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A Systems Approach to Understanding and Managing Risk

Erich R.v.O. Wolf, Todd Walsh

Summary: This paper defines a systems approach to managing the uncertainty inherent in decisions (e.g., when is it profitable to upgrade turbines?). The approach looks at problems and solutions in a systems perspective by incorporating system inputs, outputs, and parameter relationships. Within the systems approach there are two types of uncertainty management:

- Identifying, evaluating and mitigating risks/uncertainties associated with incomplete knowledge of the system (e.g., hydraulic flows in reservoir)
- Identifying, evaluating, and mitigating risks/uncertainties associated with impacts of system changes (e.g.,. implementing new technology)

This paper highlights one tool in an uncertainty management approach: system dynamics modeling. A system dynamics model can be used to examine acute (specific event) and chronic (general system conditions) impacts to clarify what uncertianties exist and determine how the potential deviations could impact the system, as well assisting in developing likely mitigation strategies. A case study[1] outlining the creation and use of a dam/reservoir operations system model is provided to illustrate the process, highlight challenges, and demonstrate results.

Keywords: System Dynamics, Risk, Opportunity, Modeling, Uncertainty, Uncertianty Management, Risk Mitigation.

1 About Us

Sapere Consulting, Inc. is a management-consulting firm that focuses on providing risk management, strategic and project planning, decision analysis, and technical facilitation services to clients across the United States. Collectively, we have over 35 years of uncertainty management experience assisting clients to identify, assess, and mitigate cost and schedule risks to their projects. I have been an employee of Sapere Consulting for 1.5 years and earned my BA from Whitman College in Economics.

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[1] The case study is a generic example derived from a real application.

1.1 Our Approach to Uncertainty Management

Our approach to uncertainty management is based on the understanding that risk is derived from uncertainty in system conditions. We think about uncertainties, particularly in projects governed by regulation such as hydropower projects, in technical, regulatory, and programmatic categories. We apply our risk methodology to understand which assumptions are sufficiently uncertain such that they impair the ability to achieve system objectives and/or result in significant cost or schedule risk to completing the project as envisioned.

When we approach a project we implement our approach by defining:

1. System objectives
    - Technical, Cost, and Schedule Objectives
2. System structure
    - Components - e.g., passage routes
    - Relationships - e.g., increasing turbine survival increases fish survival
    - Influence Diagrams
3. System baseline (differentiating between assumption and fact)
    - Estimated values and bounds for ranges to include actual values.
4. Uncertainties (both risks and opportunities)
    - Incomplete Knowledge – e.g., Turbine survival rates, spill efficiencies, Bypass FPE.
    - System Changes – e.g., Spill adjustment method, operational changes.
5. Expected Condition for each uncertainty
6. Realistic Potential Deviations of each uncertainty
7. Likelihood that deviations will occur
8. Deviation impacts on system objectives

2 Case Study

2.1 Project Background

Our client has entered into a long-term agreement with resource agencies designed to protect andromonous fish populations. The agreement commits our client to achieving specific performance based objectives while allowing them the flexibility to optimize operations. Specifically the overall objective of the agreement is to mitigate for juveinle and adult fish mortality A major component of this mitigation is demonstrating that juvenile survival across the project achieves a prescribed standard through multiple years of survival studies. If the standard is not demonstrated then operational changes and additional actions are required to ensure that subsequent of survival studies will demonstrate standard attainment. Mortality occurs as a result of passage through three routes; turbines, spillway, and a specialized fish bypass system; turbines have the lowest survival rate and the fish bypass system has the highest. The relationships of all routes are described in the influence diagram (Figure 1).

Historically spill has been the only method to providing an alternative to turbine passage in an attempt to reduce the impact to juvenile migrants and has been a negotiated number. Under our clients new agreement, spill will be set based on calculations using bypass performance for the duration of survival studies. After the studies are complete, spill will be based on measured fish survival.

