U.S. Army Corps of Engineers
Walla Walla District

Numerical Model Analysis of System-wide Dissolved Gas Abatement Alternatives

Appendix B

Model Configuration and Optimization

Draft Report

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1 Introduction

This appendix documents, in detail, the models used in this analysis, their configuration, and sources of boundary condition data, particularly gas production at dams for various alternatives. Only a brief overview was presented in the main report (Section 2).

Sections 2 and 3 present the mathematical formulation of MASS1 and MASS2, respectively. Section 4 describes the details of how the models were applied for this analysis. Section 5 presents the assumed project gas production under the various abatement alternatives, and their sources.

2 MASS1 Formulation

This sections describes the MASS1 (Modular Aquatic Simulation System 1D) model. MASS1 is a one-dimensional, unsteady hydrodynamic and water quality model for river systems. This model is applicable to any branched channel system and it has been applied extensively to the Columbia and Snake Rivers.

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

2.1 Mathematical Formulation

2.1.1 Hydrodynamics

Unsteady flow in rivers and canals is simulated in MASS1 by solving the one-dimensional equations of mass (2.1) and momentum (2.2) conservation. These equations are often referred to as the St. Venant equations.

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial t} = 0 \tag{2.1}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}(\alpha \frac{Q^2}{A}) + gA\frac{\partial y}{\partial x} + gAS_f = 0 \tag{2.2}$$

where

A = river cross-sectional area, ft^2,
Q = water discharge, ft^3/sec,
y = water surface elevation, ft,
S_f = friction slope, ft/ft, as defined in (2.3),
α = momentum friction correction factor,
t = time, s, and
x = coordinate along the channel, ft.

The friction slope term can be computed using either the Manning or Chezy equations (see Chow (1959)). In MASS1 the friction slope is expressed in terms of the discharge and channel conveyance (K) as

$$S_f = \frac{Q \mid Q \mid}{K^2} \tag{2.3}$$

and the conveyance is computed using the Manning equation

$$K = \frac{C_0}{n} A R^{2/3} \tag{2.4}$$

where

C_0 = 1.49 for English units and 1.0 for metric units,
n = Manning channel roughness coefficient,
R = hydraulic radius, feet,
= A/P, and
P = channel wetted perimeter, ft.

Equations 2.3 and 2.4 represent the combined effects of variable channel geometry and resistance to flow (roughness) on the hydrodynamic simulation.

The average shear stress acting on the channel bottom can be computed from

$$\tau = \gamma R S_f \tag{2.5}$$

where

τ = bed shear stress, lb/ft^2, and
γ = unit weight of water, lb/ft^3.

2.1.2 General Species Transport

A transport equation describing the time and space distribution of a dissolved species or contaminant in a river can be derived by applying the conservation of mass principle to a channel reach. This results in the following equation for the cross-sectional average concentration:

$$\frac{\partial(AC)}{\partial t} + \frac{\partial(QC)}{\partial x} = \frac{\partial}{\partial x}\left(K_T A \frac{\partial C}{\partial x}\right) - \lambda AC \tag{2.6}$$

where

C = concentration, mass/ft^3
K_T = longitudinal dispersion coefficient, ft^2/s, and
λ = contaminant decay rate, 1/s.

2.1.3 Dissolved Gas Transport

An equation for the transport of total dissolved gas in a river can be derived by applying the conservation of mass principle to a channel reach. This results in the following equation for the cross-sectional average total dissolved gas concentration:

$$\frac{\partial(AC_g)}{\partial t} + \frac{\partial(QC_g)}{\partial x} = \frac{\partial}{\partial x}\left(K_T A \frac{\partial C_g}{\partial x}\right) + K_L B(C_* - C_g) \tag{2.7}$$

where

C_g = concentration of total dissolved gas, mass/ft^3,
C_* = saturation concentration of air at the water surface mass/ft^3,
B = channel top-width, ft,
K_T = longitudinal dispersion coefficient, ft^2/s, and
K_L = air-water transfer coefficient, ft/s.

Calculation of TDG pressures and saturations from a given concentration or vice versa is accomplished using the relationships presented in Colt (1984). The mass concentration of TDG is computed as

$$C_{TDG} = \frac{(P_{TDG} - P_{H_2O})\,\beta_{air}}{A_{air}} \tag{2.8}$$

where

C_{TDG} = apparent total dissolved gas concentration, mg/L,
P_{TDG} = total dissolved gas pressure, mm Hg,
P_{H_20} = vapor pressure of water, mm Hg,
β_{air} = apparent Bunsen coefficient for air, L/L·atm, and
A_{air} = apparent molecular volume of air (with unit conversion), atm·L/mg·mm Hg

Air is assumed to be composed of a limited number, N, of individual gases. These are shown in Table 1. The apparent Bunsen coefficient for air is computed as an aggregate of the Bunsen coefficients for individual gas fractions:

$$\beta_{air} = \frac{\sum_{i=1}^{N} \beta_i X_i}{\sum_{i=1}^{N} X_i} \tag{2.9}$$

where

β_i = Bunsen coefficient for gas fraction i, L/L·atm, and
X_i = mole fraction of gas i.

The mole fractions used are those for atmospheric air and are shown in Table 1. Individual gas fraction Bunsen coefficients are computed, as functions of temperature and salinity (assumed zero), using relationships presented by Colt (1984), as is water vapor pressure, P_{H_20}.[1] The apparent molecular volume of air is also computed as an aggregate of individual gas fractions:

$$A_{air} = \frac{760}{1000}\left(\frac{\sum_{i=1}^{N} \beta_i X_i}{\sum_{i=1}^{N} K_i \beta_i X_i}\right) \tag{2.10}$$

where K_i is the ratio of molecular weight to molecular volume, g/L, for gas fraction i, the values of which are shown in Table 2.1.

[1]For brevity, these equations are not presented here.

Table 2.1: Gas fractions used to compute gas mass concentrations from gas pressures (Colt, 1984). Mole fractions are for atmospheric air.

Gas Fraction	X_i	$K_i, g/L$
Nitrogen (N_2)	0.78084	1.25043
Oxygen (0_2)	0.20946	1.42903
Argon (Ar)	0.00934	1.78419
Carbon Dioxide (CO_2)	0.00032	1.97681

Surface Gas Exchange

Many air-water gas exchange formulas are available in the literature. At this time, the air-water surface transfer coefficient in MASS1 is a function of wind speed is given by a curve fit to empirical data presented in (O'Connor, 1982). Figure 6 intermediate scale data.)

A general cubic polynomial equation is currently implemented in MASS1 and the coefficients are:

$$K_L = -0.0045W^3 + 0.1535W^2 - 0.5026W + 0.6885 \tag{2.11}$$

where W is the wind speed 10 meters above the water surface, in m/s. The user can specify different coefficients in the equation though modification of an input file.

In the future, it may be desirable to implement a mechanistic surface gas exchange formulation along the lines presented by O'Connor (1982). However, given the uncertainties associated with estimating the wind speed using remote measurements the curve-fit relationship is used in the model at this time.

2.1.4 Thermal Energy (Temperature) Transport

Applying the principle of conservation of energy to a channel reach, relating the internal energy to temperature, and then averaging over a cross-section yields

$$\frac{\partial(AT)}{\partial t} + \frac{\partial(QT)}{\partial x} = \frac{\partial}{\partial x}\left(K_T A \frac{\partial T}{\partial x}\right) + \frac{B\sum H}{c_p \rho} \tag{2.12}$$

where

T = cross-sectional average water temperature, °C,

B = channel top-width,

$\sum H$ = net surface heat flux, W/m^2,

ρ = density of water

= 1000 kg/m^3, and

c_p = specific heat of water at 15 °C

= 4186 J/kg·°C.

Surface Heat Exchange

Heat exchange at the water surface is computed as the net heat flux which is represented as

$$\sum H = H_{sn} + H_{an} - (H_b + H_e + H_c) \tag{2.13}$$

where

$\sum H$ = net surface heat flux, W/m^2,
H_{sn} = net solar short wave radiation, W/m^2,
H_{an} = net atmospheric long wave radiation, W/m^2,
H_b = long wave back radiation, W/m^2,
H_e = heat flux due to evaporation, W/m^2, and
H_c = heat flux due to conduction, W/m^2.

If measured radiation is available, the net solar short wave radiation is computed as

$$H_{sn} = H_a (1 - R_s) \tag{2.14}$$

where

H_a = measured short-wave solar radiation, W/m^2, and
R_s = albedo or reflection coefficient.

The albedo is computed as (Brown and Barnwell, 1987)

$$R_s = A \left(\frac{180\alpha}{\pi} \right)^B \tag{2.15}$$

where α is the solar altitude radians,

$$A = \begin{cases} 1.18 for C_L < 0.1 \\ 2.20 for 0.1 \le C_L < 0.5 \\ 0.95 for 0.5 \le C_L < 0.9 \\ 0.35 for C_L > 0.9 \end{cases}$$

and

$$B = \begin{cases} -0.77 for C_L < 0.1 \\ -0.97 for 0.1 \le C_L < 0.5 \\ -0.75 for 0.5 \le C_L \le 0.9 \\ -0.45 for C_L > 0.9 \end{cases}$$

When measured radiation is not available, net incoming short-wave solar radiation is estimated using (Brown and Barnwell, 1987)

$$H_{sn} = H_o a_t (1 - R_s) \left(1 - 0.65 C_L^2\right) \tag{2.16}$$

where

H_o = the radiation flux reaching the earth's atmosphere, W/m^2,
a_t = atmospheric transmission coefficient, and
C_L = cloudiness as a fraction of sky covered.

H_o is estimated using (Wigmosta and Perkins, 1997, Appendix C)

$$H_o = H_{sc}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right]\sin\alpha \tag{2.17}$$

where

H_{sc} = the solar constant, approximately 1360 W/m^2,
n = day of the year,

and the solar altitude is calculated using

$$\sin\alpha = \sin\phi\sin\delta + \cos\phi\cos\delta\cos h \tag{2.18}$$

where

ϕ = site latitude, radians,
δ = declination of the sun, radians
$= 23.45\frac{\pi}{180d}\sin\left(2\pi\left[\frac{284+n}{365}\right]\right)$
h = hour angle of the sun, radians
$= \frac{\pi}{12}(T_s - 12)$

T_s is the solar time, in hours, given by

$$T_s = T_l + \frac{12}{\pi}(L_{st} - L_{loc}) + E \tag{2.19}$$

where

T_l = local time, hr,
L_{st} = standard longitude for the local time zone ($120\pi/180$ for the Pacific time zone),
L_{st} = local longitude, radians,
E = equation of time, hours
$= (9.87\sin 2B - 7.53\cos B - 1.5\sin B)/60$,
$B = \frac{2\pi(n-81)}{364}$

The net atmospheric long wave radiation is computed using formula 2.1.1 in Edinger et al. (1974):

$$H_a = 4.4\times 10^{-8}(T_a + 273)^4\left[C_a + 0.031\sqrt{e_a}\right] \tag{2.20}$$

where

T_a = air temperature, °C,

e_a = air vapor pressure, mm Hg, and

C_a = Brunt's coefficient (average value = 0.65).

The long wave back radiation is computed using formula 2.1.4 in Edinger et al. (1974):

$$H_b = \varepsilon_w \sigma^* (T_s + 273.15)^4 \tag{2.21}$$

where

ε_a = emissivity of water

= 0.97, and

σ^* = Stephan-Boltzmann constant

= 5.67×10^{-8} W/m^{2}K^4.

The evaporation heat flux is computed using formula 2.1.5 in Edinger et al. (1974):

$$H_e = f(W)(e_s - e_a) \tag{2.22}$$

where

$f(W)$ = wind speed function

= $9.2 + 0.46W^2$, W/(m^2 mm Hg),

W = wind speed, m/s,

e_a = air vapor pressure, mm Hg,

e_s = saturation vapor pressure of air at the water surface at T_s, mm Hg,

The conduction heat flux is computed using formula 2.1.11 in Edinger et al. (1974):

$$H_c = 0.47 f(W)(T_s - T_a) \tag{2.23}$$

2.1.5 Model Topology

The first step in developing the numerical solution procedures implemented in MASS1 is to define the topology of the river systems that can be simulated. Here the topological definition defines how the channel system is connected as well as the location and type hydraulic control structures. Note again that the current version of MASS1 is applicable to single and branched channel systems; looped or multiply-connected channel networks cannot be simulated at this time.

The topology of the channel system is represented by dividing the river system into a series of links and these are further divided into series of computational points along that link. Nodes occur at upstream or downstream boundary points and at the junction of two or more links.

2.2 Solution Methods

The foregoing equations are individual and coupled systems of linear and nonlinear partial differential equations. In general, analytical solutions to these equations can only be obtained for simplified channel geometries and boundary conditions. Therefore numerical methods must be used to solve these equations for most practical situations. Finite-difference methods that are appropriate for each equation are used in MASS1.

2.2.1 Hydrodynamics

In MASS1, the hydrodynamic equations (2.1 and 2.2) are discretized using the Preissmann four-point implicit finite-difference scheme and the resulting system of nonlinear algebraic equations are solved using the double sweep method as described in Cunge et al. (1980).

2.2.2 Scalar Transport

The various transport equations are solved using the split-operator method. The advective part of the system is solved using an explicit TVD (total variation diminishing) scheme presented by Gupta et al. (1991). Explicit methods are also used for the diffusive (finite-volume) and source term parts (Euler method) of the transport equation. A time sub-cycling scheme is used to allow the hydrodynamics to run at the larger time steps allowed by the implicit scheme while using a smaller time step that satisfies the explicit stability criteria.

The Courant number must be less than 1.0 to maintain stability in the explicit method used. The stability criteria for advection is

$$\Delta t < \frac{\Delta x}{(Q/A)} \tag{2.24}$$

Physically this means that a particle can not move more than a single grid cell in one time step. The stability criteria for diffusion is

$$\Delta t < \frac{(\Delta x)^2}{2K_T} \tag{2.25}$$

3 MASS2 Formulation

MASS2 is a two-dimensional-depth averaged hydrodynamics and transport model. The model simulates time varying distributions of the depth-averaged velocities, water, temperature and dissolved gas. The model is coded in standard FORTRAN90 and runs on WindowsNT (compiled with Digital Visual Fortran90) or a Silicon Graphics Unix system (compiled with MIPSpro Fortran90 version 7.2) platform.

The model is an unsteady finite-volume code that is formulated using the general principles described by Patankar (1980). The model uses a structured multi-block scheme on a curvilinear grid system. The coupling of the momentum and mass conservation (continuity) equations is achieved using a variation of Patankar (1980) SIMPLE algorithm extended to shallow-water flows by Zhou (1995). Spasojevic and Holly (1990) give an example of a two-dimensional model of this type.

3.1 Coordinates and Grid System

The model is formulated using an orthogonal, curvilinear coordinate system. The governing equations are formulated in a conservation form using a full-transformation in the curvilinear system Richmond et al. (1986). The physical coordinates (x_1, x_2) are denoted by (x, y). The orthogonal computational coordinates (ξ_1, ξ_2) are denoted by (ξ, η). Note that the subscripts 1 and 2 in the following equations refer to the respective coordinate directions.

When the physical coordinate system is Cartesian, the metric coefficients take the form

$$h_1 = \left[\left(\frac{\partial x}{\partial \xi} \right)^2 + \left(\frac{\partial y}{\partial \xi} \right)^2 \right]^{1/2} \tag{3.1}$$

$$h_2 = \left[\left(\frac{\partial x}{\partial \eta} \right)^2 + \left(\frac{\partial y}{\partial \eta} \right)^2 \right]^{1/2} \tag{3.2}$$

where

$h_1 =$ metric coefficient in the ξ_1 or ξ direction
$h_2 =$ metric coefficient in the ξ_2 or η direction
$(x, y) =$ Cartesian physical coordinates, i.e. State Plane coordinates
$(\xi, \eta) =$ orthogonal computational coordinates

3.2 Hydrodynamics

Depth-averaged equations for the conservation of mass and momentum are the following:

3.2.1 Continuity (water mass conservation) Equation

$$h_1 h_2 \frac{\partial d}{\partial t} + \frac{\partial (h_2 d U)}{\partial \xi} + \frac{\partial (h_1 d V)}{\partial \eta} = 0 \tag{3.3}$$

where

$d =$ water depth
$t =$ time
$U =$ depth-averaged velocity component in the ξ direction
$V =$ depth-averaged velocity component in the η direction

3.2.2 U or ξ-direction momentum equation

$$\begin{aligned} h_1 h_2 \quad & \frac{\partial (dU)}{\partial t} + \frac{\partial \left(h_2 d U^2\right)}{\partial \xi} + \frac{\partial (h_1 d V U)}{\partial \eta} + d\frac{\partial h_1}{\partial \eta} UV - d\frac{\partial h_2}{\partial \xi} V^2 = -g h_2 d \frac{\partial (z_b + d)}{\partial \xi} \\ + \quad & \frac{1}{\rho}\frac{\partial (h_2 d T_1 1)}{\partial \xi} + \frac{1}{\rho}\frac{\partial (h_1 d T_2 1)}{\partial \eta} + \frac{d}{\rho}\frac{\partial h_1}{\partial \eta} T_2 1 - \frac{d}{\rho}\frac{\partial h_2}{\partial \xi} T_2 2 + \frac{h_1 h_2}{\rho}\left(\tau_{s1} - \tau_{b1}\right) \end{aligned} \tag{3.4}$$

where

$g =$ gravitational constant
$\rho =$ fluid density
$T_1 1, T_2 1, T_2 2 =$ effective stresses
$z_b =$ channel bottom elevation
$\tau_{b1} =$ bottom shear stress in the ξ-direction
$\tau_{s1} =$ surface shear stress in the ξ-direction

3.2.3 V or η-direction momentum equation

$$\begin{aligned} h_1 h_2 \quad & \frac{\partial (dV)}{\partial t} + \frac{\partial (h_2 d U V)}{\partial \xi} + \frac{\partial \left(h_1 d V^2\right)}{\partial \eta} + d\frac{\partial h_2}{\partial \xi} UV - d\frac{\partial_1}{\partial \eta} U^2 = -g h_1 d \frac{\partial (z_b + d)}{\partial \eta} \\ + \quad & frac1\rho \frac{\partial (h_2 d T_{12})}{\partial \xi} + \frac{1}{\rho}\frac{\partial (h_1 d T_{22})}{\partial \eta} + \frac{d}{\rho}\frac{\partial h_2}{\partial \xi} T_1 2 - \frac{d}{\rho}\frac{\partial h_2}{\partial \eta} T_{11} + \frac{h_1 h_2}{\rho}\left(\tau_{s2} - \tau_{b2}\right) \end{aligned} \tag{3.5}$$

where

$T_{11}, T_{21}, T_{22} =$ effective stresses
$z_b =$ channel bottom elevation
$\tau_{b2} =$ bottom shear stress in the η-direction
$\tau_{s2} =$ surface shear stress in the η-direction

The components of the stress tensor, $T_1 1, T_2 1, T_2 2$, are the so-called effective stresses and these are linearly related to the fluid strain rate in an incompressible fluid through the following equations:

$$\begin{aligned} T_1 1 &= 2\mu e_\xi e_\xi \\ T_2 2 &= 2\mu e_\eta e_\eta \\ T_1 2 &= T_2 1 = \mu e_\xi e_\eta \end{aligned} \tag{3.6}$$

where

$$e_\xi e_\xi = \frac{1}{h_1}\frac{\partial U}{\partial \xi} + \frac{V}{h_1 h_2}\frac{\partial h_1}{\partial \eta} \tag{3.7}$$

$$e_\eta e_\eta = \frac{1}{h_2}\frac{\partial V}{\partial \eta} + \frac{U}{h_1 h_2}\frac{\partial h_2}{\partial \xi} \tag{3.8}$$

$$e_\xi e_\eta = \frac{h_2}{h_1}\frac{\partial}{\partial \xi}\left(\frac{V}{h_2}\right) + \frac{h_1}{h_2}\frac{\partial}{\partial \eta}\left(\frac{U}{h_1}\right) \tag{3.9}$$

If a Bousinessq eddy viscosity model is used to represent the turbulence stresses then the viscosity coefficient in (3.6) is a turbulent eddy viscosity. A two-equation turbulence model could be introduced in the future if necessary.

Bottom shear stress is computed using the following equations:

$$\tau_{b1} = \rho C_b U \sqrt{U^2 + V^2} \tag{3.10}$$

$$\tau_{b2} = \rho C_b V \sqrt{U^2 + V^2} \tag{3.11}$$

where the bed-friction coefficient is calculated based on the Manning n-value roughness using

$$C_b = g\left(\frac{n^2}{1.49 d^{1/3}}\right) \tag{3.12}$$

Surface shear stress resulting from wind can be computed using formulae similar to those above for bottom shear stress, but using a wind-stress coefficient instead.

3.3 General Scalar Transport

The governing equation for the transport of a scalar is obtained by applying the principle of conservation of mass to a fluid element. In orthogonal curvilinear coordinates the governing equation is

$$h_1 h_2 \frac{\partial (dC)}{\partial t} + \frac{\partial (h_2 dUC)}{\partial \xi} + \frac{\partial (h_1 dVC)}{\partial \eta} = \frac{\partial}{\partial \xi}\left(h_2 \frac{\varepsilon_1}{h_1}\frac{\partial C}{\partial \xi}\right) + \frac{\partial}{\partial \eta}\left(h_1 \frac{\varepsilon_2}{h_2}\frac{\partial C}{\partial \eta}\right) + h_1 h_2 S \tag{3.13}$$

where

$C =$ scalar concentration per unit volume
$\varepsilon_1 =$ turbulent diffusion coefficient in the ξ-direction
$\varepsilon_2 =$ turbulent diffusion coefficient in the η-direction
$S =$ source term

3.4 Dissolved Gas Transport

3.4.1 Governing Equation

The conservation equation for depth-averaged total dissolved gas is

$$h_1 h_2 \frac{\partial (dC)}{\partial t} + \frac{\partial (h_1 dVC)}{\partial \eta} = \frac{\partial}{\partial \xi}\left(h_2 \frac{\varepsilon_1}{h_1}\frac{\partial C}{\partial \xi}\right) + \frac{\partial}{\partial \eta}\left(h_1 \frac{\varepsilon_2}{h_2}\frac{\partial C}{\partial \eta}\right) + h_1 h_2 S_{TDG} \tag{3.14}$$

where

$C =$ depth-averaged total dissolved gas concentration (mg/l)
$S =$ sources and/or sinks of total dissolved gas

Calculation of TDG pressures and saturations from a given concentration or vice versa is accomplished using the relationships presented in Section 2.1.3 for MASS1.

3.4.2 Surface Gas Exchange

The source term for air/water gas exchange is of the form

$$S_{TDG} = K_L (C_* - C) \tag{3.15}$$

where

K_L = surface transfer coefficient, m/day, given by equation 2.11, and
C_* = saturation concentration of air at the water surface, mg/l.

In the future, it may be desirable to implement a mechanistic surface gas exchange formulation along the lines presented by O'Connor (1982). However, given the uncertainties associated with estimating the wind speed using remote measurements the curve-fit relationship is used in the model at this time.

3.5 Thermal Energy Transport

3.5.1 Governing Equation

Applying the principle of conservation of energy to a fluid volume, relating the internal energy to temperature, and then depth-averaging yields

$$h_1 h_2 \frac{\partial (dT)}{\partial t} + \frac{\partial (h_2 dUT)}{\partial \xi} + \frac{\partial (h_1 dVT)}{\partial \eta} = \frac{\partial}{\partial \xi}\left(h_2 \frac{\varepsilon_1}{h_1}\frac{\partial T}{\partial \xi}\right) + \frac{\partial}{\partial \eta}\left(h_1 \frac{\varepsilon_2}{h_2}\frac{\partial T}{\partial \eta}\right) + \frac{h_1 h_2 H}{\rho c_v} \tag{3.16}$$

where

T = depth-averaged water temperature, °C,
H = net heat flux at the water surface, W/m^2,
ρ = water density

$$
\begin{aligned}
&= 1000\ \text{kg/m}^3\text{, and} \\
c_v &= \text{specific heat of water at } 15°\text{C} \\
&= 4186\ \text{J/kg}\cdot°\text{C}.
\end{aligned}
$$

3.5.2 Surface Heat Exchange

In MASS2, heat exchange at the water surface is represented in the same way as it is in MASS1, namely equation 2.13. See Section 2.1.4 for a complete description.

3.6 Discretization

The governing equations in the model are discretized using the finite-volume formulation described by Patankar (1980). The power-law scheme is used for the convective-diffusion terms. The time derivative is approximated using an implicit backward difference scheme. The reader is referred to Zhou (1995) for an example of the form of the discretization equations in a Cartesian coordinate system. The orthogonal curvilinear form of the discretization equations used herein reduce to the Cartesian form when the metric coefficients are unity.

It should be noted that the power-law scheme reduces to 1^{st} order accuracy for high values of the grid Peclet number (advection-dominated cases) and therefore introduces artificial diffusion when the computational grid lines and streamlines are not aligned. In the majority of the river system considered here the artificial diffusion should be minimal since the grid lines and streamlines will be approximately aligned with one another. Higher-order schemes can be used to minimize artificial diffusion but this increased accuracy comes at the price of additional computational effort that Ye and McCorquodale (1997) estimate to be 40-70% more than the power-law scheme. Presently MASS2 uses the power-law scheme, but it could be easily extended to include an option for a higher order method.

3.7 Velocity-Depth Coupling

The coupling of the momentum and mass conservation (continuity) equations is achieved using a variation of Patankar (1980) SIMPLE algorithm extended to shallow-water flows by Zhou (1995). Zhou's method has been extended here to orthogonal curvilinear coordinates in the present study. As in Patankar (1980), a staggered numerical grid is employed to avoid the computation of unrealistic depth and velocity fields.

3.8 Initial and Boundary Conditions

To numerically solve the system of governing equations initial and boundary conditions must be specified. Initial conditions for each dependent variable (velocity, depth, and species) are assigned at the start of each simulation either as approximate values or using the results of a previous simulation (i.e., hotstart or restart file). Boundary conditions are specified at each boundary. At the upstream boundary the incoming velocity or discharge is specified as a function of time for each cell and depth is extrapolated from the nearest interior cell. At the downstream boundary the depth for each cell is specified as a function of time and zero gradient conditions are assigned for the velocity. Along the shoreline, a zero gradient or slip condition is applied to the longitudinal velocity component and the normal velocity to the shore is set to zero. The depth is extrapolated from the nearest interior cell to the shore.

3.9 Solution Procedure

The discretization equations are implicit in space and time. the assembly of these equations for each numerical element results in a system of linear equations that are solved using a line-by-line tridiagonal matrix algorithm. Non-linearity and coupling of the equations are handled through an iterative solution procedure.

The overall solution procedure is summarized as follows:

1. Read in general parameters and input/output file specifications.
2. Read in computational gird data files.
3. Set initial conditions or read in a hotstart file from a previous simulation
4. Begin time marching loop
5. Begin hydrodynamic iteration loop
6. Compute discretization coefficients
7. Solve for velocity field
8. Solve for depth-correction field
9. Compute new depth field
10. Update velocity field using depth-corrections
11. Return to step 5 until mass source is reduced to the desired level or the maximum number of iterations for a time step are exceeded.
12. Solve scalar transport equation for each species
13. Write out data to output files
14. Return to step 4 for the next time step or stop if the ending date/time is reached.

4 Model Configuration

This section presents the details of the application of MASS1 and MASS2 to the Lower Columbia and Snake River system. Section 4.1 describes the bathymetry data used, which was shared by both models. The remaining sections describe the three model configurations: one-dimensional (Section 4.2), full two-dimensional (Section 4.3), and one/two-dimensional hybrid (Section 4.4).

