Procedural Guideline for Evaluating Alternative Fish Protection Technologies to Meet Section 316(b) Requirements of the Clean Water Act

Technical Report

Procedural Guideline for Evaluating Alternative Fish Protection Technologies to Meet Section 316(b) Requirements of the Clean Water Act

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REPORT SUMMARY

As part of an effort to develop implementation rules for Section 316(b) of the Clean Water Act (CWA), EPRI commissioned this effort. The goal is to create a technically and biologically defensible screening process for evaluating and identifying alternative fish protection technologies that merit more rigorous evaluation.

Background
Section 316(b) of CWA, 33 U.S.C. §1326(b) requires that the location, design, construction, and capacity of a “cooling water intake structure” (CWIS) reflect the “best technology available” (BTA) for minimizing adverse environmental impacts (AEI). Adverse environmental impacts from CWIS's may occur as the result of entrainment of small aquatic organisms into the cooling water system via the CWIS and the impingement of larger life stages on traveling water screens. In 1976, the United States Environmental Protection Agency (EPA) issued §316(b) regulations requiring site-specific §316(b) determinations. Those regulations were suspended on procedural grounds in 1977. Since then, EPA has used only general draft guidelines to implement §316(b). In 1995, however, EPA undertook a rulemaking to develop §316(b) implementation rules. As input to that rulemaking process, ERPI commissioned this effort.

Objective
To develop an efficient, consistent, and technically and biologically defensible screening process for evaluating alternative fish protection technologies currently available and for identifying those worthy of more rigorous evaluation as part of the BTA selection process.

Approach
The authors outline a process for evaluating cooling water intake structure technologies in a consistent manner. The process is suitable for application to both new and existing facilities. While this approach has been developed specifically with reference to power plants, other types of facilities could apply it with equal ease.

Results
The overall technology evaluation process involves three basic tasks:

- Compile and review available baseline data and information
- Screen alternatives based purely on their general technical feasibility and potential for biological effectiveness
- Evaluate CWIS technologies that remain alternatives after screening

These procedural guidelines describe the three tasks in detail. This report assumes that, like EPA's previous rules, §316(b) implementation would proceed on a site–specific basis.

EPRI Perspective

It is not the intent of this report to address the issue of what constitutes AEI or to make any judgment, whether stated or implied, on the potential for a given technology to minimize the potential for AEI. Technology information provided in this report is for the sole purpose of directing users to sources of historical data that might assist in the preliminary CWIS technology evaluation process. The underlying assumption in using the process described in this report is that AEI, or a meaningful risk of AEI, has been identified and that an evaluation of technologies that may be capable of minimizing AEI is required.

Keywords

Fish protection
316(b)
Cooling water intake structures
Intake Screens
Circulating water systems
NPDES permit

CONTENTS

1

INTRODUCTION

Section 316(b) of the Clean Water Act (CWA), 33 U.S.C. §1326(b) requires that the location, design, construction, and capacity of a "cooling water intake structure" (CWIS) reflect the "best technology available" (BTA) for minimizing adverse environmental impacts (AEI). Adverse environmental impacts from CWISs may occur as the result of entrainment of small aquatic organisms into the cooling water system via the CWIS and the impingement of larger life stages on traveling water screens. Extensive research has been conducted since the early 1970's to develop technologies that will minimize AEI caused by entrainment and impingement. In cases where a proposed or existing CWIS is causing or is reasonably anticipated to cause AEI, a variety of cooling water intake structure technologies now exist that can be considered in the evaluation of BTA alternatives. The Electric Power Research Institute (EPRI) published a comprehensive review of the status of these technologies in 1999 (EPRI 1999).

Although the United States Environmental Protection Agency (EPA), in 1976, issued §316(b) regulations requiring site-specific §316(b) determinations, those regulations were suspended on procedural grounds in 1977. Since then, EPA has used only general draft guidelines to implement §316(b). In 1995, however, EPA undertook a rulemaking to develop §316(b) implementation rules. As input to that rulemaking process, ERPI commissioned this effort to develop an efficient, consistent, and technically and biologically defensible screening process for evaluating the wide range of alternative fish protection technologies currently available and identify those worthy of more rigorous evaluation as part of the BTA selection process. This report assumes that, like EPA's previous rules, §316(b) implementation would proceed on a site–specific basis.

In addition to cooling water intake structure technologies, permitters have in some cases explored use of a variety of cooling water flow reduction measures as means of reducing the potential for AEI. Such measures include variable speed circulating water pumps to permit seasonal flow reductions, seasonal plant outages, cooling towers (various types), and cooling canals and lakes. While these measures sometimes have been evaluated along with CWIS technologies, they do not fall into the category of "CWIS technologies" and therefore, are not, considered in this report.

This report outlines a process for conducting an evaluation of cooling water intake structure technologies in a consistent manner. The process is suitable for application to both new and existing facilities. While it has been developed specifically with reference to power plants, it could be applied with equal ease to other types of facilities.

The overall technology evaluation process involves three basic tasks:

- Compilation and review of available baseline data and information;

- Screening of alternatives based purely on their general technical feasibility and potential for biological effectiveness; and
- Detailed evaluation of technologies that remain alternatives after screening

In the first step of the screening process, the evaluator uses available information to narrow down the list of options from a suite of possible technologies to a smaller number of options that, based on initial analysis, could be practicable to install and operate and that have the potential to reduce losses of the types of aquatic organisms that contribute to the actual or reasonably anticipated "AEI" that has been identified.

The second step in the technology evaluation process is to perform a detailed, site-specific analysis to identify important engineering, biological and cost factors associated with each alternative identified in the preliminary evaluation. In this step, all pertinent information is assembled to provide a basis for making informed decisions on which alternative (or alternatives) best satisfies BTA requirements.

