Optimization of Spill for Reduction of Dam and Reservoir Mortality in CRiSP

Modeling Support to Army Corps of Engineers Columbia River Fisheries Programs

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Project: CRiSP juvenile passage model development and calibration for alternative analysis of the Lower Snake River Juvenile Salmon Migration Feasibility Study (LSRFS)

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Overview

Holding all other variables constant, the effects of spill on both direct dam mortality and reservoir mortality in yearling chinook are considered. Spill may often enhance juvenile passage, but can also lead to an increase in dissolved gas concentrations in downstream reservoirs. High levels of dissolved nitrogen are known to be harmful to chinook. Whether the combined effects result in a net increase or decrease in survival through various projects depends on how high spill is adjusted during the period of downstream migration.

Dam Mortality

Direct dam survival, S, may be expressed simply as:

$$S = (P_B + P_T + P_S)/(N_S + N_T + N_B)$$

where

- P_S is the number of fish passing the spillway
- P_T is the number of fish passing the turbines
- P_B is the number of fish passing the bypass system
- N_S is the number of fish entering the spillway
- N_T is the number of fish entering the turbines
- N_B is the number of fish entering the bypass system

The number of fish passing (surviving) each route is given by

- $P_S = N_S S_S$
- $P_T = N_T S_T$
- $P_B = N_B S_B$

where

- $N_S = N_0(SE)(SF)$
- $N_T = N_0 – N_S - N_B$
- $N_B = FGE(N_0 – N_S)$

and

- S_S is the spill survival
- S_T is the turbine survival
- S_B is the bypass system survival
- SF is the spill fraction
- SE is the spill effectiveness
- FGE is the fish guidance efficiency
- N_0 is the number arriving at the dam = $N_S + N_T + N_B$

Values for S_S, S_T, S_B, SE and FGE have been determined by the PATH Work Group and Hydro Group (PATH, 1998; Toole, 1998; Giorgi, 1998). Recommended values and their associated uncertanties are presented in Table 1.

Table 1: Recommended Values for Spill Optimization

FGE			
	high	**mean**	**low**
LGR	0.53	0.51	0.49
LGS	0.45	0.45	0.45
LMN	0.49	0.49	0.49
ICE	0.46	0.46	0.46
MCN	0.68	0.525	0.37
JDA	0.34	0.34	0.34
DAL	0.46	0.46	0.46
BON	0.47	0.47	0.47
SE			
Use 1.5 +/- 0.5 for all dams except The Dalles.			
For The Dalles:			
SE = 2.0			for SF < = 30%
SE = 2.43 - 1.43 (spill fraction)			for SF > 30%
Bypass Mortality			
Use 0.02 for LGR, LMN and BON1			
Use 0.03 for all other dams			
Turbine Mortality			
Use 0.10 +/- 0.03 for all dams.			
Spill Mortality			
Use 0.02 for all dams.			

Four scenarios were considered. In the first scenario (Scenario A), parameter values were set to maximize survival, within specified uncertanties. For this scenario, high FGE values were assumed (Table 1), a spill effectiveness of 2.0 was used for all dams (except The Dalles), and turbine mortality was set at 0.07 for all dams. The second scenario (Scenario B) represents the worst case scenario, within specified uncertanties. For this scenario, low values for FGE and SE were assumed, and turbine mortality was set to 0.13.

For the third and forth scenarios (Scenario C and Scenario D), parameter values were set so as to minimize and maximize the effects of spill on direct dam survival, respectively.

For Scenario C, high FGE values were used while turbine mortality was set to 0.07 and SE was set to 1.0 (except at The Dalles). For Scenario D, low FGE values were used, turbine mortality was set to 0.13, and SE was set to 2.0.

For the Dalles, SE was calculated using the relationship in Table1. Values are shown in Table 2.

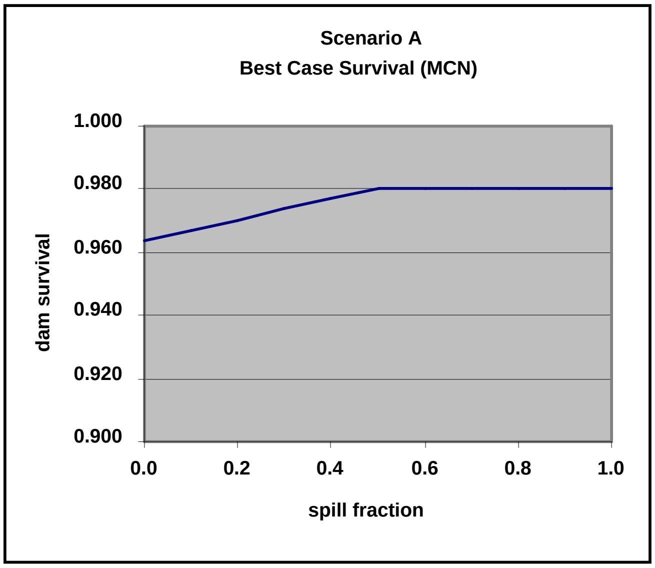
Table 2: SE Values for The Dalles

spill fraction	SE
0-0.3	2.00
0.4	1.86
0.5	1.72
0.6	1.57
0.7	1.43
0.8	1.29
0.9	1.14
1	1.00

Figure 1 shows how direct dam survival is expected to change over a range of spill fractions for McNary Dam, given the above assumptions, for Scenarios A and B. Because the uncertainty in the estimate for FGE is greatest at McNary, we see the largest change in predicted direct survival for this dam. For other dams, the difference between best and worst case scenarios is expected to be less significant.

Figure 2 shows the range of uncertainty associated with the effects of increased spill on direct dam survival. Assumptions used in Scenario C yield the smallest expected benefits in direct dam survival from increased spill, while assumptions used in Scenario D yield the largest expected benefits in direct dam survival. Again, the difference between Scenarios C and D is most pronounced at McNary, due to the large degree of uncertainty associated with FGE at that dam.