4.1 Bathymetry

Bathymetric data (river bottom elevations) are a primary data requirement of any surface water hydrodynamic and transport model. The bathymetry used for the lower Columbia and Snake rivers was derived from various bathymetry data sets. In the Snake River, this consisted primarily of NOAA navigation charts, where available, dense bathymetric surveys near the projects, and sedimentation survey range lines. In the Columbia, relatively dense surveys were available for the entire pools, which were supplemented with denser surveys near the projects, and navigation charts. The specific sources of Snake River bathymetric data are listed in Richmond and Perkins (1999b), Richmond and Perkins (1999c), Richmond and Perkins (1999d) and Richmond and Perkins (1999e). Those for the Columbia are listed in Richmond and Perkins (1999f), Richmond and Perkins (1999g), Richmond and Perkins (1999h), Richmond and Perkins (1999i), and Richmond and Perkins (1999a). Additionally, the U.S. Army Corps of Engineers, Seattle District performed a cross section survey of the Hanford Reach. Figure 4.1 shows the locations of some of these sections near the Hanford reactor areas.

These individual sets of bathymetry data (except the Hanford reach cross sections, which were used directly by MASS1) were combined into a three-dimensional surface, typically one per pool or reach. These surfaces were sampled in an manner appropriate to the dimensionality of the model.

MASS1 requires bathymetry as a series of cross sections. A cross section is a series of elevations along a (not necessarily straight) line extending laterally across the river. Cross section elevations were sampled from the bathymetric surfaces using the process described by Hanrahan et al. (1998). Cross section spacing was approximately $1/4$ mile in the first few miles below the dams, and in the Hanford reach, and $1/2$ mile elsewhere. For example, Figure 4.2 shows the generated cross sections in the Snake River portion of McNary Pool.

MASS2 requires a river bottom elevation at each individual grid location. The bathymetric surfaces were then sampled directly for each grid node. This was a simpler but involved considerably more data than with the cross section sampling.

4.2 One-Dimensional

MASS1 (Section 2) was applied to the lower Columbia and Snake rivers in order to do a comparative analysis of the various system-wide gas abatement scenarios. This analysis was an initial screen of the alternative scenarios.

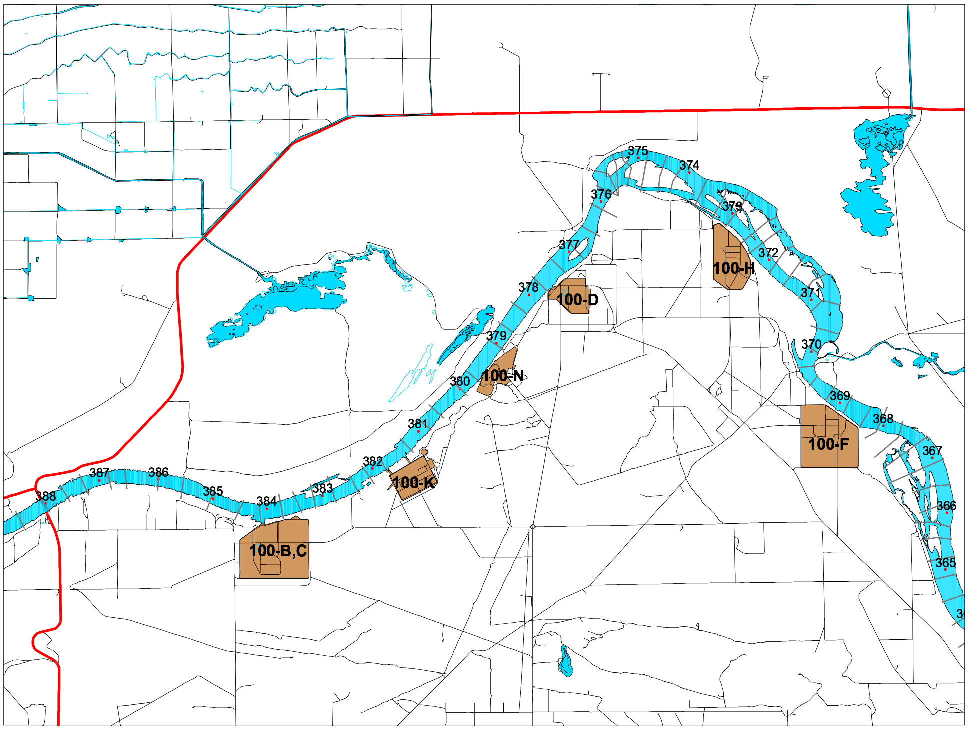


Figure 4.1: Detail showing the cross section locations near the Hanford Site reactor areas

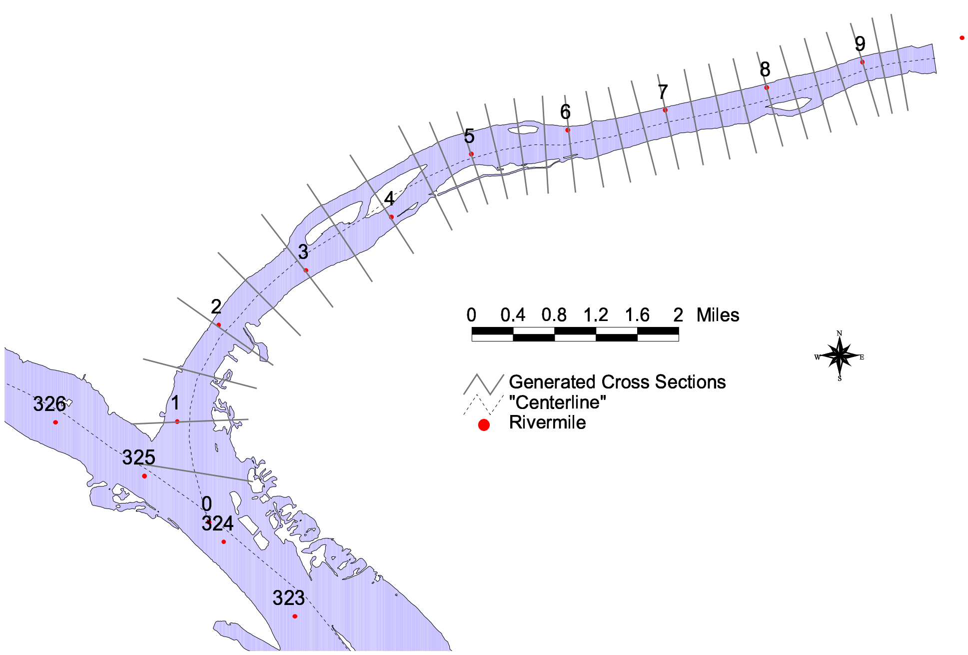


Figure 4.2: Locations of Snake River cross sections in the McNary Pool

The lower Columbia and Snake rivers were simulated using the configuration shown in Figure 4.3, in which observed flows were used as boundary conditions at the projects. Appendix F presents a detailed discussion of the calibration/verification of this configuration.

4.2.1 Boundary Conditions

At the uppermost limits of the modeled region, observed flows were used as boundary conditions. Flow data for Priest Rapids on the Columbia River and Dworshak dam on the North Fork of the Clearwater were obtained from the DGAS project operations database (Carroll et al., 1998), as were flows the other projects. Observed flows for the upstream boundaries on Clearwater and Snake rivers were obtained from an appropriate USGS stream gage. Observed stage was used at the downstream boundary, near Astoria, Oregon. Stage data for that location was obtained from the NOAA tide gage near Astoria [1]

Tributaries were either assigned daily flows from an appropriate stream gage or assumed constant. In most cases, a USGS stream gage was located on the tributary and daily data from that gage was obtained using the USGS Water Data Retrieval service[2]. Table 4.1 lists the tributaries and the source of the discharge data.

4.2.2 Meteorology

The MASS1 model can accept meteorological data for multiple weather zones. Four meteorologic zones were configured into MASS1, as shown in Figure 4.3. MASS1 requires the following meteorological variables:

- air temperature,
- dew point temperature,
- wind speed,
- barometric pressure, and
- incoming short wave solar radiation.

For each of the zones, data was obtained for a nearby NWS station from the DGAS meteorological database (Carroll et al., 1998). Air and dew point temperatures were obtained from the NWS station. Barometric pressure was taken from a nearby FMS. Cloud cover from the NWS stations was used to estimate incoming solar radiation by the procedure presented by Richmond et al. (1999). Table 4.2 shows the weather station and FMS used for each zone.

[1] NOAA gage 94339040, "Astoria, Tongue Point, Columbia River, OR"; see http://www.co-ops.nos.noaa.gov/tidesonline/ for more information.

[2] URL:http://waterdata.usgs.gov/nwis-w/US/

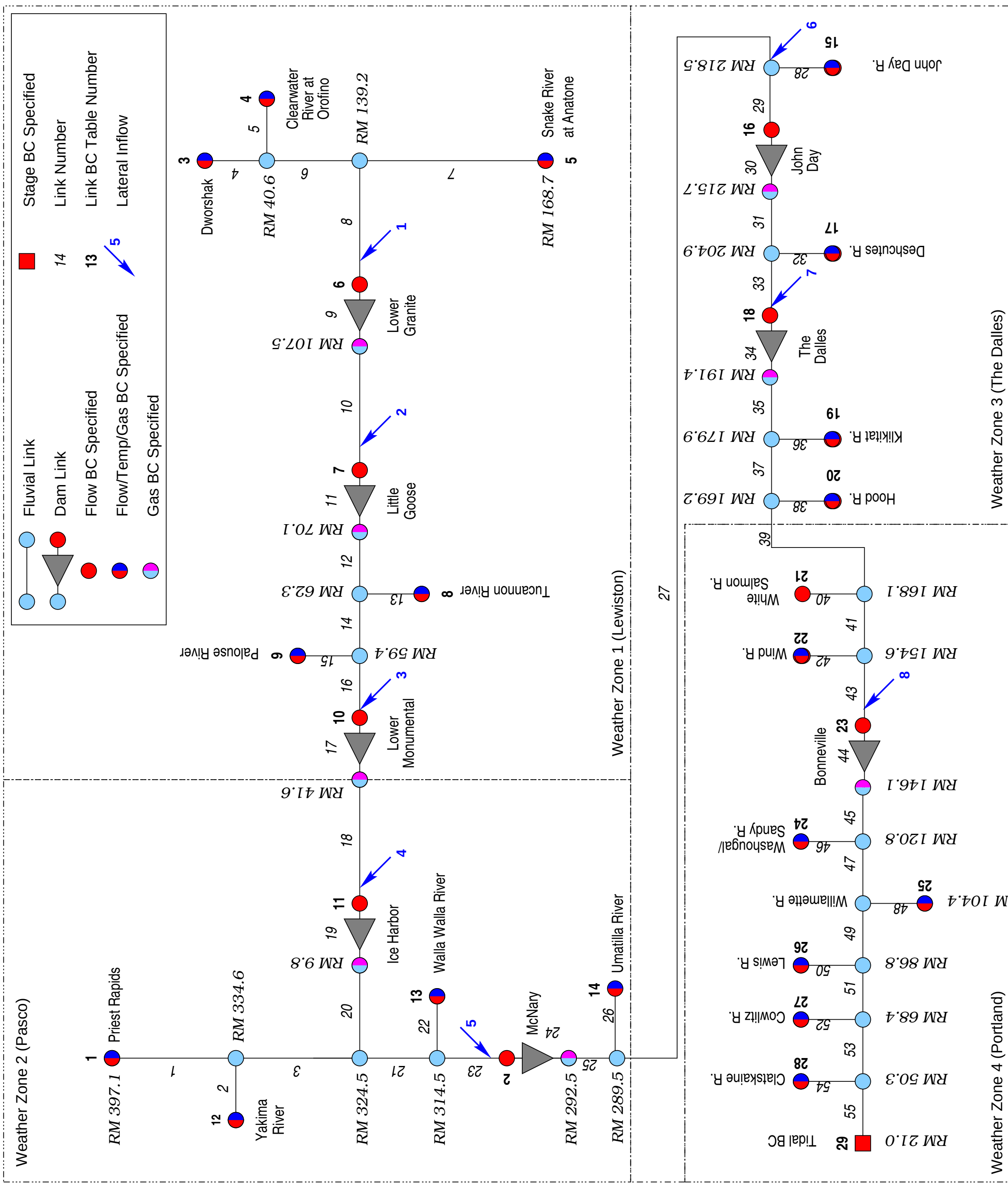


Figure 4.3: Schematic of the MASS1 configuration for the lower Columbia and Snake rivers, using flow boundary conditions at the dams and lateral inflow to "correct" forebay stages.

Table 4.1: Sources of boundary condition and tributary flow for the lower Columbia and Snake River MASS1 application.

Boundary or Tributary	**Gage Gage ID**	**Description**
Clatskaine River		constant 500 cfs assumed
Cowlitz River	14243000	Cowlitz River At Castle Rock, Wa
Lewis River	Assumed to	be the sum of
	14220500	Lewis River At Ariel, Wa
	14222500	East Fork Lewis River Near Heisson, Wa
Willamette River	14211720	Willamette River At Portland, Or
Sandy/Washougal Rivers		constant 1000 cfs assumed
Wind River		constant 0 cfs assumed
White Salmon River	14123500	White Salmon R Nr Underwood, Wa
Hood River	14120000	Hood River At Tucker Bridge,Nr Hood River,Or
Klikitat River	14113000	Klickitat River Near Pitt, Wa
Deschutes River	14103000	Deschutes River At Moody, Near Biggs, Or
John Day River	14048000	John Day R At Mcdonald Ferry, Or
Umatilla River	14033500	Umatilla R Nr Umatilla, Or
Walla Walla River	14018500	Walla Walla River Near Touchet, Wa
Yakima River	12510500	Yakima River At Kiona, Wa
Palouse River	13351000	Palouse River At Hooper, Wa
Tucannon River	13344500	Tucannon River Near Starbuck, Wa
Clearwater River	13340000	Clearwater River At Orofino, Id
Snake River	13334300	Snake River Nr Anatone, Wa

Table 4.2: Sources of meteorological data for each of the zones in the lower Columbia and Snake river MASS1 application.

	Station		**Fixed**
Zone	**Name**	**Identifier**	**Monitor**
1	Lewiston (AMOS)	LWS	LGNW
2	Pasco	PSC	MCQO
3	The Dalles	DLS	TDA
4	Portland	PDX	BON

4.3 Two-Dimensional Full-pool

MASS2 (Section 3) was used to simulate the lower Columbia and Snake rivers in order to do an additional comparative analysis of the various system-wide gas abatement scenarios.

The region modeled in this analysis extended downstream from Lower Granite dam on the Snake River and Clover Island[3] to about river mile 110 on the Columbia River[4]. Richmond et al. (1999) documents the calibration and verification of MASS2 for this region. The MASS2 grids developed in (Richmond et al., 1999) were used for this analysis, except for the simulation of some long term alternatives (Section 5.3).

Each pool is run separately in two modes: pool-by-pool simulations where arbitrary upstream forebay conditions were assumed, and system-wide were upstream forebay conditions were supplied by the 1-D model.

4.3.1 Boundary Conditions

MASS2 typically requires a flow and water quality boundary condition upstream and a stage boundary condition downstream. In each simulated pool, the observed flows from the upstream project, and the observed stages from the downstream project were applied as boundary conditions. At the upstream end of the pool, flow was divided in to spillway and powerhouse flow and distributed across model grid. The gas concentrations for the powerhouse were assigned the values simulated by the one-dimensional model (Section 4.2) in the upstream dam forebay. Spillway flow was further divided by bay as described in Section 5. The spill bay flows were assigned to the MASS2 grid as shown in Figure 4.4 for Columbia River projects and Figure 4.5 for Snake River projects. In most cases, there was a one-to-one correspondence between grid cells and spill bays. In other cases, like at John Day (Figure 4.4, lower left), flow and gas concentrations from multiple bays were combined and applied to a single cell.

There were two exceptions to this general pool configuration of MASS2. First, in McNary pool, an upstream flow boundary condition was necessary in the Columbia River near Clover Island. This flow, and its water quality, was supplied by the appropriate one-dimensional simulation (Section 4.2). Second, the downstream stage boundary condition in the Tidal reach was assigned stage simulated by the one-dimensional model for that location.

4.3.2 Meteorology

A single weather data set was assigned to each pool. The necessary data values (the same as those used for MASS1 see Section 4.2.2), except for barometric pressure were obtained from a nearby NWS station. The barometric pressure was obtained from a nearby FMS. Table 4.3 lists the weather station and FMS assigned to each pool.

[3]near Kennewick, Washington
[4]near Portland international airport

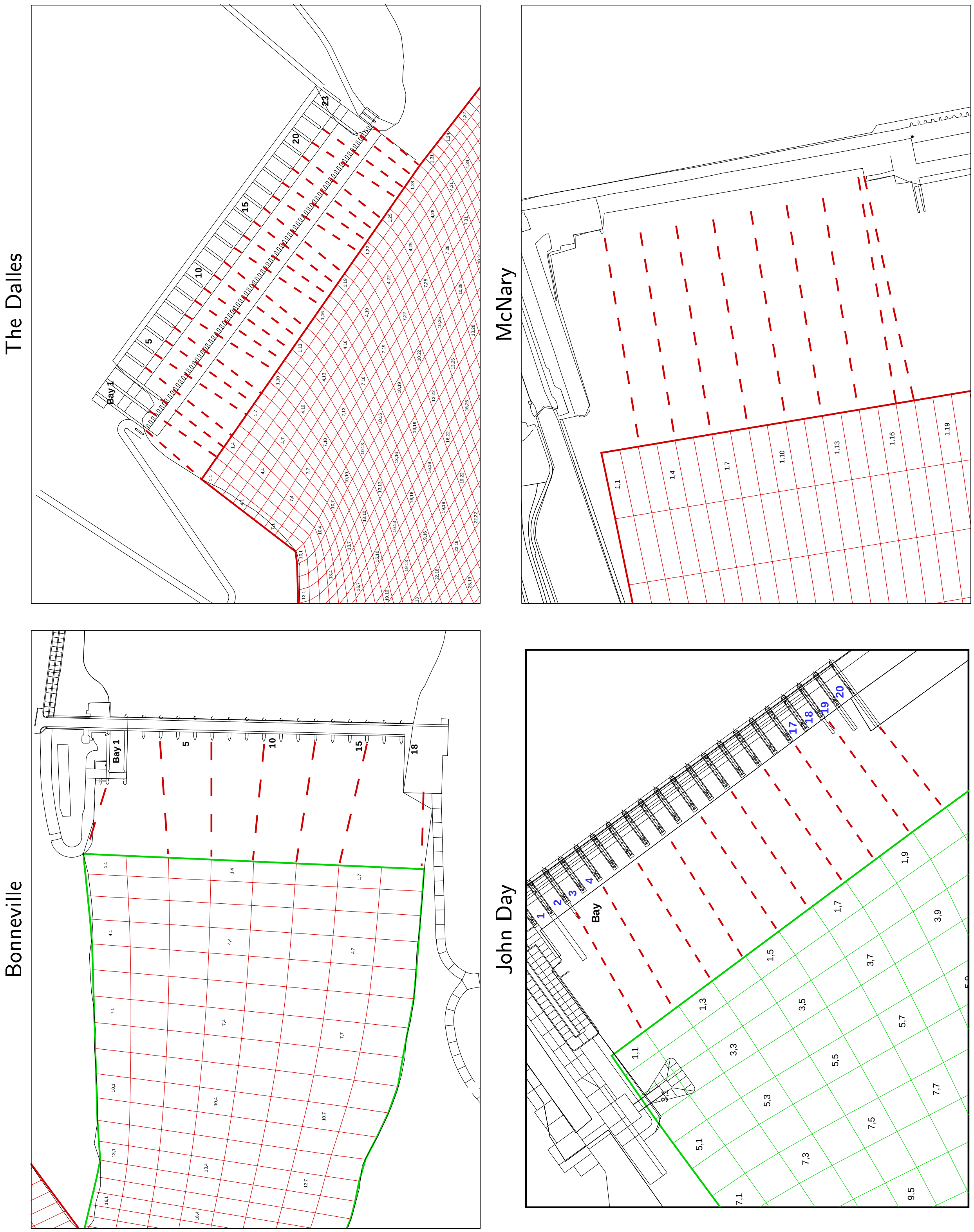


Figure 4.4: Correspondence between the MASS2 model grids and dam spillway bays for projects on the Columbia River.

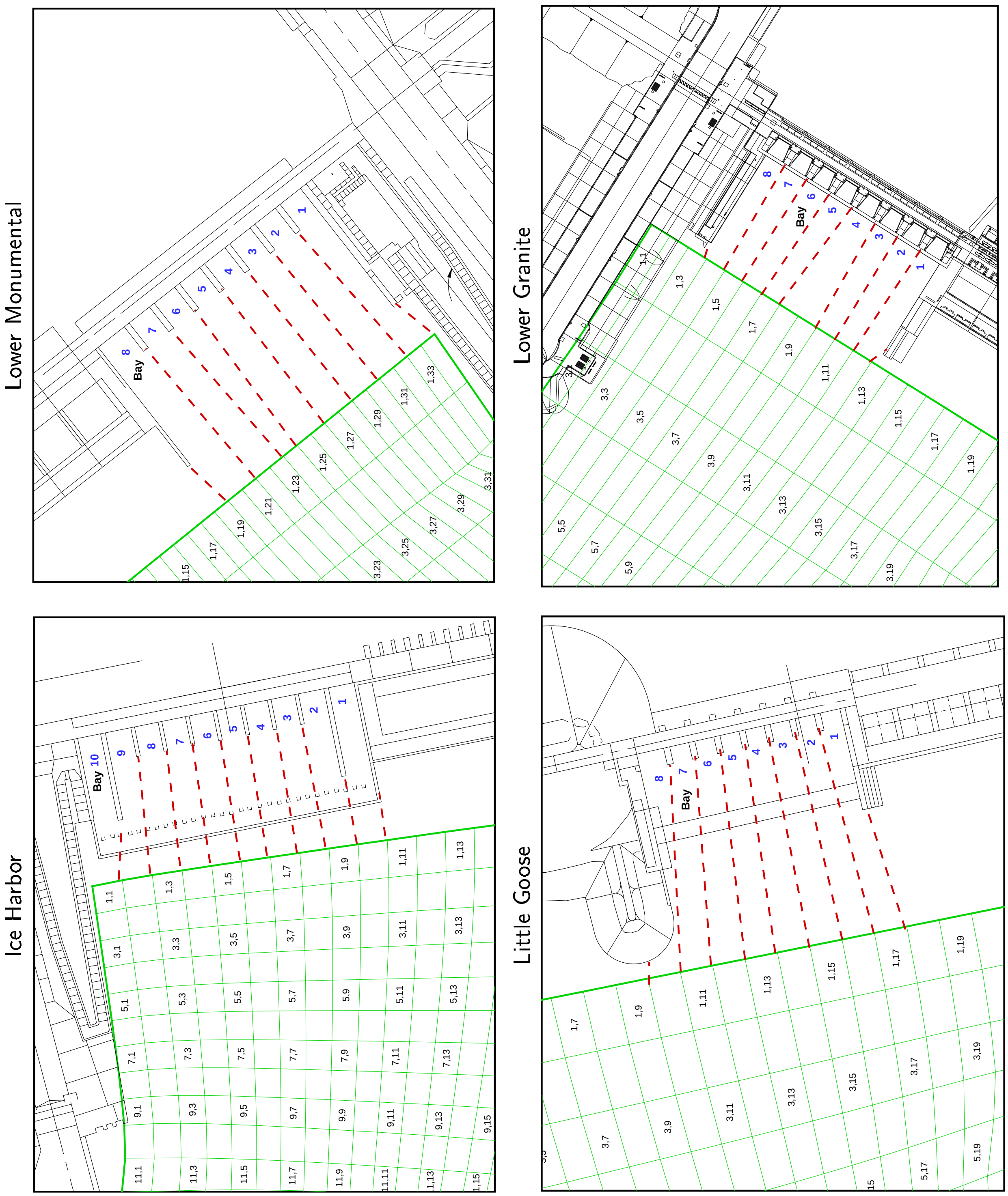


Figure 4.5: Correspondence between the MASS2 model grids and dam spillway bays for projects on the Snake River.

Table 4.3: Sources of meteorological data for each of the lower Columbia and Snake River pools/reaches modeled by MASS2.

Pool/Reach	Station Name	Station Identifier	Fixed Monitor
Little Goose	Lewiston (AMOS)	LWS	LGNW
Lower Monumental	Pasco	PSC	MCQO
Ice Harbor	Pasco	PSC	MCQO
McNary	Pasco	PSC	MCQO
John Day	The Dalles	DLS	TDA
The Dalles	The Dalles	DLS	TDA
Bonneville	Portland	PDX	BON
Tidal	Portland	PDX	BON

4.4 One/Two-Dimensional Hybrid

Using the two-dimensional full-pool model was found to be very computationally expensive. In order to get simulation results in a more reasonable time frame, an approach was used where the two-dimensional model simulated that only portion of the pool where detail was needed and the simulation of the rest of the pool was left to the one-dimensional model. This one/two-dimensional hybrid model, as it called here, was used to further analyze selected alternative scenarios which were simulated with the one-dimensional model.

Figures 4.5 and 4.5 show the limits of the areas simulated with two dimensions in the Snake and Columbia River, respectively. Table 4.4 lists the approximate river miles for those areas.

Table 4.4: Limits of two-dimensionally simulated areas in the hybrid model.

Pool/Reach	Project	Upstream Rivermile	Downstream Rivermile
Little Goose	LWG	107.5	97.0
Lower Monumental	LGS	70.1	60.0
Ice Harbor	LMN	41.6	31.0
McNary	IHR	*PSC*	*MCQO*
John Day	MCN	292.5	282.5
The Dalles	JDA	215.8	207.5
Bonneville	191.5	182.5	
Tidal	BON	146.5	136.0

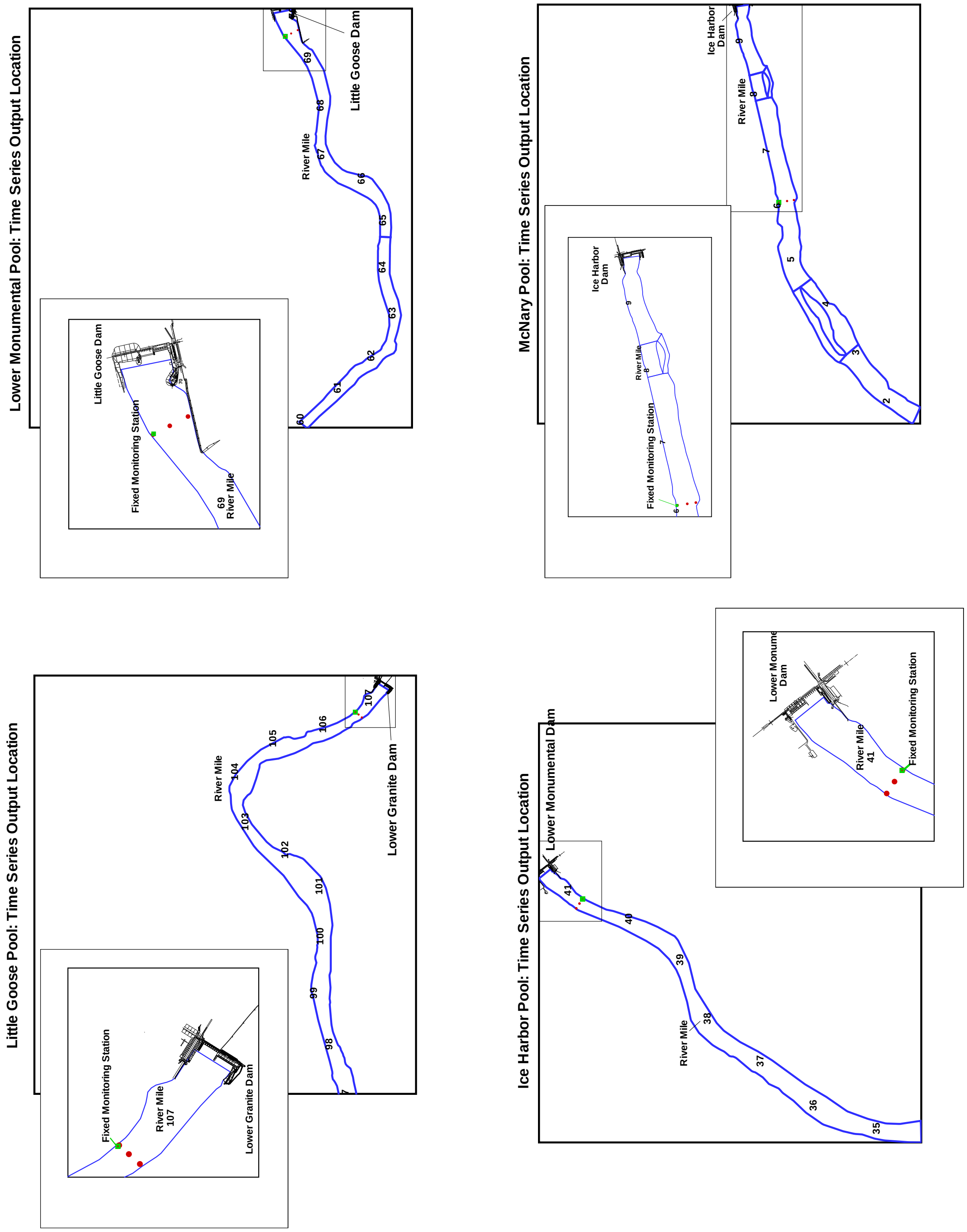


Figure 4.6: Grid and FMS locations for pool areas of the Snake River simulated in two dimensions with the one/two-dimensional hybrid model.

