HydroBasin:
Relicensing Planning for Hydroelectric Watersheds

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Problem: We need a basin-wide planning and multiple-objectives optimization tool to manage the risks inherent in relicensing a complex network of hydroelectric facilities and to increase the probability of a successful outcome. The goal is to find the best-suited and most cost-effective locations for enhancing environmental and recreation benefits of the watershed while containing costs, reducing the risk of generation losses, and preserving existing hydro assets. Public involvement of stakeholders is critical for successful relicensing under Federal Energy Regulatory Commission (FERC) guidelines.

Solution: *HydroBasin™*, developed by *Facet Decision Systems* for EPRI and Southern California Edison (SCE), is a watershed planning tool that integrates models for systems operation, fisheries, recreation, and runoff prediction to create and evaluate watershed management scenarios. The model is designed for negotiation support with relicensing stakeholders. A new optimization method was developed based on "adaptive simulated annealing" but with conservation of mass within a network. HydroBasin finds the best places, according to **stakeholder values**, for fish and recreation while optimizing electricity revenue.

Features: These include integrating the "best available models" describing critical watershed systems, and treating both power and non-power benefits as part of the optimization objective function, instead of treating fish and recreation as constraints to generation. This lets us create and explore watershed management strategies so that we can find scenarios with good enhancement alternatives at locations that have high probabilities for providing environmental and public benefits over the long term. Then **trade-off analysis** shows how, for instance, revenue is impacted with increasing emphasis on fish habitat or recreation. **Stakeholder Modeling™** finds good trade-offs among the benefits to stakeholders and "expands the pie" by finding cost-effective ways to provide a given level of non-power benefits to the most stakeholders. This supports negotiation with stakeholders about the best use of limited enhancement funding.

Benefits: A **knowledge management framework** arises from the data and software integration in HydroBasin. This is anticipated to increase staff efficiency and reduce costs over lengthy relicensing projects through: better use of existing data; exploration of more scenarios; better presentation of results; continuity of process; and avoiding redundant or low-value studies. HydroBasin improves communication with stakeholders and regulators by addressing stakeholders' values. Building a team approach among stakeholders before relicensing submissions may forestall subsequent litigation. As a

planning system it provides a framework that captures much of the pertinent information in one system and supplies summaries of scenarios and trade-off analyses for FERC relicensing.

Introduction

HydroBasin™ is a watershed planning tool that integrates models for systems operation, fisheries, recreation, and runoff prediction in order to create and evaluate watershed management scenarios for watersheds with hydroelectric facilities. The overall objective of the HydroBasin tool is to find hydropower license conditions that provide good trade-offs among power generation, environmental, and recreation benefits throughout a hydro watershed. This software system supports the **strategic planning** and **public involvement** required to relicense hydroelectric projects and was designed to meet the Federal Power Act mandate for a balance of power and non-power uses of a watershed. HydroBasin was developed by *Facet Decision Systems, Inc.* of Vancouver, Canada for Southern California Edison's (SCE). Development was funded by EPRI and SCE. HydroBasin is undergoing final testing and validation using SCE's Big Creek project as a pilot while simultaneously using the tool for planning the strategic relicensing of the project. The Big Creek system, in the upper San Joachin watershed in the central Sierra Nevada mountains of California, contains six major reservoirs, numerous diversions and over 1000 MW of hydro generation.

Today's situation for hydroelectric utilities is a competitive environment for relicensing and energy sales. HydroBasin addresses the FERC relicensing process which is focused on developing an integrated watershed management plan. Such a plan involves a proactive approach to environmental issues, compliance with the National Environmental Policy Act (NEPA), Electric Consumers Protection Act (ECPA), etc., and an economic assessment of facilities and generation revenue. Public involvement of stakeholders is critical for a successful relicensing effort.