Throughout this report, it is suggested that the user present certain information in a "technology evaluation report." It is recognized that, in a site-specific §316(b) implementation framework, such a "report" often would be a section or chapter of a larger §316(b) Demonstration document that is prepared during the NPDES permitting process. However, many times in the past technology evaluations have been conducted outside of the formal permitting process. In either case, it is important that all information needed by review agencies to make informed decisions be centrally compiled, be it a section of a larger document or an independent report.

It is not the intent of this report to address the issue of what constitutes AEI or to make any judgment, whether stated or implied, on the potential for a given technology to minimize the potential for AEI. Technology information provided in this report is for the sole purpose of directing the user to sources of historical data that might assist in the CWIS technology evaluation process. The underlying assumption in using the process presented in this report is that AEI or a meaningful risk of AEI, has been identified and that an evaluation of technologies that may be capable of minimizing AEI is required.

2
REVIEW OF AVAILABLE INFORMATION

2.1 Overview

During the technology evaluation process, available information is reviewed at two different levels. During the initial evaluation stage, basic engineering, operational (facility and technology) and environmental information are developed to a level that permits a screening of available alternatives that leads to the selection of a smaller number of potentially effective alternatives for more detailed assessment. In the detailed stage, available information is reviewed in greater depth, with a focus on site-specific factors that might influence the potential effectiveness or practicability of each selected alternative.

Specific information necessary to conduct an assessment of intake technologies includes: the regulatory history of the facility; specific facility layout; design features and environmental factors that may affect evaluation of CWIS technologies; and aquatic organisms (species and life stage) that occur near the intake. All of this information must be thoroughly reviewed and presented in the process of identifying alternative CWIS technologies (or combinations of technologies) that might be considered for application at the site under review. A discussion of the types of information needed is presented below.

2.2 Regulatory History

The regulatory history of a specific facility is important when evaluating alternative technologies. For a new plant, there may be little in the way of regulatory history. For existing plants, there may be extensive history tied to the NPDES permitting process. Licensing history to be reviewed includes previous §316(b) evaluations and determinations, subsequent actions taken (if any), and the result of these actions. Where studies or research and development (R&D) efforts have been performed at the plant under review to evaluate the efficacy of specific fish protection measures, the results of these studies are important when evaluating alternatives and they should be detailed in the §316(b) technology evaluation report.

2.3 Pertinent Station Design and Operational Parameters

While a cooling water intake structure is only a discrete component of the larger cooling system, it is a very important component, and it must be consistent with, and adapted to, the needs of the cooling system. By the same token, the cooling system must be designed and operated consistent with the needs of the other key components of the system, such as the steam turbine. Thus, critical to any evaluation of alternative CWIS technologies is a review and understanding of overall facility design and operational parameters. For a new plant, these parameters can remain somewhat flexible in the design phase until a BTA determination has been made. In this way, the technology can be incorporated into the original design with full consideration and awareness of the impact to project costs.

For existing plants, overall facility design and operating parameters impose constraints on the potential for effective application of a given technology. In either case, all important facility design and operational factors that might influence the engineering practicability and biological effectiveness of a specific CWIS technology at the site under review (as outlined below) must be identified and presented during the technology evaluation process.

2.3.1 Station Design and Operation

A basic understanding of general design and operational features is necessary to identify constraints that may affect application of alternative technologies at a specific facility. Facility information that should be reviewed includes:

- Location of the station;
- Facility size in MW;
- Type of operation (base loaded or peaking);
- Type of intake (shoreline, offshore, canal, etc.);
- Cooling water source (water body type);
- Cooling water type (once-through, closed-cycle, etc.);
- Cooling systems served (circulating water, service water, cooling tower make-up water, etc.); and
- Pump inlet configuration and sizes (bellmouths, elbows, inlet expansions)

Specific features of the existing or proposed CWIS are also important when evaluating alternative intake technologies. Available drawings and plant descriptions should be reviewed to identify the following CWIS features:

- Location on shoreline or position in waterbody for offshore intakes;
- Configuration (ice/debris curtains, trash racks, isolation stop logs and gates, traveling water screens, circulating water pumps, service water pumps, deicing features, and the like);
- Number and width of intake bays;
- Invert elevations;
- Construction materials (e.g., concrete, steel sheet pile);
- Design water levels;
- Size and location of guides;
- Ice/debris curtain and skimmer wall bottom elevations, construction materials and removability;

- Trash rack bar sizing, clear spacing, and materials (steel, fiberglass, plastic);
- Traveling water screen basket size (width and height), number of baskets, and mesh size, clear opening, and materials (e.g., carbon steel, stainless steel, coating and paint);
- Mode of screen operation (continuous or intermittent);
- Design approach velocity;
- Design head loss;
- Traveling water screen backwash system configuration and pressures;
- Traveling water screen debris removal trough layout and discharge location;
- Traveling water screen fish handling capacity, if any, spraywash configuration and pressure, fish trough layout and discharge location.

A description of the CWIS design features and figures showing the basic dimensions of the structures and important elevations should be included in the alternative technology evaluation report. As mentioned previously, for new intakes, these features can remain somewhat flexible in the design phase until a final BTA determination has been made. For existing plants, these features define the structural framework around which a technology must be backfitted. As such, they represent more of a constraint on the potential for practicable and/or effective application of a given technology.

In addition to the physical features of the actual or proposed CWIS, it also is important to consider (1) the effect of any given alternative under evaluation on velocity and flow patterns at the site, and (2) the effect of any targeted velocity on the capacity or operation of the facility as a whole. Velocities and flow patterns at existing CWISs may be negatively impacted by the installation of a technology. Technologies that cause substantial added head loss can cause power penalties and jeopardize reliable circulating water pump operation. Further, the velocity through and/or around a technology influences the structural loading for which support structures must be sized. At existing intakes, available support structures may not be capable of withstanding additional forces resulting from the installation of a technology. Therefore, it is important to identify existing or proposed velocities within the location being considered for possible installation of a technology. Minimum, normal and maximum velocities should be calculated for locations upstream of ice/debris barriers and trash racks; at the inlet of an offshore intake; approaching traveling water screens or other types of screens; and through the screen openings.

