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The Visual Aesthetic Impact of Alternative Closed Cycle Cooling Systems

Executive Summary

Prepared by J. W. Currie

Battelle-Pacific Northwest Laboratory

Prepared for
U. S. Nuclear Regulatory
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Prepared by
J. W. Currie

Battelle-Pacific Northwest Laboratory
Richland, WA 99352

Prepared for
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ABSTRACT

The primary objective was to produce, for the Nuclear Regulatory Commission, a validated methodology that can provide timely predictions, using secondary data, of the visual aesthetic impact of alternative closed-cycle cooling systems. This was accomplished by first collecting data at six U.S. sites on individuals' willingness to pay (WTP) and accept compensation (WTA) for visible cooling tower and plume changes on nuclear power plant landscapes. These data were then combined with individuals' socio-demographic characteristics to estimate and validate an econometric model for explaining and predicting visual aesthetic impact.

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INTRODUCTION

The research described in this document was performed by the Pacific Northwest Laboratory (PNL) for the U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research. It was undertaken in compliance with the National Environmental Policy Act of 1969 (NEPA) to assist NRC in making decisions during the nuclear power plant siting process. The major objective of this research was to produce a validated methodology for providing timely predictions, using secondary data, of the visual aesthetic impact on people viewing alternative closed-cycle cooling systems on nuclear power plant landscapes.

BACKGROUND

In choosing cooling systems for large (1000 MWe) thermal power plants, utilities have historically favored open-cycle (once-through) cooling because it has been the least-cost method available. However, environmental regulations have all but precluded the viability of the once-through cooling option. Consequently, utilities have turned to closed-cycle cooling systems; specifically, natural draft and mechanical draft evaporative tower systems.

Although either type of system may have a cost advantage at any given site, the current trend is toward installing natural draft towers because these systems offer greater reliability (no fans), require less land area, and provide more efficient plume movement and dispersal than do mechanical draft towers. Natural draft towers have their disadvantages, however. Their immense height (over 500 feet) make them more highly visible in contrast to the low-profile (60 to 80 feet tall) mechanical draft towers.

The difference in visibility between the two tower types has become an important issue in siting nuclear power plants. During environmental impact statement (EIS) hearings, local citizens and environmental groups have expressed concern over the potential negative impacts from viewing large natural draft towers and their associated plumes. The NRC must pass judgment on the validity of these concerns as well as on the testimony provided by the utility applying for a plant construction permit. In making these judgments, the Commission must be in a position to produce reliable and valid impact estimates in a timely and cost-effective manner. This is mandated by NEPA, Section 102, which states that systematic, interdisciplinary research is required to develop methods and procedures for appropriately considering unquantified environmental amenities and values. These are the circumstances that led to this research project.

OUTLINE OF RESEARCH STEPS

Within the context of the background just presented, the following specific questions were posed, forming the objectives of this research project.

- What is meant by visual aesthetic impact? Is it definable?
- If so, can visual aesthetic impact be measured in terms that can be compared with other costs and benefits of nuclear power plants?
- How important is visual aesthetic impact?
- Can a valid scientific methodology be developed for predicting visual aesthetic impact using available secondary data?

The research outline in Figure 1 delineates the tasks required to achieve the objectives. The first task was to define visual aesthetic impact (VAI). The definition was to be comprehensive while allowing for quantitative measurement. The second task was to formulate a VAI prediction methodology. The methodology was formulated with two constraints. First, empirical estimation of the methodology would require a minimal data collection effort. Second, prediction with the method would be possible using available secondary data. The third task was to design the experiment. Data were collected in