Figure 1. Best and Worst Case Survival, McNary Dam



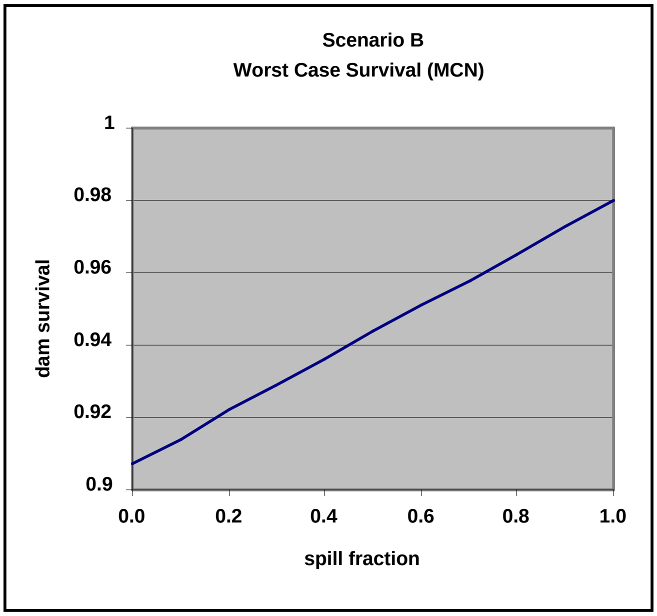
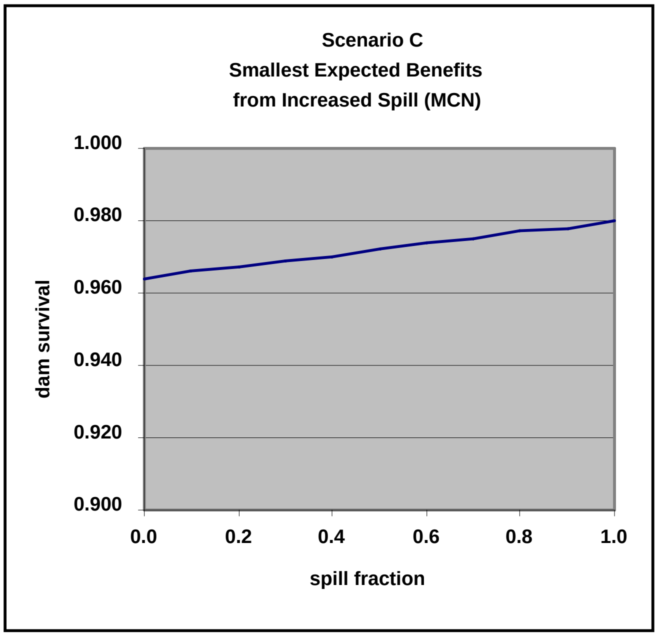
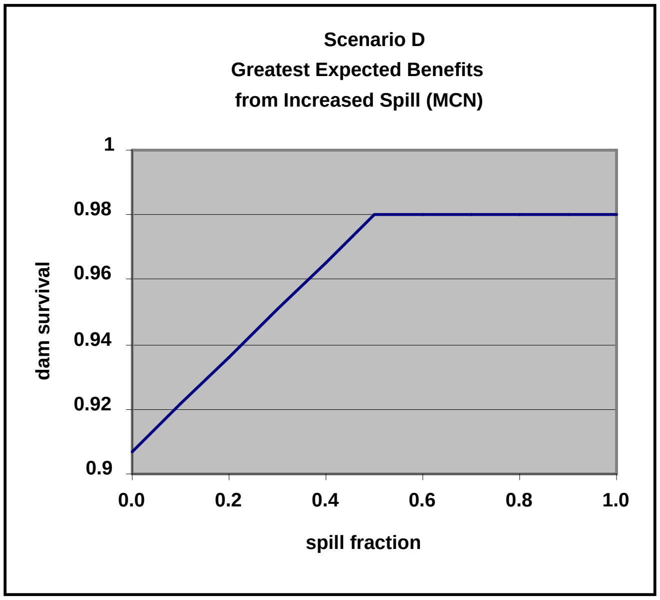


Figure 2. Effect of Spill on Dam Survival at McNary





Indirect and Reach Mortality

Indirect and reach survival, which depends on tailrace and reach predation, dissolved nitrogen concentrations and other factors, was estimated for each scenario over a range of flows using the Columbia River Salmon Passage Model (CRiSP), Version 1.6.

Model headwater flow probability distributions were estimated from historical gaged flows. For the Columbia, Snake and Clearwater, five modeled flows were derived by calculating the mean flow for each river at its modeled headwater (med. flow) during the period of spring chinook downstream migration, and adding or subtracting one or two times the standard deviation to derive flows for the other four scenarios. Flows for other headwaters were calculated by linearly interpolating between historical minimum and maximum spring flows.

Headwater flows used in the modeled spill scenarios are shown in Table 3.

Table 3: Modeled Headwater Flows (kcfs)

	COL	DES	ANA	CLW	NFC	MFC	SAL	WEN	MET
Run									
1	4.1	2.0	0.9	0.5	0.4	0.2	1.0	0.5	0.3
2	82.5	20.3	29.5	17.0	6.8	5.2	15.8	10.4	10.2
3	160.9	38.5	58.1	33.5	13.2	10.1	30.5	20.3	20.1
4	239.3	56.8	86.7	50.1	19.6	15.1	45.3	30.1	30.1
5	317.6	75.0	115.3	66.6	26.0	20.0	60.0	40.0	40.0

Dissolved gas concentrations were calibrated to observed concentrations at each dam between 1995 and 1998 using CRiSP 1.6 (Shaw, 1998). No significant variation in model parameters was required, with the exception of the parameter "k_entrain", which determines the dissolved gas concentration in the fraction of flow passing through the powerhouse (Beer, 1999). Values for k_entrain can be expected to vary annually with differences in spill, flow and dam operations. Calibrated values for k_entrain are shown in Table 4. The sensitivity of survival to a range of values was examined using medium to high flow and varying the spill fraction between 20% and 100% (planned spill) at Lower Granite, Little Goose and Ice Harbor. These are summarized in Table 5. Because variations in survival were small (less than 1%), average values were used for k_entrain were used for these three dams.