The objectives of HydroBasin are to:

- integrate "best available models" into a tool for FERC relicensing plans;
- create and explore alternative relicensing strategies;
- simultaneously maximize fish populations, recreation value, and hydro revenue;
- maximize benefit to all stakeholders;
- show trade-offs: e.g. revenue *vs.* fish, flat-water *vs.* white-water recreation;
- find low-risk, cost-effective enhancement alternatives;
- provide controlled access to all parties in a public process via the Internet; and
- support negotiation with stakeholders on how to best use limited enhancement funding.

HydroBasin is an expression of leadership by EPRI and SCE in watershed planning and cumulative impacts models. The watershed approach provides better focus for environmental mitigation, so that habitat improvements within a watershed can be placed for maximum benefit, rather than constraining these to the region of each individual relicensing project. It improves communication with stakeholders and regulators by providing a stable and consistent message that addresses stakeholders' values. It provides a communications protocol for a FERC "Alternative Process" so that basin-wide planning and multiple-objective optimization can be applied to relicensing a network of hydroelectric facilities. This approach ensures a balanced treatment of power and non-power resources, reduces the risk of generation loss, preserves existing beneficial hydro assets, and increases the probability of success for relicensing a

suite of FERC projects.

A **knowledge management framework** arises from the data and software integration in HydroBasin. This is anticipated to increase staff efficiency over lengthy relicensing projects by providing an accessible system for relicensing through: better use of data; exploration of scenarios; better presentation of results; avoiding redundant or low-value studies; and continuity of process. The overall effect is an optimal watershed management plan and reduced relicensing costs.

HydroBasin Structure

HydroBasin interacts with a model configuration and sets of flow plans. HydroBasin allows the user to define alternate configurations and flow plans for water management and compare. The goal is to come up with optimal management plans in order to most efficiently manage water resources according to the stakeholder values placed upon the physical resources or accounts affected by such plans.

A model configuration is composed of a physical network, a set of input parameters and a stakeholder model. The physical network defines how the components of the hydro project (water objects) are physically connected as shown in Figure 1.