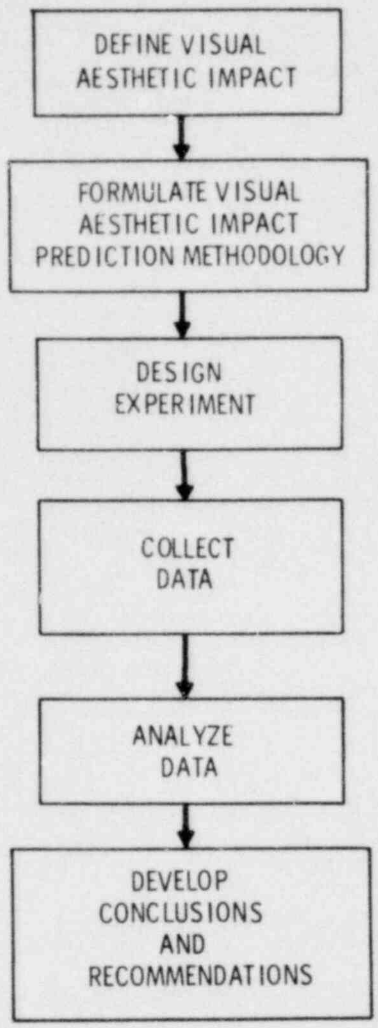

FIGURE 1. Research Outline

Task 4. The data were then analyzed in Task 5 to empirically estimate a valid prediction methodology and determine the importance of VAI. Finally, conclusions and recommendations were to be derived in Task 6.

METHODOLOGY

Tasks 1 and 2 are discussed in this section. First, visual aesthetic impact is defined. Next, the method of its measurement is discussed. Third, the prediction methodology formulation is described.

VISUAL AESTHETIC IMPACT DEFINITION

Three different visual aesthetic impact measures were identified. As shown in Figure 2, the first measure relies on "expert" judgment; the second and third rely on "public" judgment.

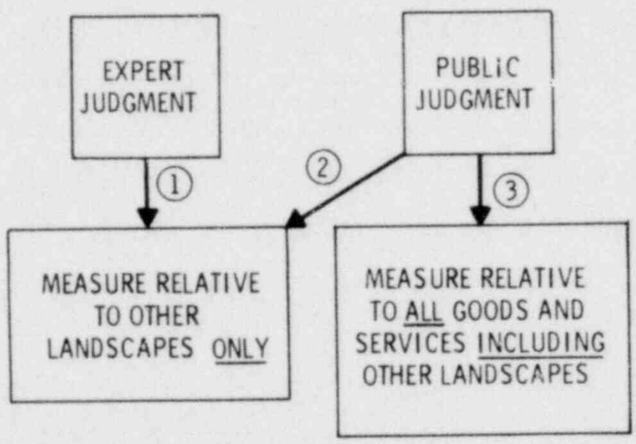

FIGURE 2. Visual Aesthetic Impact Measures

The expert judgment measure was rejected as inappropriate for meeting the project objectives. The use of expert valuations for interpreting and judging visual aesthetics is scientifically indefensible because the judgments are inherently subjective. Further, public input is required during the EIS process.

Evaluation of public input requires a measure based on public judgment. In using the second VAI measure, which does rely on public judgment, individuals typically examine landscape photographs and either rank or score the visual aesthetics of the landscape on a relative value scale. Visual aesthetic impact is then measured by comparing the visual aesthetic score assigned to a landscape before and after a visible landscape change. The difference between the two scores is a measure of the VAI from introducing the visible landscape change. Unfortunately, this method measures the value of visible change only among landscapes. That is, this method produces a measure of value that cannot be directly compared to any of the other benefits and costs of nuclear power. Thus, the second measure by itself is not sufficiently comprehensive to fulfill either the NEPA requirements or the project objectives.

The third measure of VAI uses public judgment and can be directly related to all goods and services, including the aesthetics of other landscapes. This measure is the maximum amount individuals would be willing to pay (WTP) or the minimum amount they would be willing to accept (WTA) in compensation for visible aesthetic changes on nuclear power plant landscapes. Measure 3 was defined as VAI for this project because it more closely satisfied the NEPA and project objective requirements than did Measure 2.