Spill levels determined by survival studies conducted will be influenced by the calculated spill level. The parameters of the formula are: 1) Historic non-turbine passage; 2) actual bypass performance ; and 3) Spill efficiency (the % of fish through the spillway divided by the percent of water spilled. The data source for spill efficiency is not defined in the agreement; it could be historical, measured from 2003 FPE study, or average of the previous two).

Based on this information we had several questions:

1. What does this calculation mean? What are the possible outcomes and is the calculation the best way to adjust spill for the survival studies?
2. After the Bypass FPE study is complete what are the impacts of data selection within the range of measured values?
3. After the survival studies are complete what is the best way to operate based on actual survival data?

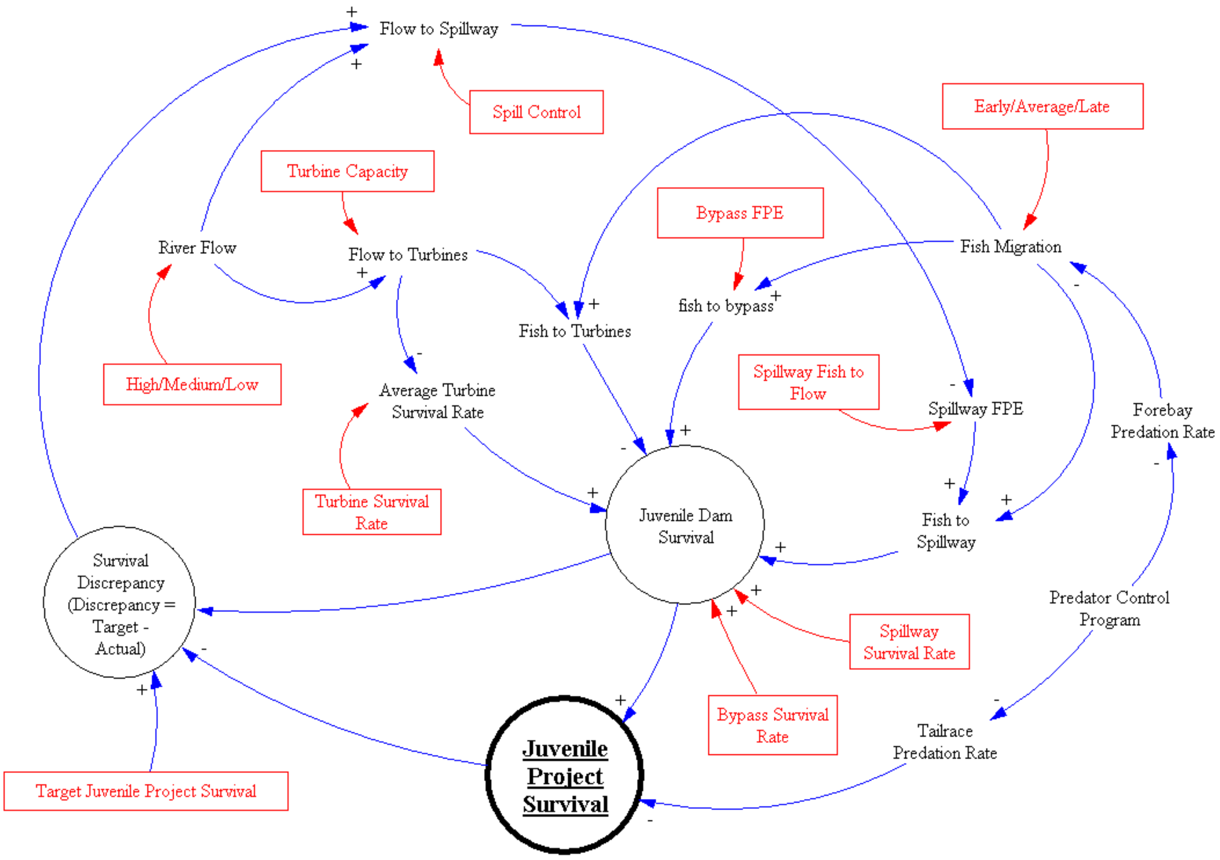

Figure 2: Influence Diagram[2]

These questions helped identify uncertainties pertaining to the calculation and study outcomes. One example uncertainty is provided in the uncertainty matrix (Table 1). The full uncertainty matrix provides a list of all uncertainties and defines the expected condition, potential deviation, impacts of deviations, and likelihood of deviation for each uncertainty. Management approaches, further analyses, and useful updates are proposed.