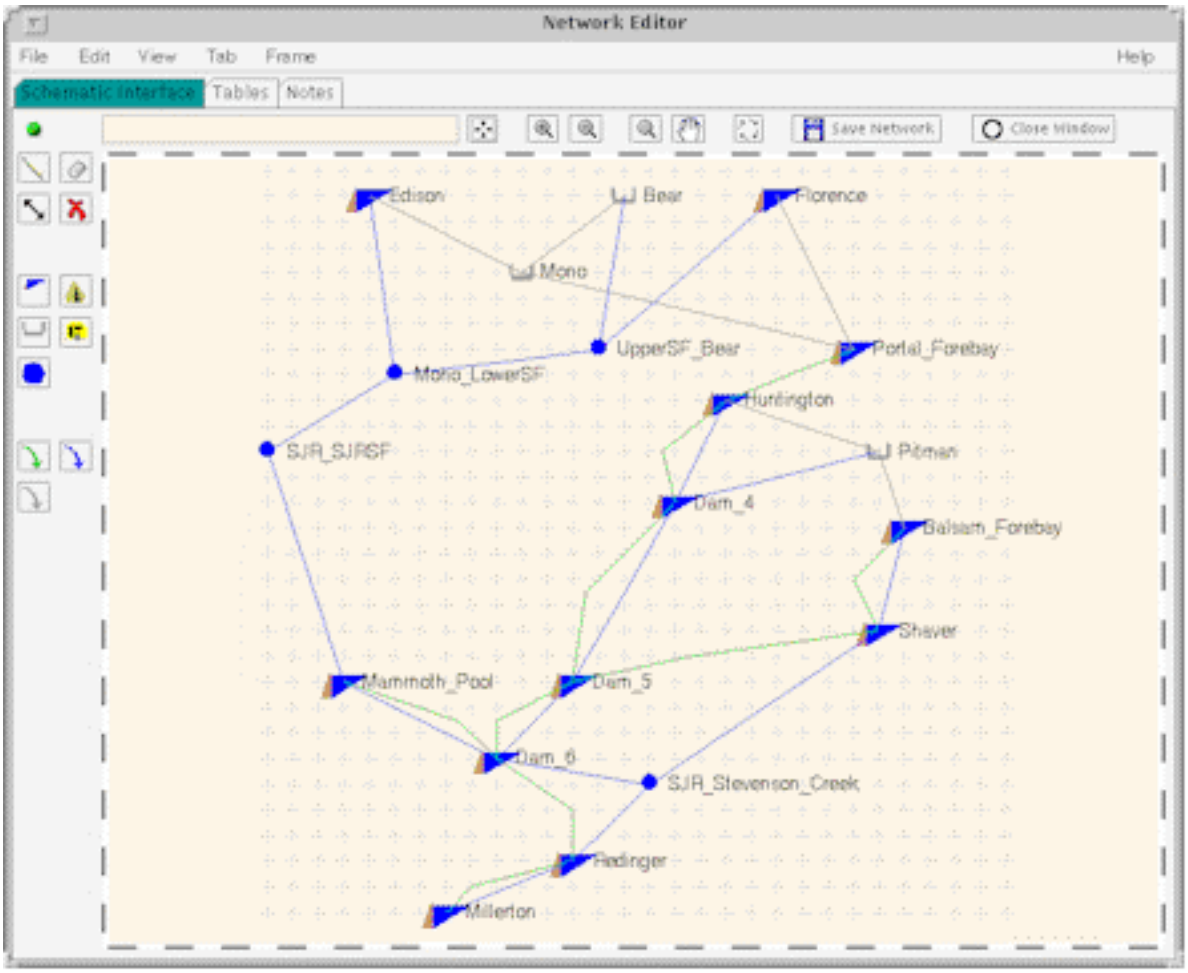

Figure 1. - Schematic representation of SCE's Big Creek project built from HydroBasin's network objects.

Input parameters (runoff, starting reservoir volumes and legal constraints) provide a water budget and impose additional restrictions on how water may flow through the network. The stakeholder model defines how flows through water objects are transformed to stakeholder values (utility). This is a two step process where accounts are used to calculate technical scores, or currencies, from flows followed by

the application of stakeholder value settings to convert the currencies to stakeholder utilities. Flow plans are evaluated based on the total utility produced under a particular model configuration.

After the physical network and the input parameters have been defined or selected, they are combined to define a 12 month, time-series network of flows. This time-series network, when combined with the stakeholder model settings, defines a model configuration. Once this configuration is complete, water plans - possible flows for each river and reservoir for each month - can be generated, analyzed and compared. By varying the model configuration - particularly the stakeholder settings - users will be able to comparatively assess the utility of alternate management plans.

A new optimization algorithm, based on "adaptive simulated annealing", but with conservation of mass and constraints on water management based on regulatory and legal contracts, was developed to optimize over indices of power generation, fish, and recreation that are in turn translated into the values of multiple stakeholders. The optimization finds the best places, according to stakeholder values, for more fish and more recreation with the least reduction in electricity revenue. A key output is a trade-off analysis that shows how, for instance, revenue is impacted with increasing emphasis on fish or white-water rafting.

The optimizer is based on a mathematical representation of the physical Big Creek system, expressed as an object-oriented network of flows and facilities, including reservoirs, powerhouses, run-offs and other inflows, diversions, confluences, and water releases for power and non-power uses. The network is the interface to an object-oriented database for defining runoff, generation efficiency (power by flow and head), min/max reservoir volume, depth/volume curves, stream lengths and elevations, recreation opportunities, preferred fish models, and network topology. The submodels for fish or recreation at each site can be selected on the basis of data availability and site-specific considerations (the kinds of fish and recreation occurring and the factors affecting them). A new type of modeling interface called **Accounts Builder**, shown in Figure 2, is used to build and manage the various decision variables (accounts) arising from flows.