VISUAL AESTHETIC IMPACT MEASUREMENT

Visual aesthetic impact could be measured by analyzing data from either observed (actual) behavior or individual statements of intentions to behave. Everything being equal, data on actual behavior should be more reliable than data on intentions to behave. However, using observed behavior data to measure VAI introduces the major problem of empirically determining that portion of the behavior attributable to visible landscape changes. For example, using the "property value approach" requires determining to what extent housing values are influenced by visible landscape changes.

Visual aesthetic impact could also be measured with statements of intentions to behave. A "bidding game" could be used, in which individuals are shown two nuclear power plant landscapes, identical except for different cooling tower/plume configurations. The individuals would be asked their WTP to avoid or acquire, or WTA to forego or incur, one landscape instead of the other.

In-depth literature reviews were conducted for both the property value and bidding game approaches. It was concluded that using property value data to measure VAI either required unrealistic assumptions or would be prohibitively expensive because of the extensive data required to overcome the assumption constraints. Although bidding games have disadvantages (people may intentionally under- or overstate their bid, the procedure is hypothetical, etc.), it was concluded that a well-conceptualized bidding game experimental design would yield more representative data at lower cost than would the property value approach. Thus, a bidding game approach was chosen as the method for measuring VAI.

With the bidding game approach, visual aesthetic impact would be typically measured as follows. Individuals would be shown two color photographs of a nuclear power plant landscape. The two photographs would be identical except for visibly different tower/plume configurations. The individuals would then be asked one of four questions:

- What is the largest amount you would be willing to pay to keep Scene A and not get Scene B?
- What is the smallest payment you would be willing to accept to get Scene B and give up Scene A?
- What is the largest amount you would be willing to pay to give up Scene B and get Scene A?
- What is the smallest payment you would be willing to accept to keep Scene B and not get Scene A?

As required by the project objectives, visual aesthetic impact (WTP, WTA) measured with bidding games would be quantifiable and comprehensive. The measure was, in fact, significantly more comprehensive than Measure 2 because it could be directly compared with the expenditures required for different cooling tower alternatives.

PREDICTION METHODOLOGY FORMULATION

The primary objective of this research was to develop a valid method for predicting visual aesthetic impact (VAI). To accomplish this, the relationships determining VAI must be developed. The hypothesized relationships are shown in Figure 3.

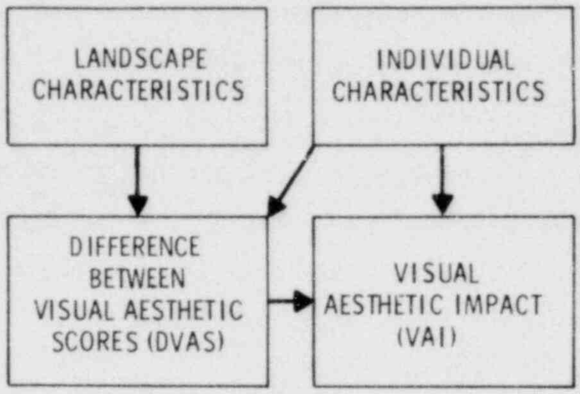

FIGURE 3. Relationships for Determining and Predicting Visual Aesthetic Impact

Visual aesthetic impact was expected to depend on the difference between visual aesthetic scores and three individual characteristics:

- nuclear power attitude
- family income
- distance from residence to plant site.

Difference between visual aesthetic scores (DVAS) is the difference between the public's judgment of the aesthetics of one nuclear power plant landscape relative to the aesthetics of an identical landscape altered by a visibly different cooling tower/plume configuration. The visual aesthetic score (VAS) of each landscape would be measured by asking bidding game respondents to assign each landscape a score between 0 and 50 according to the following criteria:

- 50 = the most beautiful scene ever seen
- 25 = an average scene

- 0 = the least beautiful scene ever seen
- none of the photos had to be scored a 50 or a 0
- more than one photo could receive the same score.

Nuclear power attitude (NPA) is defined as the public's stated pro- or antinuclear position measured on a 1-to-7 integer scale, on which antinuclear attitude increased moving from 1 to 7.