2.3.2 Waterbody Features

Environmental and hydrologic factors that influence the engineering practicability of installing and operating fish protection technologies should be assessed to identify conditions that may preclude the use of a technology. If specific information on these factors is not available to determine whether a given alternative technology is appropriate for a facility, field studies may be required to complete the evaluation. Environmental and hydrologic factors of importance include:

- Water level variations (tides and storm events);

- Variations in flow direction and magnitude during tide or hydrologic changes;
- River or shoreline currents and flow patterns near the intake;
- Sediment conditions (suspended and bed load);
- Debris loading;
- Icing conditions (frazil, sheet, and pack ice).

An understanding of these conditions is necessary in the evaluation of alternative technologies.

Water level variations must be identified to complete conceptual designs of alternative intakes. Storm events, drought conditions, and tidal changes will affect design water levels, which must be selected to assure acceptable operation of the intake over the range of expected conditions. Low water levels dictate bottom elevations for structures necessary to provide appropriate velocities approaching screens and adequate pump submergence. Low water levels also determine submergence requirements over structures for navigation. High water levels set operating deck elevations for the intake structure.

Changes in flow patterns at intakes are important in developing alternative intake designs. The magnitude and direction of flow affects the amount of debris and sediment in a water body and the type of habitat available for fish. Tide changes will affect the occurrence of some species at the intake location. Tide changes are also important in locating fish return systems for technologies that divert fish into a bypass or collection system (fish should be returned to a location that will minimize the potential for recirculation). Hydrologic variations impact design forces during flood events. At existing facilities, flow patterns and velocities may be negatively affected by the installation of a technology. Technologies that cause substantial head loss can cause power penalties and jeopardize reliable circulating water pump operation. Further, the velocity through and around a technology influences the structural loading for which support structures must be sized.

River or shoreline currents and flow patterns are also important for evaluating approach flow conditions at an intake. Flow approach conditions determine the extent of guide walls, turning vanes, and channel lengths necessary to provide acceptable hydraulic conditions at a fish protection device.

Sediment conditions at a site, both suspended matter and bed load, affect design of intake structures and fish protection components. High sediment bed loadings can require bottom sills on intake entrance structures and sediment traps incorporated into the intake design. Suspended sediments will affect the material selection for screens, pumps, and other components in cooling water systems.

The amount of debris at the intake location will determine the extent of debris handling features necessary for alternative intakes. Heavy debris loading will require a trash rack with a mechanical rake to allow frequent cleaning. Heavy debris loading will also require frequent screen cleaning and may require continuous screen rotation. A site with small debris will require trash racks with closer spaced bars and screens with a finer mesh than sites with larger debris.

Icing conditions create significant forces on intake structures that must be addressed in conceptual designs of alternatives. Frazil ice can completely block flow into intakes. Sheet and pack ice can extend to significant water depths, creating the possibility for blockage of the flow passage and large external forces on the intake structures. The intake location and design must consider the ice conditions at a site. Submerged intakes should be located in water depths greater than the pack ice depths. Intakes at sites where frazil ice is present should include features, such as plant discharge recirculation or heating systems, to prevent frazil ice accumulation.

2.3.3 Existing Fish Protection Systems

Existing plants may have evaluated or installed specific CWIS fish protection technologies pursuant to past permits. These technologies should be thoroughly described in the technology evaluation report. In some cases, fish protection technologies have been evaluated at sites on a pilot scale to study their potential for effective application at those sites. For example, at Big Bend Station in Florida, a stand-alone, pilot-scale fine mesh screen system was installed in the plant’s intake canal and evaluated for three years prior to being installed as BTA for two of the station’s units (Brueggemeyer et al. 1988). In other cases, evaluations of modified traveling screens have been performed by replacing one of a station’s conventional screens with a modified screen and evaluating its effectiveness. These pilot studies are very useful in that they provide *in situ* data on which informed decisions on potential biological effectiveness and engineering practicability can be made.

Pilot studies do not always lead to installation at a given site. If the pilot technology is found to perform poorly at that site, a decision may be made to investigate other alternatives. In any case, these studies provide a wealth of information that is useful in evaluating technologies. Therefore, if such studies have been performed in the past at the site under review, the results should be fully disclosed in the intake technology report.

2.4 Biological Data

The evaluation of alternative technologies also must make full use of all available site-specific biological data, including data developed during any prior §316(b) studies. Because the evaluation process eventually leads to estimation of potential biological effectiveness at the species/life stage level, it is critical to identify some representative subset of the aquatic species potentially affected by the CWIS, often referred to as “Representative Important Species,” and collect data on its occurrence and abundance. Typically, these species are selected on the basis of, among other things, their commercial or recreational value, their value to the food chain and their status as being rare or endangered. Development of detailed guidelines for selection of such species is beyond the scope of this report.

In the preliminary phase of the evaluation process, all technologies are assessed in terms of their past effectiveness in protecting aquatic organisms. The extent to which a given technology has been proven effective with the RIS is an important factor in the decision to carry a technology forward to the detailed evaluation phase. Therefore, the availability of information on the biological effectiveness of technologies also is an important factor in the evaluation process. Without effectiveness data, the potential biological effectiveness of a technology is difficult to assess, even qualitatively. The degree to which individual fish protection technologies have been studied varies widely. It is important, however, for the reviewer to compile all available information for use in the preliminary evaluation (as presented in the next section).

Data are available from a wide variety of journal articles, technology workshop proceedings, utility reports and other sources of gray literature. One of the most recent compilations on fish protection technologies is an EPRI report entitled "*Status Report on Fish Protection at Cooling Water Intakes*" (EPRI 1999). The information presented in this report is summarized in tabular form and the latest version is available to EPRI members at www.epri.com. The information is presented in two groups of tables that will be useful in both the preliminary and detailed evaluation phases of the technology evaluation process. The first group of tables is sorted by technology. These tables will help reviewers to quickly determine which species have been tested with each of the technologies for which information exists. The second set of tables presents similar information grouped by taxonomic family so that reviewers can search for which technologies have been used to protect specific species chosen as RIS at the site under review. Both sets of tables include scientific and common names of species, and the name of the facility at which the technology was evaluated. Additionally, the type of water body from which the facility draws water is included to assist users in weighing the relevance of individual references. Regardless of which tables are used, the reviewers are directed to pertinent references that provide data on the past biological effectiveness of fish protection technologies. Many of these references also contain information on engineering design, construction, operation and maintenance aspects of the technologies.