It is assumed that predation and other parameters that affect survival do not vary with spill fraction. Other assumptions are summarized in the Appendix.

Table 4: k_entrain values

1995:	Lower_Granite_Dam		0.009	
	Little_Goose_Dam		0.143	
	Ice_Harbor_Dam		0.000	
1996:	Lower_Granite_Dam		0.009	
	Little_Goose_Dam		0.960	
	Ice_Harbor_Dam		0.220	
1997:	Lower_Granite_Dam		0.012	
	Little_Goose_Dam		0.555	
	Ice_Harbor_Dam		0.000	
1998:	Lower_Granite_Dam		0.017	
	Little_Goose_Dam		0.802	
	Ice_Harbor_Dam		0.004	
		max	**min**	**avg**
Lower_Granite_Dam		0.017	0.009	0.012
Little_Goose_Dam		0.960	0.143	0.615
Ice_Harbor_Dam		0.220	0.000	0.056

Table 5: Sensitivity to k_entrain

20% Spill - Med-Hi Flow			
Survival to:		max k	min k
Little Goose		81.7%	81.9%
Lower Monumental		73.1%	73.2%
Ice Harbor		67.3%	67.4%
McNary		62.2%	62.3%
100% Spill - Med-Hi Flow			
Survival to:		max k	min k
Little Goose		81.3%	81.3%
Lower Monumental		73.5%	73.5%
Ice Harbor		68.3%	68.3%
McNary		64.1%	64.1%

Model Results

Model results for Lower Granite are shown in Figure 3. For Lower Granite Dam, it is important to note that in the high flow scenario, the powerhouse is running at capacity between 0% and 50% planned spill, and the actual spill fraction remains constant at 55%. Planned spills above 55%, however, are allowed. The medium flow at Lower Granite is 145.4 kcfs, which is 15.4 kcfs higher than the powerhouse capacity. Thus, in the medium flow scenario, the minimum allowable spill is 11%. Above 11%, the planned spill is equal to the actual spill.

Modeling survival through Little Goose Pool takes into account indirect mortality and nitrogen gas-related mortality associated with operations at Lower Granite. For most flows, reach mortality associated with nitrogen gas supersaturation in Little Goose Pool results in a gradual decline in reach survival of a couple percentage points as spill increases. This effect is small, however, compared to the model uncertainty in direct dam survival and the effects of flow itself. In Scenario B (low FGE’s, low SE, high turbine mortality), the beneficial effects of increased spill on dam survival outweigh the adverse impacts of nitrogen gas-related mortality, resulting in an increase in survival with spill, even at very high levels of spill.

This is not the case for McNary (Figure 4). Because the flows are much higher, and because dissolved gas dissipates slowly in John Day Pool, the adverse effects of high spill fractions on reach survival outweigh the benefits of decreased turbine mortality at very high rates of spill (greater than about 350 kcfs). Higher survival is possible at lower flows because, at flows greater than about 600 kcfs, total spill is constrained to remain at levels (greater than 368 kcfs) that compromise any benefits derived from enhanced dam survival or decreased travel time and predation.

Results for John Day, The Dalles, and Bonneville are shown in Figures 5, 6, and 7, respectively. Further analysis and interpretation is ongoing.

System-wide survival was calculated by applying constant spill schedules at all dams simultaneously. System-wide results are shown in Figures 8 (to Bonneville tailrace) and 9 (to Estuary).

Conclusions

Results suggest that during low to medium flow years (0 to 350 kcfs at McNary during the spring), increasing spill will generally enhance downstream survival of yearling chinook. Benefits are seen up to a spill fraction of about 50% at most dams, regardless of what values are assumed for FGE, SE and turbine mortality. Results suggest that increasing spill to 50% at all dams will lead to an improvement in system-wide survival of between about 2% to 10%. There is too much uncertainty to recommend spilling more than 50% at any dam to enhance passage, even at very low flows.

At high flows (greater than 350 kcfs at McNary, or 145 kcfs at Lower Granite), additional spill in excess of forced spill does not appear to enhance survival, and cannot be justified based on our assumptions.