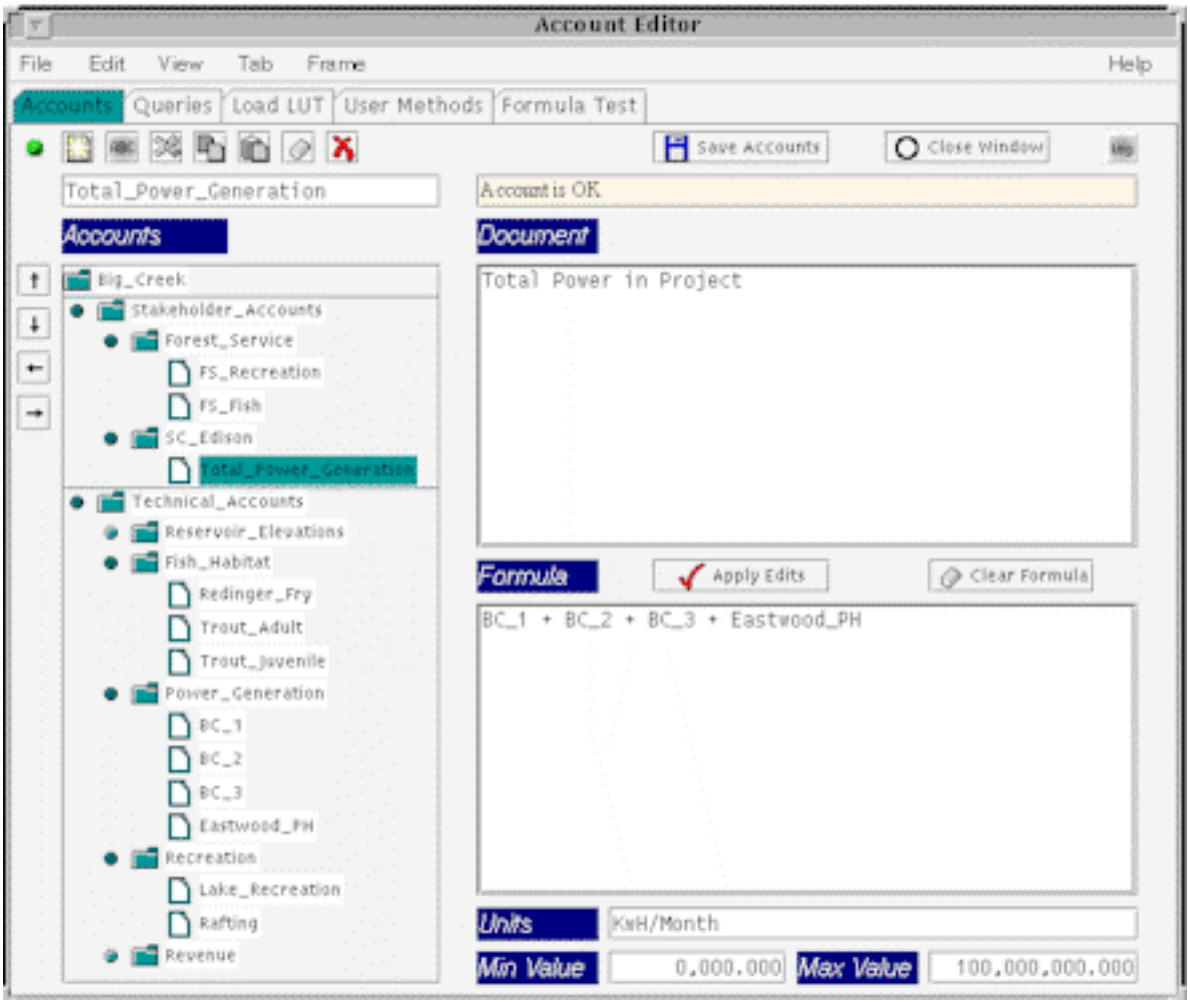

Figure 2. - HydroBasin's Account Builder is used to create both stakeholder and technical accounts. Shown here is the "Total_Power_Generation" stakeholder account for SCE that is the sum of four technical accounts that calculate power output at individual powerhouses.

The optimizer then calculates, on a monthly basis, water releases for power generation, non-power water releases to rivers and reservoir spills. The current pilot for Big Creek optimizes these releases to maximize the combination of power, fish, white-water recreation, and reservoir recreation benefits.