3
PRELIMINARY SCREENING

In the next step of the technology evaluation process, the baseline information is used to screen the alternatives to reduce the relatively large number of alternative technologies down to a smaller number deserving of more detailed evaluation. The primary questions to be addressed in this preliminary screening step are:

- Has the CWIS technology been used successfully to protect fish (albeit not necessarily the species and life stages of interest at the facility under review)?
- Is the CWIS technology practicable to install and maintain at the facility under review?

Answering these questions involves a three-part analysis, as set forth below.

3.1 Assessment of Potential Biological Effectiveness

In this part of the analysis, the factors considered are:

- Whether the technology has ever been used in any commercial application;
- Effectiveness at other sites (not necessarily for the RIS in question); and
- Potential for effectiveness at the site under review.

Determining whether the technology has ever been used is relatively straightforward, given that the EPRI resources discussed above provide a comprehensive overview of the technologies developed and applied to date. Based on that information, CWIS fish protection technologies generally fall into four categories, which may function differently depending on the life stage of the organisms involved. Following is a chart showing the four categories and the primary life stages to which they afford protection.

	Life Stages Potentially Protected			
Category	**Eggs**	**Larvae**	**Juveniles**	**Adults**
Diversion Systems	No	No	Yes	Yes
Collection Systems	Yes	Yes	Yes	Yes
Physical Barriers	Yes	Yes	Yes	Yes
Behavioral Barriers	No	No	Yes	Yes

This information may be used to categorize each technology under consideration as one of the following:

- Not previously evaluated;
- Previously evaluated, but not in full-scale application;
- Previously used, but not with RIS life stages of concern at the facility under review; or
- Previously used with one or more of the relevant life stages of RIS or comparable species.

Naturally, it would be desirable to have all technologies fall into the last category. Often, this is not the case. In the preliminary phase of the evaluation process, however, it is most important to determine that a technology has been evaluated in some manner with aquatic organisms and that it has been demonstrated to be biologically effective with at least one species. CWIS technologies for which this determination can be made merit further review. The categorizations listed above come into play when two or more technologies have been deemed to be potentially effective, but more data on the RIS (or closely-related species) exist for one technology than the others. That is, the potential effectiveness of one or more technologies is better understood than for the others, it is appropriate to focus subsequent analyses on those technologies.

3.2 Assessment of Engineering Practicability

In the second part of the preliminary screening, the reviewer considers whether or not the remaining alternatives are practicable to install and operate at the site under review. Here, the reviewer considers:

- Circumstances of previous use;
- General practicability;
- Potential for practicable use at the power plant under review; and
- Advantages over other alternatives.

Technologies may be eliminated from further consideration on a number of engineering grounds, including:

- It has not been shown to be practicable to install at other sites having similar layouts;
- It has been shown to be impracticable to install or operate in the waterbody type used by the site under review;
- There is insufficient area available for installation and operation in a manner that maximizes biological effectiveness; or
- Icing, debris, biofouling, or siltation concerns minimize the potential for maintaining it in acceptable operating condition.

The following is a brief description of some of the key factors that may affect the engineering practicability of CWIS technologies.

Topography/Bathymetry – The topography and bathymetry of the site will influence where technologies might be located and whether those locations meet engineering requirements for structural integrity, operation and maintenance. For example, if existing depth is not available to provide adequate submergence for offshore intake structures for protection from navigation (*e.g.*, velocity caps and wedge-wire screens), their use will be precluded. Water bodies with daily or seasonal fluctuations in water levels (*e.g.*, tidal oceans, estuary tides and rivers) are not conducive to the use of rotary drum screens or other technologies that require a relatively constant submergence level. If an existing CWIS is located within a dock line or near a shipping channel, there may not be sufficient area available to install technologies such as barrier net systems or the Gunderboom (EPRI 1999).

Flow Patterns – Flow patterns approaching and entering a CWIS can be important in determining the practicability of a technology. Daily and seasonal changes in the magnitude and direction of flow can influence practicability in a number of ways. In tidal areas, it may not be possible to locate fish return system discharges at a sufficient distance from the CWIS to prevent recirculation of organisms. Technologies that require adequate ambient cross-flow to carry debris and organisms to safety, such as cylindrical wedge-wire screens, will not be practicable in locations where such currents do not exist. Local flow patterns also determine the movement patterns of the plant’s thermal discharge. Where recirculation of the discharge is a concern (due to loss of plant efficiency or attraction of fish), technologies may be precluded from use if recirculation is unavoidable.

Sediment/Debris – High loadings of sediment and/or silt can preclude the use of technologies that are prone to sedimentation problems and cannot be adequately cleaned to maintain reliable operation. For example, partial blocking of intake screens with silt skews flow patterns resulting in non-uniform velocity distributions resulting in areas of high velocity. Similarly, the amount of debris present will determine whether sufficient debris handling features can be incorporated to maintain a technology in an effective operating condition. For example, during periods of heavy debris loading on traveling screens, continuous rotation may not be adequate to prevent injury to fish embedded in the debris. Ristroph-modified screens may not be capable of handling severe debris loading present at some locations; in fact, the interaction of organisms and debris might actually increase mortality. Finally, offshore intakes may not be practicable if sufficient water depth is not available within a reasonable distance from shore to prevent damage due to ice and wave action.

Biofouling – Biofouling can greatly impact the reliability of a technology. The inability to maintain a technology in a relatively non-fouled state may result in the elimination of a technology from further evaluation. For example, the use of fine-spaced (*e.g.*, 0.5 to 2 mm) wedge-wire screens may not be possible in areas where rapid and extensive colonization of fouling organisms occurs (*e.g.*, barnacles, bryozoa and zebra mussels).