**Figure 3. Lower Granite:
Dam and Downstream Reach Survival**

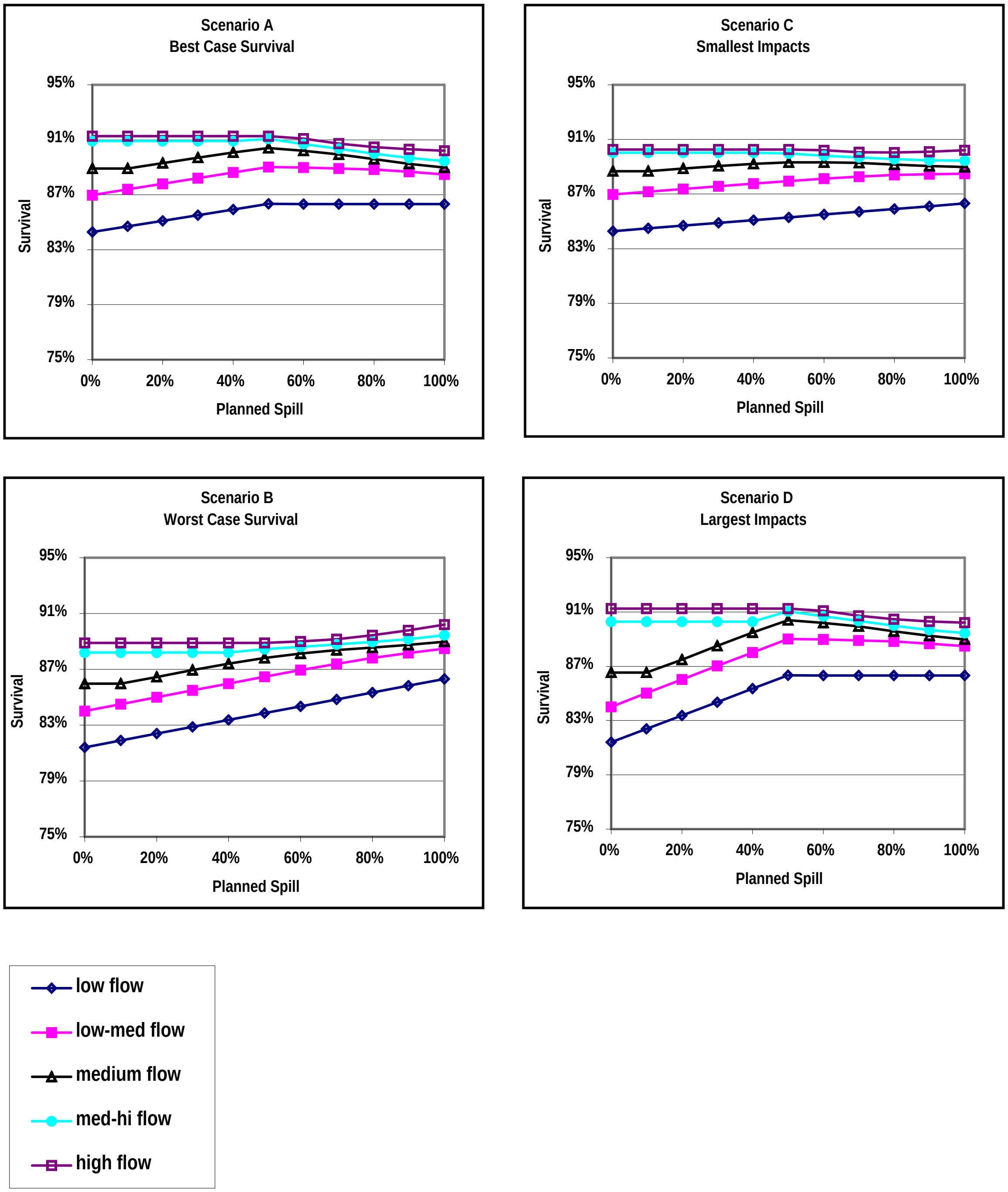


Figure 4. McNary:
Dam and Downstream Reach Survival

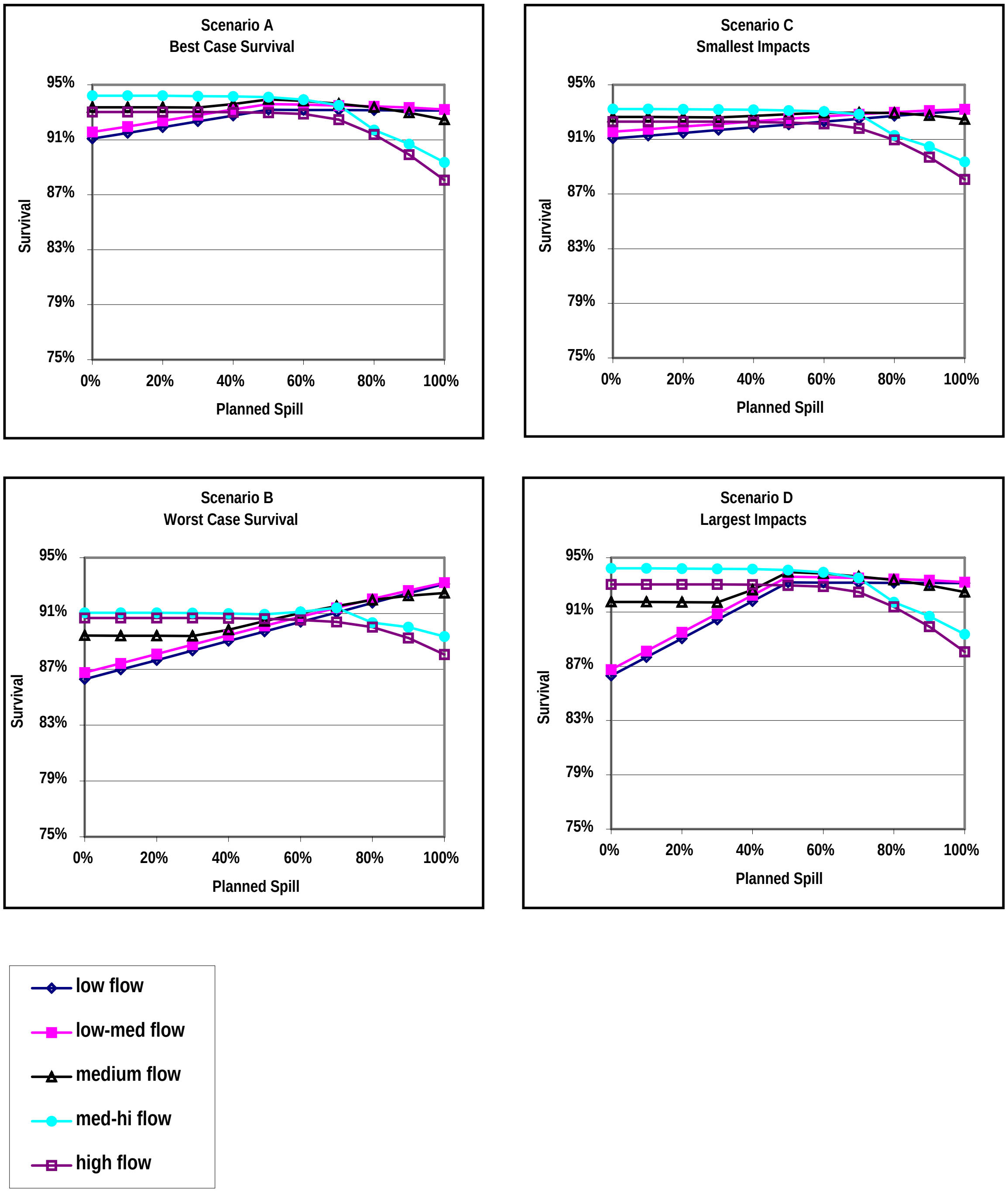


Figure 5. John Day:
Dam and Downstream Reach Survival