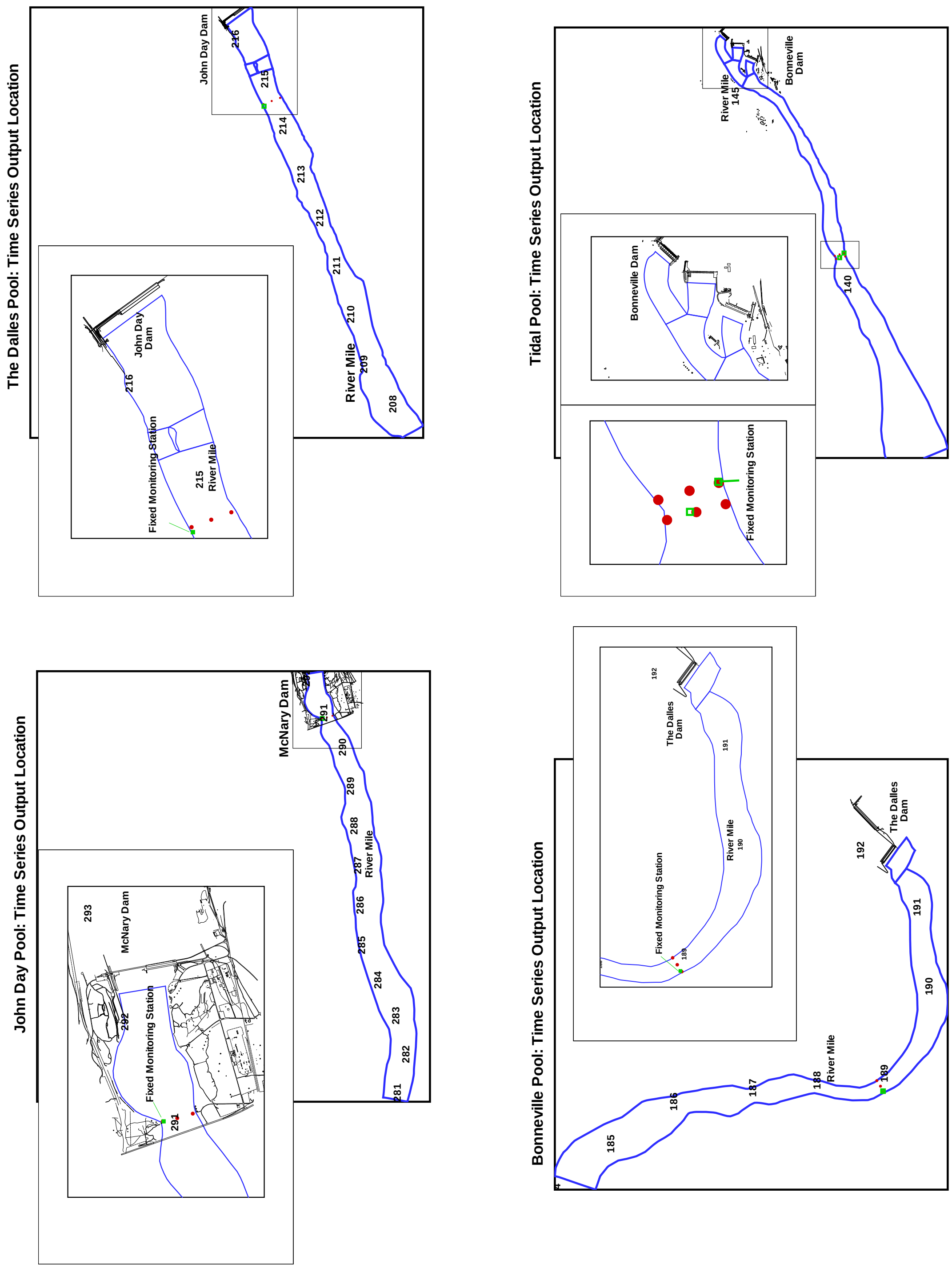


Figure 4.7: Grid and FMS locations for pool areas of the Columbia River simulated in two dimensions with the one/two-dimensional hybrid model.

4.4.1 Boundary Conditions

The upstream boundary conditions for the two-dimensional portion of the hybrid model were the same as that described for the full-pool configuration (Section 4.3.1). The downstream stage boundary condition was extracted for the appropriated location in the one-dimensional simulations.

4.4.2 Meteorology

Meteorologic used in the two-dimensional portion of the hybrid model was the same as the two-dimensional full-pool model (Table 4.3).

5 Gas Production

This section documents, in detail, hydrodynamic and dissolved gas boundary conditions used for the spillway of individual projects when simulating the pool downstream. The preparation of hydrodynamic and water quality boundary conditions was performed using a relational database, not only to store the necessary time-dependent information, like project flow and water quality data, but also to maintain a list of appropriate TDG gas production functions, project spill patterns and procedures to perform necessary calculations.

The following are the basic steps used to compute and apply spill flow and water quality boundary conditions for the various simulations:

1. Hourly project operations were assembled, including total spill, total project flow, and total generation flow. Total generation flow was assumed to be the total project flow less spill.

2. Hourly spillway flows were allocated to each spill bay using a spill pattern (see Section 5.5) in the following manner:

   (a) The largest total spill less than or equal to the current hourly spill, Q_s, was found in the pattern and from that record the number of open stops for bay i (S_i) determined.

   (b) From the same pattern record, open stops for all bays was totaled (S_{total}).

   (c) Spill in bay i was computed as a fraction of the total spill:

   $$q_{s_i} = Q_s \frac{S_i}{S_{\text{total}}} \tag{5.1}$$

   This q_{s_i} was used for hydrodynamic boundary conditions.

3. The TDG concentration was computed for individual bays, using gas production functions presented in the sections below. These production functions estimate the excess dissolved gas pressure, ΔP, from individual bay spill, q_s, and other information. ΔP was converted to concentration, in milligrams per liter, as described by Richmond et al. (1998), using the barometric pressure and temperature measured at the project forebay monitor.

   If spill for a bay was zero, ΔP was set to zero. If the computed ΔP was less than zero, it was set to zero.

4. If the project was subject to powerhouse flow entrainment, the entrainment flow (Q_e) was estimated as a linear function of total spillway flow:

   $$Q_e = aQ_s + b \tag{5.2}$$

   where a and b are constants and Q_e is less than or equal to the total powerhouse discharge. For simulation purposes, powerhouse was considered to increase spill, and decrease generation, but not increase individual spill bay TDG concentrations. The estimated entrainment flow was evenly distributed among all of the open spill bays (as determined in 2) subject to entrainment.

5. For one-dimensional simulations, a single concentration was required for the entire spillway. This was as a flow-weighted average of the concentrations from 3:

$$\overline{C_s} = \frac{\sum_{i=1}^{\text{bays}} C_{s_i} q_{s_i}}{\sum_{i=1}^{\text{bays}} q_{s_i}} \tag{5.3}$$

6. For two-dimensional simulations, computed spill bay flows and TDG concentrations were spatially distributed along the model grid upstream boundary. In some cases, the flow and concentration from several spill bays was combined and applied to a single grid cell. In others, flow and concentration from a single bay is spread over several grid cells.

The following sections document the production functions, mentioned in step 3 above, for a baseline condition (Section 5.1) and for various gas abatement alternatives.

5.1 Baseline Conditions

This section presents, for each of the lower Columbia and Snake River projects, documentation of hydrodynamic and water quality boundary conditions used for the baseline simulations of the pool downstream. The following is presented for each project:

- the existing configuration of the project spillway bays, mainly which bays have deflectors and which do not (summarized in Table 5.1);
- the baseline project spill pattern; and
- functions which predict TDG production based on spill bay flow and other parameters used for baseline simulations (summarized in Table 5.3).

Table 5.1: Lower Columbia and Snake River project spillway bays in which deflectors are currently installed (USACE, 1999c).

Project	**River**	**River Mile**	**Spill Bays**	**Deflectored Bays**	**Bay 1 Location**
Bonneville	Columbia	146.0	18	13: #4 – #15 & #18	north
The Dalles	Columbia	192.0	23	none	northwest
John Day	Columbia	215.0	20	18: #2 – #19	north
McNary	Columbia	292.0	22	18: #3 – #20	north
Ice Harbor	Snake	9.7	10	8: all	south
Lower Monumental	Snake	41.6	8	6: #2 – #7	south
Little Goose	Snake	70.3	8	6: #2 – #7	south
Lower Granite	Snake	107.5	8	all	south

Table 5.2: Coefficients used to compute powerhouse entrainment flow at those projects subject to powerhouse entrainment.

Project	**Coefficients (equation 5.2)** *a*	*b*	**Source**
John Day	0.00	35000.0	Mike Scheider, personal communication, October 14, 1999
McNary	0.00	35000.0	Mike Scheider, personal communication, August 17, 1999
Ice Harbor	0.00	32500.0	Mike Scheider, personal communication, October 14, 1999
Lower Monumental	0.10	0.0	Mike Scheider, personal communication, August 17, 1999
Little Goose	1.00	0.0	Schneider and Wilhelms (1999a)
Lower Granite	0.75	0.0	Schneider and Wilhelms (1999a)

5.1.1 Bonneville Dam

Bonneville dam is located on the Columbia River at approximately river mile 146. The Bonneville spillway has 18 bays, of which 13, bays 4 through 15 and 18, have deflectors installed. Bay 1 is on the north end of the spillway. Total dissolved gas production by bays with deflectors was estimated using (Schneider and Wilhelms, 1999b)

$$\Delta P = -0.0567 q_s^3 + 0.421 q_s^2 + 27.823 q_s - 37.067 \tag{5.4}$$

where

$$\begin{aligned} \Delta P &= P_{tw} - P_{atm}; \\ P_{tw} &= \text{total dissolved gas pressure at the tailwater, mm Hg;} \\ P_{atm} &= \text{atmospheric pressure, mm Hg;} \\ q_s &= \text{spill bay discharge, kcfs/bay;} \end{aligned}$$

Gas production by bays without deflectors was estimated using (Schneider and Wilhelms, 1999b)

$$\Delta P = 255.58 - 1031.58 \exp\left(-0.639 q_s\right) \tag{5.5}$$

Figure 5.1 shows a graphical summary of the baseline spill pattern for Bonneville dam (USACE, 1999a). The complete pattern is in Section 5.5.

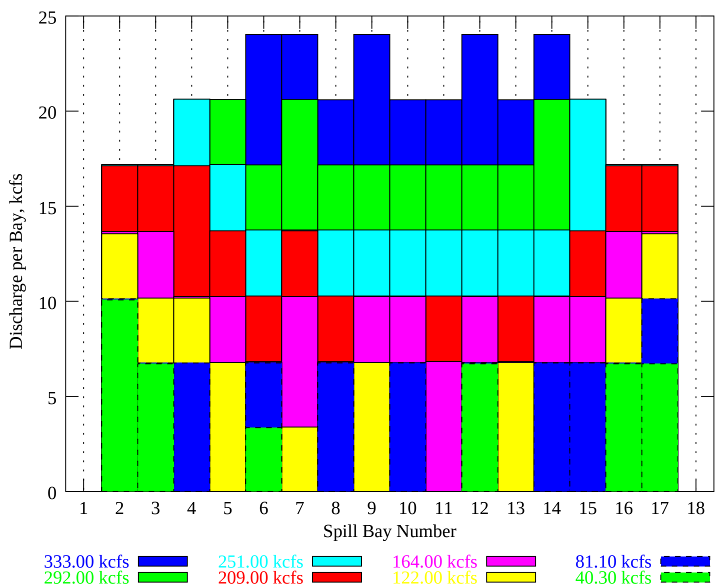


Figure 5.1: Graphic summary of the baseline spill pattern for Bonneville dam (USACE, 1999a).

5.1.2 The Dalles Dam

The Dalles dam spillway has 23 bays, none of which have deflectors. Bay 1 is located at the northwest end of the spillway. Spill bay dissolved gas production was estimated using (Schneider and Wilhelms, 1999a)

$$\Delta P = D_{tw}^{1.02} q_s^{0.33} + 145.9 \tag{5.6}$$

Table 5.3: Summary of baseline TDG production functions for Lower Columbia and Snake River projects.

Project	E_{ch}, **feet**	**Powerhouse Flow Entrainment?**	**Bays**	**Production Function**
Bonneville	−30.0	no	deflector	$\Delta P = -0.0567q_s^3 + 0.421q_s^2 + 27.823q_s - 37.067$
			no deflector	$\Delta P = 255.58 - 1031.58\exp(-0.639q_s)$
The Dalles	68.0	no	all	$\Delta P = D_{tw}^{1.02} q_s^{0.33} + 145.9$
John Day	125.0	yes	deflector	$\Delta P = 4.97D_{tw}[1 - \exp(-0.23q_s)]$
			no deflector	$\Delta P = 315.29 - 519.09\exp(-0.365q_s)$
McNary	220.0	yes	deflector	$\Delta P = 11.4q_s + 47.3$
			no deflector	$\Delta P = 11.35q_s + 143.01$
Ice Harbor	327.0	yes	all	$\Delta P = 0.014D_{tw}^{2.097} q_s^{0.772} + 84.57$
Lower Monumental	400.0	yes	deflector	$\Delta P = 5.056D_{tw}[1 - \exp(-0.21q_s)]$
			no deflector	$\Delta P = 5.427D_{tw}[1 - \exp(-0.58q_s)]$
Little Goose	500.0	yes	deflector	$\Delta P = 5.566D_{tw}[1 - \exp(-0.15q_s)]$
			no deflector	not available, but not necessary
Lower Granite	585.0	yes	all	$\Delta P = 5.307D_{tw}[1 - \exp(-0.1059q_s)]$

where: $\Delta P = P_{tw} - P_{atm}$;

P_{tw} = total dissolved gas pressure at the tailwater, mm Hg;

P_{atm} = atmospheric pressure, mm Hg;

q_s = spill bay discharge, kcfs/bay;

D_{tw} = tailwater channel depth, feet = $E_{tw} - E_{ch}$;

E_{tw} = elevation of the tailwater, feet;

E_{ch} = average elevation of the tailwater channel, feet;

Q_s = actual spillway flow; and

Q_{se} = effective spillway flow (actual + powerhouse entrainment).

where

$$D_{tw} = \text{tailwater channel depth, feet} = E_{tw} - E_{ch};$$
$$E_{tw} = \text{elevation of the tailwater, feet; and}$$
$$E_{ch} = \text{average elevation of the tailwater channel}$$
$$= 68 \text{ feet msl.}$$

Figure 5.2 shows a graphical summary of the baseline spill pattern for The Dalles dam (USACE, 1999b). The entire spill pattern is in Section 5.5.

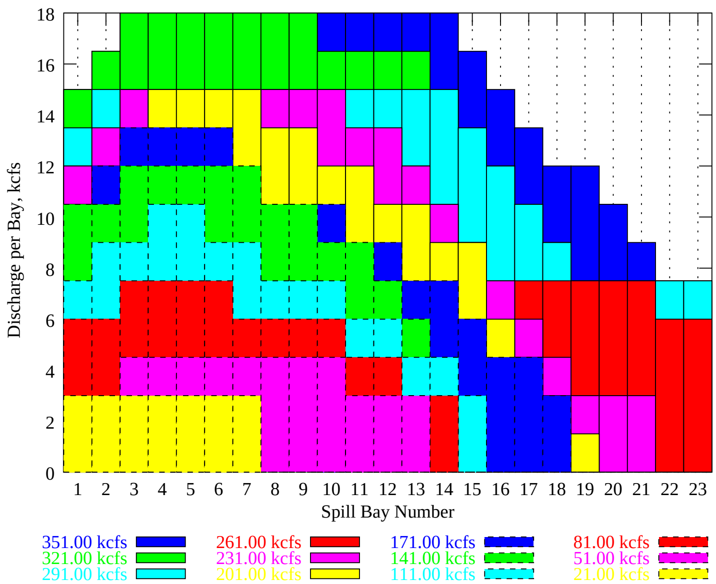


Figure 5.2: Graphic summary of the baseline spill pattern for The Dalles dam (USACE, 1999b).

5.1.3 John Day Dam

The John Day dam spillway has 20 bays, 18 of which have deflectors installed: bays 2 through 19. Production of dissolved gas for bays with deflectors was estimated for baseline conditions as (Schneider and Wilhelms, 1999a)

$$\Delta P = 4.97 D_{tw} \left[1 - \exp\left(-0.23 q_s\right)\right] \tag{5.7}$$

and for bays without deflectors as

$$\Delta P = 315.29 - 519.09 \exp\left(-0.365 q_s\right) \tag{5.8}$$

where the tailwater channel elevation, E_{ch} used to compute D_{tw}, is 125 feet. Figure 5.3 shows a graphical summary of the "standard" spill pattern for John Day dam (USACE, 1999e). See Section 5.5 for the complete spill pattern.

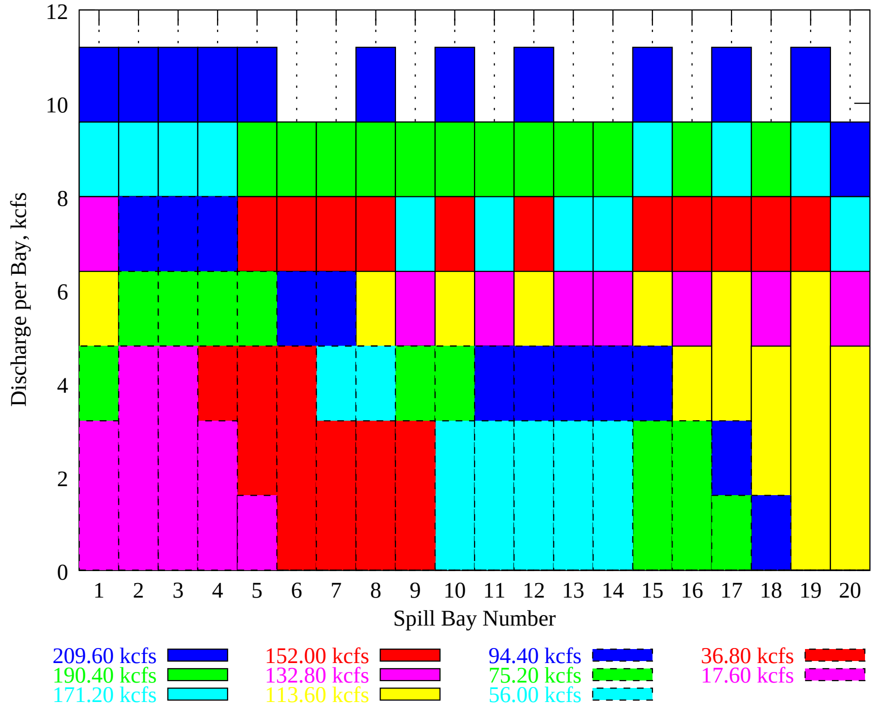


Figure 5.3: Graphic summary of the baseline spill pattern for John Day dam (USACE, 1999e).

5.1.4 McNary Dam

The McNary dam spillway has 22 bays, of which 18 are deflectored: bays 3 through 20. Spill bay 22 is currently inoperable. Production of dissolved gas from deflectored bays was estimated using

$$\Delta P = 11.4q_s + 47.3 \tag{5.9}$$

and from non-deflectored bays as

$$\Delta P = 11.35q_s + 143.01 \tag{5.10}$$

Field studies indicate that the McNary powerhouse flow up to 35,000 cfs at McNary will become entrained by the spill[1]. Figure 5.4 shows a graphical summary of the baseline spill pattern for McNary dam. The entire spill pattern is shown in Section 5.5.

5.1.5 Ice Harbor Dam

The Ice Harbor dam spillway has 10 bays, all of which have deflectors installed. Spill bay dissolved gas production was estimated using:

$$\Delta P = 0.014D_{tw}^{2.097}q_s^{0.772} + 84.57 \tag{5.11}$$

where D_{tw} is computed using E_{ch} equal to 327.0 feet. A graphical summary of the baseline spill pattern for Ice Harbor dam is shown in Figure 5.5. The entire spill pattern is presented in Section 5.5.

[1]Equations 5.9 and 5.10, and the powerhouse entrainment, for McNary were obtained from Mike Schneider via personal communication August 17, 1999.

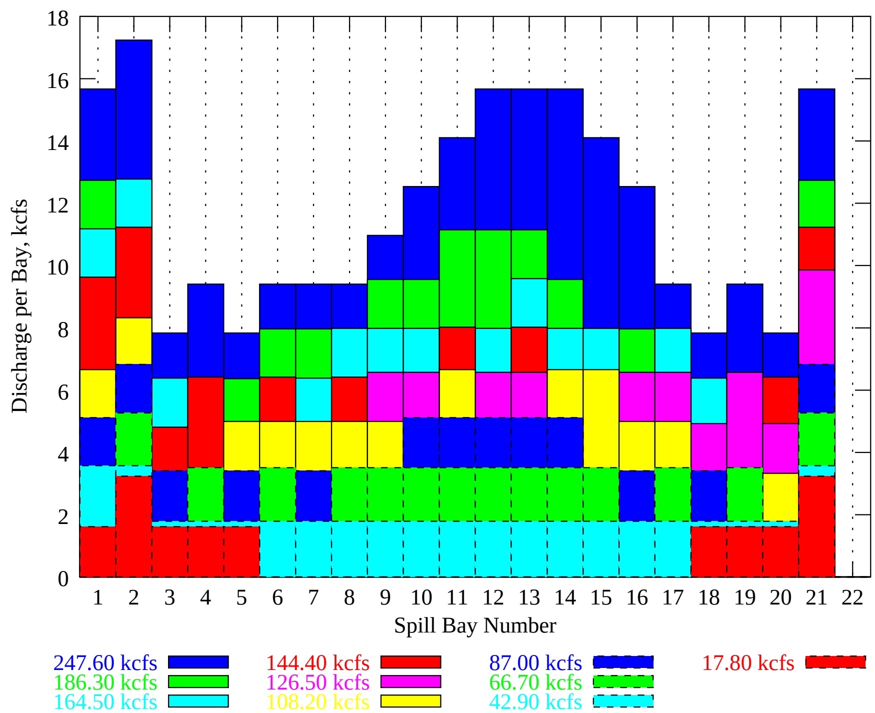


Figure 5.4: Graphical summary of the baseline spill pattern for McNary dam (USACE, 1999i).

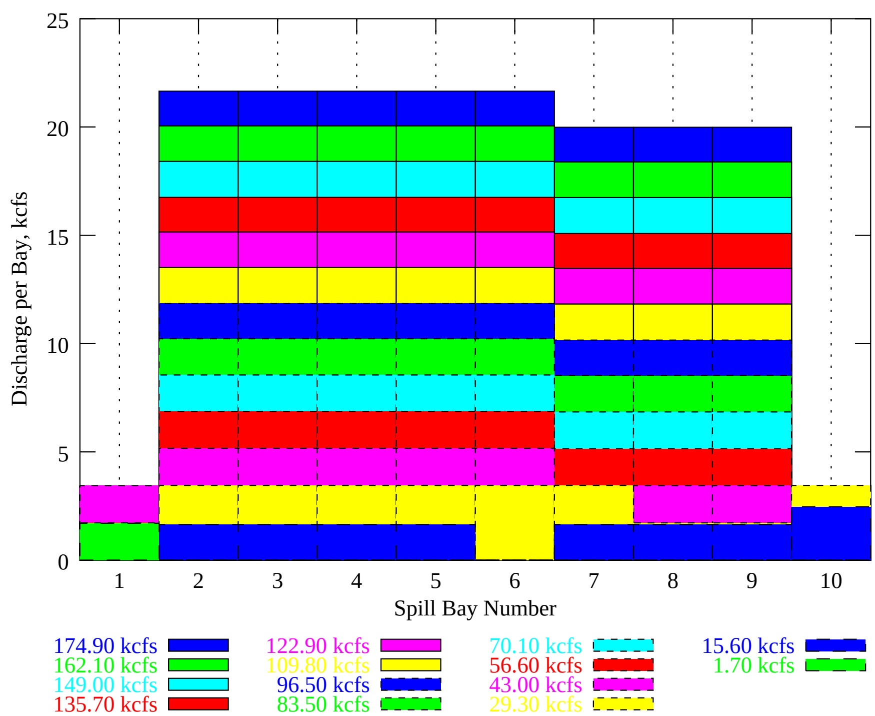


Figure 5.5: Graphical representation of the baseline spill pattern for Ice Harbor dam (USACE, 1999d).

5.1.6 Lower Monumental Dam

The Lower Monumental dam spillway has 8 bays, of which 6 have deflectors installed: bays 2 through 6. Gas production by bays with deflectors was estimated using (Schneider and Wilhelms, 1999a)

$$\Delta P = 5.056 D_{tw} \left[1 - \exp\left(-0.21 q_s\right)\right] \tag{5.12}$$

and by bays without deflectors using

$$\Delta P = 5.427 D_{tw} \left[1 - \exp\left(-0.58 q_s\right)\right] \tag{5.13}$$

where D_{tw} is computed using E_{ch} = 400.0 feet. Powerhouse flow from Lower Monumental is entrained in the spillway. $Q_{se} = 1.1 Q_s$ is indicated by field measurements[2]. A summarization of the baseline spill pattern for Lower Monumental dam is shown in Figure 5.6; the entire pattern is in Section 5.5.