Ice – In northern latitudes, icing conditions can create significant forces on structures that might preclude the use of a technology. Frazil ice can completely block flow into intakes. Sheet and pack ice can extend to significant water depths, creating the possibility for blockage of the flow passage and large external forces on the intake structures. As stated previously, offshore, submerged technologies (*e.g.*, wedge-wire screens) may not be practicable to install if the available depth a reasonable distance from shore is not sufficient to provide adequate protection from ice.

3.3 Comparative Assessment of Advantages and Disadvantages

As the final part of the preliminary screening process, the evaluator assesses the relative advantages and disadvantages of the alternatives remaining after biological and engineering analysis. The purpose of this assessment is to ensure that only the “best” technologies, in terms of biological performance and engineering feasibility, carry forward into the detailed evaluation. For example, three behavioral barriers may have been identified that effectively repel juvenile fish from intakes. One technology, however, has been shown to be highly effective with the RIS at the site under review, while the other technologies have been evaluated mostly with other species. In addition, this technology is simpler to install and maintain that the other two. Therefore, the technology has clear advantages over the others, resulting in its selection for detailed evaluation.

Similarly, certain behavioral barriers require that fish visually perceive the behavioral stimulus. At sites where turbidity is very high, these barriers will be at a disadvantage to barriers that are not influenced by water clarity, even if both types of barriers have been shown to be effective with the RIS under other water quality conditions at other sites.

As for physical barriers, there are a variety of traveling and fixed screens that may have been shown to be biologically effective. However, if the site under review has heavy debris loading, traveling screens will be required. Further, those screen designs with maximum debris-handling capabilities have an engineering advantage over other designs. Conversely, at a site where debris loading is light, a stationary screen might have the advantage of being simpler in design and operation, with less extensive maintenance required.

Other types of physical barriers, such as barrier nets and cylindrical wedge-wire screens, have been proven to be biologically effective with a variety of species. At sites with high ambient current velocities, wedge-wire screens might have an advantage over the other barriers. Maintaining nets in place can be difficult in high velocity areas. Conversely, wedge-wire screens require a relatively high-velocity cross-flow to be biologically effective and to maximize debris removal, giving these screens a relative advantage at these types of sites.

Many more examples are possible. However, these examples should suffice to demonstrate the way in which the biological and engineering advantages and disadvantages of the technologies are identified and weighed against each other as part of the process of selecting those technologies that offer the best potential for being effective and practicable at the site under review.

4

DETAILED EVALUATION OF CWIS ALTERNATIVES

The detailed evaluation process involves a site-specific analysis to identify important biological, engineering, and cost factors associated with each alternative identified as a result of the preliminary screening and comparative assessment described above. The detailed evaluation process includes three parts:

- Consideration of design, construction, and operating and maintenance (O&M) features for each alternative, which is used to estimate the costs of each alternative;
- A determination regarding biological effectiveness, which is used as part of the analysis of the net benefits of applying a given alternative versus the base case (that is, the proposed CWIS); and
- Development of cost estimates.

Most of the same kinds of questions addressed very generally during the preliminary screening process also will come into play in the detailed analysis, but the level of evaluation will be far more detailed, and costs will now be included. While the analysis will rely on available site-specific information whenever possible, it also may be necessary in some cases (particularly for new facilities) to collect additional data.

4.1 Site-Specific Design, Construction, and O&M Analysis

The first part of the detailed evaluation process involves: (1) the development of site-specific design, construction and, operating criteria, and (2) preparation of conceptual layouts (plans and sections) used to evaluate each alternative to determine whether it will satisfy those criteria. For proposed facilities, it may be possible to adjust some of the design criteria to accommodate CWIS alternatives. The costs and other implications of such adjustments would be taken into account in subsequent steps in the BTA selection process. For existing facilities, knowledgeable plant operating personnel should be involved in this part of the process to identify, obtain, and or verify site-characteristics that may affect intake operations.

4.1.1 Design and Operating Analysis

A description of the intake design features and figures showing the basic dimensions of the structures should be included in the alternative technology evaluation report for each concept considered for detailed evaluation. These features can remain somewhat flexible in the conceptual design phase until a preferred technology or other measure for minimizing the potential for AEI has been identified and received regulatory agency approval. For existing plants, these features define the structural framework around which a technology must be retrofitted. As such, existing features represent a constraint on the potential for practicable and/or effective application of a given technology or measure.

Existing plants may have installed fish protection technologies or applied other measures to minimize the potential for AEI. These technologies should be thoroughly described in the technology evaluation report. Some modifications that increase fish protection can cause design and operational problems. While curtain walls on existing intakes are designed to prevent large floating debris, warm water, and/or ice from entering the intake, such walls can also create non-uniform flow distributions that cause areas of high velocity through the screen. Removing curtain walls may create more uniform velocities and result in improved handling of fish on a modified screen located downstream. However, removal may lead to increased debris loading or higher temperature that could negatively affect plant operations and performance.

The conceptual design should identify all equipment necessary to allow an alternative intake technology to be effective at a site, including components for debris removal and handling, screen cleaning, and fish return.

Velocities and flow patterns at existing CWISs may be influenced by the installation of a technology. The velocity through or around a technology influences the structural loading for which support structures must be sized. Therefore, it is important to identify existing or proposed velocities within the location being considered for possible installation of a technology. For existing sites, velocity measurements should be presented, if available. If such information is not available, minimum, normal and maximum velocities should be calculated for the following locations (as appropriate for each intake alternative): approaching the intake (*e.g.*, upstream of ice/debris barriers and trash racks; at the inlet of an offshore intake); under ice/debris barriers and curtain walls; approaching trash racks; through trash rack bars; through stop log and gate openings; and approaching traveling water screens or other types of screens. Maximum, normal, and minimum velocities at these locations should be identified over the range of plant flows and water levels at the various flow areas in the intake structure. Velocity information should be presented in summary tables in the technology evaluation report.