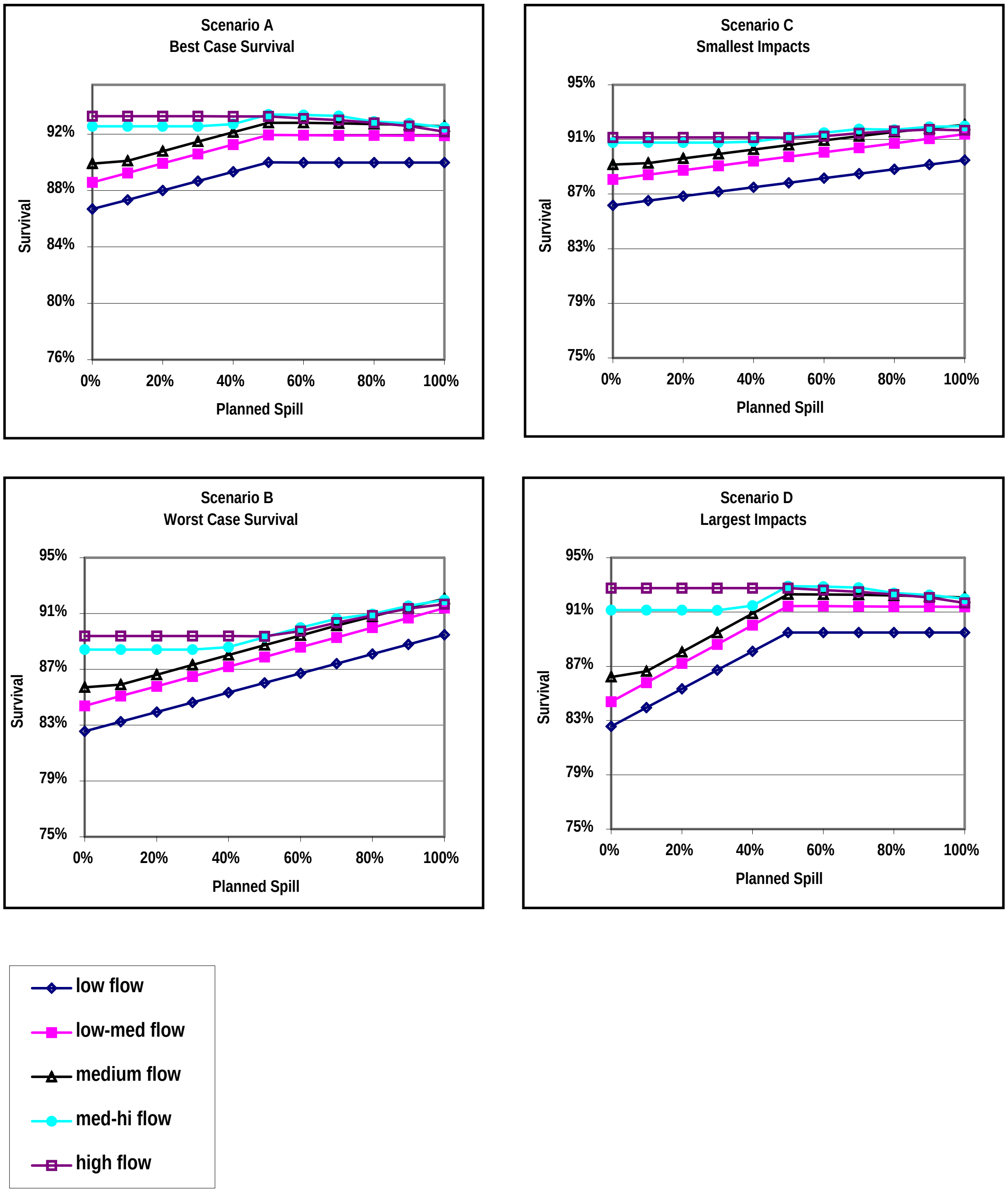
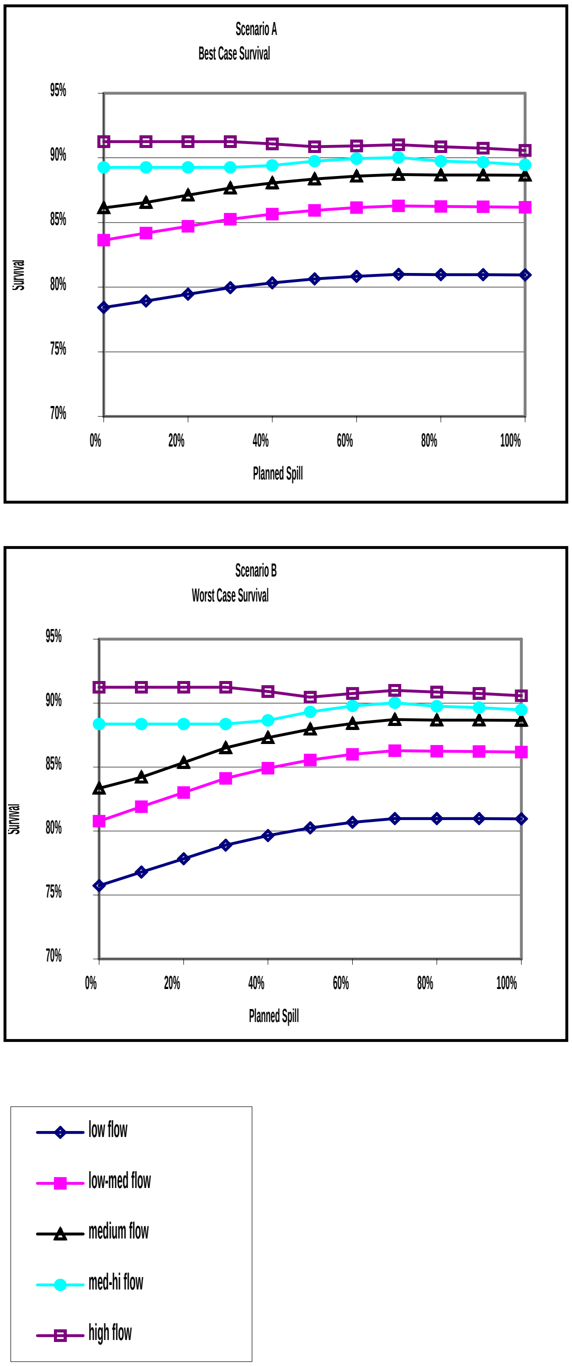


Figure 6. The Dalles: Dam and Downstream Reach Survival



Note: Because there is no uncertainty assumed for FGE values at The Dalles, Scenarios C and D are the same as Scenarios A and B.