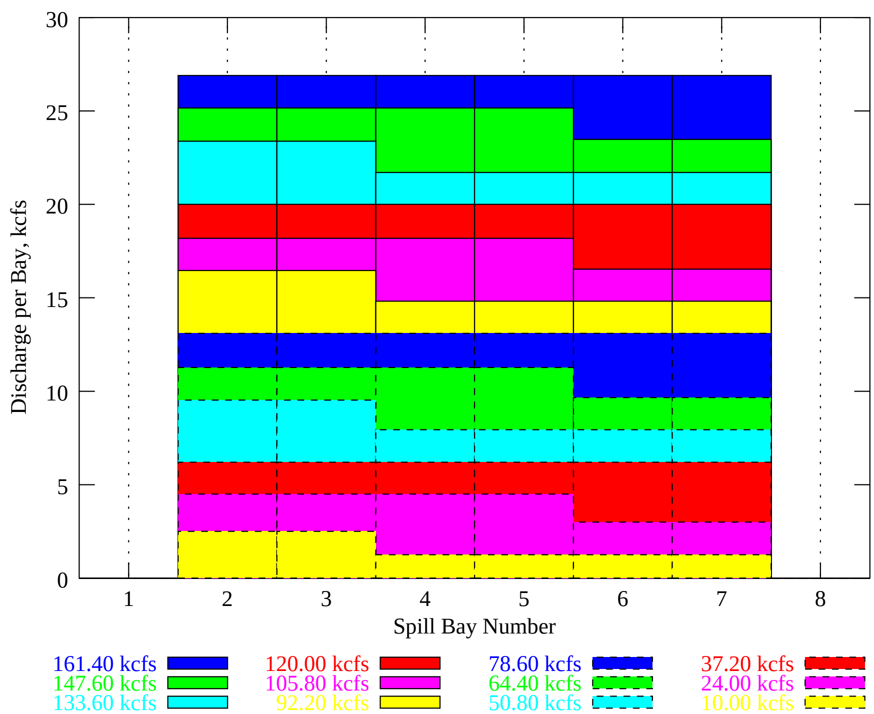


Figure 5.6: Graphical representation of the baseline spill pattern for Lower Monumental dam (USACE, 1999h).

5.1.7 Little Goose Dam

The Little Goose dam spillway has 8 bays, 6 of which have deflectors: bays 2 through 7. Bay 1 is on the south end. Gas production by deflectored spill bays was estimated using (Schneider and Wilhelms, 1999a, "juvenile" pattern)

$$\Delta P = 5.566 D_{tw} \left[1 - \exp\left(-0.15 q_s\right)\right] \tag{5.14}$$

[2] Mike Schneider, personal communication, August 17, 1999

where D_{tw} is calculated using E_{ch} = 500.0 feet. A gas production function was not available for bays without deflectors, but this was not necessary for baseline simulations since the non-deflectored bays (1 and 8) are not used in the baseline spill pattern. A graphical summary of the spill pattern is shown in Figure 5.7. The entire pattern is shown in Section 5.5. Powerhouse entrainment is high at Little Goose; field studies indicate that Q_{se}/Q_s = 2.00 (Schneider and Wilhelms, 1999a).

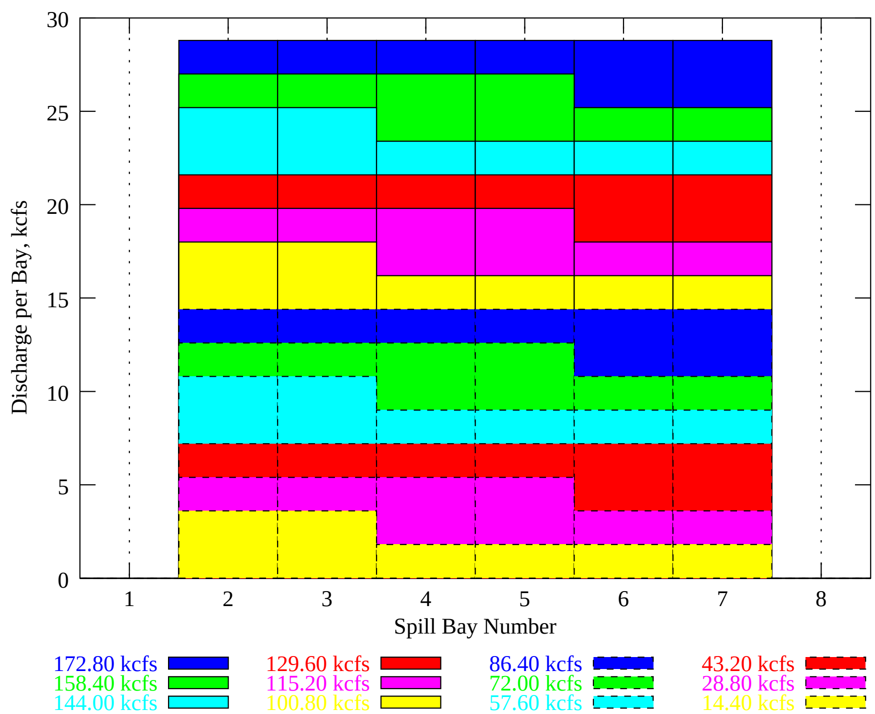


Figure 5.7: Graphical representation of the baseline spill pattern for Little Goose dam (USACE, 1999f).

5.1.8 Lower Granite Dam

The Lower Granite dam spillway has 8 bays, all of which have deflectors installed. The bays are numbered starting with bay 1 on the south end. Spill bay gas production was estimated using (Schneider and Wilhelms, 1999a)

$$\Delta P = 5.307 D_{tw} \left[1 - \exp\left(-0.1059 q_s\right)\right] \quad (5.15)$$

where E_{ch}, used to computed D_{tw} is 585.0 feet. Powerhouse flow is subject to entrainment; field studies indicate that Q_{se}/Q_s = 1.75 (Schneider and Wilhelms, 1999a). The spill pattern used for baseline simulations is show graphically in Figure 5.8. The entire spill pattern is shown in Section 5.5.

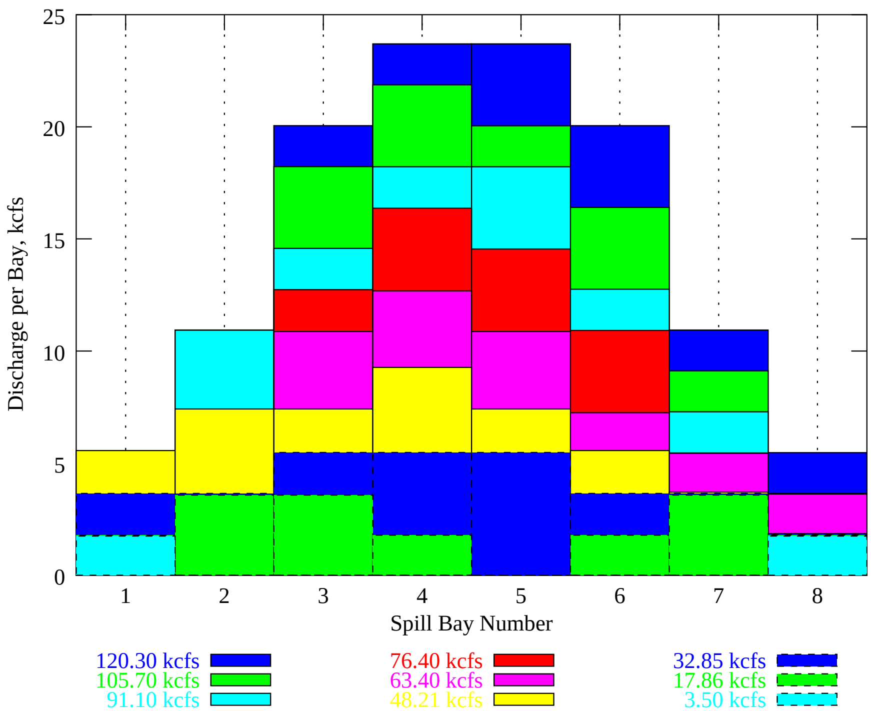


Figure 5.8: Graphical representation of the baseline spill pattern for Lower Granite dam (USACE, 1999g).

5.2 Fast Track Gas Abatement Alternative Scenarios

This section documents the preparation of simulation boundary conditions for the various fast-track gas abatement alternatives. These are summarized in Table 5.4.

5.2.1 Bonneville Dam

Deflectors Installed

For this alternative, deflectors would be installed in those spill bays which currently do not have deflectors (bays 1, 2, 3, 16, and 17). For simulation of this alternative, equation 5.4 was used to estimate gas production from all spill bays.

Raised Tailrace

In the raised tailrace alternative, the channel below the dam stilling basin is raised over the width of the spillway to a certain elevation, E_{rt}. The raised tailrace extends for a specified length, L_{rt}. At Bonneville dam, the proposed tailrace has dimensions of E_{rt} = 8 feet msl and L_{rt} = 250 feet. Installation of a raised tail race would be done only if the dam had a full complement of spill deflectors installed.

The gas production by raised tailrace alternative was estimated by subtracting some loss factor, ΔP_{tr}, from the production function for deflectored bays (equation 5.4). The loss factor is given by

$$\Delta P_{\text{tr}} = \Delta P_f - \Delta P_f^* \tag{5.16}$$

where

$$\Delta P_f = \Delta P_{eq} \left(1 - \exp\left(-k_L a T_{\text{ret}}\right)\right) + \Delta P_i \exp\left(-k_L a T_{\text{ret}}\right) \tag{5.17}$$

where

$$\begin{aligned}
\Delta P_i &= \text{the excess gas pressure produced in the spilling basin, mm Hg} \\
&= 24.07 q_s + 35.68, \text{ where } q_s \text{ is in kcfs;} \\
\Delta P_{eq} &= \text{the } \Delta P \text{ which is produced by deflectored bays (equation 5.4),} \\
T_{\text{ret}} &= \text{a retention time} \\
&= \tfrac{D_{tw} + L_{rt}}{q_s 1000/60} \\
k_L a &= \text{an atmospheric exchange coefficient} \\
&= \min\left(k_L a', 0.012\right), \text{ where} \\
k_L a' &= \left(\frac{20}{D_{tw}}\right)^{1.3} \left(0.0014 q_s + 0.0013\right)
\end{aligned}$$

and

$$\Delta P_f^* = \Delta P_{eq}^* \left(1 - \exp\left(-k_L a^* T_{\text{ret}}\right)\right) + \Delta P_i \exp\left(-k_L a^* T_{\text{ret}}\right) \tag{5.18}$$

where

$$\begin{aligned}
\Delta P_{eq}^* &= 0.014 D_{tw}^{2.097} q_s^{0.772} + 84.57, \text{ and} \\
k_L a^* &= \min\left(k_L a', 0.030\right)
\end{aligned}$$

Table 5.4: Summary of simulated gas abatement alternatives for lower Columbia and Snake River projects.

Alternative	Powerhouse Flow Entrainment?	Production Function	Spill Pattern	Raised Tailrace E_{rt}	Raised Tailrace L_{rt}
Bonneville					
Deflectors Installed	no	$\Delta P = -0.0567q_s^3 + 0.421q_s^2 + 27.823q_s - 37.067$	baseline		
Raised Tailrace	no	$\Delta P = -0.0567q_s^3 + 0.421q_s^2 + 27.823q_s - 37.067 - \Delta P_{\text{tr}}$	baseline	8.0	250.0
The Dalles					
Deflectors	no	$\Delta P =$	baseline		
John Day					
Additional Deflectors	yes	$\Delta P = 4.97D_{tw}[1 - \exp(-0.23q_s)]$	baseline		
Divider Wall Only	no	$\Delta P = 4.97D_{tw}[1 - \exp(-0.23q_s)]$ (w/ deflector)	baseline		
		$\Delta P = 315.29 - 519.09\exp(-0.365q_s)$ (w/o deflector)			
McNary					
4 Additional Deflectors	yes	$\Delta P = 11.4q_s + 47.3$	uniform		
Divider Wall Only	no	$\Delta P = 11.4q_s + 47.3$ (w/ deflectors)	baseline		
		$\Delta P = 11.35q_s + 143.01$ (w/o deflectors)			
4 Add. Defl. + R. T.	yes	$\Delta P = 11.4q_s + 47.3 - \Delta P_{\text{tr}}$	uniform	235.0	250.0
4 Add. Defl. + R. T. + D. W.	no	$\Delta P = 11.4q_s + 47.3 - \Delta P_{\text{tr}}$	uniform	235.0	250.0
Ice Harbor					
Divider Wall Only	no	$\Delta P = 0.014D_{tw}^{2.097}q_s^{0.772} + 84.57$	baseline		
Lower Monumental					
2 Additional Deflectors	yes	$\Delta P = 5.056D_{tw}[1 - \exp(-0.21q_s)]$	uniform		
Modified Deflectors	no	$\Delta P = 5.056D_{tw}[1 - \exp(-0.21q_s)] - 5.0$	uniform		
Divider Wall Only	no	$\Delta P = 5.056D_{tw}[1 - \exp(-0.21q_s)]$ (w/ deflectors)	baseline		
		$\Delta P = 5.427D_{tw}[1 - \exp(-0.58q_s)]$ (w/o deflectors)			
2 Add. Defl. + R. T. + D. W.	no	$\Delta P = 5.056D_{tw}[1 - \exp(-0.21q_s)] - \Delta P_{\text{tr}}$	uniform	425.0	250.0
Little Goose					
2 Additional Deflectors	yes	$\Delta P = 5.566D_{tw}[1 - \exp(-0.15q_s)]$	uniform		
Modified Deflectors	yes	$\Delta P = 5.566D_{tw}[1 - \exp(-0.15q_s)] - 5.0$	baseline		
Divider Wall Only	no	$\Delta P = 5.566D_{tw}[1 - \exp(-0.15q_s)]$	baseline		
Modified Deflectors + D. W.	no	$\Delta P = 5.566D_{tw}[1 - \exp(-0.15q_s)] - 5.0$	baseline		
2 Add. Defl. + R. T. + D. W.	no	$\Delta P = 5.566D_{tw}[1 - \exp(-0.15q_s)] - \Delta P_{\text{tr}}$	uniform	527.0	250.0
Lower Granite					
Modified Deflectors	yes	$\Delta P = 5.307D_{tw}[1 - \exp(-0.1059q_s)] - 5.0$	baseline		
Divider Wall Only	no	$\Delta P = 5.307D_{tw}[1 - \exp(-0.1059q_s)]$	baseline		
Modified Deflectors + D. W.	no	$\Delta P = 5.307D_{tw}[1 - \exp(-0.1059q_s)] - 5.0$	baseline		
Raised Tailrace	yes	$\Delta P = 5.307D_{tw}[1 - \exp(-0.1059q_s)] - \Delta P_{\text{tr}}$	baseline	624.0	250.0

5.2.2 The Dalles Dam

Deflectors Installed

For this scenario, deflectors would be installed in all of the spill bays at The Dalles dam. Spill bay gas production estimates used for simulation of this alternative were made using

$$\Delta P = \min\left(\Delta P_f, \Delta P_o\right) \tag{5.19}$$

where ΔP_o is the TDG excess pressure estimated by the baseline production function for The Dalles, equation 5.6, and

$$\Delta P_f = \min\left\{\left(\Delta P_e - \Delta P_i\right)\left(1.0 - \exp\left[-k_L a T_{\text{ret}}\right]\right) + \Delta P_i, D_{tw}^{1.02} q_s^{0.33} + 145.9\right\} \tag{5.20}$$

where

$$\Delta P_e = 0.014 D_{tw}^{2.097} q_s^{0.772} + 84.57$$

and

$$\Delta P_i = \min\left[49.3 \log\left(q_s\right) + 118.5, 91.25 \log\left(q_s\right) + 24.97\right]$$

In equation 5.20 $k_L a$ is computed as

$$k_L a = \begin{cases} min\left(0.03, 0.005 q_s\right) & \text{for } D_{tw} < 10.0, \\ & \text{for } 10.0 \leq D_{tw} \leq 20.0, \text{and} \\ \min\left(0.012, 0.0016 q_s\right) & \text{for } D_{tw} > 20.0 \end{cases}$$

and T_{ret}

5.2.3 John Day Dam

Additional Deflectors

In this alternative, deflectors would be installed in the two spill bays which currently do not have deflectors (bays 1 and 20). During simulation of this alternative gas production from all bays was estimated by equation 5.7, which was used for deflectored bays in the baseline simulation (Section 5.1.3).

5.2.4 McNary Dam

Four Additional Deflectors Only

This alternative proposes to install deflectors in the spill bays which currently do not have deflectors installed: bays 1, 2, 21, and 22. For simulation of this alternative, gas production from all McNary bays was estimated using equation 5.9, which was used for deflectored bays in the baseline simulation (Section 5.1.4).

Divider Wall Only

This alternative proposes the eliminate entrainment of powerhouse flow by installing a guide wall between the spillway and powerhouse. For simulation of this alternative, gas production was estimated as it was in the baseline (Section 5.1.4), except that the effective spill, Q_{se} was equal to the actual spill, Q_s.

Four Additional Deflectors plus Raised Tailrace

This alternative involves installing deflectors in all bays and raising the tailrace below McNary dam from 220 feet (E_{ch}) to 235 feet msl (E_{rt}) for a distance of 250 feet (L_{rt}) downstream of the stilling basin. Gas production by individual bays was estimated in a fashion similar to the Bonneville dam raised tailrace alternative (Section 5.2.1), with ΔP_e given by equation 5.9.

Four Additional Deflectors plus Raised Tailrace plus Divider Wall

Estimation of gas production for simulation of this alternative was the same as the previous alternative except that the effective spill, Q_{se} was equal to the actual spill, Q_s.

5.2.5 Ice Harbor Dam

Divider Wall Only

This alternative proposes to eliminate entrainment of powerhouse flow by installing a guide wall between the spillway and powerhouse. For simulation of this alternative, gas production was estimated as it was in the baseline (Section 5.1.5), except that the powerhouse entrainment was not considered.

5.2.6 Lower Monumental Dam

Two Additional Deflectors

In this alternative, two deflectors would be installed in the bays which currently do not have deflectors: bays 1 and 8. Gas production of all bays in this scenario would be estimated using equation 5.12, which was used to estimate gas production of deflectored bays for the baseline simulation (Section 5.1.6).

Eight Modified Deflectors

This alternative proposes to install, in all spill bays, deflectors which would perform similarly to, but slightly better than, existing deflectors. It was assumed that the modified deflectors would reduce the TDG ΔP by approximately 5 mm Hg. Consequently, gas production for simulation of this alternative was estimated using equation 5.12, as in the baseline (Section 5.1.6), but with a 5 mm Hg reduction:

$$\Delta P = 5.056 D_{tw} \left[1 - \exp\left(-0.21 q_s\right)\right] - 5.0 \qquad (5.21)$$

Divider Wall Only

This alternative proposes to eliminate entrainment of powerhouse flow by installing a guide wall between the spillway and powerhouse. For simulation of this alternative, gas production was estimated as it was in the baseline (Section 5.1.6), except that the effective spill, Q_{se} was equal to the actual spill, Q_s.

Two Additional Deflectors plus Raised Tailrace plus Divider Wall

This alternative involves installing deflectors in all bays and raising the tailrace below Lower Monumental dam from 400 feet (E_{ch}) to 425 feet msl (E_{rt}) for a distance of 250 feet (L_{rt}) downstream of the stilling basin. Gas production by individual bays was estimated in a fashion similar to the Bonneville dam raised tailrace alternative (Section 5.2.1), with ΔP_e given by equation 5.12. In addition, a spillway/powerhouse flow divider would be installed to eliminate powerhouse entrainment.

5.2.7 Little Goose Dam

Two Additional Deflectors

In this alternative, two deflectors would be installed in the bays which currently do not have deflectors: bays 1 and 8. Gas production of all bays in this scenario would be estimated using equation 5.14, which was used to estimate gas production of deflectored bays for the baseline simulation (Section 5.1.7). Since the baseline spill pattern for Little Goose did not utilize bays 1 and 8 (see Figure 5.7), a uniform spill pattern was used to estimate individual bay flows for this alternative.

Modified Deflectors

In this alternative, existing deflectors in the Little Goose spill bays would be replaced with deflectors that would perform slightly better. It was assumed that the modified deflectors would produce a TDG ΔP approximately 5 mm Hg below that of the existing deflectors. Gas production was then estimated using equation 5.14, but with a 5 mm Hg reduction:

$$\Delta P = 5.566 D_{tw} \left[1 - \exp\left(-0.15 q_s\right)\right] - 5.0 \tag{5.22}$$

The baseline spill pattern (Figure 5.7) was used to assign spill to individual bays.

Divider Wall Only

This alternative proposes to eliminate entrainment of powerhouse flow by installing a guide wall between the spillway and powerhouse. For simulation of this alternative, gas production was estimated as it was in the baseline (Section 5.1.7), except that the effective spill, Q_{se} was equal to the actual spill, Q_s. The baseline spill pattern (Figure 5.7) was used to determine spill for individual bays.

Divider Wall plus Modified Deflectors

This alternative combines the two alternatives above. Gas production was estimated using equation 5.22, with the effective spill, Q_{se} set equal to the actual spill, Q_s. The baseline spill pattern (Figure 5.7) was used to determine spill for individual bays.

Two Additional Deflectors plus Raised Tailrace plus Divider Wall

This alternative involves installing deflectors in all bays and raising the tailrace below Little Goose dam from 500 feet (E_{ch}) to 527 feet msl (E_{rt}) for a distance of 250 feet (L_{rt}) downstream of the stilling basin. Gas production by individual bays was estimated in a fashion similar to the Bonneville dam raised tailrace alternative (Section 5.2.1), with ΔP_e given by equation 5.14. In addition, a spillway/powerhouse flow divider would be installed to eliminate powerhouse entrainment.

5.2.8 Lower Granite Dam

Modified Deflectors

In this alternative, existing deflectors in the Lower Granite spill way would be replaced with deflectors that perform slightly better. It was assumed that the modified deflectors would produce a TDG ΔP approximately 5 mm Hg below that of the existing deflectors. Gas production was then estimated using equation 5.15, but with a 5 mm Hg reduction:

$$\Delta P = 5.307 D_{tw} \left[1 - \exp\left(-0.1059 q_s\right)\right] - 5.0 \tag{5.23}$$

The baseline spill pattern (Figure 5.8) was used to determine individual bay flows.

Divider Wall Only

This alternative proposes to eliminate entrainment of powerhouse flow by installing a guide wall between the spillway and powerhouse. For simulation of this alternative, gas production was estimated as it was in the baseline (Section 5.1.8), except that the effective spill, Q_{se} was set equal to the actual spill, Q_s. The baseline spill pattern (Figure 5.8) was used to determine spill for individual bays.

Divider Wall plus Modified Deflectors

This alternative combines the two discussed above. Spill bay gas production was estimated using equation 5.23 and the effective spill, Q_{se} was set equal to the actual spill, Q_s. The baseline spill pattern (Figure 5.8) was used to determine spill for individual bays.

Raised Tailrace

This alternative involves raising the tailrace below Lower Granite dam from 585 feet (E_{ch}) to 624 feet msl (E_{rt}) for a distance of 250 feet (L_{rt}) downstream of the stilling basin. Gas production by individual bays was estimated in a fashion similar to the Bonneville dam raised tailrace alternative (Section 5.2.1) with ΔP_e given by equation 5.15.

Raised Tailrace plus Divider Wall

In addition to the **Raised Tailrace** option, a spillway/powerhouse divider would be installed to eliminate powerhouse entrainment.

5.3 Long Term Gas Abatement Alternative Scenarios

This section documents documents the preparation of simulation spill boundary conditions for the various long term gas abatement alternatives. The physical modifications required by these alternatives are described in USACE (1999c). This section documents the gas generation assumed for simulation.

5.3.1 Bonneville Dam

Large Submerged Radial Gates

This alternative entails lowering of the spillway sill and replacement of existing slide gates with large radial gates. The sill would be lowered enough to keep the spillway jet submerged, thus making the jet unable to entrain air. It was assumed, for simulation purposes, that the gas concentration of water spilled from these gates would be the same as the forebay concentration.

5.3.2 John Day Dam

Additional Spill Bays

In this alternative (which is not considered in USACE (1999c)), six new spill bays would be built in the now empty skeleton bays between the existing spillway and powerhouse. This would be in addition to the **Deflectors Installed** fast track alternative above (Section 5.2.3). The approximate location of the new bays is shown in Figure 5.9. For simulation purposes, the new bays were assumed to be similar to the existing bays having deflectors installed. Consequently, gas production was estimated using equation 5.7.

For the purposes of simulation, these new bays would had a operational limit of 6300 cfs and were opened one at a time. That is, the second bay was opened only if the first bay was at 6300 cfs, and so on. After all of the new bays were at the operational limit, additional spill was distributed uniformly over the 20 original bays.

When this alternative was simulated, no changes to the MASS2 grid were necessary. It was necessary, however, to reassign some of the boundary cells to the extended spillway, as shown in Figure 5.9.

5.3.3 McNary Dam

Additional Spill Bays

This alternative consists of adding nine new spill bays to the **Four Additional Deflectors Only** fast-track alternative above (Section 5.2.4). The new bays would be installed in the earthen portion of McNary dam, north of the navigation lock. The area downstream of the new spillway would be excavated to an elevation of 259 feet for at least 500 feet downstream. The approximate location of the proposed spillway is shown in Figure 5.10.

For simulation of this alternative, it was assumed that the entire excavated area had an elevation of 259 feet. It was also assumed that the spill bay design would be similar to that at Ice Harbor, so gas production was estimated using equation 5.11 with a downstream channel elevation, E_{ch}, of 259 feet.

Table 5.5: Summary of simulated long term gas abatement alternatives lower Columbia and Snake projects.

Project	**Existing Bays**		**New Bays**		
Alternative	**Production Function**	**Entrain?**	**No.**	**Production Function**	**Entrain?**
Bonneville					
Submerged Radial Gates	$\Delta P = \text{forebay } \Delta P$	no	N/A		
John Day					
Additional Bays	$\Delta P = 4.97 D_{tw} [1 - \exp(-0.23 q_s)]$	yes	6	$\Delta P = 4.97 D_{tw} [1 - \exp(-0.23 q_s)]$	yes
McNary					
Additional Bays	$\Delta P = 11.4 q_s + 47.3$	yes	9	$\Delta P = 0.014 D_{tw}^{2.097} q_s^{0.772} + 84.57$	no
Lower Monumental					
Additional Bays w/ Divider	$\Delta P = 5.056 D_{tw} [1 - \exp(-0.21 q_s)]$	no	9	$\Delta P = 0.014 D_{tw}^{2.097} q_s^{0.772} + 84.57$	no
Little Goose					
Additional Bays w/ Divider	$\Delta P = 5.566 D_{tw} [1 - \exp(-0.15 q_s)]$	no	9	$\Delta P = 0.014 D_{tw}^{2.097} q_s^{0.772} + 84.57$	no
Lower Granite					
Additional Bays	$\Delta P = 5.307 D_{tw} [1 - \exp(-0.1059 q_s)]$	yes	9	$\Delta P = 0.014 D_{tw}^{2.097} q_s^{0.772} + 84.57$	no
Additional Bays w/ Divider	$\Delta P = 5.307 D_{tw} [1 - \exp(-0.1059 q_s)]$	no	9	$\Delta P = 0.014 D_{tw}^{2.097} q_s^{0.772} + 84.57$	no

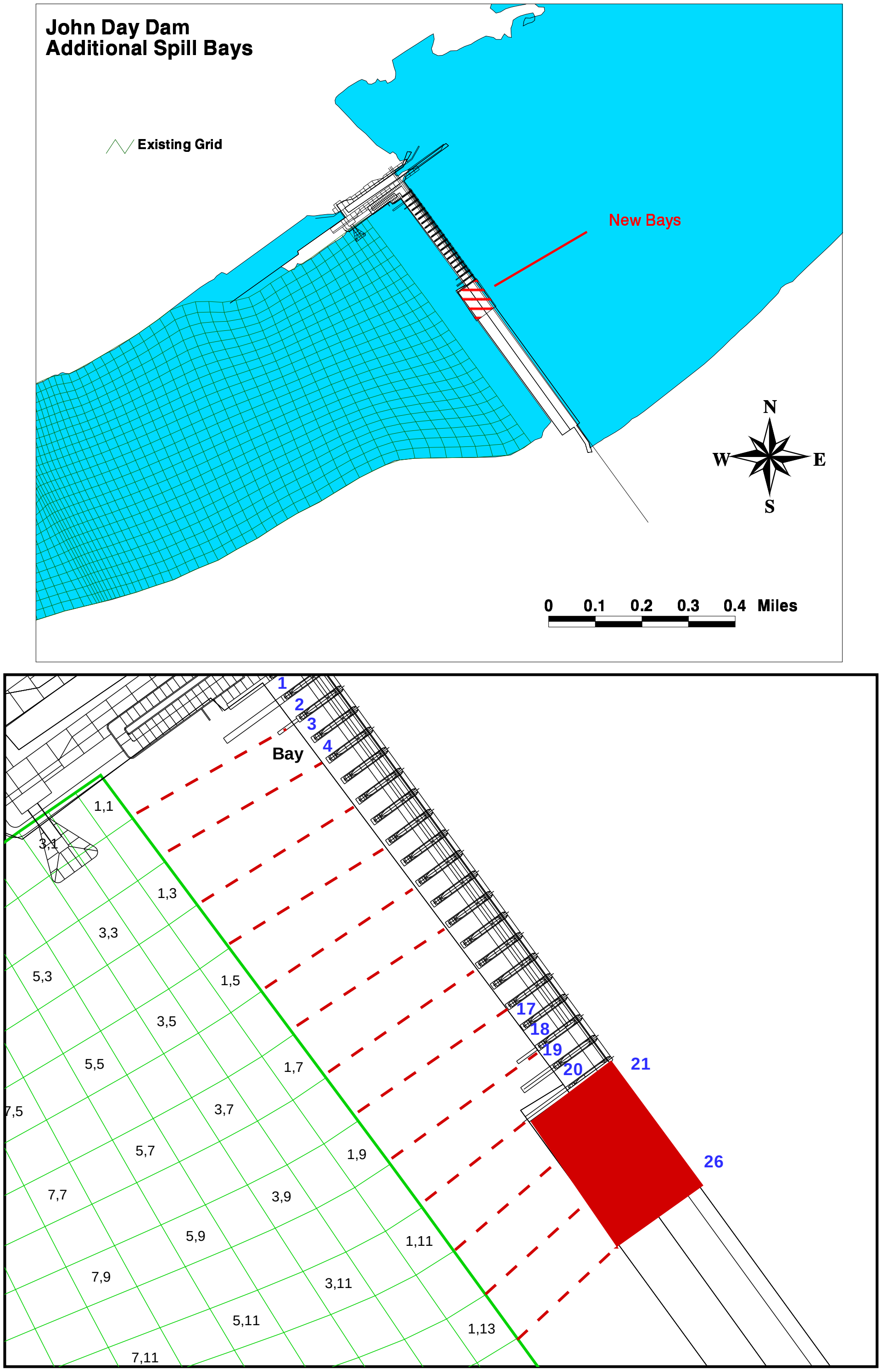


Figure 5.9: Approximate location of additional spill bays added to John Day dam in the long term alternative (above) and spill bay to grid mapping (below).