4.1.2 Construction Analysis

Appropriate construction techniques for the various intake alternatives must be reflected in the evaluation process. For many intakes, the civil works required for installation of the technology can be more extensive than construction of the intake structure. Some alternatives, such as a shoreline intake with flush-mounted traveling water screen intakes, have to be constructed “in the dry” using earth or sheetpile cofferdams. Other alternatives, such as submerged velocity caps or cylindrical wedge-wire screens, can be installed “in the wet” using barge-mounted cranes and divers.

Subsurface conditions are an important factor affecting the construction methods to be used for installation of an alternative technology at a site. The types of material below grade and on river bottoms generally determine excavation and shoring methods required for installation of foundations for the structures. The subsurface materials also dictate the method for anchoring structures to prevent sliding, overturning, and flotation. For example, minimizing excavation in hard rock results in more cost-effective structure due the high cost for rock removal. Similarly, soft, clay foundation materials can require deep support piles to stabilize the structure. Therefore, where appropriate, subsurface conditions must be considered in selecting the location for installation of a fish protection technology.

Access for construction equipment is another factor that should be included in the evaluation of alternative intakes. Shoreline areas near power plants may be heavily developed with other industry or may not have available access roads. For offshore intakes (and some onshore intakes), access to the construction site will typically be provided through the use of barge-mounted cranes and other equipment.

The construction season available for installing intakes is another important factor in the evaluation of alternatives. In cold weather regions, contractors may have to demobilize at the end of a short construction season and mobilize several times to complete construction over several seasons. Work on the water may be limited by weather conditions. Short construction seasons may require more expensive winter construction techniques to be employed. Obviously, more complex structures with more extensive cofferdams will typically have longer construction durations, possibly over several periods, than a simple intake modification that does not require a significant amount of civil works.

Plant outages required to complete installation of an intake alternative at an existing plant are an important consideration in the evaluation of alternatives. Construction methods and sequencing should be identified in the conceptual design to minimize the impacts on plant operations during construction. Double shifts and overtime should be used to reduce the downtime for operating units.

4.1.3 O&M Analysis

Operation and maintenance (O&M) requirements of various types of intakes are important factors in evaluating alternative designs. Operating parameters include: (1) the electric power (kWh) necessary to operate specific equipment (such as trash rakes, traveling water screens, or screen wash pumps), and (2) the manpower (hours) needed to inspect and operate the equipment in an acceptable condition for effective fish protection. Maintenance parameters that have to be considered include manpower (hours, such as the time and material required to grease rotating elements on a continuously operating traveling screen) and components (spare parts) that are needed on-hand for the performance of routine equipment maintenance.

Technologies are sometimes located remotely from the existing CWIS (*e.g.*, to withdraw water from less biologically productive areas or to provide adequate submergence). The effective open area of the inlet openings and the pipes that are required to convey flow from a new, remote intake to the plant can impact system head losses and water levels at the pumps. System components must be sized to minimize head losses and to maintain adequate suction head on the pumps. At existing plants, lower water levels in the pump bay resulting from an alternative technology could reduce pressures in the cooling water system, thereby reducing plant capacity. Therefore, all alternative intakes must provide at least the minimum water level at the pumps that would be acceptable for plant operations. Lost power costs, if any, should be included in the estimated cost of the alternative.

Clogging by debris, sediment, and ice can reduce flow through an intake structure, increase head losses in the system, and increase hydrostatic forces on the intake. If clogging is serious, a structure can become plugged and unable to convey an adequate amount of water to the plant. Therefore, clogging potential is an important consideration in the evaluation of any intake alternative.

Finally, O&M considerations must be addressed in terms of the impacts of routine activities associated with a technology on plant operations. Most maintenance activities can be accomplished with the plant operating normally or can be performed during scheduled plant outages. However, some technologies may require portions of the intake to be shutdown on a more frequent basis, such as inspection of an underwater, light/air bubble curtain (a fish barrier system) by divers in high velocity zones. The technology evaluation report should clearly identify the impacts of O&M activities on plant operations and capacity.

4.2 Biological Effectiveness Analysis

The next step in the detailed evaluation process is to develop estimates of the potential biological effectiveness of each alternative CWIS technology selected for review. These estimates are used to determine the net benefits of each technology versus the base case. The base case represents the number of organisms lost as a result of entrainment and impingement. For new sources, the base case will be represented by estimates of potential entrainment and impingement mortality predicted from baseline biological field collections in the plant vicinity. For existing plants, the base case will generally reflect actual entrainment and impingement sampling results at the CWIS (or other appropriate location).

The process of developing effectiveness estimates takes place at the species/life stage level. Therefore, it is important to have data on the occurrence and abundance of all species and life stages of concern. As noted above, this evaluation typically focuses on selected “Representative Indicator Species” or RIS.

On the basis of baseline or historic data, the occurrence and abundance of each life stage of the individual RIS can be identified. The estimation of potential biological effectiveness of each CWIS alternative can then be performed at the species/life stage level. Such estimates are derived from available data from other sites of CWIS application or other evaluations (*e.g.*, laboratory and pilot-scale studies). Measures of biological effectiveness vary by technology and intended mode of operation. Generally, these measures can be identified as follows:

Category	Life Stages Potentially Protected	Measure of Effectiveness
Diversion Technologies	Juveniles, adults	Diversion efficiency and latent survival (test vs. control)
Collection Systems	Eggs, larvae, juveniles, adults	Immediate and latent mortality
Physical Barriers	Eggs, larvae, juveniles, adults	Reduction in entrainment and/or impingement
Behavioral Barriers	Juveniles, adults	Reduction in impingement

Ideally, data will be available for each alternative under consideration at a given site and for each RIS life stage. However, this often is not the case. More often, data are available for some RIS and technologies, and lacking for others. Therefore, the process of estimating potential biological effectiveness of a given technology involves the use of available data in two ways:

- Direct application for those RIS life stages for which effectiveness data exist; and
- Extrapolation of the available data to other RIS life stages for which no data exist.