Stakeholder preferences form the basis for finding an optimum solution. The **Stakeholder Modeling** in HydroBasin stores, for each stakeholder, their relative interests in each technical or financial account and their reactions to different levels of those accounts by month and site (see Figure 3).

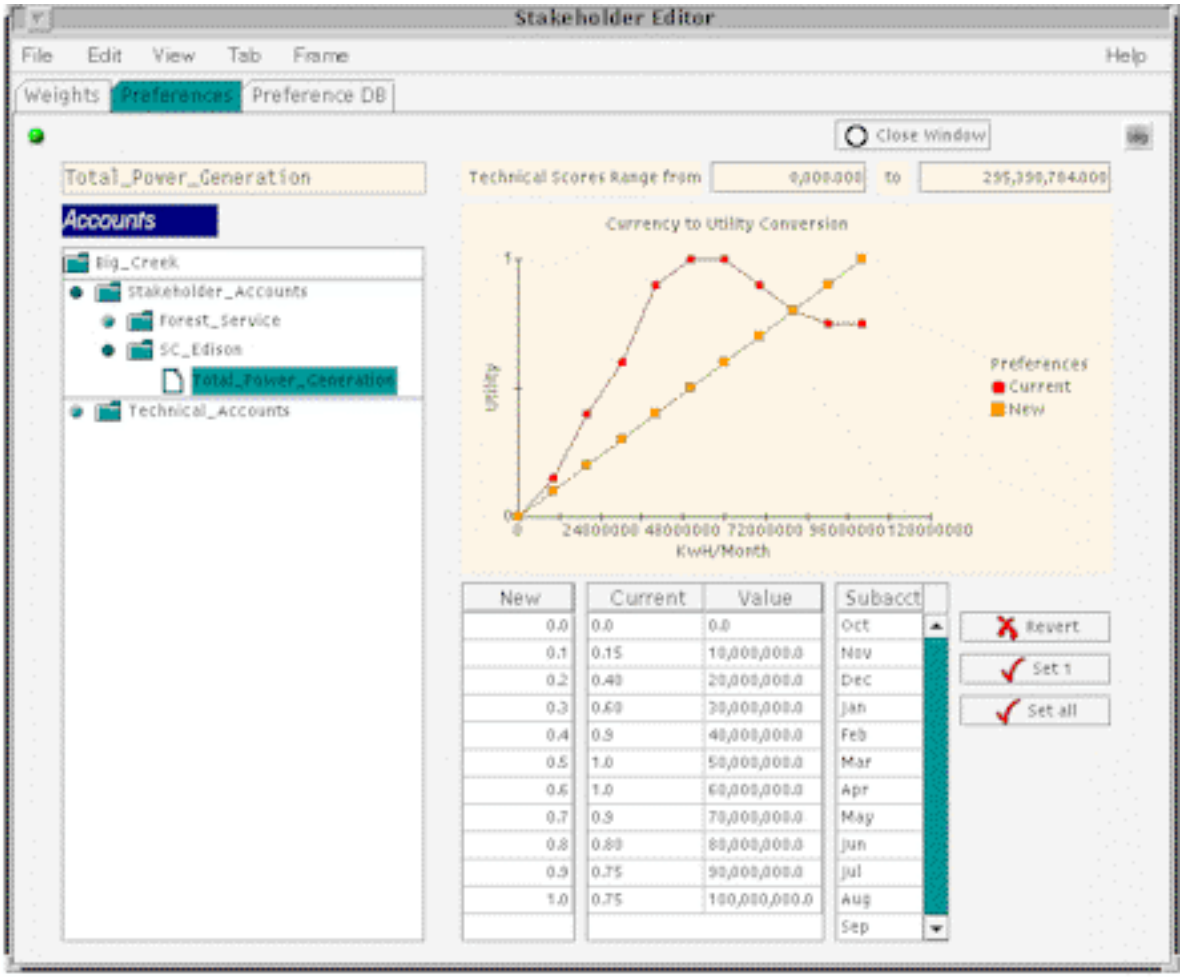

Figure 3. - The Stakeholder Model in HydroBasin translates the "currency" of a technical account into stakeholder "utility". In this example, a new relationship has been created which suggests the "utility" or value of "Total_Power_Generation" increases linearly for the stakeholder SCE.