It was necessary to modify the MASS2 grid in order to simulate this alternative. The modified grid is compared to the original grid in Figure 5.10. The spill bay to grid mapping is also shown there.

5.3.4 Lower Monumental Dam

Additional Spill Bays and Divider Wall

In this alternative, nine new spill bays would be built in the earthen portion of Lower Monumental dam, south of the navigation lock. Figure 5.11 shows the approximate location of the new spillway. The area below the new spillway would be excavated to an elevation of 428 feet. The spill bay design would be similar to Ice Harbor, so gas production of the new spill bays were estimated using equation 5.11. It was assumed that the original spillway would have a full complement of deflectors and that a powerhouse/spillway divider wall would be installed (corresponding to a combination of fast-track alternatives in Section 5.2.6).

In order to simulate this option, modifications to the MASS2 grid were necessary. The modified grid, and its mapping to the spill bays, is shown in Figure 5.11.

5.3.5 Little Goose Dam

Additional Spill Bays and Divider Wall

Under this alternative, nine new bays would be built in the earthen part of Little Goose dam north of the exiting spillway. The approximate location of the new bays is shown in Figure 5.12. The area approximately 500 feet downstream of the new spillway would be filled to an elevation of 520 feet. The spill bay design would be such that the Ice Harbor gas production function, equation 5.11, would be applicable. It was assumed that the original spillway would have a full complement of deflectors and that a powerhouse/spillway divider wall would be installed (corresponding to a combination of fast-track alternatives in Section 5.2.7).

No MASS2 grid alterations were necessary to simulate this alternative. Figure 5.12 shows the spillway to grid mapping used for spill boundary conditions.

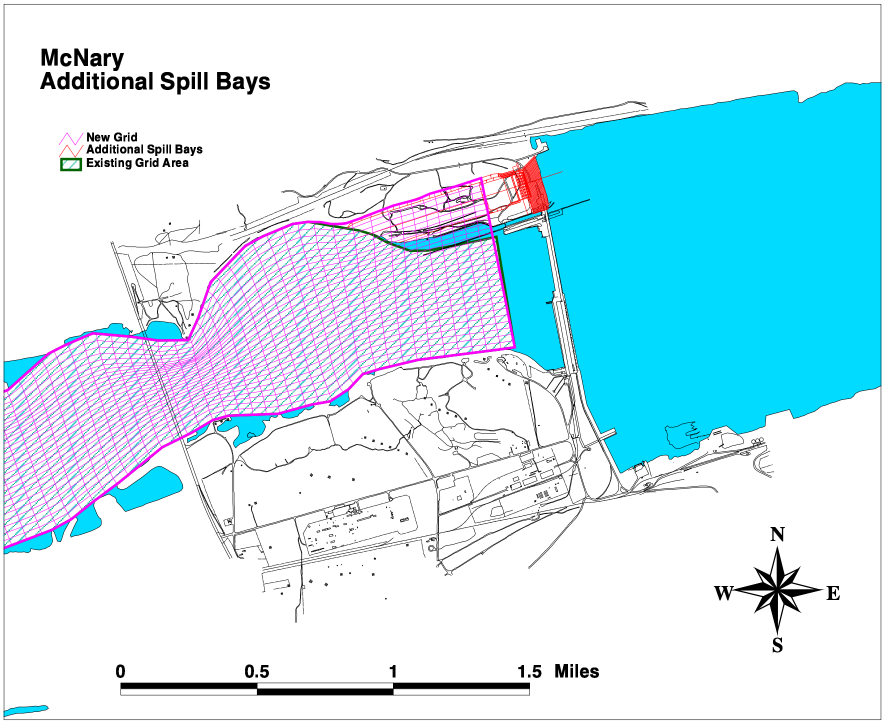
5.3.6 Lower Granite Dam

Additional Spill Bays

In this alternative, nine additional spill bays would be built into the earthen portion of Lower Granite dam (USACE, 1999c, Section 11.10). The tail race area would be filled to an elevation of 617 for approximately 500 feet downstream. The design of the spill way would be such that the Ice Harbor gas production function, equation 5.11, would be applicable.

Additional Spill Bays and Divider Wall

In addition to additional spill bays alternative above, a divider wall would be installed to separate spill and powerhouse flow. For simulation purposes, this was assumed to eliminate any powerhouse entrainment caused by spill in the existing spillway.



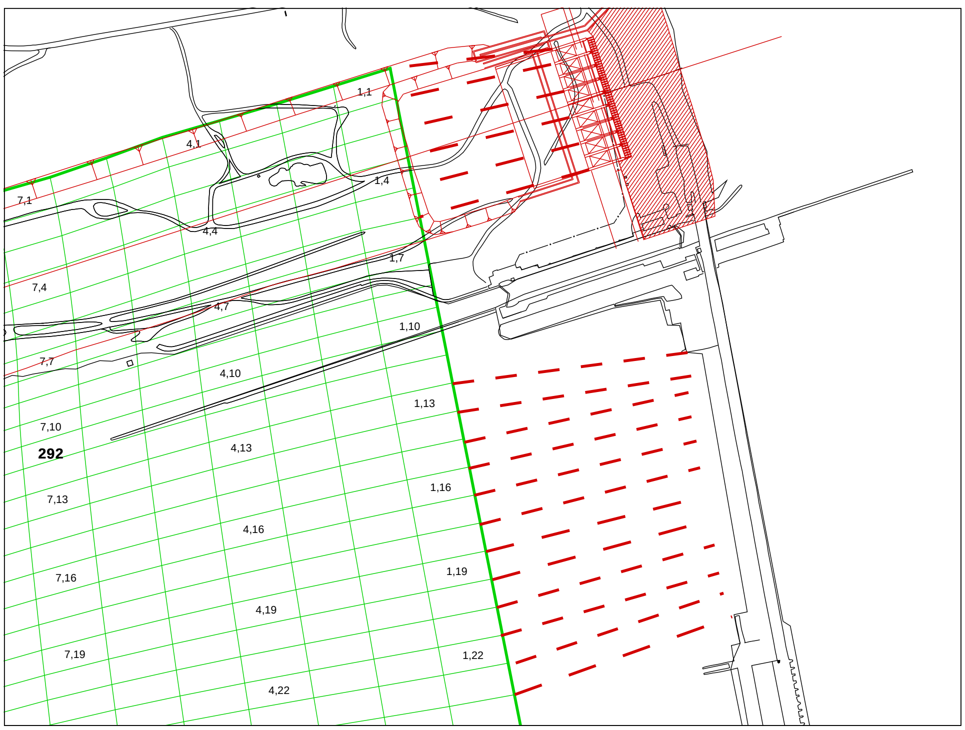


Figure 5.10: Model grid changes near McNary dam (above) and spill bay to grid mapping (below) to simulate additional spill bays.

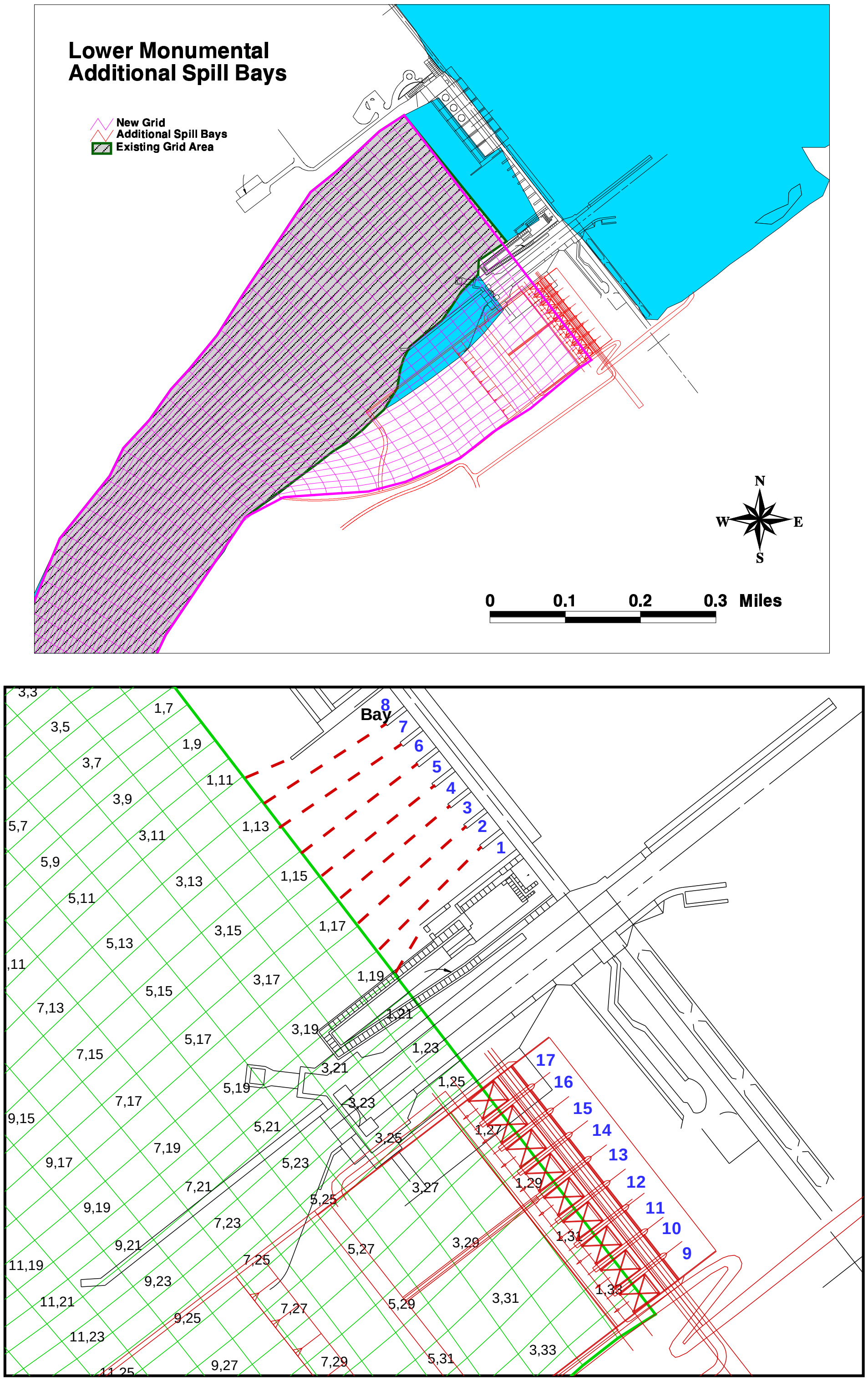


Figure 5.11: Model grid changes near Lower Monumental dam (above) and spill bay to grid mapping (below) to simulate additional spill bays.

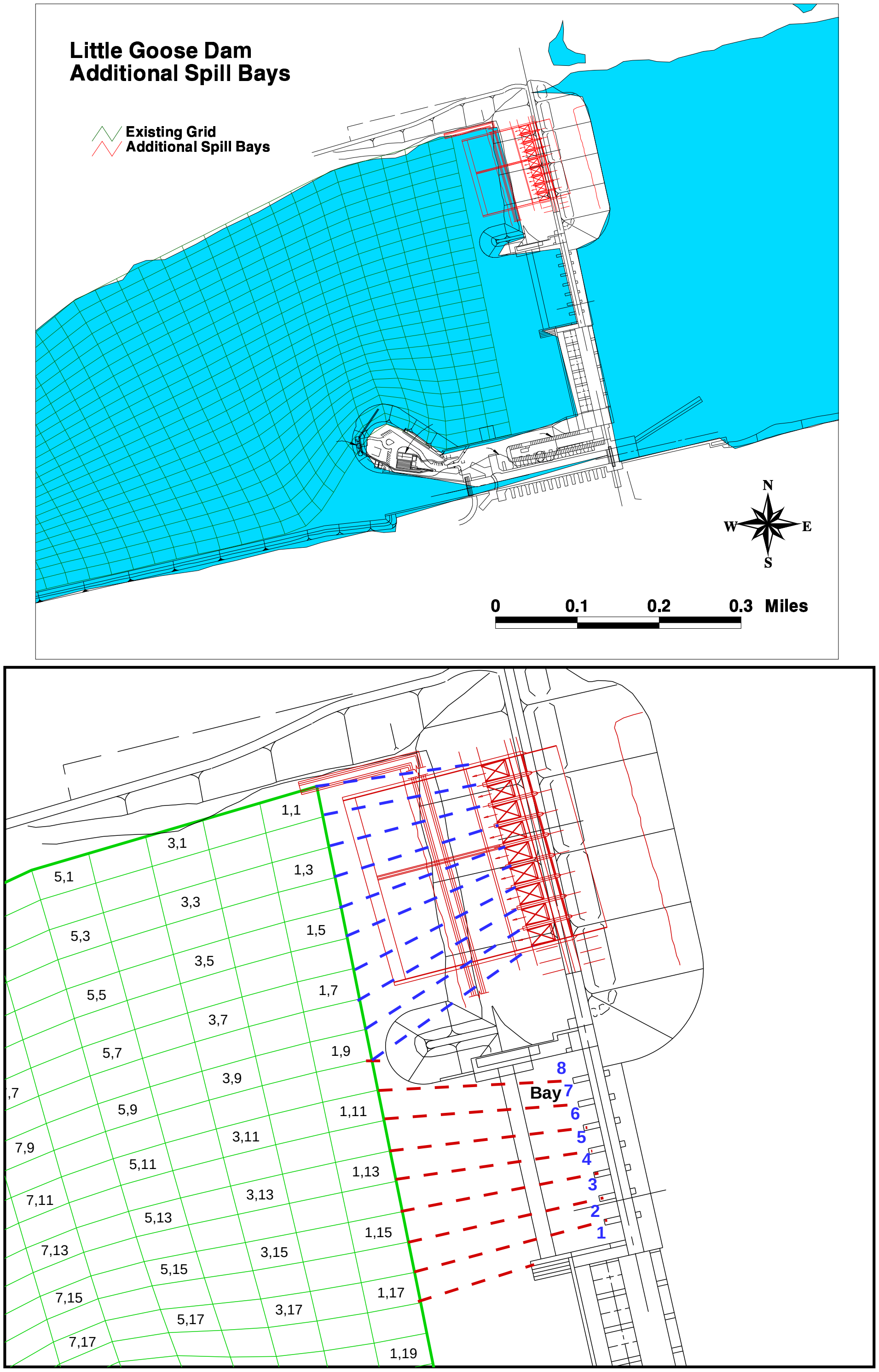


Figure 5.12: Model grid changes near Little Goose dam (above) and spill bay to grid mapping (below) to simulate additional spill bays.

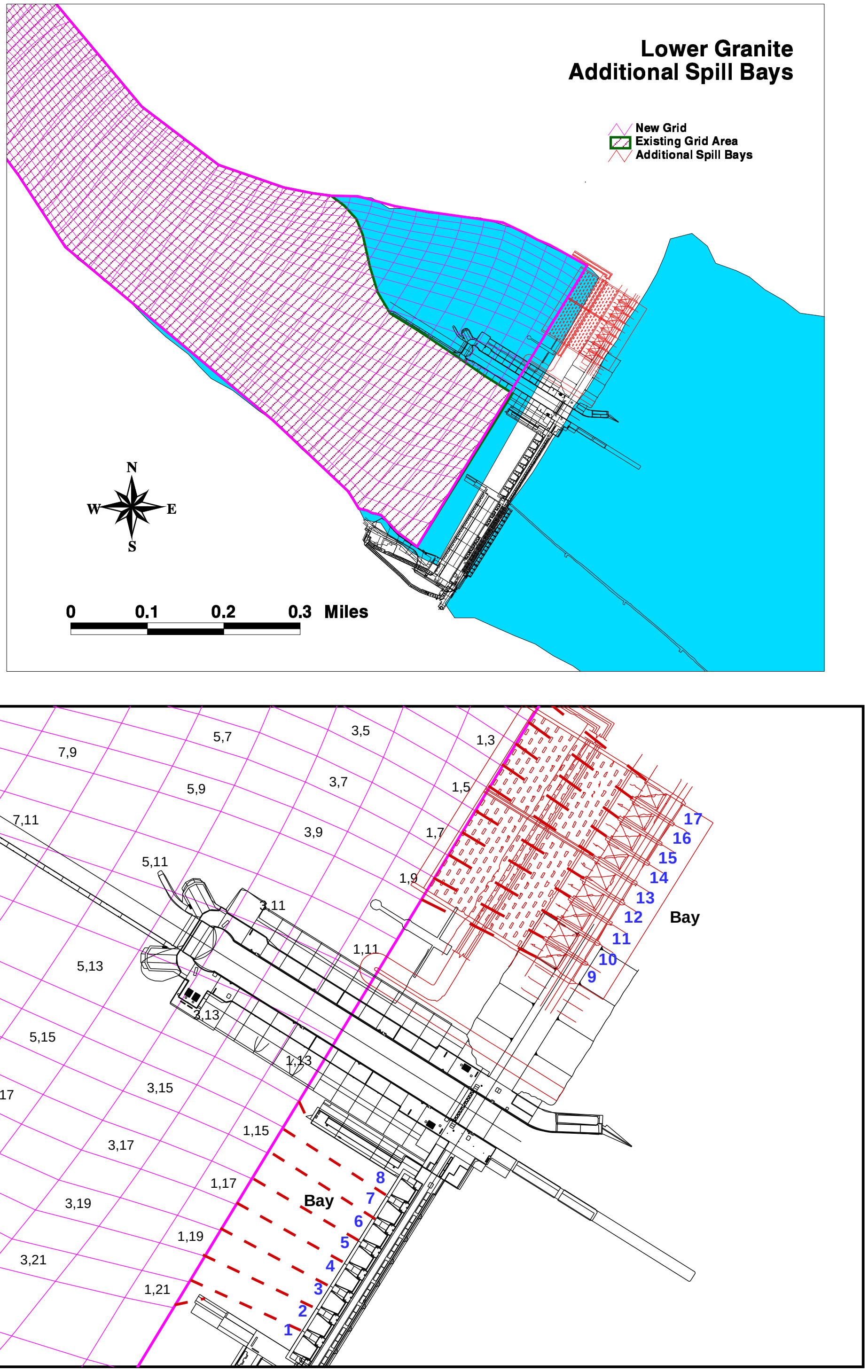


Figure 5.13: Model grid changes near Lower Granite dam (above) and spill bay to grid mapping (below) to simulate additional spill bays.

5.4 Alternative Spill Scenarios

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

In order to address this question, two other simulation scenarios were developed. In these scenarios, an hourly spill (something other than the observed) is set based on a set of rules. The spill was computed in advance of the simulation, then the #2, "Operations"[3], alternative scenario, described above, was simulated using the computed spills.

The first scenario was called "Spill Cap", where spill was set based on the 1998 Dissolved Gas Management Plan. This scenario is discussed in Section 5.4.1. The second scenario was called "Spill Management", where spill was set based on a TDG saturation limit in the spillway (based on the available production functions). This scenario is discussed in Section 5.4.2.

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

While not directly related to the selection of gas abatement alternatives, these simulations do illustrate the range of operational possibilities during low flow seasons. The also illustrate a methodology whereby the operation of given set of project configurations could be fine tuned to meet, or attempt to meet, varying objectives.

5.4.1 Spill Cap

In this scenario, spill at each project was chosen in accordance with the rules stipulated in the *1998 Total Dissolved Gas Management Plan*[4], except that power generation requirements were not considered. It was assumed that, regardless of conditions, the powerhouse had a constant maximum capacity for flow and that discharge through the powerhouse could be anything up to the maximum. The assumed maximum powerhouse hydraulic capacity was based on the average project head observed during all of the simulated spill seasons. At the average head, the maximum turbine flow at 1% efficiency for each turbine was summed, as shown in Table 5.6. This sum was reduced by assuming 1 unit off line in Snake projects, and two units off line in Columbia projects.

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

1. If the hourly total project flow does not exceed the trigger flow in Table 5.7, "voluntary" spill was considered to be zero.

2. For projects with a 12-hour spill duration in Table 5.7 was 12 hours, voluntary spill could only occur at night between the hours of 6:00 pm and 6:00 am. Outside that interval, voluntary spill was considered to be zero.

[3]Essentially, all projects had uniform spill on deflectored bays only. At The Dalles (where there are no deflectors), spill was uniform over all bays.

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

3. If it was not set to zero in 1 or 2, voluntary spill was set to the spill cap in Table 5.7, subject to the limits listed there, if any. For Bonneville, the maximum spill limit of 75 kcfs was applied during the day (6:00 am to 18:00 pm).

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

5. When the generation flow from 4 was higher than the powerhouse hydraulic capacity (Table 5.6, the excess was added to the spill (involuntary spill).

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

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

The hourly spills computed for this scenario are compared to the actual spills in Appendix C, Section 1.3.1. Season-wide summaries are shown in Tables 5.8 through 5.15.

Table 5.6: Basis of assumed powerhouse hydraulic capacity used in the spill cap scenario. Listed turbine capacities are the maximum turbine flow at 1% efficiency and the average head (difference between forebay and tailwater stage).

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

5.4.2 Spill Management

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

Table 5.7: Summary of 1998 TDG spill management plan project spill requirements.

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

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

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

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

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

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

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

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

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

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

Comparisons of the simulated hourly spill with actual spill at each project and simulated season are in Appendix C, Section 1.3.2. Season-wide summaries are shown in Table 5.8 through 5.15.

Table 5.8: Comparison of observed flow and spill at Bonneville during the three simuation seasons.

Month	**Flow Year**		**Average Project Flow** Total (kcfs)	Spill (kcfs)	Spill (%)	**"Spill Man."** Spill (kcfs)	Spill (%)	**"Spill Cap"** Spill (kcfs)	Spill (%)
April	Low	(1994)	154.0	43.6	26.3	87.9	59.2	94.5	63.9
	Med.	(1996)	330.6	137.9	40.3	119.9	35.8	123.5	37.0
	High	(1997)	336.1	115.4	30.6	130.6	37.4	134.7	38.9
May	Low	(1994)	212.0	94.5	44.2	87.7	41.6	95.6	45.2
	Med.	(1996)	351.2	154.6	43.0	132.0	36.8	135.6	38.0
	High	(1997)	456.3	243.9	53.1	229.4	49.9	229.3	49.8
June	Low	(1994)	195.0	72.4	37.5	87.7	45.8	95.6	50.1
	Med.	(1996)	385.5	199.5	51.0	161.1	40.7	163.8	41.6
	High	(1997)	483.6	281.9	57.3	256.5	52.1	256.7	52.2
July	Low	(1994)	152.5	59.8	39.4	87.7	58.4	95.4	63.6
	Med.	(1996)	247.8	85.9	35.5	87.7	36.3	95.6	39.4
	High	(1997)	277.3	93.9	34.6	88.4	32.3	95.9	35.0
August	Low	(1994)	94.9	30.0	29.9	83.7	89.9	84.9	90.8
	Med.	(1996)	189.2	91.0	49.0	87.6	47.1	95.6	51.4
	High	(1997)	202.9	106.7	52.0	87.6	43.8	95.6	47.2

Table 5.9: Comparison of observed flow and spill at The Dalles during the three simuation seasons.

Month	**Flow Year**		**Average Project Flow** Total (kcfs)	Spill (kcfs)	Spill (%)	**"Spill Man."** Spill (kcfs)	Spill (%)	**"Spill Cap"** Spill (kcfs)	Spill (%)
April	Low	(1994)	147.2	0.7	0.5	5.9	4.9	94.2	64.0
	Med.	(1996)	320.7	150.5	44.1	27.7	7.5	200.8	62.9
	High	(1997)	326.9	118.1	29.8	42.6	9.9	193.5	60.5
May	Low	(1994)	203.6	52.3	25.8	3.0	1.5	130.3	64.0
	Med.	(1996)	341.8	195.9	56.3	40.1	10.3	209.0	61.6
	High	(1997)	458.0	293.9	64.2	144.1	30.6	229.9	50.8
June	Low	(1994)	188.7	56.8	29.5	3.4	2.0	120.7	64.0
	Med.	(1996)	377.9	226.6	59.4	70.0	16.7	217.7	58.4
	High	(1997)	487.3	316.2	64.6	174.2	34.0	233.1	48.8
July	Low	(1994)	147.8	8.7	7.0	4.8	3.9	94.5	64.0
	Med.	(1996)	236.6	134.1	57.0	2.6	1.2	151.1	64.0
	High	(1997)	266.9	169.7	63.7	4.3	1.6	171.0	64.0
August	Low	(1994)	90.7	4.2	5.4	8.6	10.9	58.1	64.0
	Med.	(1996)	179.0	100.1	56.9	3.9	2.4	114.5	64.0
	High	(1997)	194.5	123.9	63.7	3.5	2.0	124.6	64.0

Table 5.10: Comparison of observed flow and spill at John Day during the three simuation seasons.