Uncertainty about the adjusted spill level for survival studies is driven by a lack of knowledge, specifically knowledge about bypass performance. The uncertainty regarding bypass performance can be managed both before and after the actual values are known and the management of these uncertainties impacts the decision to peruse an alternate spill adjustment method.

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[2] Rectangles and plain text are parameters while the circles are calculated values. The significance of shapes/colors will be discussed with the model.

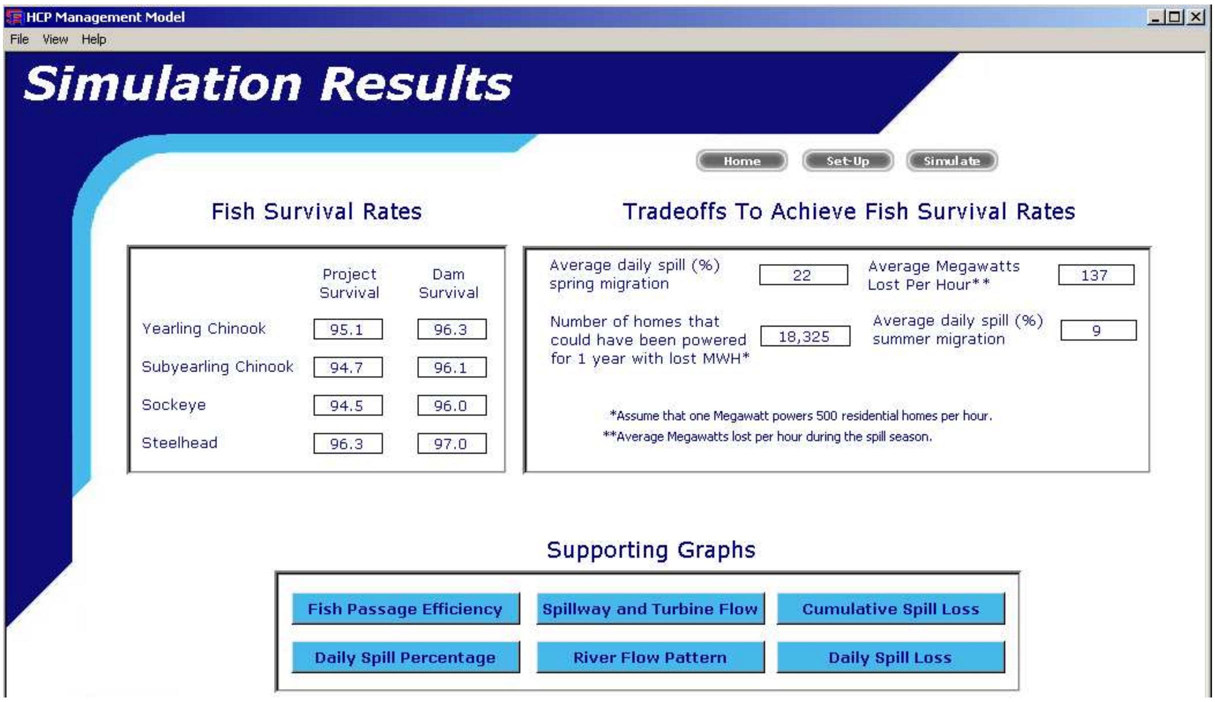
Table 1 Uncertianty Matrix

Uncertainty	Adjusted spill level for survival studies based on calculation.				
Expected Condition	Potential Deviation	Likelihood	Cost Impact	Schedule Impact	Notes
15%	>25%	Low	+ 20%	None	The permanent bypass is predicted to perform better than the prototype, however, assuming that the bypass performs 5% worse that the prototype the calculation requires 26.4% spill.
	<10%	Moderate	- 10%	None	The permanent bypass is predicted to perform better than the prototype; assuming that the bypass performs 10% worse that the prototype the calculation requires 7.5% spill.
Management Approach	Maximize bypass performance by evaluating bypass operations against design expectations. Test bypass before conducting the full bypass performance study. See bypass system uncertainty analysis and Management Model findings for more detailed information.				