Figure 7. Bonneville:
Survival Through Dam to Estuary

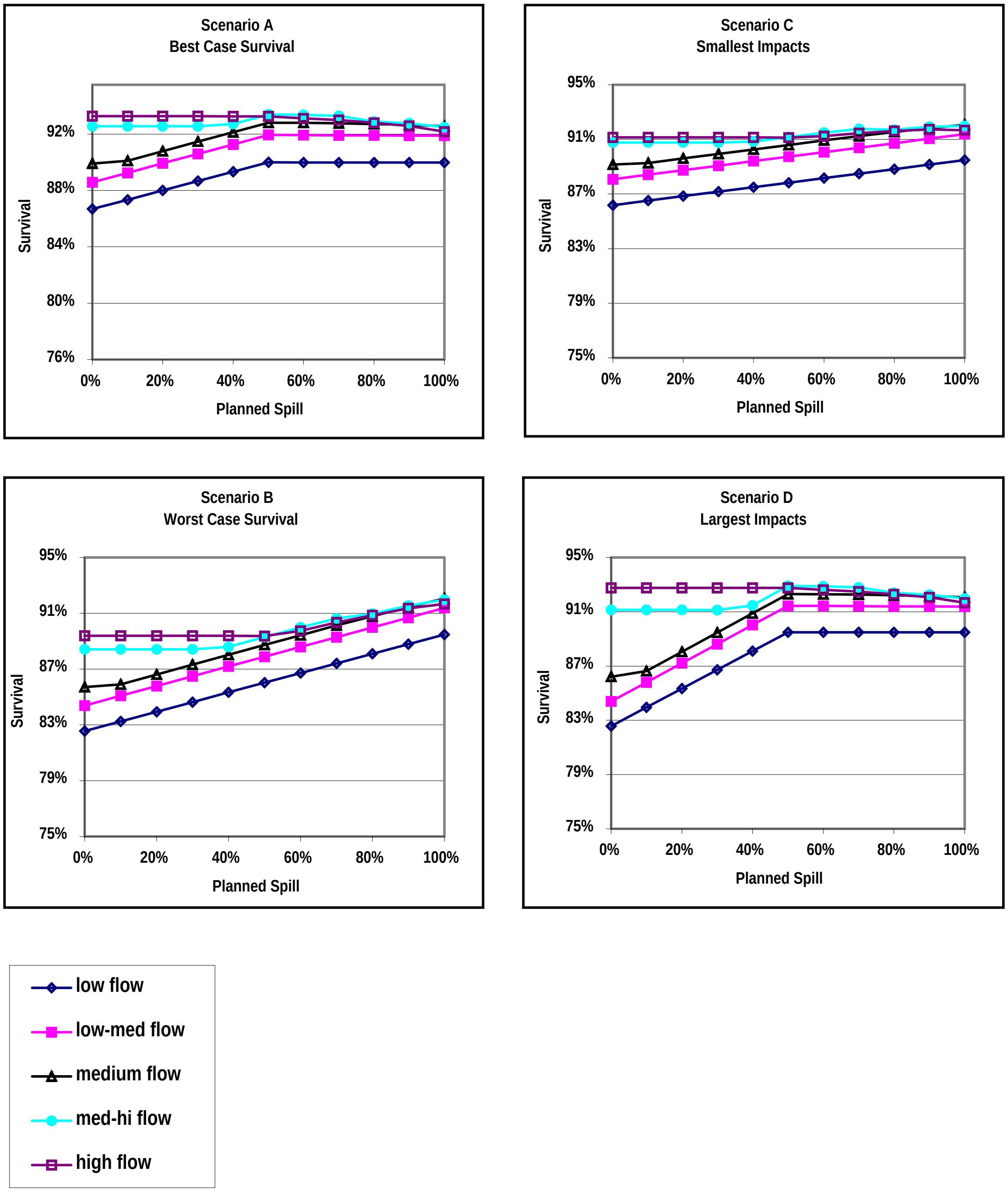


Figure 8. System-wide Survival:
to Bonneville Tailrace

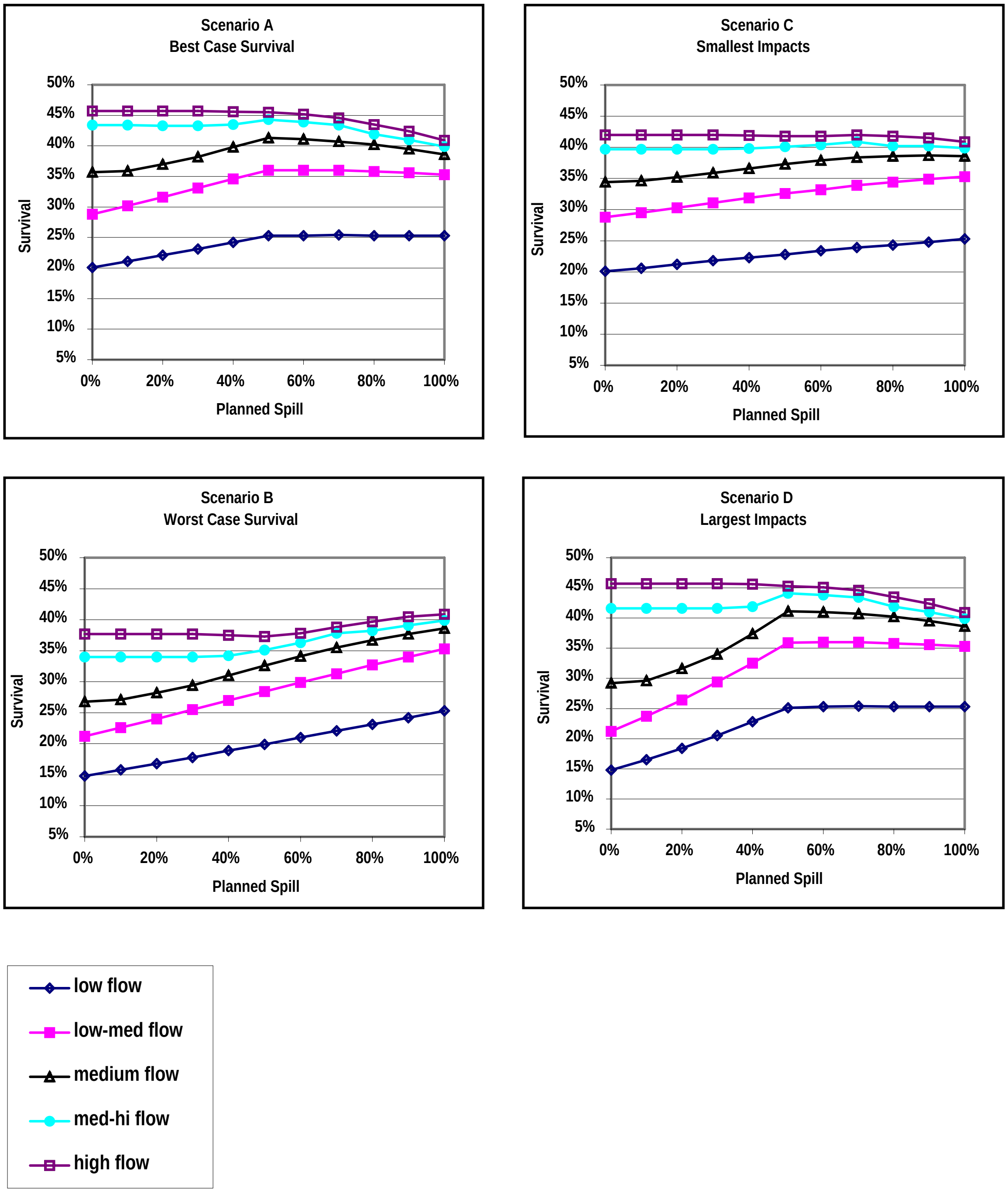
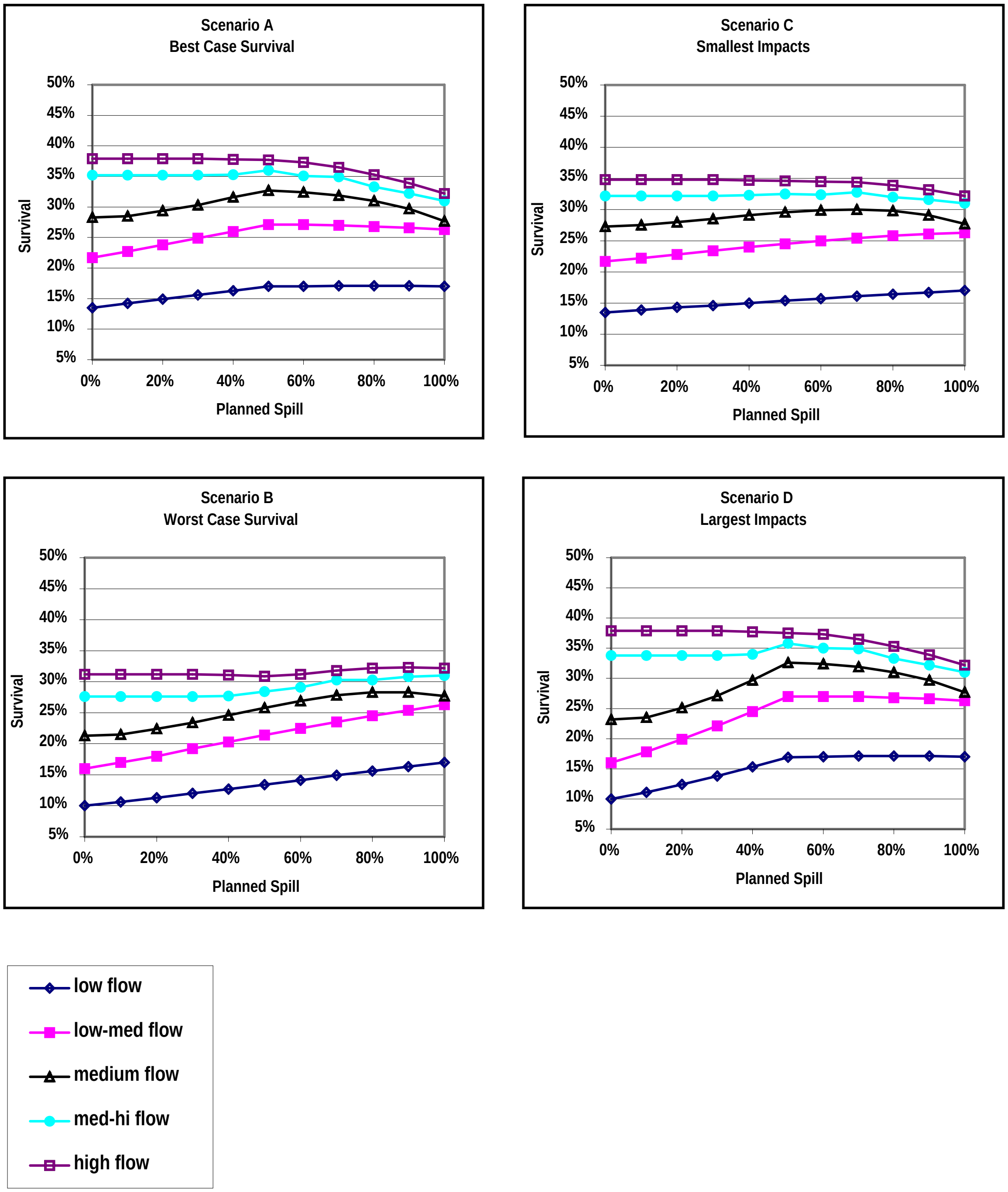


**Figure 9. System-wide Survival:
to Estuary**



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Giorgi, A. “Scoping Spill Efficiency/Effectiveness Estimates of Subyearling Chinook Salmon, and an Update of Information for Spring Migrants: Snake River & Lower Columbia River Projects,” February 3, 1998.