Primary data collection was required to statistically determine how DVAS and the three individual characteristics combine to determine VAI. However, using the estimated VAI relationship to predict VAI for a community was to rely, as much as possible, on available secondary data. Prediction would only require mean community information on individual characteristics and DVAS. Secondary data are available on mean family income. Also, distances from residences to the plant site can be measured from maps. However, no secondary data sources are available for DVAS or NPA. Therefore, secondary data sources were used to estimate relationships for DVAS and NPA.

DVAS was expected to depend on landscape characteristics and individual characteristics. NPA was expected to depend on individual characteristics.

Given developed relationships for VAI, DVAS, and NPA, it would be possible to predict VAI for a proposed nuclear power plant site. NPA and DVAS would be calculated first. Visual aesthetic impact would then be predicted using DVAS, NPA, family income, and distance from residence to site.

Landscape characteristics (e.g., percentage of scene occupied by clear still water) are the only variables on which primary data must be collected to predict VAI. However, much of the information required to produce the landscape characteristic variables is currently collected for preparing the EIS at each site. Thus, obtaining these data would not be prohibitively costly.

EXPERIMENTAL DESIGN

The next task was to design the experiment. This included choosing sampling methods, selecting sampling sites, and developing questionnaires. These efforts produced the data used in determining the importance of VAI and in empirically estimating the VAI prediction methodology.

SAMPLING METHODS

It was anticipated that measuring VAI and DVAS could be difficult. To simulate the siting process, bidding game respondents were to be told they were viewing nuclear power plant landscapes. Consequently, the photographs might remind them of other nuclear power attributes they perceive to be more important to them than visual aesthetics.

Early field tests led to the hypothesis that growth and employment benefits and health and safety impacts were more important than VAI. If this were true, respondents might not take the time or be able to differentiate among these attributes in stating their VAS and VAI. Some might even rebel if they felt the issues important to them were not being addressed. These factors implied two things. First, many of the VAS and VAI measurements probably would have to be discarded as nonrepresentative visual aesthetic statements. Second, nonrepresentative measurements would likely increase with extreme pro- or antinuclear power attitude. To compensate for nonrepresentative visual aesthetic measurements, a procedure was designed to "oversample" that portion of the population expected to exhibit extreme nuclear power attitude. The oversampling resulted in a comprehensive representative data set from which to develop the prediction methodology.

SITE SELECTION

To fully address the project objectives, it was necessary to collect a broad range of information on the VAI-determining variables at several sites around the United States. The principal site selection objective was to achieve variation among individual and landscape characteristics as well as among regions. Two sites with an existing nuclear power plant were selected, as well as two with a proposed plant and two with neither a proposed nor existing plant. One site was selected from each of six major U.S. geographic areas--Northeast, north Midwest, Northwest, Southwest, south Midwest, and Southeast. The six sites selected are shown in Table 1.

TABLE 1. Sampling Sites Chosen

Site	Power Plant	Cooling System
Rancho Seco, California	Nuclear Existing	Natural Draft Towers
Prairie Island, Minnesota	Nuclear Existing	Mechanical Draft Towers
Black Fox, Oklahoma	Nuclear Proposed	Mechanical Draft Towers
Perkins, North Carolina	Nuclear Proposed	Mechanical Draft Towers
Bangor-Augusta, Maine	None Nor Any Proposed	---
Puyallup, Washington	None Nor Any Proposed	---

QUESTIONNAIRE DEVELOPMENT

A questionnaire was required for measuring VAI (WTP, WTA), VAS, and NPA, and for collecting data on other relevant variables. The questionnaires were developed using landscape photographs of the four sites with either an existing or a proposed plant. Computer simulations of plume conditions from both mechanical and natural draft towers were performed for these sites. Several photographs of each landscape were then produced showing both mechanical and natural draft towers with simulated plume conditions.

The questionnaires were specifically designed to help identify those individuals who registered bids that were not representative of their VAI.