2.2 Management Model

The Management Model is a system dynamics model that defines the relationships within a simulation tool, which is representative of a specific system and its objectives. The influence diagram defined earlier is the basis of the fish passage/survival portion of the Management Model. The red rectangles are user inputs, plain texts are system parameters set within the model or modified during a simulation, and the circles are calculated values. Juvenile survival is the main output along with average lost megawatts as shown in the model output example (Figure 2).

The purpose of the Management Model is to provide an effective but simple to use tool for analyzing habitat management decisions for hydro generation projects on yearly spill loss and fish survival. The model is indexed according to fish species to account for these species' characteristics when passing through the hydro projects. The Management Model has proven very reliable in providing representations of differences in the cost of spill and fish survival using different operational, route specific survival, and fish passage parameters. This comparison and analysis supports ongoing contingency and technology development planning for our Client.



Simulation Results

Fish Survival Rates

	Project Survival	Dam Survival
Yearling Chinook	95.1	96.3
Subyearling Chinook	94.7	96.1
Sockeye	94.5	96.0
Steelhead	96.3	97.0

Tradeoffs To Achieve Fish Survival Rates

Average daily spill (%) spring migration: 22

Average Megawatts Lost Per Hour**: 137

Number of homes that could have been powered for 1 year with lost MWH*: 18,325

Average daily spill (%) summer migration: 9

*Assume that one Megawatt powers 500 residential homes per hour.

**Average Megawatts lost per hour during the spill season.

Supporting Graphs

Figure 3: Model Output Example

2.3 Pre FPE Study – Actual Bypass Performance Unknown

One of the uses of the Management Model is to analyze the impact of the previously described equation on spill levels and therefore lost opportunity cost. The agreement allows for other methods of spill level calculation if agreed to by the parties. Based on model analysis the calculation produces a conservative spill level and as our client wants to minimize their spill they needed to decide if an alternate method would be preferable and what new calculation would be optimal. The model was used in this decision by allowing a comparison of the different spill levels, and therefore costs, of remaining with the existing calculation or proposing a new calculation method closer to optimal performance. The model can calculate the optimal spill for a given scenario so that for each possible outcome (varying bypass performance and turbine survival rates) we can calculate the required spill level from the calculation and compare it to the optimal spill under the same conditions. The results of this analysis are provided in the graph below (Figure 3). These results were weighed against other influences (political – impact to future spill adjustment decisions, and increased risk of not demonstrating the juvenile survival standard) and the decision was made to stay with the existing calculation and negotiate for a favorable spill efficiency data source (i.e., not rely on only the most recent point estimate).