Direct application is relatively straightforward. For each technology, the available data are reviewed and a “best estimate” of potential effectiveness is derived. The best estimate will be one that is based on results from other sites at which effectiveness evaluations have been performed. In most cases, a range of effectiveness values is available for a given species/life stage and technology as a result of evaluations at more than one site. Therefore, it is necessary to select an estimate within the available range. When the range of values is small (*e.g.*, 10 percent), it is reasonable to select a best estimate of effectiveness based on a review of the similarity between the site under review and the sites from which data are available (water body type, design and operating specifications of the technology, debris loading, etc.). Within a small range, the degree of uncertainty surrounding the estimate will also be relatively small.

When the range of reported effectiveness is large (*e.g.*, 50 percent or greater), the accuracy of the estimate selected will be less certain. For example, literature values for mortality of juvenile Alosa spp. collected from Ristroph-modified screens can range from 20 to 100 percent. Again, the process of selecting a best estimate involves a review of all data and the identification of those data that are most representative of the site under review. However, with the larger range of reported values, the uncertainty surrounding the estimate will be greater. In this case, the evaluator must assess the available data and use best professional judgment to develop a best estimate of potential effectiveness.

The degree of uncertainty around an estimated effectiveness value is even greater in cases where there are no data available for one or more of the RIS life stages under consideration. Several approaches can be taken in such cases. For technologies that involve handling or other possible sources of physical contact that might injure or kill fish (*e.g.,* collection screens, bypasses, and pumps), one approach is to evaluate effectiveness data (*e.g.,* survival) for closely-related species, genera or families with similar physiological characteristics.

A second approach is to group species and life stages into categories reflecting their relative “hardiness.” Effectiveness values based on survival of similar species or other species and life stages in the same “hardiness” category for which data do exist can then be assigned. It has been well documented that species such as shad, herrings and bay anchovy (all of which are abundant species in impingement samples in different water bodies) are relatively “fragile.” That is, they lose their mucous coating and scales and bruise easily, making them more susceptible to immediate mortality and latent stress and mortality resulting from primary and secondary infections and loss of osmoregulatory capability. Injured and stressed fish are also more susceptible to predation by birds, mammals and other fish species. On the other hand, species such as flat fishes (*e.g.*, flounders and hogchokers) are not as easily stressed, and are considered to be relatively “hearty.” Intermediate to these extremes are fish that appear to be “moderately hearty”, such as striped bass, shiners, and weakfish. Generally, sufficient information is available on the relative hardiness of most fish species that species for which technology effectiveness data are not available can be broadly grouped into one of these three categories. They can then be assigned a best estimate based on professional judgment.

Another approach to developing technology effectiveness estimates for species and life stages for which data do not exist is to examine their morphology (size and shape), physiology and relative swimming capabilities for comparison to other species with similar characteristics for which data do exist. The earliest life stages, eggs and early larvae, have little or no motility. Therefore, they will interact passively with fish protection technologies. If the technology is designed to protect these life stages passively, then they will be relatively effective given that all other design and operational requirements of the technology needed for biological effectiveness have been met.

Older larvae begin to develop swimming capabilities that vary by species. The size and swimming capability of developing larvae will determine whether larvae of a given species will interact passively or actively with a given CWIS technology. Examination of morphology and swimming capabilities can thus be used in a comparative manner to extrapolate data from past studies of technologies to species that have not been previously studied. The technology itself also interacts with larval size and swimming capability to influence the potential for biological effectiveness. For example, both traveling fine mesh screens and cylindrical wedge-wire screens act as a physical barrier to fish. While later larvae will actively swim in front of a fine mesh screen located within a screenwell structure, the usual outcome of the interaction with this technology is impingement. The same larvae interacting with a submerged, cylindrical wedge-wire screen can avoid impingement for the short period needed for it to pass around the screen to safety.

As a worst case, the evaluation may determine that there are insufficient data of any kind to develop a best estimate of potential biological effectiveness of a technology. New technologies or technologies that are considered to be experimental due to limited evaluations to date could fall into this category. In such cases, it is likely that some type of laboratory or pilot-scale field study will be needed to obtain the data necessary to predict effectiveness. Such studies have been common in the past and have advanced the state-of-the-art in fish protection.

Whichever method is used to derive estimates of potential biological effectiveness, the sources of information should be cited and the methodology clearly explained in the technology report. The information should be summarized to document previous use and biological effectiveness and generally present the engineering design and operational and environmental factors that have influenced past results. The type of information that should be presented includes:

- Location of previous use;
- Water body type;
- Plant size (number of units, size and capacity);
- Cooling system type and flow rate;
- Intake type (*e.g.*, shoreline, canal, offshore);
- Design parameters (*e.g.*, mesh size or slot opening, mesh type, flow velocity);
- Operational parameters (*e.g.*, frequency of use or operation, screen rotation speed);
- Pertinent water characteristics (*e.g.*, temperature, salinity, turbidity);
- Debris, siltation and biofouling characteristics;
- Biological effectiveness by (*e.g.*, percent diversion, percent survival, percent reduction in numbers of fish impinged); and
- Pertinent references.

Extensive literature is available to assist evaluators in assessing the potential biological effectiveness of fish protection technologies for application at CWISs. One of the more recent, comprehensive reviews was prepared by the Electric Power Research Institute (EPRI 1999). Other important reviews, books, conference proceedings, and reports providing substantial information on fish protection technologies are presented in the List of References.

4.3 Cost Analysis

The next step in the process is to develop order-of-magnitude project costs for the candidate alternatives. Order-of-magnitude cost estimates are based on conceptual level designs of project components necessary for installation and operation of a CWIS technology. The costs are based on historical data taken from other projects and are adjusted for identifiable differences between the cost database and construction of an alternative at a specific site. The following list provides the cost items and cost bases that should be included in the evaluation process:

4.3.1 Design Phase

Costs for labor and related expenses for engineering services to prepare drawings, specifications, and design documents. These costs are typically identified as “indirect costs” in an estimate and are taken as a percentage (*e.g.*, 10 percent) of the “direct costs” (defined below) for each alternative.