Month	Flow Year		Average Project Flow			"Spill Man."		"Spill Cap"	
			Total (kcfs)	**Spill** (kcfs)	**Spill** (%)	**Spill** (kcfs)	**Spill** (%)	**Spill** (kcfs)	**Spill** (%)
April	Low	(1994)	148.0	0.9	0.6	132.9	92.1	43.7	32.5
	Med.	(1996)	326.9	57.2	16.0	124.6	40.3	95.1	29.5
	High	(1997)	332.6	45.9	10.5	117.3	38.7	100.7	30.3
May	Low	(1994)	208.8	9.4	4.4	146.4	71.1	67.8	32.5
	Med.	(1996)	354.2	73.3	19.8	116.0	34.3	102.4	29.4
	High	(1997)	472.5	154.0	32.1	118.1	24.9	142.5	30.0
June	Low	(1994)	193.3	8.3	4.7	147.7	78.7	59.6	32.5
	Med.	(1996)	392.9	94.9	23.3	108.6	28.8	115.6	29.7
	High	(1997)	503.8	189.6	36.2	149.4	29.4	160.6	31.7
July	Low	(1994)	149.4	7.8	6.3	136.5	93.2	43.5	32.5
	Med.	(1996)	244.8	33.7	14.6	136.9	58.7	77.2	32.4
	High	(1997)	278.3	50.4	18.7	123.3	46.4	84.9	31.7
August	Low	(1994)	89.7	5.8	7.2	89.6	100.0	26.0	32.5
	Med.	(1996)	183.9	38.5	21.7	150.4	84.4	59.2	32.5
	High	(1997)	200.6	41.2	22.6	136.7	72.1	61.8	32.5

Table 5.11: Comparison of observed flow and spill at McNary during the three simuation seasons.

Month	Flow Year		Average Project Flow			"Spill Man."		"Spill Cap"	
			Total (kcfs)	**Spill** (kcfs)	**Spill** (%)	**Spill** (kcfs)	**Spill** (%)	**Spill** (kcfs)	**Spill** (%)
April	Low	(1994)	142.1	0.2	0.1	137.8	97.8	76.8	55.0
	Med.	(1996)	311.9	142.7	44.4	185.1	59.9	175.0	55.7
	High	(1997)	312.9	151.5	45.6	196.0	62.9	182.1	57.2
May	Low	(1994)	200.3	27.5	13.0	162.4	81.8	108.8	54.0
	Med.	(1996)	338.6	183.4	52.8	202.2	59.6	197.3	57.7
	High	(1997)	449.2	281.2	62.2	301.2	66.7	301.2	66.7
June	Low	(1994)	189.0	21.2	9.9	160.7	86.5	101.5	53.4
	Med.	(1996)	381.2	246.4	64.0	237.1	61.6	235.9	61.1
	High	(1997)	482.4	319.6	65.2	334.9	68.8	334.7	68.7
July	Low	(1994)	146.2	4.7	3.3	145.0	99.4	81.0	55.7
	Med.	(1996)	246.0	98.4	38.6	161.7	67.4	133.2	54.9
	High	(1997)	274.8	109.3	38.9	164.3	60.8	148.4	54.2
August	Low	(1994)	89.9	0.4	0.4	89.8	100.0	44.6	54.0
	Med.	(1996)	183.1	33.7	17.1	159.6	88.5	103.0	56.3
	High	(1997)	198.5	46.6	21.7	160.6	82.8	114.1	59.2

Table 5.12: Comparison of observed flow and spill at Ice Harbor during the three simuation seasons.

Month	Flow Year		Average Project Flow			"Spill Man."		"Spill Cap"	
			Total (kcfs)	Spill (kcfs)	Spill (%)	Spill (kcfs)	Spill (%)	Spill (kcfs)	Spill (%)
April	Low	(1994)	51.3	12.2	20.4	51.4	100.0	50.3	98.7
	Med.	(1996)	115.1	42.1	35.0	107.1	94.9	75.3	68.2
	High	(1997)	126.2	56.6	40.0	104.3	87.6	82.4	69.0
May	Low	(1994)	76.9	26.1	34.4	76.8	100.0	71.5	94.1
	Med.	(1996)	123.2	48.7	36.6	107.7	90.7	78.1	66.8
	High	(1997)	165.5	93.7	55.6	120.8	74.9	91.8	55.1
June	Low	(1994)	38.0	16.7	42.9	38.0	100.0	38.0	100.0
	Med.	(1996)	139.9	70.0	47.2	107.0	81.0	84.6	63.4
	High	(1997)	163.9	98.7	58.4	114.8	73.1	94.7	58.2
July	Low	(1994)	40.3	9.0	24.6	40.3	100.0	40.3	100.0
	Med.	(1996)	56.1	24.5	49.3	56.1	100.0	53.9	97.5
	High	(1997)	75.2	38.0	54.7	75.1	100.0	65.6	90.3
August	Low	(1994)	12.7	0.0	0.1	12.7	100.0	12.7	100.0
	Med.	(1996)	39.0	24.1	63.5	39.0	100.0	38.9	100.0
	High	(1997)	51.6	36.5	76.9	51.5	100.0	50.2	98.7

Table 5.13: Comparison of observed flow and spill at Lower Monumental during the three simuation seasons.

Month	Flow Year		Average Project Flow			"Spill Man."		"Spill Cap"	
			Total (kcfs)	Spill (kcfs)	Spill (%)	Spill (kcfs)	Spill (%)	Spill (kcfs)	Spill (%)
April	Low	(1994)	50.2	0.0	0.0	35.7	79.3	0.5	0.6
	Med.	(1996)	115.6	31.0	24.8	39.1	34.9	29.0	23.1
	High	(1997)	130.1	33.0	21.9	52.8	40.1	42.4	27.9
May	Low	(1994)	75.2	9.0	12.2	39.1	53.5	3.7	4.0
	Med.	(1996)	125.1	44.7	32.9	46.1	37.3	36.9	25.9
	High	(1997)	174.0	64.0	35.3	73.4	40.6	73.2	40.4
June	Low	(1994)	37.1	5.1	12.1	34.5	95.2	0.0	0.0
	Med.	(1996)	145.3	61.8	39.9	59.4	39.9	53.4	33.0
	High	(1997)	166.1	64.2	35.4	69.7	40.6	68.4	39.4
July	Low	(1994)	39.5	0.0	0.0	35.9	93.0	0.0	0.0
	Med.	(1996)	56.3	5.0	7.6	37.0	73.2	1.5	1.6
	High	(1997)	73.1	1.9	2.0	36.8	56.6	4.6	4.6
August	Low	(1994)	12.7	0.2	2.1	12.7	100.0	0.0	0.0
	Med.	(1996)	38.9	1.1	2.3	35.7	93.6	0.0	0.0
	High	(1997)	49.3	0.6	1.6	34.9	78.2	0.1	0.1

Table 5.14: Comparison of observed flow and spill at Little Goose during the three simuation seasons.

Month	Flow Year		Average Project Flow			"Spill Man."		"Spill Cap"	
			Total (kcfs)	Spill (kcfs)	Spill (%)	Spill (kcfs)	Spill (%)	Spill (kcfs)	Spill (%)
April	Low	(1994)	50.1	7.0	9.1	40.7	87.5	0.4	0.4
	Med.	(1996)	112.8	33.3	28.1	47.5	44.2	26.8	21.9
	High	(1997)	120.2	33.7	26.2	53.4	47.7	32.3	22.1
May	Low	(1994)	76.6	23.3	30.0	49.0	65.6	3.5	3.7
	Med.	(1996)	121.2	49.7	39.5	51.4	44.9	33.4	24.5
	High	(1997)	162.4	65.2	39.4	63.3	38.1	61.7	36.8
June	Low	(1994)	37.5	4.6	10.8	36.7	98.7	0.0	0.0
	Med.	(1996)	140.2	58.5	39.7	59.3	43.5	47.4	30.3
	High	(1997)	155.5	53.5	31.9	62.2	40.0	56.7	34.8
July	Low	(1994)	39.3	0.0	0.0	38.6	98.8	0.0	0.0
	Med.	(1996)	54.6	4.3	6.5	43.6	85.3	1.0	1.1
	High	(1997)	67.7	0.4	0.6	45.9	72.7	2.2	2.3
August	Low	(1994)	12.8	0.0	0.0	12.8	100.0	0.0	0.0
	Med.	(1996)	38.3	0.1	0.2	37.7	99.2	0.0	0.0
	High	(1997)	46	0.5	1.4	40.6	91.7	0.0	0.0

Table 5.15: Comparison of observed flow and spill at Lower Granite during the three simuation seasons.

Month	Flow Year		Average Project Flow			"Spill Man."		"Spill Cap"	
			Total (kcfs)	Spill (kcfs)	Spill (%)	Spill (kcfs)	Spill (%)	Spill (kcfs)	Spill (%)
April	Low	(1994)	48.6	0.0	0.0	45.4	95.8	0.6	0.7
	Med.	(1996)	114.5	47.4	39.7	61.9	56.8	30.1	24.9
	High	(1997)	121.9	27.7	20.0	63.2	56.6	36.5	25.8
May	Low	(1994)	77.0	16.3	20.8	63.1	83.2	5.6	6.1
	Med.	(1996)	127.1	47.6	36.0	62.9	52.9	39.3	28.6
	High	(1997)	169.0	58.7	33.6	72.8	42.5	66.5	38.0
June	Low	(1994)	38.1	7.7	16.5	38.0	100.0	0.0	0.0
	Med.	(1996)	145.0	51.6	33.0	68.6	50.1	52.4	33.0
	High	(1997)	161.4	60.8	34.6	71.7	45.3	63.2	37.7
July	Low	(1994)	39.2	0.0	0.0	39.2	100.0	0.0	0.0
	Med.	(1996)	54.4	3.4	4.4	50.0	94.6	1.6	1.8
	High	(1997)	68.9	3.4	5.2	58.3	87.9	3.3	3.4
August	Low	(1994)	12.9	0.4	2.8	12.9	100.0	0.0	0.0
	Med.	(1996)	37.7	0.1	0.2	37.6	100.0	0.0	0.0
	High	(1997)	46.2	0.4	1.0	45.7	99.4	0.0	0.0

5.5 Baseline Spill Patterns

Table 5.16: Bonneville dam baseline spill pattern.

Spill Bay Number																		Total	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Stops	Spill
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3100
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	6200
0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3	9300
0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	4	12400
0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	5	15500
0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	6	18600
0	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	0	7	21700
0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	8	24800
0	1	2	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	9	28500
0	3	2	0	0	0	0	0	0	0	0	2	0	0	0	1	2	0	10	33600
0	3	2	0	0	0	0	0	0	0	0	2	0	0	0	2	2	0	11	37200
0	3	2	0	0	1	0	0	0	0	0	2	0	0	0	2	2	0	12	40300
0	3	2	0	0	2	0	0	0	0	0	2	0	0	0	2	2	0	13	43900
0	3	2	1	0	2	0	0	0	0	0	2	0	0	0	2	2	0	14	47000
0	3	2	1	0	2	0	0	0	0	0	2	0	0	1	2	2	0	15	50100
0	3	2	1	0	2	0	0	0	1	0	2	0	0	1	2	2	0	16	53200
0	3	2	1	0	2	0	0	0	2	0	2	0	0	1	2	2	0	17	56900
0	3	2	2	0	2	0	0	0	2	0	2	0	0	1	2	2	0	18	60500
0	3	2	2	0	2	0	1	0	2	0	2	0	0	1	2	2	0	19	63600
0	3	2	2	0	2	0	2	0	2	0	2	0	0	1	2	2	0	20	67200
0	3	2	2	0	2	0	2	0	2	0	2	0	1	1	2	2	0	21	70300
0	3	2	2	0	2	0	2	0	2	0	2	0	2	1	2	2	0	22	74000
0	3	2	2	0	2	0	2	0	2	0	2	0	2	1	2	3	0	23	77500
0	3	2	2	0	2	0	2	0	2	0	2	0	2	2	2	3	0	24	81100
0	3	3	2	0	2	0	2	0	2	0	2	0	2	2	2	3	0	25	84600
0	3	3	2	0	2	0	2	1	2	0	2	0	2	2	2	3	0	26	87700
0	3	3	2	0	2	0	2	2	2	0	2	0	2	2	2	3	0	27	91400
0	4	3	2	0	2	0	2	2	2	0	2	0	2	2	2	3	0	28	94900
0	4	3	2	0	2	0	2	2	2	0	2	0	2	2	3	3	0	29	98400
0	4	3	2	0	2	0	2	2	2	0	2	0	2	2	3	4	0	30	102000

Table 5.16: Bonneville dam baseline spill pattern. (continued).

Spill Bay Number																		Total	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Stops	Spill
0	4	3	3	0	2	0	2	2	2	0	2	0	2	2	3	4	0	31	105000
0	4	3	3	1	2	0	2	2	2	0	2	0	2	2	3	4	0	32	109000
0	4	3	3	2	2	0	2	2	2	0	2	0	2	2	3	4	0	33	112000
0	4	3	3	2	2	0	2	2	2	0	2	1	2	2	3	4	0	34	115000
0	4	3	3	2	2	0	2	2	2	0	2	2	2	2	3	4	0	35	119000
0	4	3	3	2	2	1	2	2	2	0	2	2	2	2	3	4	0	36	122000
0	4	3	3	2	2	2	2	2	2	0	2	2	2	2	3	4	0	37	126000
0	4	3	3	2	2	2	2	2	2	1	2	2	2	2	3	4	0	38	129000
0	4	3	3	2	2	2	2	2	2	2	2	2	2	2	3	4	0	39	132000
0	4	4	3	2	2	2	2	2	2	2	2	2	2	2	3	4	0	40	136000
0	4	4	3	2	2	2	2	2	2	2	2	2	2	3	3	4	0	41	139000
0	4	4	3	2	2	2	2	2	2	2	2	2	2	3	4	4	0	42	143000
0	4	4	3	3	2	2	2	2	2	2	2	2	2	3	4	4	0	43	146000
0	4	4	3	3	2	2	2	2	2	2	3	2	2	3	4	4	0	44	150000
0	4	4	3	3	2	2	2	2	2	2	3	2	3	3	4	4	0	45	153000
0	4	4	3	3	2	3	2	2	2	2	3	2	3	3	4	4	0	46	157000
0	4	4	3	3	2	3	2	2	3	2	3	2	3	3	4	4	0	47	160000
0	4	4	3	3	2	3	2	3	3	2	3	2	3	3	4	4	0	48	164000
0	5	4	3	3	2	3	2	3	3	2	3	2	3	3	4	4	0	49	167000
0	5	4	3	3	2	3	2	3	3	2	3	2	3	3	4	5	0	50	171000
0	5	4	4	3	2	3	2	3	3	2	3	2	3	3	4	5	0	51	174000
0	5	5	4	3	2	3	2	3	3	2	3	2	3	3	4	5	0	52	178000
0	5	5	4	3	2	3	2	3	3	2	3	2	3	3	5	5	0	53	181000
0	5	5	4	3	2	3	2	3	3	3	3	2	3	3	5	5	0	54	185000
0	5	5	4	3	2	3	3	3	3	3	3	2	3	3	5	5	0	55	188000
0	5	5	4	3	2	3	3	3	3	3	3	2	3	4	5	5	0	56	192000
0	5	5	4	4	2	3	3	3	3	3	3	2	3	4	5	5	0	57	195000
0	5	5	5	4	3	3	3	3	3	3	3	2	3	4	5	5	0	59	202000
0	5	5	5	4	3	3	3	3	3	3	3	3	3	4	5	5	0	60	206000
0	5	5	5	4	3	4	3	3	3	3	3	3	3	4	5	5	0	61	209000

Table 5.16: Bonneville dam baseline spill pattern. (continued).

Spill Bay Number																		Total	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Stops	Spill
0	5	5	5	4	3	4	3	3	3	3	4	3	3	4	5	5	0	62	213000
0	5	5	5	4	4	4	3	3	3	3	4	3	3	4	5	5	0	63	216000
0	5	5	5	4	4	4	3	4	3	3	4	3	3	4	5	5	0	64	220000
0	5	5	5	4	4	4	3	4	3	3	4	3	4	4	5	5	0	65	223000
0	5	5	5	4	4	4	3	4	4	3	4	3	4	4	5	5	0	66	227000
0	5	5	5	4	4	4	3	4	4	3	4	3	4	5	5	5	0	67	230000
0	5	5	5	4	4	4	3	4	4	4	4	3	4	5	5	5	0	68	234000
0	5	5	5	4	4	4	3	4	4	4	4	4	4	5	5	5	0	69	237000
0	5	5	5	5	4	4	3	4	4	4	4	4	4	5	5	5	0	70	241000
0	5	5	6	5	4	4	3	4	4	4	4	4	4	5	5	5	0	71	244000
0	5	5	6	5	4	4	4	4	4	4	4	4	4	5	5	5	0	72	248000
0	5	5	6	5	4	4	4	4	4	4	4	4	4	6	5	5	0	73	251000
0	5	5	6	5	4	5	4	4	4	4	4	4	4	6	5	5	0	74	255000
0	5	5	6	5	4	5	4	4	4	4	4	4	5	6	5	5	0	75	258000
0	5	5	6	5	4	5	4	4	4	4	5	4	5	6	5	5	0	76	262000
0	5	5	6	5	5	5	4	4	4	4	5	4	5	6	5	5	0	77	265000
0	5	5	6	6	5	5	4	4	4	4	5	4	5	6	5	5	0	78	268000
0	5	5	6	6	5	5	4	5	4	4	5	4	5	6	5	5	0	79	272000
0	5	5	6	6	5	5	4	5	4	5	5	4	5	6	5	5	0	80	275000
0	5	5	6	6	5	5	4	5	5	5	5	4	5	6	5	5	0	81	279000
0	5	5	6	6	5	5	4	5	5	5	5	5	5	6	5	5	0	82	282000
0	5	5	6	6	5	5	5	5	5	5	5	5	5	6	5	5	0	83	286000
0	5	5	6	6	5	6	5	5	5	5	5	5	5	6	5	5	0	84	289000
0	5	5	6	6	5	6	5	5	5	5	5	5	6	6	5	5	0	85	292000
0	5	5	6	6	5	6	5	5	5	5	6	5	6	6	5	5	0	86	296000
0	5	5	6	6	6	6	5	5	5	5	6	5	6	6	5	5	0	87	299000
0	5	5	6	6	6	6	5	6	5	5	6	5	6	6	5	5	0	88	302000
0	5	5	6	6	6	6	5	6	6	5	6	5	6	6	5	5	0	89	306000
0	5	5	6	6	6	6	5	6	6	6	6	5	6	6	5	5	0	90	309000
0	5	5	6	6	6	6	5	6	6	6	6	6	6	6	5	5	0	91	312000

Table 5.16: Bonneville dam baseline spill pattern. (continued).

Spill Bay Number																		Total	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Stops	Spill
0	5	5	6	6	6	6	6	6	6	6	6	6	6	6	5	5	0	92	316000
0	5	5	6	6	6	7	6	6	6	6	6	6	6	6	5	5	0	93	319000
0	5	5	6	6	6	7	6	6	6	6	6	6	7	6	5	5	0	94	323000
0	5	5	6	6	6	7	6	6	6	6	7	6	7	6	5	5	0	95	326000
0	5	5	6	6	7	7	6	6	6	6	7	6	7	6	5	5	0	96	330000
0	5	5	6	6	7	7	6	7	6	6	7	6	7	6	5	5	0	97	333000

Table 5.17: The Dalles dam baseline spill pattern.

Spill Bay Number																							Total	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Stops	Spill
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1500
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3000
2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4500
2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	6000
2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	7500
2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	9000
2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	10500
2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	12000
2	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	13500
2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	15000
2	2	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	16500
2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	18000
2	2	2	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	19500
2	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	21000
2	2	2	2	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	22500
2	2	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	24000
2	2	2	2	2	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	25500
2	2	2	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	27000
2	2	2	2	2	2	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	19	28500
2	2	2	2	2	2	2	2	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	20	30000
2	2	2	2	2	2	2	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	21	31500
2	2	2	2	2	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	22	33000
2	2	2	3	2	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	23	34500
2	2	2	3	3	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	24	36000
2	2	3	3	3	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	25	37500
2	2	3	3	3	3	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	26	39000
2	2	3	3	3	3	2	2	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	27	40500
2	2	3	3	3	3	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	28	42000
2	2	3	3	3	3	3	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	29	43500
2	2	3	3	3	3	3	3	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	30	45000

Table 5.17: The Dalles dam baseline spill pattern. (continued).

Spill Bay Number																							Total	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Stops	Spill
2	2	3	3	3	3	3	3	3	2	2	2	0	0	0	0	0	0	0	0	0	0	0	31	46500
2	2	3	3	3	3	3	3	3	3	2	2	0	0	0	0	0	0	0	0	0	0	0	32	48000
2	2	3	3	3	3	3	3	3	3	2	2	1	0	0	0	0	0	0	0	0	0	0	33	49500
2	2	3	3	3	3	3	3	3	3	2	2	2	0	0	0	0	0	0	0	0	0	0	34	51000
2	2	3	4	3	3	3	3	3	3	2	2	2	0	0	0	0	0	0	0	0	0	0	35	52500
2	3	3	4	3	3	3	3	3	3	2	2	2	0	0	0	0	0	0	0	0	0	0	36	54000
2	3	3	4	4	3	3	3	3	3	2	2	2	0	0	0	0	0	0	0	0	0	0	37	55500
2	3	4	4	4	3	3	3	3	3	2	2	2	0	0	0	0	0	0	0	0	0	0	38	57000
3	3	4	4	4	3	3	3	3	3	2	2	2	0	0	0	0	0	0	0	0	0	0	39	58500
3	3	4	4	4	3	3	3	3	3	3	2	2	0	0	0	0	0	0	0	0	0	0	40	60000
3	3	4	4	4	3	3	3	3	3	3	3	2	0	0	0	0	0	0	0	0	0	0	41	61500
3	3	4	4	4	3	3	3	3	3	3	3	2	1	0	0	0	0	0	0	0	0	0	42	63000
3	3	4	4	4	3	3	3	3	3	3	3	2	2	0	0	0	0	0	0	0	0	0	43	64500
3	3	4	4	4	4	3	3	3	3	3	3	2	2	0	0	0	0	0	0	0	0	0	44	66000
3	3	4	5	4	4	3	3	3	3	3	3	2	2	0	0	0	0	0	0	0	0	0	45	67500
3	3	4	5	4	4	4	3	3	3	3	3	2	2	0	0	0	0	0	0	0	0	0	46	69000
3	3	4	5	5	4	4	3	3	3	3	3	2	2	0	0	0	0	0	0	0	0	0	47	70500
3	4	4	5	5	4	4	3	3	3	3	3	2	2	0	0	0	0	0	0	0	0	0	48	72000
3	4	4	5	5	4	4	4	3	3	3	3	2	2	0	0	0	0	0	0	0	0	0	49	73500
3	4	4	5	5	4	4	4	4	3	3	3	2	2	0	0	0	0	0	0	0	0	0	50	75000
4	4	4	5	5	4	4	4	4	3	3	3	2	2	0	0	0	0	0	0	0	0	0	51	76500
4	4	4	5	5	4	4	4	4	4	3	3	2	2	0	0	0	0	0	0	0	0	0	52	78000
4	4	5	5	5	4	4	4	4	4	3	3	2	2	0	0	0	0	0	0	0	0	0	53	79500
4	4	5	5	5	5	4	4	4	4	3	3	2	2	0	0	0	0	0	0	0	0	0	54	81000
4	4	5	5	5	5	5	4	4	4	3	3	2	2	0	0	0	0	0	0	0	0	0	55	82500
4	4	5	5	5	5	5	4	4	4	4	3	2	2	0	0	0	0	0	0	0	0	0	56	84000
4	4	5	6	5	5	5	4	4	4	4	3	2	2	0	0	0	0	0	0	0	0	0	57	85500
4	4	5	6	5	5	5	4	4	4	4	3	2	2	1	0	0	0	0	0	0	0	0	58	87000
4	4	5	6	5	5	5	4	4	4	4	3	2	2	2	0	0	0	0	0	0	0	0	59	88500
4	4	5	6	6	5	5	4	4	4	4	3	2	2	2	0	0	0	0	0	0	0	0	60	90000

Table 5.17: The Dalles dam baseline spill pattern. (continued).

Spill Bay Number																							Total	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Stops	Spill
4	4	5	6	6	5	5	5	4	4	4	3	2	2	2	0	0	0	0	0	0	0	0	61	91500
4	4	5	6	6	5	5	5	4	4	4	3	3	2	2	0	0	0	0	0	0	0	0	62	93000
4	5	5	6	6	5	5	5	4	4	4	3	3	2	2	0	0	0	0	0	0	0	0	63	94500
4	5	5	6	6	5	5	5	4	4	4	4	3	2	2	0	0	0	0	0	0	0	0	64	96000
4	5	5	6	6	5	5	5	5	4	4	4	3	2	2	0	0	0	0	0	0	0	0	65	97500
4	5	5	6	6	6	5	5	5	4	4	4	3	2	2	0	0	0	0	0	0	0	0	66	99000
5	5	5	6	6	6	5	5	5	4	4	4	3	2	2	0	0	0	0	0	0	0	0	67	100500
5	5	6	6	6	6	5	5	5	4	4	4	3	2	2	0	0	0	0	0	0	0	0	68	102000
5	5	6	7	6	6	5	5	5	4	4	4	3	2	2	0	0	0	0	0	0	0	0	69	103500
5	6	6	7	6	6	5	5	5	4	4	4	3	2	2	0	0	0	0	0	0	0	0	70	105000
5	6	6	7	6	6	5	5	5	4	4	4	3	3	2	0	0	0	0	0	0	0	0	71	106500
5	6	6	7	7	6	5	5	5	4	4	4	3	3	2	0	0	0	0	0	0	0	0	72	108000
5	6	6	7	7	6	6	5	5	4	4	4	3	3	2	0	0	0	0	0	0	0	0	73	109500
5	6	6	7	7	6	6	5	5	5	4	4	3	3	2	0	0	0	0	0	0	0	0	74	111000
5	6	7	7	7	6	6	5	5	5	4	4	3	3	2	0	0	0	0	0	0	0	0	75	113000
5	6	7	7	7	6	6	5	5	5	4	4	4	3	2	0	0	0	0	0	0	0	0	76	114000
5	6	7	7	7	6	6	6	5	5	4	4	4	3	2	0	0	0	0	0	0	0	0	77	115500
5	6	7	7	7	6	6	6	5	5	5	4	4	3	2	0	0	0	0	0	0	0	0	78	117000
6	6	7	7	7	6	6	6	5	5	5	4	4	3	2	0	0	0	0	0	0	0	0	79	118500
6	6	7	7	7	6	6	6	6	5	5	4	4	3	2	0	0	0	0	0	0	0	0	80	120000
6	6	7	7	7	7	6	6	6	5	5	4	4	3	2	0	0	0	0	0	0	0	0	81	121500
6	6	7	7	7	7	6	6	6	5	5	5	4	3	2	0	0	0	0	0	0	0	0	82	123000
6	6	7	7	7	7	6	6	6	6	5	5	4	3	2	0	0	0	0	0	0	0	0	83	124500
6	6	7	8	7	7	6	6	6	6	5	5	4	3	2	0	0	0	0	0	0	0	0	84	126000
6	6	7	8	7	7	7	6	6	6	5	5	4	3	2	0	0	0	0	0	0	0	0	85	127500
6	6	7	8	8	7	7	6	6	6	5	5	4	3	2	0	0	0	0	0	0	0	0	86	129000
6	7	7	8	8	7	7	6	6	6	5	5	4	3	2	0	0	0	0	0	0	0	0	87	130500
6	7	7	8	8	7	7	7	6	6	5	5	4	3	2	0	0	0	0	0	0	0	0	88	132000
6	7	7	8	8	8	7	7	6	6	5	5	4	3	2	0	0	0	0	0	0	0	0	89	133500
6	7	7	8	8	8	7	7	6	6	6	5	4	3	2	0	0	0	0	0	0	0	0	90	135000

Table 5.17: The Dalles dam baseline spill pattern. (continued).