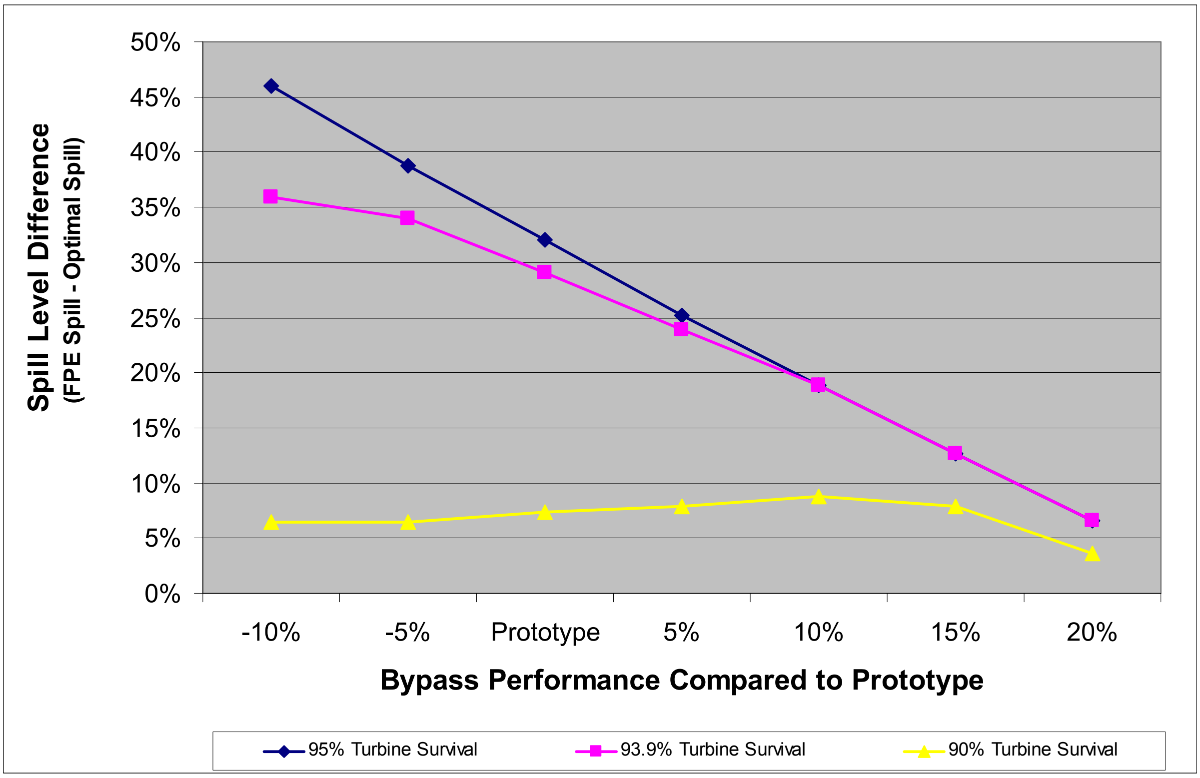


Figure 4: Calculation Spill vs. Optimal Spill Across Bypass Performance and Turbine Survival Rates

2.4 Post FPE Study – Actual 2003 Bypass Performance Known

Once the decision was made to work within the FPE calculation our clients needed to decide which set of data to use for spill efficiency. The range in spill efficiency values can have an impact of $0 to $15,000,000 a year depending on bypass performance. To evaluate which set of data was the best to use we looked at the measured bypass performance and determined the relative difference between the sets and calculated the expected survival rate for each resulting spill level.

This analysis allowed our clients to quantify the impacts of their turbine survival assumptions and showed them the cost benefits of accepting specific risks.

Table 2 Annual Costs and Expected JPS for Spill Efficiency Scenarios

Spill Efficiency Scenario	Spill Level	Expected JPS for Spill Efficiency Scenario			
		Yearling Chinook	Steelhead	Sockeye	Sub-yearling Chinook
Historical	16%	95.4%	96.4%	94.6%	94.8%
Measured (2003 FPE Study)	39%	96.6%	97.6%	95.5%	95.7%
Average (Historical and Measured)	13%	95.1%	96.3%	94.5%	94.7%

2.5 After Survival Studies

After the survival studies are complete spill levels will be based on actual survival data. Our client will have the flexibility to optimize their spill so that they are consistently at the survival standard. The Management Model will be used to experiment with different spill levels and create a spill scenario that minimizes costs and maintains achievement of the survival standard.

3 Summary

Uncertainty management is an essential part of managing any complex system such as a hydropower dam. The case study we have presented is an example of how this approach was implemented to address a specific uncertainty, however it can be applied to uncertainties in many different kinds of systems. We have successfully used this approach in many different applications ranging from planning hazardous waste cleanup to analyzing bio-diesel use in generator farms, to developing business plans. The tools that were described in the case study are essential to uncertainty management because they allow our clients to quickly understand the significance of the uncertainties they face and the impacts of their decisions on system objectives.

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