DATA ANAYLSIS

The data analysis task is described in this section. First, data selection is discussed. An analysis of the importance of towers and plumes is presented next. Following this, the empirical estimation of the prediction methodology is described.

DATA SELECTION

Bids that did not represent VAI were removed from the data set. This was accomplished by applying several criteria to the data, including statistical analyses demonstrating that the bids removed were not related to DVAS.

IMPORTANCE OF TOWERS AND PLUMES

Several statistical tests were applied to bidding game data from the Perkins, North Carolina, site to determine the statistical significance of different tower/plume configurations. The results indicated that there is less than one chance in 100 of being wrong if it were concluded that residents surrounding the Perkins site would, in aggregate,

- be willing to pay to have a mechanical draft tower system instead of a natural draft tower system, for times when no visible plume is emitted;
- be willing to accept compensation to forego a mechanical draft tower system for a natural draft tower system, for times when no visible plume is emitted;
- be willing to pay to have no visible plume emitted from the tower instead of having a large visible plume emitted; and
- be willing to accept compensation to forego having no visible plume emitted from a tower for a large visible plume emitted.

These results are very conclusive; tower configurations and plumes do create statistically significant visual aesthetic impacts.

The actual amounts the Perkins, North Carolina population would be willing to pay for different tower/plume configurations are of practical significance. Examples of these amounts are:

- $4.18 per mean household per month to have a mechanical draft tower system instead of a natural draft tower system for times when no plume is emitted
- $2.82 per mean household per month to have a natural draft tower with no visible plume emitted from the tower instead of having a large visible plume emitted.

PREDICTION METHODOLOGY ESTIMATION

Development of the VAI prediction methodology required estimation of the VAI, DVAS and NPA relationships. Included are refinements of the relationship presented in the Methodology section.

Determining the Visual Aesthetic Impact Relationship

It was found that VAI measured in terms of dollars per household per month depends on:

- the difference between two visual aesthetic scores (DVAS)
- nuclear power/pollution control attitude (NPA/PCA)
- family income (FY)
- distance from residence to site (DRS).

Visual aesthetic score was measured for each landscape used in the bidding game on a 0-to-50 scale. Visual aesthetic impact was measured as willingness to pay or be compensated for changes between landscapes. Thus, a VAI measure for the difference between two landscapes was directly related to the difference between the VAS measures for the two landscapes. As the difference between two visual aesthetic scores (DVAS) increased while the other VAI-determining variables were held constant, VAI increased.

Visual aesthetic impact was determined, in part, by nuclear power attitude, except at those sites with neither an existing nor a proposed plant. Because residents in these areas had no direct contact with a nuclear power plant but were familiar with visible plumes, their VAI was determined more by their pollution control attitude than by their nuclear power attitude. Holding other VAI-determining variables constant, the more antinuclear or pro-pollution control the group's attitude, the greater the VAI.

Family income was positively related to VAI. Holding all other VAI-determining variables constant, the greater the family income, the greater the WTP and WTA.

Distance from residence to site was negatively related to VAI. Holding all other VAI-determining variables constant, the closer to the site an individual lived, the greater were his WTP and WTA. This variable was used only for sites with an existing or proposed plant.

The most important VAI-determining variable was nuclear power/pollution control attitude (NPA/PCA). The second most important variable was family income, followed by the difference in visual aesthetic score (DVAS) and distance from residence to site.

The way in which the variables combined to determine VAI differed depending on whether 1) VAI was measured with WTP or WTA, 2) the site in question had an existing or proposed plant as opposed to neither an existing nor proposed plant, and 3) both landscape photograph sets used to measure VAI showed visible cooling towers and/or plumes. Tests to determine if VAI differs among geographic regions were inconclusive.

Determining the Difference in Visual Aesthetic Score Relationship

It was necessary to determine the VAS relationship to determine the DVAS relationship. It was found that VAS measured on a 0-to-50 scale depends on:

- mean landscape characteristic aesthetic score (MLCAS)
- nuclear power/pollution control attitude (NPA/PCA)
- sex (SEX)
- education (ED)
- whether or not the landscape photographs viewed showed the type of cooling tower that existed at the judging community's local power plant (OWTW).