Spill Bay Number																							Total	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Stops	Spill
6	7	8	8	8	8	7	7	6	6	6	5	4	3	2	0	0	0	0	0	0	0	0	91	136500
6	7	8	8	8	8	7	7	7	6	6	5	4	3	2	0	0	0	0	0	0	0	0	92	138000
7	7	8	8	8	8	7	7	7	6	6	5	4	3	2	0	0	0	0	0	0	0	0	93	139500
7	7	8	8	8	8	8	7	7	6	6	5	4	3	2	0	0	0	0	0	0	0	0	94	141000
7	8	8	8	8	8	8	7	7	6	6	5	4	3	2	0	0	0	0	0	0	0	0	95	142500
7	8	8	9	8	8	8	7	7	6	6	5	4	3	2	0	0	0	0	0	0	0	0	96	144000
7	8	8	9	9	8	8	7	7	6	6	5	4	3	2	0	0	0	0	0	0	0	0	97	145500
7	8	8	9	9	8	8	7	7	7	6	5	4	3	2	0	0	0	0	0	0	0	0	98	147000
7	8	9	9	9	8	8	7	7	7	6	5	4	3	2	0	0	0	0	0	0	0	0	99	148500
7	8	9	9	9	9	8	7	7	7	6	5	4	3	2	0	0	0	0	0	0	0	0	100	150000
7	8	9	9	9	9	8	7	7	7	6	5	4	3	2	1	0	0	0	0	0	0	0	101	151500
7	8	9	9	9	9	8	7	7	7	6	5	4	3	2	2	0	0	0	0	0	0	0	102	153000
7	8	9	9	9	9	8	7	7	7	6	5	4	3	3	2	0	0	0	0	0	0	0	103	154500
7	8	9	9	9	9	8	7	7	7	6	5	4	4	3	2	0	0	0	0	0	0	0	104	156000
7	8	9	9	9	9	8	7	7	7	6	5	5	4	3	2	0	0	0	0	0	0	0	105	157500
7	8	9	9	9	9	8	7	7	7	6	6	5	4	3	2	0	0	0	0	0	0	0	106	159000
7	8	9	9	9	9	8	7	7	7	6	6	5	4	3	2	1	0	0	0	0	0	0	107	160500
7	8	9	9	9	9	8	7	7	7	6	6	5	4	3	2	2	0	0	0	0	0	0	108	162000
7	8	9	9	9	9	8	7	7	7	6	6	5	4	3	3	2	0	0	0	0	0	0	109	163500
7	8	9	9	9	9	8	7	7	7	6	6	5	4	4	3	2	0	0	0	0	0	0	110	165000
7	8	9	9	9	9	8	7	7	7	6	6	5	5	4	3	2	0	0	0	0	0	0	111	166500
7	8	9	9	9	9	8	7	7	7	6	6	5	5	4	3	2	1	0	0	0	0	0	112	168000
7	8	9	9	9	9	8	7	7	7	6	6	5	5	4	3	2	2	0	0	0	0	0	113	169500
7	8	9	9	9	9	8	7	7	7	6	6	5	5	4	3	3	2	0	0	0	0	0	114	171000
7	8	9	9	9	9	8	7	7	7	6	6	5	5	4	4	3	2	0	0	0	0	0	115	172500
7	8	9	9	9	9	8	8	7	7	6	6	5	5	4	4	3	2	0	0	0	0	0	116	174000
7	8	9	9	9	9	9	8	7	7	6	6	5	5	4	4	3	2	0	0	0	0	0	117	175500
7	8	9	9	9	9	9	8	8	7	6	6	5	5	4	4	3	2	0	0	0	0	0	118	177000
7	8	9	9	9	9	9	8	8	7	7	6	5	5	4	4	3	2	0	0	0	0	0	119	178500
7	8	9	9	9	9	9	8	8	7	7	6	6	5	4	4	3	2	0	0	0	0	0	120	180000

Table 5.17: The Dalles dam baseline spill pattern. (continued).

Spill Bay Number																							Total	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Stops	Spill
7	8	9	9	9	9	9	8	8	7	7	6	6	5	5	4	3	2	0	0	0	0	0	121	181500
7	8	9	9	10	9	9	8	8	7	7	6	6	5	5	4	3	2	0	0	0	0	0	122	183000
7	8	9	9	10	9	9	8	8	7	7	6	6	6	5	4	3	2	0	0	0	0	0	123	184500
7	8	9	9	10	9	9	8	8	7	7	7	6	6	5	4	3	2	0	0	0	0	0	124	186000
7	8	9	9	10	9	9	8	8	8	7	7	6	6	5	4	3	2	0	0	0	0	0	125	187500
7	8	9	9	10	9	9	9	8	8	7	7	6	6	5	4	3	2	0	0	0	0	0	126	189000
7	8	9	9	10	10	9	9	8	8	7	7	6	6	5	4	3	2	0	0	0	0	0	127	190500
7	8	9	9	10	10	9	9	8	8	7	7	7	6	5	4	3	2	0	0	0	0	0	128	192000
7	8	9	9	10	10	9	9	8	8	8	7	7	6	5	4	3	2	0	0	0	0	0	129	193500
7	8	9	9	10	10	9	9	9	8	8	7	7	6	5	4	3	2	0	0	0	0	0	130	195000
7	8	9	10	10	10	9	9	9	8	8	7	7	6	5	4	3	2	0	0	0	0	0	131	196500
7	8	9	10	10	10	10	9	9	8	8	7	7	6	5	4	3	2	0	0	0	0	0	132	198000
7	8	9	10	10	10	10	9	9	8	8	7	7	6	6	4	3	2	0	0	0	0	0	133	199500
7	8	9	10	10	10	10	9	9	8	8	7	7	6	6	4	3	2	1	0	0	0	0	134	201000
7	8	9	10	10	10	10	9	9	8	8	7	7	6	6	4	3	2	2	0	0	0	0	135	202500
7	8	9	10	10	10	10	9	9	8	8	8	7	6	6	4	3	2	2	0	0	0	0	136	204000
7	8	9	10	10	10	10	9	9	9	8	8	7	6	6	4	3	2	2	0	0	0	0	137	205500
7	8	9	10	10	10	10	9	9	9	8	8	7	6	6	4	3	3	2	0	0	0	0	138	207000
7	8	9	10	10	10	10	9	9	9	8	8	7	6	6	4	4	3	2	0	0	0	0	139	208500
7	8	9	10	10	10	10	9	9	9	8	8	7	6	6	5	4	3	2	0	0	0	0	140	210000
7	8	9	10	10	10	10	10	9	9	8	8	7	6	6	5	4	3	2	0	0	0	0	141	211500
7	8	9	10	10	10	10	10	9	9	9	8	7	6	6	5	4	3	2	0	0	0	0	142	213000
7	8	9	10	10	10	10	10	10	9	9	8	7	6	6	5	4	3	2	0	0	0	0	143	214500
7	8	9	10	10	10	10	10	10	9	9	8	7	7	6	5	4	3	2	0	0	0	0	144	216000
8	8	9	10	10	10	10	10	10	9	9	8	7	7	6	5	4	3	2	0	0	0	0	145	217500
8	8	9	10	10	10	10	10	10	9	9	8	8	7	6	5	4	3	2	0	0	0	0	146	219000
8	9	9	10	10	10	10	10	10	9	9	8	8	7	6	5	4	3	2	0	0	0	0	147	220500
8	9	9	10	10	10	10	10	10	9	9	9	8	7	6	5	4	3	2	0	0	0	0	148	222000
8	9	9	10	10	10	10	10	10	10	9	9	8	7	6	5	4	3	2	0	0	0	0	149	223500
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	4	3	2	0	0	0	0	150	225000

Table 5.17: The Dalles dam baseline spill pattern. (continued).

Spill Bay Number																							Total	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Stops	Spill
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	4	3	2	1	0	0	0	151	226500
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	4	3	2	2	0	0	0	152	228000
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	4	3	2	2	1	0	0	153	229500
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	4	3	2	2	2	0	0	154	231000
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	4	3	2	2	2	1	0	155	232500
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	4	3	2	2	2	2	0	156	234000
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	4	3	2	2	2	2	1	157	235500
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	4	3	2	2	2	2	2	158	237000
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	4	3	3	2	2	2	2	159	238500
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	4	3	3	3	2	2	2	160	240000
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	4	3	3	3	3	2	2	161	241500
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	4	3	3	3	3	3	2	162	243000
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	4	3	3	3	3	3	3	163	244500
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	4	4	3	3	3	3	3	164	246000
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	4	4	4	3	3	3	3	165	247500
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	5	4	4	3	3	3	3	166	249000
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	5	4	4	4	3	3	3	167	250500
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	5	4	4	4	4	3	3	168	252000
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	5	4	4	4	4	4	3	169	253500
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	5	4	4	4	4	4	4	170	255000
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	5	5	4	4	4	4	4	171	256500
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	5	5	5	4	4	4	4	172	258000
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	5	5	5	5	4	4	4	173	259500
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	5	5	5	5	5	4	4	174	261000
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	5	5	5	5	5	5	4	175	262500
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	5	5	5	5	5	5	5	5	176	264000
8	9	10	10	10	10	10	10	10	10	9	9	8	7	6	6	5	5	5	5	5	5	5	177	265500
8	9	10	10	10	10	10	10	10	10	10	9	8	7	6	6	5	5	5	5	5	5	5	178	267000
8	9	10	10	10	10	10	10	10	10	10	9	8	7	7	6	5	5	5	5	5	5	5	179	268500
8	9	10	10	10	10	10	10	10	10	10	9	8	8	7	6	5	5	5	5	5	5	5	180	270000

Table 5.17: The Dalles dam baseline spill pattern. (continued).

Spill Bay Number																							Total	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Stops	Spill
8	9	10	10	10	10	10	10	10	10	10	9	9	8	7	6	5	5	5	5	5	5	5	181	271500
8	9	10	10	10	10	10	10	10	10	10	9	9	8	7	6	6	5	5	5	5	5	5	182	273000
8	9	10	10	10	10	10	10	10	10	10	10	9	8	7	6	6	5	5	5	5	5	5	183	274500
8	9	10	10	10	10	10	10	10	10	10	10	9	8	7	7	6	5	5	5	5	5	5	184	276000
8	9	10	10	10	10	10	10	10	10	10	10	9	8	8	7	6	5	5	5	5	5	5	185	277500
8	9	10	10	10	10	10	10	10	10	10	10	9	9	8	7	6	5	5	5	5	5	5	186	279000
8	9	10	10	10	10	10	10	10	10	10	10	10	9	8	7	6	5	5	5	5	5	5	187	280500
8	9	10	10	10	10	10	10	10	10	10	10	10	9	8	7	6	6	5	5	5	5	5	188	282000
8	9	10	10	10	10	10	10	10	10	10	10	10	9	8	7	7	6	5	5	5	5	5	189	283500
8	9	10	10	10	10	10	10	10	10	10	10	10	9	8	8	7	6	5	5	5	5	5	190	285000
8	9	10	10	10	10	10	10	10	10	10	10	10	9	9	8	7	6	5	5	5	5	5	191	286500
8	9	10	10	10	10	10	10	10	10	10	10	10	10	9	8	7	6	5	5	5	5	5	192	288000
9	9	10	10	10	10	10	10	10	10	10	10	10	10	9	8	7	6	5	5	5	5	5	193	289500
9	10	10	10	10	10	10	10	10	10	10	10	10	10	9	8	7	6	5	5	5	5	5	194	291000
9	10	11	10	10	10	10	10	10	10	10	10	10	10	9	8	7	6	5	5	5	5	5	195	292500
9	10	11	11	10	10	10	10	10	10	10	10	10	10	9	8	7	6	5	5	5	5	5	196	294000
9	10	11	11	11	10	10	10	10	10	10	10	10	10	9	8	7	6	5	5	5	5	5	197	295500
9	10	11	11	11	11	10	10	10	10	10	10	10	10	9	8	7	6	5	5	5	5	5	198	297000
9	10	11	11	11	11	11	10	10	10	10	10	10	10	9	8	7	6	5	5	5	5	5	199	298500
9	10	11	11	11	11	11	11	10	10	10	10	10	10	9	8	7	6	5	5	5	5	5	200	300000
9	10	11	11	11	11	11	11	11	10	10	10	10	10	9	8	7	6	5	5	5	5	5	201	301500
9	10	11	11	11	11	11	11	11	11	10	10	10	10	9	8	7	6	5	5	5	5	5	202	303000
9	10	11	11	11	11	11	11	11	11	11	10	10	10	9	8	7	6	5	5	5	5	5	203	304500
9	10	11	11	11	11	11	11	11	11	11	11	10	10	9	8	7	6	5	5	5	5	5	204	306000
9	10	11	11	11	11	11	11	11	11	11	11	11	10	9	8	7	6	5	5	5	5	5	205	307500
10	10	11	11	11	11	11	11	11	11	11	11	11	10	9	8	7	6	5	5	5	5	5	206	309000
10	11	11	11	11	11	11	11	11	11	11	11	11	10	9	8	7	6	5	5	5	5	5	207	310500
10	11	12	11	11	11	11	11	11	11	11	11	11	10	9	8	7	6	5	5	5	5	5	208	312000
10	11	12	12	11	11	11	11	11	11	11	11	11	10	9	8	7	6	5	5	5	5	5	209	313500
10	11	12	12	12	11	11	11	11	11	11	11	11	10	9	8	7	6	5	5	5	5	5	210	315000

Table 5.17: The Dalles dam baseline spill pattern. (continued).

Spill Bay Number																							Total	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Stops	Spill
10	11	12	12	12	12	11	11	11	11	11	11	11	10	9	8	7	6	5	5	5	5	5	211	316500
10	11	12	12	12	12	12	11	11	11	11	11	11	10	9	8	7	6	5	5	5	5	5	212	318000
10	11	12	12	12	12	12	12	11	11	11	11	11	10	9	8	7	6	5	5	5	5	5	213	319500
10	11	12	12	12	12	12	12	12	11	11	11	11	10	9	8	7	6	5	5	5	5	5	214	321000
10	11	12	12	12	12	12	12	12	12	11	11	11	10	9	8	7	6	5	5	5	5	5	215	322500
10	11	12	12	12	12	12	12	12	12	12	11	11	10	9	8	7	6	5	5	5	5	5	216	324000
10	11	12	12	12	12	12	12	12	12	12	12	11	10	9	8	7	6	5	5	5	5	5	217	325500
10	11	12	12	12	12	12	12	12	12	12	12	11	10	9	8	7	6	6	5	5	5	5	218	327000
10	11	12	12	12	12	12	12	12	12	12	12	11	10	9	8	7	7	6	5	5	5	5	219	328500
10	11	12	12	12	12	12	12	12	12	12	12	11	10	9	8	8	7	6	5	5	5	5	220	330000
10	11	12	12	12	12	12	12	12	12	12	12	11	10	9	9	8	7	6	5	5	5	5	221	331500
10	11	12	12	12	12	12	12	12	12	12	12	11	10	10	9	8	7	6	5	5	5	5	222	333000
10	11	12	12	12	12	12	12	12	12	12	12	11	11	10	9	8	7	6	5	5	5	5	223	334500
10	11	12	12	12	12	12	12	12	12	12	12	12	11	10	9	8	7	6	5	5	5	5	224	336000
10	11	12	12	12	12	12	12	12	12	12	12	12	11	10	9	8	7	6	6	5	5	5	225	337500
10	11	12	12	12	12	12	12	12	12	12	12	12	11	10	9	8	7	7	6	5	5	5	226	339000
10	11	12	12	12	12	12	12	12	12	12	12	12	11	10	9	8	8	7	6	5	5	5	227	340500
10	11	12	12	12	12	12	12	12	12	12	12	12	11	10	9	9	8	7	6	5	5	5	228	342000
10	11	12	12	12	12	12	12	12	12	12	12	12	11	10	10	9	8	7	6	5	5	5	229	343500
10	11	12	12	12	12	12	12	12	12	12	12	12	11	11	10	9	8	7	6	5	5	5	230	345000
10	11	12	12	12	12	12	12	12	12	12	12	12	12	11	10	9	8	7	6	5	5	5	231	346500
10	11	12	12	12	12	12	12	12	12	12	12	12	12	11	10	9	8	7	6	6	5	5	232	348000
10	11	12	12	12	12	12	12	12	12	12	12	12	12	11	10	9	8	7	7	6	5	5	233	349500
10	11	12	12	12	12	12	12	12	12	12	12	12	12	11	10	9	8	8	7	6	5	5	234	351000

Table 5.18: John Day dam baseline spill pattern.

Spill Bay Number																				Total	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Stops	Spill
2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	9600
2	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	11200
2	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	12800
2	3	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	14400
2	3	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	16000
2	3	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	17600
2	3	3	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	19200
2	3	3	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	20800
2	3	3	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	22400
2	3	3	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	15	24000
2	3	3	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	16	25600
2	3	3	2	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	17	27200
2	3	3	3	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	18	28800
2	3	3	3	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	19	30400
2	3	3	3	2	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	20	32000
2	3	3	3	3	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	21	33600
2	3	3	3	3	3	2	2	1	0	0	0	0	0	0	0	0	0	0	0	22	35200
2	3	3	3	3	3	2	2	2	0	0	0	0	0	0	0	0	0	0	0	23	36800
2	3	3	3	3	3	2	2	2	1	0	0	0	0	0	0	0	0	0	0	24	38400
2	3	3	3	3	3	2	2	2	2	0	0	0	0	0	0	0	0	0	0	25	40000
2	3	3	3	3	3	2	2	2	2	1	0	0	0	0	0	0	0	0	0	26	41600
2	3	3	3	3	3	2	2	2	2	2	0	0	0	0	0	0	0	0	0	27	43200
2	3	3	3	3	3	2	2	2	2	2	1	0	0	0	0	0	0	0	0	28	44800
2	3	3	3	3	3	2	2	2	2	2	2	0	0	0	0	0	0	0	0	29	46400
2	3	3	3	3	3	3	2	2	2	2	2	0	0	0	0	0	0	0	0	30	48000
2	3	3	3	3	3	3	2	2	2	2	2	1	0	0	0	0	0	0	0	31	49600
2	3	3	3	3	3	3	2	2	2	2	2	2	0	0	0	0	0	0	0	32	51200
2	3	3	3	3	3	3	3	2	2	2	2	2	1	0	0	0	0	0	0	33	52800
2	3	3	3	3	3	3	3	2	2	2	2	2	1	0	0	0	0	0	0	34	54400
2	3	3	3	3	3	3	3	2	2	2	2	2	2	0	0	0	0	0	0	35	56000

Table 5.18: John Day dam baseline spill pattern. (continued).

Spill Bay Number																				Total	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Stops	Spill
2	3	3	3	3	3	3	3	2	2	2	2	2	2	1	0	0	0	0	0	36	57600
2	3	3	3	3	3	3	3	2	2	2	2	2	2	2	0	0	0	0	0	37	59200
2	3	3	3	3	3	3	3	2	2	2	2	2	2	2	1	0	0	0	0	38	60800
2	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	0	0	0	0	39	62400
2	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	1	0	0	0	40	64000
2	4	3	3	3	3	3	3	2	2	2	2	2	2	2	2	1	0	0	0	41	65600
2	4	4	3	3	3	3	3	2	2	2	2	2	2	2	2	1	0	0	0	42	67200
2	4	4	4	3	3	3	3	2	2	2	2	2	2	2	2	1	0	0	0	43	68800
2	4	4	4	4	3	3	3	2	2	2	2	2	2	2	2	1	0	0	0	44	70400
2	4	4	4	4	3	3	3	3	2	2	2	2	2	2	2	1	0	0	0	45	72000
2	4	4	4	4	3	3	3	3	3	2	2	2	2	2	2	1	0	0	0	46	73600
3	4	4	4	4	3	3	3	3	3	2	2	2	2	2	2	1	0	0	0	47	75200
3	5	4	4	4	3	3	3	3	3	2	2	2	2	2	2	1	0	0	0	48	76800
3	5	5	4	4	3	3	3	3	3	2	2	2	2	2	2	1	0	0	0	49	78400
3	5	5	4	4	4	3	3	3	2	2	2	2	2	2	2	2	0	0	0	50	80000
3	5	5	4	4	4	3	3	3	2	2	2	2	2	2	2	2	1	0	0	51	81600
3	5	5	4	4	4	3	3	3	3	2	2	2	2	2	2	2	1	0	0	52	83200
3	5	5	4	4	4	3	3	3	3	3	2	2	2	2	2	2	1	0	0	53	84800
3	5	5	4	4	4	3	3	3	3	3	3	2	2	2	2	2	1	0	0	54	86400
3	5	5	5	4	4	3	3	3	3	3	3	2	2	2	2	2	1	0	0	55	88000
3	5	5	5	4	4	4	3	3	3	3	3	2	2	2	2	2	1	0	0	56	89600
3	5	5	5	4	4	4	3	3	3	3	3	3	2	2	2	2	1	0	0	57	91200
3	5	5	5	4	4	4	3	3	3	3	3	3	3	2	2	2	1	0	0	58	92800
3	5	5	5	4	4	4	3	3	3	3	3	3	3	3	2	2	1	0	0	59	94400
3	5	5	5	4	4	4	3	3	3	3	3	3	3	3	3	2	1	0	0	60	96000
3	5	5	5	4	4	4	4	3	3	3	3	3	3	3	3	2	1	0	0	61	97600
3	5	5	5	4	4	4	4	4	3	3	3	3	3	3	3	2	1	0	0	62	99200
3	5	5	5	5	4	4	4	4	3	3	3	3	3	3	3	2	1	0	0	63	100800
3	5	5	5	5	4	4	4	4	3	3	3	3	3	3	3	2	2	0	0	64	102400
3	5	5	5	5	4	4	4	4	4	3	3	3	3	3	3	2	2	0	0	65	104000

Table 5.18: John Day dam baseline spill pattern. (continued).

Spill Bay Number																				Total	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Stops	Spill
3	5	5	5	5	4	4	4	4	4	3	3	3	3	3	3	2	2	1	0	66	105600
3	5	5	5	5	4	4	4	4	4	3	3	3	3	3	3	3	2	1	0	67	107200
4	4	4	4	4	3	3	3	3	3	3	3	3	3	4	3	4	3	4	3	68	108800
4	4	4	4	4	3	3	4	3	3	3	3	3	3	4	3	4	3	4	3	69	110400
4	4	4	4	4	3	3	4	3	4	3	3	3	3	4	3	4	3	4	3	70	112000
4	4	4	4	4	3	3	4	3	4	3	4	3	3	4	3	4	3	4	3	71	113600
4	4	4	4	4	4	3	4	3	4	3	4	3	3	4	3	4	3	4	3	72	115200
4	4	4	4	4	4	3	4	3	4	3	4	3	3	4	3	4	4	4	3	73	116800
4	4	4	4	4	4	3	4	3	4	3	4	3	3	4	4	4	4	4	3	74	118400
4	4	4	4	4	4	3	4	3	4	3	4	3	4	4	4	4	4	4	3	75	120000
4	4	4	4	4	4	4	4	3	4	3	4	3	4	4	4	4	4	4	3	76	121600
4	4	4	4	4	4	4	4	4	4	3	4	3	4	4	4	4	4	4	3	77	123200
4	4	4	4	4	4	4	4	4	4	4	4	3	4	4	4	4	4	4	3	78	124800
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	79	126400
4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	80	128000
5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	81	129600
5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	82	131200
5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	83	132800
5	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	84	134400
5	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4	5	4	85	136000
5	5	5	5	4	4	4	4	4	4	4	4	4	4	4	4	5	4	5	4	86	137600
5	5	5	5	4	4	4	4	4	4	4	4	4	4	5	4	5	4	5	4	87	139200
5	5	5	5	5	4	4	4	4	4	4	4	4	4	5	4	5	4	5	4	88	140800
5	5	5	5	5	4	4	5	4	4	4	4	4	4	5	4	5	4	5	4	89	142400
5	5	5	5	5	4	4	5	4	5	4	4	4	4	5	4	5	4	5	4	90	144000
5	5	5	5	5	4	4	5	4	5	4	5	4	4	5	4	5	4	5	4	91	145600
5	5	5	5	5	5	4	5	4	5	4	5	4	4	5	4	5	4	5	4	92	147200
5	5	5	5	5	5	4	5	4	5	4	5	4	4	4	5	5	5	5	4	93	148800
5	5	5	5	5	5	4	5	4	5	4	5	4	4	5	5	5	5	5	4	94	150400
5	5	5	5	5	5	5	5	4	5	4	5	4	4	5	5	5	5	5	4	95	152000

Table 5.18: John Day dam baseline spill pattern. (continued).

Spill Bay Number																				Total	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Stops	Spill
5	5	5	5	5	5	5	5	4	5	4	5	4	5	5	5	5	5	5	4	96	153600
5	5	5	5	5	5	5	5	5	5	4	5	4	5	5	5	5	5	5	4	97	155200
5	5	5	5	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	4	98	156800
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4	99	158400
5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	100	160000
6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	101	161600
6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	102	163200
6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	103	164800
6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	104	166400
6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	5	5	6	5	105	168000
6	6	6	6	5	5	5	5	5	5	5	5	5	5	5	5	6	5	6	5	106	169600
6	6	6	6	5	5	5	5	5	5	5	5	5	5	6	5	6	5	6	5	107	171200
6	6	6	6	6	5	5	5	5	5	5	5	5	5	6	5	6	5	6	5	108	172800
6	6	6	6	6	5	5	6	5	5	5	5	5	5	6	5	6	5	6	5	109	174400
6	6	6	6	6	5	5	6	5	6	5	5	5	5	6	5	6	5	6	5	110	176000
6	6	6	6	6	5	5	6	5	6	5	6	5	5	6	5	6	5	6	5	111	177600
6	6	6	6	6	6	5	6	5	6	5	6	5	5	6	5	6	5	6	5	112	179200
6	6	6	6	6	6	5	6	5	6	5	6	5	5	6	5	6	6	6	5	113	180800
6	6	6	6	6	6	5	6	5	6	5	6	5	5	6	6	6	6	6	5	114	182400
6	6	6	6	6	6	6	6	5	6	5	6	5	5	6	6	6	6	6	5	115	184000
6	6	6	6	6	6	6	6	5	6	5	6	5	6	6	6	6	6	6	5	116	185600
6	6	6	6	6	6	6	6	6	6	5	6	5	6	6	6	6	6	6	5	117	187200
6	6	6	6	6	6	6	6	6	6	6	6	5	6	6	6	6	6	6	5	118	188800
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	5	119	190400
6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	120	192000
7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	121	193600
7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	122	195200
7	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	123	196800
7	7	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	124	198400
7	7	7	7	6	6	6	6	6	6	6	6	6	6	6	6	6	6	7	6	125	200000

Table 5.18: John Day dam baseline spill pattern. (continued).

Spill Bay Number																				Total	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Stops	Spill
7	7	7	7	6	6	6	6	6	6	6	6	6	6	6	6	7	6	7	6	126	201600
7	7	7	7	6	6	6	6	6	6	6	6	6	6	7	6	7	6	7	6	127	203200
7	7	7	7	7	6	6	6	6	6	6	6	6	6	7	6	7	6	7	6	128	204800
7	7	7	7	7	6	6	7	6	6	6	6	6	6	7	6	7	6	7	6	129	206400
7	7	7	7	7	6	6	7	6	7	6	6	6	6	7	6	7	6	7	6	130	208000
7	7	7	7	7	6	6	7	6	7	6	7	6	6	7	6	7	6	7	6	131	209600

Table 5.19: McNary dam baseline spill pattern.