The general idea is that each water release is converted to net value over all stakeholders. The objective function is the "utility" summed across all stakeholders, of power production, fish, white-water recreation, and reservoir recreation, over all months in a year, all powerhouses, all reservoirs, and all controlled river reaches in a watershed. The utility values are converted from raw flows through submodels for recreation impact, fish, and generation revenue so they are meaningful to resource users and decision-makers as described below.

- Monthly power generation is converted to power value using monthly power prices.
- Fish benefits are evaluated as the sum of catchable trout or trout habitat in all reaches at summer's end. There are three fish models (PHabSim, CompMech, and linear regression) available for every reach in the Big Creek implementation. "River reaches" are sub-accounts within network flows.
- White-water recreation is evaluated as the number of days with white-water releases, weighted to reflect the desirability of white water at a site by month.
- Reservoir recreation is evaluated as user-days (a function of reservoir elevation), weighted by how the value of recreation varies by month and reservoir.

This optimization is complex, with no obvious solution, due to the non-linear nature of the models, physical and legal constraints, the high dimensionality of the search space, the effects of operational history on future months, and interactions upstream and downstream. A change to one release in one month affects all downstream storages and releases in all subsequent months. Most optimization

algorithms, including linear programming, will find local maxima when presented with this problem. Our modified simulated annealing approach is less susceptible to converging on local maxima and will instead find several or many "good" solutions. The search involves conserving mass at all times, and trials are created by randomizing the schedules for descretized water releases.

The primary advantage of the simulated annealing approach is that it requires no simplification of even the most complex hydro systems. It is also very flexible, allowing changes in the hydro system (e.g., to evaluate the effects of new or altered generation units, conveyances, or reservoirs) or in the optimization objectives (e.g., adding additional environmental or recreation benefits to the analysis). The method is designed to examine all parts of the potential solution space to find a wide range of good solutions and to avoid getting trapped in local maxima.

Application

The HydroBasin approach to planning monthly flows for power, fish, and recreation has several key strengths. The primary strength of the approach is that it does a comprehensive job of finding good trade-offs among the various power and non-power benefits. HydroBasin does not just quantify the cost of increased releases for fish or recreation, but "expands the pie" by finding the least-cost way to provide a given level of non-power benefits. Relicensing planning applications may include:

- **Finding the best environmental enhancement measures.** The model can determine how the benefits and costs of environmental and recreation enhancements vary among sites and months, so the most effective sites to improve fisheries and recreation opportunities can be found.
- **Determining potential benefits of relicensing a whole watershed at once *vs.* relicensing individual plants at different times.** Many utilities have watersheds with several project licenses that expire at different times. Relicensing these projects separately may appear to be a low-risk approach, but that foregoes the benefits of finding good trade-offs across all sites in the watershed. HydroBasin can evaluate the potential savings from trade-offs across multiple project licenses.
- **Determining the potential effects on power and non-power benefits of changes in hydro operations and facilities.** The model can quickly and easily predict how power generation would change if modifications were made in plant capacities, conveyance capacities, reservoir storage, water delivery contracts, etc.
- **Planning and optimizing relicensing studies.** With HydroBasin, utilities can estimate which river reaches will have the most important trade-offs among power and fish and recreation, so that study costs can be directed toward the most important sites. The model is useful for planning cost-effective field study strategies and intensities for each site.

HydroBasin could be used as an internal relicensing planning tool, i.e., to find less expensive enhancement measures or evaluate the cost of varying levels of non-power benefits. The model could also be used with relicensing stakeholders as a decision support tool in a public involvement process. Using a model like HydroBasin in a public process, with stakeholders participating in developing and interpreting model scenarios, poses certain opportunities and risks and may be appropriate in some cases. Building a team approach among stakeholders before relicensing submissions may forestall subsequent litigation. Such applications, where stakeholders accept the concept of trade-offs between limited resources, may include:

- demonstrating the cost of enhancement proposals;
- demonstrating that better trade-offs are available if stakeholders forego their preconceived notions

about what changes are needed; and

- determining cooperatively how a fixed dollar value of enhancement measures can be implemented to greatest benefit.