Plan for Analyzing Testable Hypotheses (PATH). Annual Report, FY98, 1998.

Shaw, P. 1998. Dissolved Gas Documentation for CRiSP1.6.

Toole, Chris. “Review of Dam Passage Routing and Survival,” 1998.

Appendix

CRiSP 1.6 Input Parameters

```
                          mean forebay
                          transit time
Bonneville Dam
            Chinook 1       2.00
Bonneville Dam 2
            Chinook 1       0.00
The Dalles Dam
            Chinook 1       2.00
John Day Dam
            Chinook 1       2.00
McNary Dam
            Chinook 1       2.00
Ice Harbor Dam
            Chinook 1       2.00
Lower Monumental Dam
            Chinook 1       2.00
Little Goose Dam
            Chinook 1       2.00
Lower Granite Dam
            Chinook 1       2.00
```

```
                                                                   mod         mod
                      powerhouse powerhouse powerhouse              ou          ou
                        capacity   priority  threshold               r       sigma

      Bonneville Dam      136.00          0       0.00            0.50       12.00
    Bonneville Dam 2      152.00          1       0.00            0.00        0.00
      The Dalles Dam      375.00          0       0.00            0.50       12.00
        John Day Dam      322.00          0       0.00            0.50       12.00
          McNary Dam      232.00          0       0.00            0.50       12.00
      Ice Harbor Dam      106.00          0       0.00            0.50       12.00
Lower Monumental Dam      130.00          0       0.00            0.50       12.00
    Little Goose Dam      130.00          0       0.00            0.50       12.00
   Lower Granite Dam      130.00          0       0.00            0.50       12.00
```

```
                             mod        mod       pred        pred
                            norm     weekly    density     density         gas
                           sigma        amp    forebay    tailrace       theta

      Bonneville Dam       11.00       0.00    5254.42    15168.22       10.00
    Bonneville Dam 2        0.00       0.00       0.00        0.00        0.00
      The Dalles Dam        4.10       0.00     841.76     5027.37       10.00
        John Day Dam       17.00       0.00     680.80    16330.77        0.00
          McNary Dam        3.00       0.00     191.40    15890.40        0.00
      Ice Harbor Dam        2.75       0.00     121.79     9066.32        0.00
Lower Monumental Dam        2.40       0.00     733.84     1380.13        0.00
    Little Goose Dam        5.40       0.00     676.51    16980.67        0.00
   Lower Granite Dam        3.00       0.00     628.31    27864.52        0.00
```

```
                                        tdg        tdg         tdg         tdg
                               k        day        day         day         day
                         entrain       type      parm1       parm2       parm3

      Bonneville Dam        0.00         29       5.61        0.12        0.00
    Bonneville Dam 2        0.00          0       0.00        0.00        0.00
      The Dalles Dam        0.00         30      24.30       -9.00       -0.01
        John Day Dam        0.00         30      28.40      -24.40       -0.02
          McNary Dam        0.00         29      14.90        0.05        0.00
      Ice Harbor Dam        0.06         30      20.90      -20.50       -0.02
Lower Monumental Dam        0.00         30      31.20      -36.09       -0.06
    Little Goose Dam        0.62         29       0.50        0.53        0.00
```

```
    Lower Granite Dam       0.01         30      38.00     -35.80      -0.01

                            pred       pred
                            mean       mean       pred        gas
                             v15        v16       dist      theta

              Estuary    1880.40    1880.40       1.00       0.08
  Bonneville Tailrace    6164.60    6164.60       1.00       0.08
      Bonneville Pool    2139.70    2139.70       1.00       0.08
      The Dalles Pool    1523.40    1523.40       1.00       0.08
 Deschutes Confluence    1523.40    1523.40       1.00       0.08
        John Day Pool     324.70     324.70       1.00       0.08
          McNary Pool     615.00     615.00       1.00       0.08
      Ice Harbor Pool     423.80     423.80       1.00       0.08
Lower Monumental Pool     998.90     998.90       1.00       0.08
    Little Goose Pool     557.90     557.90       1.00       0.08
   Lower Granite Pool    1246.60    1246.60       1.00       0.08

                             gas
                           dissp       fork
                             exp  threshold
               global       0.20       0.10

Species:
                                                      reach      reach
                                                       pred       pred
                                                       coef       coef
                           gmort      gmort      gmort        v15        v15
                            Mlow      Mhigh       crit       mean        low

            Chinook 1       0.00       0.01      10.90      12.70       0.00
                           reach      reach      reach      reach
                            pred       pred       pred       pred
                            coef       coef       coef       coef       time
                             v15        v16        v16        v16       coef
                            high       mean        low       high        v16

            Chinook 1       0.00      50.00       0.00       0.00       1.00

                                     forebay    forebay    forebay   tailrace
                        distance       pred       pred       pred       pred
                            coef       coef       coef       coef       coef
                             v16       mean        low       high       mean

            Chinook 1       1.00      18.00       0.00       0.00       0.00

                        tailrace   tailrace
                            pred       pred
                            coef       coef      FDens      FDens
                             low       high      DMode       DBot

            Chinook 1       0.00       0.00      12.00      36.00

Stock:
                                        migr       migr       migr
                                         var        var        var
                               v       coef       coef       coef   PredTemp
                             var       mean        low       high       type

Snake River Wild Ch0      100.00       1.00       1.00       1.00         37


                        PredTemp   PredTemp   PredTemp    MigrEqn    MigrEqn
                           parm1      parm2      parm3       type      parm1

Snake River Wild Ch0        1.00       0.21       0.00         24       1.20

                         MigrEqn    MigrEqn    MigrEqn    MigrEqn    MigrEqn
                           parm2      parm3      parm4      parm5      parm6

Snake River Wild Ch0       17.00       0.50       0.20     110.00       0.10
```