Spill Bay Number																						Total	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Stops	Spill
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1400
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	3	4200
1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	5	7600
1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	7	11600
1	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	0	9	13800
1	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2	0	11	17800
1	2	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	0	13	21800
1	2	1	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	1	2	0	15	25800
1	2	1	1	1	1	1	1	0	0	0	0	0	0	1	1	1	1	1	1	2	0	17	29800
1	2	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	2	0	19	33800
2	2	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	2	0	20	34900
2	2	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	2	0	22	38900
2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	0	24	42900
2	2	1	1	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	1	2	0	26	46500
2	2	1	1	1	1	1	2	1	1	1	2	2	1	2	1	1	1	1	1	2	0	28	51900
2	2	1	1	1	2	1	2	1	1	1	2	2	1	2	1	2	1	1	1	2	0	30	55500
2	3	1	1	1	2	1	2	1	1	1	2	2	1	2	1	2	1	1	1	3	0	32	57700
2	3	1	2	1	2	1	2	1	1	1	2	2	1	2	1	2	1	2	1	3	0	34	61300
2	3	1	2	1	2	1	2	1	2	2	2	2	1	2	1	2	1	2	1	3	0	36	64900
2	3	1	2	1	2	1	2	2	2	2	2	2	2	2	1	2	1	2	1	3	0	38	66700
3	3	1	2	1	2	1	2	2	2	2	2	2	2	2	1	2	1	2	1	3	0	39	68800
3	3	1	2	1	2	2	2	2	2	2	2	2	2	2	2	2	1	2	1	3	0	41	71400
3	4	1	2	1	2	2	2	2	2	2	2	2	2	2	2	2	1	2	1	4	0	43	73600
3	4	1	2	1	2	2	2	2	2	2	3	3	2	2	2	2	1	2	1	4	0	45	76800
3	4	2	2	1	2	2	2	2	2	2	3	3	3	2	2	2	1	2	1	4	0	47	80300
3	4	2	2	1	2	2	2	2	3	3	3	3	3	2	2	2	1	2	1	4	0	49	83400
3	4	2	2	2	2	2	2	2	3	3	3	3	3	2	2	2	2	2	1	4	0	51	87000
3	4	2	2	2	2	2	3	2	3	3	3	3	3	2	2	3	2	2	1	4	0	53	90200
3	4	2	2	2	2	2	3	3	3	3	3	3	3	3	2	3	2	2	1	4	0	55	93400
3	4	2	2	2	3	2	3	3	3	3	3	3	3	3	3	3	2	2	1	4	0	57	96600

Table 5.19: McNary dam baseline spill pattern. (continued).

Spill Bay Number																						Total	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Stops	Spill
3	4	2	2	2	3	3	3	3	3	3	3	3	3	4	3	3	2	2	1	4	0	59	99900
3	5	2	2	2	3	3	3	3	3	3	3	3	3	4	3	3	2	2	2	4	0	61	102100
3	5	2	2	3	3	3	3	3	3	4	3	3	3	4	3	3	2	2	2	4	0	63	105400
4	5	2	2	3	3	3	3	3	3	4	3	3	4	4	3	3	2	2	2	4	0	65	108200
4	5	2	2	3	3	3	3	3	3	4	3	3	4	4	3	3	3	2	2	4	0	66	109800
4	5	2	2	3	3	3	3	3	4	4	3	3	4	4	3	3	3	2	2	5	0	68	112600
4	5	2	2	3	3	3	3	3	4	4	3	3	4	4	3	3	3	3	2	5	0	69	114200
4	5	2	2	3	3	3	3	4	4	4	3	3	4	4	4	3	3	3	2	5	0	71	117600
4	5	2	2	3	3	3	3	4	4	4	3	4	4	4	4	4	3	3	2	5	0	73	121000
4	5	2	2	3	3	3	3	4	4	4	3	4	4	4	4	4	3	3	3	6	0	75	123100
4	5	2	2	3	3	3	3	4	4	4	4	4	4	4	4	4	3	4	3	6	0	77	126500
5	5	2	3	3	3	3	3	4	4	4	4	4	4	4	4	4	3	4	3	6	0	79	129200
5	5	2	3	3	3	3	4	4	4	4	4	4	4	4	4	4	3	4	3	6	0	80	130900
5	6	2	3	3	3	3	4	4	4	4	4	4	4	4	4	4	3	4	4	6	0	82	133000
5	6	3	3	3	4	3	4	4	4	4	4	4	4	4	4	4	3	4	4	6	0	84	136300
6	6	3	4	3	4	3	4	4	4	4	4	4	4	4	4	4	3	4	4	6	0	86	139000
6	6	3	4	3	4	3	4	4	4	5	4	5	4	4	4	4	3	4	4	6	0	88	142200
6	7	3	4	3	4	3	4	4	4	5	4	5	4	4	4	4	3	4	4	7	0	90	144400
6	7	3	4	3	4	4	4	4	4	5	4	5	5	4	4	4	3	4	4	7	0	92	147700
7	7	3	4	3	4	4	4	4	4	5	4	5	5	4	4	4	3	4	4	7	0	93	148800
7	7	3	4	3	4	4	5	4	4	5	4	5	5	5	4	4	3	4	4	7	0	95	152000
7	7	3	4	3	4	4	5	4	5	5	5	5	5	5	4	4	3	4	4	7	0	97	155200
7	7	4	4	3	4	4	5	4	5	5	5	5	5	5	4	4	4	4	4	7	0	99	158600
7	8	4	4	3	4	4	5	4	5	5	5	6	5	5	4	4	4	4	4	7	0	101	161300
7	8	4	4	3	4	4	5	5	5	5	5	6	5	5	4	5	4	4	4	7	0	103	164500
7	8	4	4	4	4	4	5	5	5	6	5	6	5	5	4	5	4	4	4	7	0	105	167900
7	8	4	4	4	5	4	5	5	5	6	6	6	5	5	4	5	4	4	4	7	0	107	171200
8	8	4	4	4	5	4	5	5	6	6	6	6	5	5	4	5	4	4	4	7	0	109	173900
8	8	4	4	4	5	4	5	6	6	6	6	6	6	5	4	5	4	4	4	7	0	111	177300
8	8	4	4	4	5	4	5	6	6	6	7	6	6	5	4	5	4	4	4	8	0	113	179900

Table 5.19: McNary dam baseline spill pattern. (continued).

Spill Bay Number																						Total	Total
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Stops	Spill
8	8	4	4	4	5	4	5	6	6	7	7	7	6	5	4	5	4	4	4	8	0	115	183100
8	8	4	4	4	5	5	5	6	6	7	7	7	6	5	5	5	4	4	4	8	0	117	186300
8	8	4	4	4	5	5	5	6	7	7	7	7	6	6	5	5	4	4	4	8	0	119	189600
8	9	4	4	4	5	5	6	6	7	7	7	7	6	6	5	5	4	4	4	8	0	121	192200
8	9	4	4	4	5	5	6	7	7	7	8	7	6	6	5	5	4	4	4	8	0	123	195400
9	9	4	5	4	5	5	6	7	7	7	8	7	6	6	5	5	4	5	4	8	0	126	198500
8	9	4	5	4	5	5	6	7	7	7	8	7	6	6	5	5	4	5	4	8	0	125	198600
9	10	4	5	5	6	5	6	7	8	8	9	9	9	7	6	5	5	5	4	9	0	141	222400
10	11	5	6	5	6	6	6	7	8	9	10	10	10	9	8	6	5	6	5	10	0	158	247600

Table 5.20: Ice Harbor dam baseline spill pattern.

Spill Bay Number										Total	Total
1	2	3	4	5	6	7	8	9	10	Stops	Spill
1	0	0	0	0	0	0	0	0	0	1	1700
1	0	0	0	0	0	0	0	0	1.5	2.5	3500
1	1	0	0	0	0	0	0	0	1.5	3.5	5200
1	1	0	0	0	0	0	0	1	1.5	4.5	6900
1	1	1	0	0	0	0	0	1	1.5	5.5	8700
1	1	1	0	0	0	0	1	1	1.5	6.5	10400
1	1	1	1	0	0	0	1	1	1.5	7.5	12100
1	1	1	1	0	0	1	1	1	1.5	8.5	13800
1	1	1	1	1	0	1	1	1	1.5	9.5	15600
1	1	1	1	1	1	1	1	1	1.5	10.5	17300
1	1	1	1	1	1	1	1	1	2	11	19000
1	2	1	1	1	1	1	1	1	2	12	20700
1	2	2	1	1	1	1	1	1	2	13	22500
1	2	2	2	1	1	1	1	1	2	14	24200
1	2	2	2	2	1	1	1	1	2	15	25900
1	2	2	2	2	2	1	1	1	2	16	27600
1	2	2	2	2	2	2	1	1	2	17	29300
1	2	2	2	2	2	2	2	1	2	18	31100
1	2	2	2	2	2	2	2	2	2	19	32800
2	2	2	2	2	2	2	2	2	2	20	34500
2	3	2	2	2	2	2	2	2	2	21	36200
2	3	3	2	2	2	2	2	2	2	22	37900
2	3	3	3	2	2	2	2	2	2	23	39600
2	3	3	3	3	2	2	2	2	2	24	41300
2	3	3	3	3	3	2	2	2	2	25	43000
2	3	3	3	3	3	3	2	2	2	26	44700
2	3	3	3	3	3	3	3	2	2	27	46400
2	3	3	3	3	3	3	3	3	2	28	48100
2	4	3	3	3	3	3	3	3	2	29	49800
2	4	4	3	3	3	3	3	3	2	30	51500
2	4	4	4	3	3	3	3	3	2	31	53200
2	4	4	4	4	3	3	3	3	2	32	54900
2	4	4	4	4	4	3	3	3	2	33	56600
2	4	4	4	4	4	4	3	3	2	34	58300
2	4	4	4	4	4	4	4	3	2	35	60000
2	4	4	4	4	4	4	4	4	2	36	61700
2	5	4	4	4	4	4	4	4	2	37	63400
2	5	5	4	4	4	4	4	4	2	38	65100
2	5	5	5	4	4	4	4	4	2	39	66700
2	5	5	5	5	4	4	4	4	2	40	68400
2	5	5	5	5	5	4	4	4	2	41	70100
2	5	5	5	5	5	5	4	4	2	42	71800
2	5	5	5	5	5	5	5	4	2	43	73500
2	5	5	5	5	5	5	5	5	2	44	75100

Table 5.20: Ice Harbor dam baseline spill pattern. (continued).

Spill Bay Number										Total	Total
1	2	3	4	5	6	7	8	9	10	Stops	Spill
2	6	5	5	5	5	5	5	5	2	45	76800
2	6	6	5	5	5	5	5	5	2	46	78500
2	6	6	6	5	5	5	5	5	2	47	80200
2	6	6	6	6	5	5	5	5	2	48	81800
2	6	6	6	6	6	5	5	5	2	49	83500
2	6	6	6	6	6	6	5	5	2	50	85200
2	6	6	6	6	6	6	6	5	2	51	86800
2	6	6	6	6	6	6	6	6	2	52	88500
2	7	6	6	6	6	6	6	6	2	53	90100
2	7	7	6	6	6	6	6	6	2	54	91700
2	7	7	7	6	6	6	6	6	2	55	93300
2	7	7	7	7	6	6	6	6	2	56	94900
2	7	7	7	7	7	6	6	6	2	57	96500
2	7	7	7	7	7	7	6	6	2	58	98100
2	7	7	7	7	7	7	7	6	2	59	99700
2	7	7	7	7	7	7	7	7	2	60	101300
2	8	7	7	7	7	7	7	7	2	61	103000
2	8	8	7	7	7	7	7	7	2	62	104700
2	8	8	8	7	7	7	7	7	2	63	106400
2	8	8	8	8	7	7	7	7	2	64	108100
2	8	8	8	8	8	7	7	7	2	65	109800
2	8	8	8	8	8	8	7	7	2	66	111500
2	8	8	8	8	8	8	8	7	2	67	113200
2	8	8	8	8	8	8	8	8	2	68	114900
2	9	8	8	8	8	8	8	8	2	69	116500
2	9	9	8	8	8	8	8	8	2	70	118100
2	9	9	9	8	8	8	8	8	2	71	119700
2	9	9	9	9	8	8	8	8	2	72	121300
2	9	9	9	9	9	8	8	8	2	73	122900
2	9	9	9	9	9	9	8	8	2	74	124500
2	9	9	9	9	9	9	9	8	2	75	126100
2	9	9	9	9	9	9	9	9	2	76	127700
2	10	9	9	9	9	9	9	9	2	77	129300
2	10	10	9	9	9	9	9	9	2	78	130900
2	10	10	10	9	9	9	9	9	2	79	132500
2	10	10	10	10	9	9	9	9	2	80	134100
2	10	10	10	10	10	9	9	9	2	81	135700
2	10	10	10	10	10	10	9	9	2	82	137300
2	10	10	10	10	10	10	9	9	2	82	138900
2	10	10	10	10	10	10	10	10	2	84	140500
2	11	10	10	10	10	10	10	10	2	85	142200
2	11	11	10	10	10	10	10	10	2	86	143900
2	11	11	11	10	10	10	10	10	2	87	145600
2	11	11	11	11	10	10	10	10	2	88	147300

Table 5.20: Ice Harbor dam baseline spill pattern. (continued).

Spill Bay Number										Total	Total
1	2	3	4	5	6	7	8	9	10	Stops	Spill
2	11	11	11	11	11	10	10	10	2	89	149000
2	11	11	11	11	11	11	10	10	2	90	150700
2	11	11	11	11	11	11	11	10	2	91	152400
2	11	11	11	11	11	11	11	11	2	92	154100
2	12	11	11	11	11	11	11	11	2	93	155700
2	12	12	11	11	11	11	11	11	2	94	157300
2	12	12	12	11	11	11	11	11	2	95	158900
2	12	12	12	12	11	11	11	11	2	96	160500
2	12	12	12	12	12	11	11	11	2	97	162100
2	12	12	12	12	12	12	11	11	2	98	163700
2	12	12	12	12	12	12	12	11	2	99	165300
2	12	12	12	12	12	12	12	12	2	100	166900
2	13	12	12	12	12	12	12	12	2	101	168500
2	13	13	12	12	12	12	12	12	2	102	170100
2	13	13	13	12	12	12	12	12	2	103	171700
2	13	13	13	13	12	12	12	12	2	104	173300
2	13	13	13	13	13	12	12	12	2	105	174900

Table 5.21: Lower Monumental dam baseline spill pattern.

Spill Bay Number								Total	Total
1	2	3	4	5	6	7	8	Stops	Spill
0	1	0	0	0	0	0	0	1	1100
0	1	1	0	0	0	0	0	2	2200
0	1	1	1	0	0	0	0	3	3300
0	1	1	1	1	0	0	0	4	4400
0	1	1	1	1	1	0	0	5	5500
0	1	1	1	1	1	1	0	6	6600
0	2	1	1	1	1	1	0	7	8300
0	2	2	1	1	1	1	0	8	10000
0	2	2	2	1	1	1	0	9	11700
0	2	2	2	2	1	1	0	10	13400
0	2	2	2	2	2	1	0	11	15100
0	2	2	2	2	2	2	0	12	16800
0	3	2	2	2	2	2	0	13	18600
0	3	3	2	2	2	2	0	14	20400
0	3	3	3	2	2	2	0	15	22200
0	3	3	3	3	2	2	0	16	24000
0	3	3	3	3	3	2	0	17	25800
0	3	3	3	3	3	3	0	18	27600
0	4	3	3	3	3	3	0	19	29200
0	4	4	3	3	3	3	0	20	30800
0	4	4	4	3	3	3	0	21	32400
0	4	4	4	4	3	3	0	22	34000
0	4	4	4	4	4	3	0	23	35600
0	4	4	4	4	4	4	0	24	37200
0	5	4	4	4	4	4	0	25	38900
0	5	5	4	4	4	4	0	26	40600
0	5	5	5	4	4	4	0	27	42300
0	5	5	5	5	4	4	0	28	44000
0	5	5	5	5	5	4	0	29	45700
0	5	5	5	5	5	5	0	30	47400
0	6	5	5	5	5	5	0	31	49100
0	6	6	5	5	5	5	0	32	50800
0	6	6	6	5	5	5	0	33	52500
0	6	6	6	6	5	5	0	34	54200
0	6	6	6	6	6	5	0	35	55900
0	6	6	6	6	6	6	0	36	57600
0	7	6	6	6	6	6	0	37	59300
0	7	7	6	6	6	6	0	38	61000
0	7	7	7	6	6	6	0	39	62700
0	7	7	7	7	6	6	0	40	64400
0	7	7	7	7	7	6	0	41	66100
0	7	7	7	7	7	7	0	42	67800
0	8	7	7	7	7	7	0	43	69600
0	8	8	7	7	7	7	0	44	71400

Table 5.21: Lower Monumental dam baseline spill pattern. (continued).

Spill Bay Number								Total	Total
1	2	3	4	5	6	7	8	Stops	Spill
0	8	8	8	7	7	7	0	45	73200
0	8	8	8	8	7	7	0	46	75000
0	8	8	8	8	8	7	0	47	76800
0	8	8	8	8	8	8	0	48	78600
0	9	8	8	8	8	8	0	49	80300
0	9	9	8	8	8	8	0	50	82000
0	9	9	9	8	8	8	0	51	83700
0	9	9	9	9	8	8	0	52	85400
0	9	9	9	9	9	8	0	53	87100
0	9	9	9	9	9	9	0	54	88800
0	10	9	9	9	9	9	0	55	90500
0	10	10	9	9	9	9	0	56	92200
0	10	10	10	9	9	9	0	57	93900
0	10	10	10	10	9	9	0	58	95600
0	10	10	10	10	10	9	0	59	97300
0	10	10	10	10	10	10	0	60	99000
0	11	10	10	10	10	10	0	61	100700
0	11	11	10	10	10	10	0	62	102400
0	11	11	11	10	10	10	0	63	104100
0	11	11	11	11	10	10	0	64	105800
0	11	11	11	11	11	10	0	65	107500
0	11	11	11	11	11	11	0	66	109200
0	12	11	11	11	11	11	0	67	111000
0	12	12	11	11	11	11	0	68	112800
0	12	12	12	11	11	11	0	69	114600
0	12	12	12	12	11	11	0	70	116400
0	12	12	12	12	12	11	0	71	118200
0	12	12	12	12	12	12	0	72	120000
0	13	12	12	12	12	12	0	73	121700
0	13	13	12	12	12	12	0	74	123400
0	13	13	13	12	12	12	0	75	125100
0	13	13	13	13	12	12	0	76	126800
0	13	13	13	13	13	12	0	77	128500
0	13	13	13	13	13	13	0	78	130200
0	14	13	13	13	13	13	0	79	131900
0	14	14	13	13	13	13	0	80	133600
0	14	14	14	13	13	13	0	81	135300
0	14	14	14	14	13	13	0	82	137000
0	14	14	14	14	14	13	0	83	138700
0	14	14	14	14	14	14	0	84	140400
0	15	14	14	14	14	14	0	85	142200
0	15	15	14	14	14	14	0	86	144000
0	15	15	15	14	14	14	0	87	145800

Table 5.21: Lower Monumental dam baseline spill pattern. (continued).

Spill Bay Number								Total	Total
1	2	3	4	5	6	7	8	Stops	Spill
0	15	15	15	15	14	14	0	88	147600
0	15	15	15	15	15	14	0	89	149400
0	15	15	15	15	15	15	0	90	151200
0	16	15	15	15	15	15	0	91	152900
0	16	16	15	15	15	15	0	92	154600
0	16	16	16	15	15	15	0	93	156300
0	16	16	16	16	15	15	0	94	158000
0	16	16	16	16	16	15	0	95	159700
0	16	16	16	16	16	16	0	96	161400

Table 5.22: Little Goose dam baseline spill pattern.

Spill Bay Number								Total	Total
1	2	3	4	5	6	7	8	Stops	Spill
0	1	0	0	0	0	0	0	1	1800
0	1	1	0	0	0	0	0	2	3600
0	1	1	1	0	0	0	0	3	5400
0	1	1	1	1	0	0	0	4	7200
0	1	1	1	1	1	0	0	5	9000
0	1	1	1	1	1	1	0	6	10800
0	2	1	1	1	1	1	0	7	12600
0	2	2	1	1	1	1	0	8	14400
0	2	2	2	1	1	1	0	9	16200
0	2	2	2	2	1	1	0	10	18000
0	2	2	2	2	2	1	0	11	19800
0	2	2	2	2	2	2	0	12	21600
0	3	2	2	2	2	2	0	13	23400
0	3	3	2	2	2	2	0	14	25200
0	3	3	3	2	2	2	0	15	27000
0	3	3	3	3	2	2	0	16	28800
0	3	3	3	3	3	2	0	17	30600
0	3	3	3	3	3	3	0	18	32400
0	4	3	3	3	3	3	0	19	34200
0	4	4	3	3	3	3	0	20	36000
0	4	4	4	3	3	3	0	21	37800
0	4	4	4	4	3	3	0	22	39600
0	4	4	4	4	4	3	0	23	41400
0	4	4	4	4	4	4	0	24	43200
0	5	4	4	4	4	4	0	25	45000
0	5	5	4	4	4	4	0	26	46800
0	5	5	5	4	4	4	0	27	48600
0	5	5	5	5	4	4	0	28	50400
0	5	5	5	5	5	4	0	29	52200
0	5	5	5	5	5	5	0	30	54000
0	6	5	5	5	5	5	0	31	55800
0	6	6	5	5	5	5	0	32	57600
0	6	6	6	5	5	5	0	33	59400
0	6	6	6	6	5	5	0	34	61200
0	6	6	6	6	6	5	0	35	63000
0	6	6	6	6	6	6	0	36	64800
0	7	6	6	6	6	6	0	37	66600
0	7	7	6	6	6	6	0	38	68400
0	7	7	7	6	6	6	0	39	70200
0	7	7	7	7	6	6	0	40	72000
0	7	7	7	7	7	6	0	41	73800
0	7	7	7	7	7	7	0	42	75600
0	8	7	7	7	7	7	0	43	77400
0	8	8	7	7	7	7	0	44	79200

Table 5.22: Little Goose dam baseline spill pattern. (continued).

Spill Bay Number								Total	Total
1	2	3	4	5	6	7	8	Stops	Spill
0	8	8	8	7	7	7	0	45	81000
0	8	8	8	8	7	7	0	46	82800
0	8	8	8	8	8	7	0	47	84600
0	8	8	8	8	8	8	0	48	86400
0	9	8	8	8	8	8	0	49	88200
0	9	9	8	8	8	8	0	50	90000
0	9	9	9	8	8	8	0	51	91800
0	9	9	9	9	8	8	0	52	93600
0	9	9	9	9	9	8	0	53	95400
0	9	9	9	9	9	9	0	54	97200
0	10	9	9	9	9	9	0	55	99000
0	10	10	9	9	9	9	0	56	100800
0	10	10	10	9	9	9	0	57	102600
0	10	10	10	10	9	9	0	58	104400
0	10	10	10	10	10	9	0	59	106200
0	10	10	10	10	10	10	0	60	108000
0	11	10	10	10	10	10	0	61	109800
0	11	11	10	10	10	10	0	62	111600
0	11	11	11	10	10	10	0	63	113400
0	11	11	11	11	10	10	0	64	115200
0	11	11	11	11	11	10	0	65	117000
0	11	11	11	11	11	11	0	66	118800
0	12	11	11	11	11	11	0	67	120600
0	12	12	11	11	11	11	0	68	122400
0	12	12	12	11	11	11	0	69	124200
0	12	12	12	12	11	11	0	70	126000
0	12	12	12	12	12	11	0	71	127800
0	12	12	12	12	12	12	0	72	129600
0	13	12	12	12	12	12	0	73	131400
0	13	13	12	12	12	12	0	74	133200
0	13	13	13	12	12	12	0	75	135000
0	13	13	13	13	12	12	0	76	136800
0	13	13	13	13	13	12	0	77	138600
0	13	13	13	13	13	13	0	78	140400
0	14	13	13	13	13	13	0	79	142200
0	14	14	13	13	13	13	0	80	144000
0	14	14	14	13	13	13	0	81	145800
0	14	14	14	14	13	13	0	82	147600
0	14	14	14	14	14	13	0	83	149400
0	14	14	14	14	14	14	0	84	151200
0	15	14	14	14	14	14	0	85	153000
0	15	15	14	14	14	14	0	86	154800
0	15	15	15	14	14	14	0	87	156600
0	15	15	15	15	14	14	0	88	158400

Table 5.22: Little Goose dam baseline spill pattern. (continued).

Spill Bay Number								Total	Total
1	2	3	4	5	6	7	8	Stops	Spill
0	15	15	15	15	15	14	0	89	160200
0	15	15	15	15	15	15	0	90	162000
0	16	15	15	15	15	15	0	91	163800
0	16	16	15	15	15	15	0	92	165600
0	16	16	16	15	15	15	0	93	167400
0	16	16	16	16	15	15	0	94	169200
0	16	16	16	16	16	15	0	95	171000
0	16	16	16	16	16	16	0	96	172800

Table 5.23: Lower Granite dam baseline spill pattern.

Spill Bay Number								Total	Total
1	2	3	4	5	6	7	8	Stops	Spill
1	0	0	0	0	0	0	0	1	1750
1	0	0	0	0	0	0	1	2	3500
1	0	0	0	0	0	1	1	3	5250
1	1	0	0	0	1	1	1	5	7000
1	1	0	0	0	1	1	1	5	8750
1	1	1	0	0	1	1	1	6	10500
1	2	1	0	0	1	1	1	7	12370
1	2	1	0	0	1	2	1	8	14250
1	2	1	1	0	1	2	1	9	15990
1	2	2	1	0	1	2	1	10	17860
1	2	2	1	1	1	2	1	11	19610
1	2	2	2	1	1	2	1	12	21480
1	2	2	2	2	1	2	1	13	23350
1	2	2	3	2	1	2	1	14	25270
2	2	2	3	2	1	2	1	15	27140
2	2	2	3	3	1	2	1	16	29060
2	2	2	3	3	2	2	1	17	30930
2	2	3	3	3	2	2	1	18	32850
2	3	3	3	3	2	2	1	19	34770
2	3	3	4	3	2	2	1	20	36670
3	3	3	4	3	2	2	1	21	38610
3	3	4	4	3	2	2	1	22	40530
3	3	4	4	3	3	2	1	23	42450
3	4	4	4	3	3	2	1	24	44370
3	4	4	4	4	3	2	1	25	46290
3	4	4	5	4	3	2	1	26	48210
3	4	5	5	4	3	2	1	27	50130
4	4	5	5	4	3	2	1	28	52050
4	5	5	5	4	3	2	1	29	53970
4	5	5	5	4	4	2	1	30	55890
4	5	5	5	5	4	2	1	31	57810
4	5	5	6	5	4	2	1	32	59730
4	5	6	6	5	4	2	1	33	61650
3	4	6	7	6	4	3	2	35	63400
4	6	6	6	5	4	2	1	34	63570
3	4	6	7	7	4	3	2	36	65200
3	4	7	7	7	4	3	2	37	67000
3	4	7	8	7	4	3	2	38	68900
3	4	7	8	7	5	3	2	39	70700
3	4	7	8	8	5	3	2	40	72700
3	4	7	8	8	6	3	2	41	74500
3	4	7	9	8	6	3	2	42	76400
3	4	7	9	9	6	3	2	43	78200
3	5	7	9	9	6	3	2	44	80000

Table 5.23: Lower Granite dam baseline spill pattern. (continued).

Spill Bay Number								Total	Total
1	2	3	4	5	6	7	8	Stops	Spill
3	5	7	9	9	6	4	2	45	81900
3	5	8	9	9	6	4	2	46	83800
3	5	8	10	9	6	4	2	47	85600
3	5	8	10	9	7	4	2	48	87400
3	5	8	10	10	7	4	2	49	89200
3	6	8	10	10	7	4	2	50	91100
3	6	8	11	10	7	4	2	51	92900
3	6	9	11	10	7	4	2	52	94700
3	6	9	11	10	8	4	2	53	96600
3	6	9	11	11	8	4	2	54	98400
3	6	9	11	11	8	5	2	55	100300
3	6	10	11	11	8	5	2	56	102100
3	6	10	12	11	8	5	2	57	103900
3	6	10	12	11	9	5	2	58	105700
3	6	10	12	11	9	5	3	59	107600
3	6	10	12	12	9	5	3	60	109400
3	6	10	13	12	9	5	3	61	111200
3	6	10	13	12	10	5	3	62	113000
3	6	11	13	12	10	5	3	63	114800
3	6	11	13	13	10	5	3	64	116600
3	6	11	13	13	10	6	3	65	118500
3	6	11	13	13	11	6	3	66	120300

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