Better Trade-offs

Trade-offs among power and other benefits can be examined via repeated basin-wide optimization with varying weight given to stakeholder values. The conventional approach to hydro relicensing is to a) study and relicense one project at a time even if several projects are in the same watershed, b) determine instream flow releases reach by reach, reservoir elevation targets and other resource mitigation independently, and c) implement new license conditions as site-specific constraints to power generation. Two attributes of the HydroBasin tool allow it to find better trade-offs than the conventional approach.

1. HydroBasin looks for trade-offs among sites within a watershed that allow more non-power benefits to be provided with less impact on power production. For example, the number of fish that can be provided per kWh of reduced power production varies among hydro diversions due to differences in stream habitat, diverted reach length, and plant head and efficiency. HydroBasin looks for the best-suited sites within a watershed to provide non-power benefits.
2. HydroBasin treats both power and non-power benefits as part of the optimization objective function, instead of treating fish and recreation as constraints to generation. This formulation allows the tool to find the best overall combination of power, environmental, and recreation benefits; to find the lowest-cost ways to provide non-power benefits; and to examine trade-offs among benefits by shifting the weight given to different benefits in the objective function.

Better Communication with Stakeholders

A fundamental aspect of HydroBasin is **Stakeholder Modeling™** for negotiation support in the internal and public decisions surrounding relicensing. The goal is a value-based consensus and every effort has been made to include stakeholder values in the fundamental algorithms of HydroBasin. Stakeholders are presented with comparisons of the net value of scenarios according to their interests, to help them answer the question "what does each scenario mean to me?" The Stakeholder Model can interactively create and analyze new scenarios developed by any stakeholder for consideration by all stakeholders in a public process.

Asset Enhancement

The economic value of hydro assets are enhanced by HydroBasin through several opportunities:

Opportunity	**Asset Enhancement**
strategic relicensing framework	rationalize mitigation investments, increase efficiency and cut relicensing costs
FERC "Alternative Process" master plan	enables cumulative effects analysis to protect a network of facilities, provides communications protocol platform

stakeholder communications	remove uncertainty, build alliances that help to avoid litigation, and streamline the consensus-based decision process
enlarge the pie	more opportunities for partnerships while protecting core revenue production
evaluate system upgrade and hydro acquisition opportunities	"what if" analysis by changing network component properties, transportable model for in-depth system assessments
maximize energy revenue	rigorous optimization may uncover new water release strategies

Summary

HydroBasin is a powerful tool for use in strategic planning for relicensing hydroelectric facilities, especially in watersheds with multiple hydro facilities and complex interactions among facility operations, environmental protection and recreation opportunities. HydroBasin is uniquely capable in its ability to find optimal watershed management plans using a multiple objective optimization algorithm driven by stakeholder values. Analyses of such plans can uncover cost-effective mitigation trade-off opportunities throughout the watershed. The tool can also provide a common workspace for reaching consensus among diverse stakeholders about "best use" watershed management plans during relicensing negotiations.

Harm Woldring, Facet Decision Systems, gave permission to use this case study at DSSResources.COM on Thursday, October 26, 2001. For more information, check http://www.facet.com/. Posted November 18, 2001. For further information, please contact Dr. James R. Young, Sr. Research Scientist, Environmental Affairs, Southern California Edison, 2244 Walnut Grove Ave., Rosemead, CA 91770, Phone: 626-302-9191, Fax: 626-302-9730, Email: youngjr@sce.com; or Scott Akenhead, Facet Decision Systems, Inc. 305 - 1505 West 2nd Avenue, Vancouver BC, V6H 3Y4, Phone: 604-606-8063, Fax: 604-739-7753, Email: scott@facet.com.

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