4.3.2 Construction Phase

1. Direct costs for material and labor required for construction of all project features;
2. Distributable costs for site non-manual supervision, temporary facilities, equipment rental, and support services incurred by contractors during construction. These costs typically range between 50 and 100 percent of the labor portion of the direct costs for each alternative;
3. Distributable costs may be included in the unit rates for the direct costs or may be identified as a separate line item;
4. Owner costs for administration of project contracts and for engineering and construction management. These costs are typically taken as a percentage of the direct costs for each alternative and could be as high as 10 percent of the direct costs depending on the complexity of the alternative.
5. Allowance for indeterminates to cover uncertainties in design and construction at this conceptual level of technology development; an allowance for indeterminates is a judgment factor, which is added to allow for unknowns in the data used in developing the estimates. The allowance for indeterminates is typically taken as a percentage (*e.g.*, 10 percent) of the combined direct, distributable, indirect, and company costs of each alternative technology; and
6. Contingency factor to account for possible additional costs, which might develop but cannot be predetermined (*e.g.*, labor difficulties, delivery delays, weather). The contingency factor is typically taken as a percentage (*e.g.*, 15 percent) of the combined direct, distributable, indirect, owner, and allowance for indeterminate costs of each concept.

4.3.3 Operation and Maintenance

Costs for normal operation and routine maintenance of the structures and equipment associated with an alternative intake have to be considered in developing a valid comparison of different technologies. Operating costs, including labor and power, should be identified for all components. Maintenance costs should reflect labor and materials needed to keep the structures and equipment operating to meet the intended design functions.

Manpower requirements that should be identified for evaluating alternative intakes include the following typical activities:

1. Inspecting, operating, and maintaining a technology;
2. Inspecting and maintaining mechanical equipment associated with a technology;
3. Underwater inspection of critical components required to maintain technology functionality and biological effectiveness; and
4. Routine maintenance and replacement of components at the end of their useful service life (*e.g.*, strobe lights, sound generators, screens, pumps, etc.).

In addition, the material and equipment replacement costs for these activities, and the power (kWh) required to operate the equipment should be included in the evaluation. The power required to operate alternative technologies will vary widely between technologies and will be influenced by site-specific factors.

4.3.4 Construction Impacts on Plant Operations

Construction of CWIS technologies at an existing site typically requires the existing CWIS to be taken out of operation for at least a short period of time resulting in lost generation. The duration of the outage depends on the technology being installed and the existing plant design and operating mode. Construction schedules for alternative intake technologies should be carefully developed to permit sequencing of activities in a manner that minimizes impacts on plant operations. Scheduled plant outages should be factored into the installation schedules to the maximum extent possible. The selected sequencing of activities should be described in the technology evaluation report in sufficient detail to support construction costs estimates.

All “project costs” cannot be necessarily quantified during the conceptual develop of intake alternatives. The technology evaluation report should clearly identify specific activities that have not been quantified in the evaluation. The following items are difficult to estimate based on conceptual designs, but should be included in a later detailed design cost estimate to obtain a true total capital cost estimate:

1. Costs to perform additional field studies that may be required, including effectiveness studies, hydroacoustic surveys, net sampling, soil sampling, and wetlands delineation prior to installation of an alternative technology;

2. Costs to dispose of any hazardous materials that may be encountered during excavation and dredging activities;

3. Permitting costs; and

4. Costs to evaluate the effectiveness of an intake technology after installation.

4.4 Estimate of Benefits

Once the potential biological effectiveness of each alternative technology has been identified, these estimates can be used to derive the benefits. The first step in this process is to determine the metrics by which losses will be expressed. Common metrics include equivalent adults (numbers or pounds) lost, biomass lost and production foregone. For example, for the commercially valuable striped bass, the losses associated with a technology can be determined by converting the numbers of each life stage lost into an equivalent number of recruits lost (using a model such as the Equivalent Adult model or other acceptable techniques). For forage species, losses can be converted into pounds of commercially or recreationally important fish. Whatever method is used, the overall goal is to convert numbers of organisms entrained and impinged in the base case and with each alternative under consideration into a number or weight on which a dollar value can be placed. Once a value has been assigned, a benefit-cost analysis can be performed which will ultimately serve as the basis for making BTA determinations. The technology report should present the base case losses relative to the estimated losses with each technology.

It should be noted that the benefits for a given alternative and species cannot be assumed to be positive. Some technologies may cause higher mortality of certain life stages than are occurring in the base case. For example, entrainable life stages that can travel through a cooling water system from screens to discharge with high survival may experience higher handling mortality if they are collected on a fine mesh screen. Therefore, in determining BTA, the evaluator may have to weigh the relative importance or value assigned to each species and/or life stage to identify the alternative technology that produces the highest, overall benefits.

4.5 Estimate of Other Environmental Effects

For each alternative technology evaluated, other environmental effects that might result from implementation should be identified during the detailed evaluation process. The types of effects that should be analyzed includes:

- Increased air emissions from other power plants required to increase generation to offset power losses resulting from installation of a technology;
- Increased entrainment and/or impingement at other power plants operating at increased capacity to offset power losses resulting from installation of a technology;
- Increases in the plant delta-T resulting in increased discharge temperatures and potential thermal impacts;
- Loss of habitat with footprint of technology;
- Impacts of excavation and dredging associated with construction; and
- Disposal of dredge spoil and possible contamination of the spoil material requiring handling as a hazardous waste.

While these potential impacts should be identified and stated in the technology report, it is not necessary to quantify the degree or costs of the impacts at this level of evaluation. However, other environmental impacts associated with alternative technologies should be fully quantified at the detailed engineering design stage.

5

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Section 316 (a) and (b) Fish Protection Issues

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