting the final pressure under the existing conditions from the final TDG pressure for the raised tailrace channel. Since aerated conditions will likely extend downstream of the raised tailwater channel the estimated change in TDG pressure determined from this calculational procedure and not the absolute TDG pressure. The reduction in TDG pressure is then subtracted from the base conditions predicted from the TDG exchange relationships estimated for each of the projects.

<u>TDG Exchange Estimation</u> The application of TDG production equations for spillway releases are based upon a discrete set of operating and ambient water quality conditions. The application of these relationships to events outside of the range of these base conditions will constitute an extrapolation and greater uncertainty should be associated with these estimates. The range of baseline data used to develop a project specific TDG production relationship has been summarized for each project. This data summary should be consulted when applying these equations for a given set of conditions.

A measure of the precision of the TDG production relationships is determined through the standard error of the estimate. The standard error of the estimate is a measure of the variability of the observed data about the regression response surface. In many situations, a point estimate of mean TDG pressure does not provide enough information about the uncertainty or range of expected outcome. An interval estimate provides an upper and lower confidence limit based upon some confidence coefficient or confidence level. If the population is normally distributed, the observations generally falls within about two standard errors of the observed sample at the 95 percent confidence level. For example, if the non-linear regression equation produces an estimate of the mean value of ΔP of 100 mm Hg and the equation has a standard error of estimate of 10 mm Hg, then the 95 percent confidence interval for ΔP would range from 80 to 120 mm Hg. Assuming an atmospheric pressure of 760 mm Hg, the estimated mean TDG saturation would be equal to 113.2% (760+100)/760*100 and the estimated 95 percent confidence interval would range from 110.5% (760+80)/760*100 to 115.8% (760+120)/760*100. The standard error has been summarized for each project and can be used to estimate a range in the response about the estimated mean value.

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The following statements summarize the application of the TDG exchange relationships for spill bays with flow deflectors developed above.

a. **Lower Granite - The TDG exchange relationship for Lower Granite has a general range of applicability for unit spillway discharges from 3.1 to 26.4 kcfs/bay, and tailwater elevations from 633.7 to 640.5ft. The standard error of estimate was determined to be about 11.6 mm Hg.**

b. Little Goose - The TDG exchange relationship for Little Goose has a general range of applicability for unit spillway discharges from 1.8 to 21.6 kcfs/bay, and tailwater elevations from 536.3 to 542.1 ft. The standard error of estimate was determined to be about 11.7 mm Hg.

c. Lower Monumental - The TDG exchange relationship for Lower Monumental has a general range of applicability for unit spillway discharges from 3.1 to 26.4 kcfs/bay, and tailwater elevations from 442.7 to 448.1 ft. The standard error of estimate was determined to be about 11.6 mm Hg.

d. Ice Harbor - The TDG exchange relationship for Ice Harbor has a general range of applicability for unit spillway discharges from 1.8 to 14.9 kcfs/bay, and tailwater elevations from 339.4 to 354.5 ft. The standard error of estimate was determined to be about 7.6 mm Hg.

e. McNary - The TDG exchange relationship for McNary has a general range of applicability for unit spillway discharges from 2.0 to 21.9 kcfs/bay, and tailwater elevations from 260.8 to 270.5 ft. The standard error of estimate was determined to be about 9.3 mm Hg.

f. John Day - The TDG exchange relationship for John Day has a general range of applicability for unit spillway discharges from 4.3 to 9.4 kcfs/bay, and tailwater elevations from 158.6 to 167.4 ft. The standard error of estimate was determined to be about 6.8 mm Hg.

g. The Dalles - The TDG exchange relationship for The Dalles has a general range of applicability for unit spillway discharges from 1.8 to 19.4 kcfs/bay, and tailwater elevations from 76.3 to 91.3 ft. The standard error of estimate was determined to be about 7.6 mm Hg.

h. Bonneville - The TDG exchange relationship for Bonneville has a general range of applicability for unit spillway discharges from 3.2 to 17.3 kcfs/bay. A conclusive relationship between TDG exchange and tailwater elevation has not been established at Bonneville Dam.