Mean landscape characteristic aesthetic score (MLCAS) was determined using data from individuals outside the VAI and VAS sample who scored a wide range of photographs on the 0-to-50 scale. Nuclear power plants were present in only a small percentage of the photographs. The mean of all individual scores for each photograph was calculated and statistically related to 29 landscape characteristics. Thus, the MLCAS-determining variables are limited to landscape characteristics on a broad range of photographs; individual characteristics are excluded.

The landscape characteristics used were chosen to minimize subjectivity in measurement. For example, the characteristics included percent of scene in clear still water in each photograph. All characteristics could be measured by counting or using a protractor and planimeter. The most important landscape characteristics were variables related to the extent of water, the number of manmade alterations, and the type of terrain in the scene. Holding the VAS-determining variables constant, an increase in MLCAS for a scene resulted in an increase in VAS for that scene.

It was found that NPA/PCA and VAS were related in a similar manner, as were NPA/PCA and VAI. For sites with either an existing or proposed nuclear power plant, the higher the antinuclear attitude, the lower the VAS, holding other VAS-determining variables constant. The same relationship held between VAS and PCA for sites with no plants nor any proposed.

Holding other VAS-determining variables constant, it was found that males score scenes significantly higher than females. Also, it was found that the more education an individual has, the lower the VAS he is likely to assign the photographs, holding other VAS-determining variables constant.

Finally, it was found, on average, that individuals viewing a scene with a cooling tower type like the one at an existing local plant will score that scene significantly higher than if shown the same scene with a different tower.

The most important VAS-determining variables were NPA/PCA, MLCAS, and OWTW. Sex and education were of less importance than the other VAS-determining variables.

The way in which the variables combined to determine VAS differed depending on whether the site in question had an existing or proposed plant as opposed to neither an existing nor proposed plant.

The VAS relationship was determined only to derive a DVAS relationship. For a given individual or group, the only variable that changes between photographs is MLCAS, landscape characteristics. All other VAS-determining variables (SEX, OWTW, etc.) remain the same. This means that pro- and antinuclear groups would be expected to assign different VASs to two nuclear power plant landscape scenes. However, because DVAS is related only to MLCAS, the difference between the two VASs from one group would not be significantly different from the difference between the two VASs from the other group.

Determining the Nuclear Power Attitude Relationship

It was found that nuclear power attitude (NPA), measured on a 1-to-7 integer scale, depended on age and education. For a given education level, as age increased, NPA was found to become more pronuclear. It was also found that, for a given age level, as education increased, antinuclear power attitude would increase. Education is relatively more important in determining NPA than is age. Finally, it was found that the way in which age and education combined to determine NPA did not differ among sites.

PREDICTION

The above three relationships can be used to predict VAI on a community. NPA would be calculated first using available secondary data on age and education. DVAS would be calculated next using NPA, secondary data on SEX, ED, OWTW, and primary and secondary data on MLCAS. VAI could then be predicted using the calculated values for DVAS, NPA and secondary data on family income and distance from residences to site.

Prediction validity tests were carried out for the VAI and VAS estimated relationships. The purpose of these tests was to determine whether the estimated relationships could be used to predict for groups outside the sample set used to estimate the relationships. It was concluded that these relationships can be used to predict the general range of VAI and VAS, but not to generate precise predictions.

CONCLUSIONS AND RECOMMENDATIONS

The primary objectives of this project were to develop a valid methodology for predicting visual aesthetic impact (VAI) using available secondary data and to determine the importance of VAI. The following conclusions are discussed in terms of the project objectives.

VISUAL AESTHETIC IMPACT PREDICTION

The prediction methodology can be used to predict VAI:

- measured as either willingness to pay or willingness to accept compensation in dollars per month per household for impacted communities
- between mechanical draft and natural draft towers for sites with proposed plants
- considering all possible plume characteristics
- at a single site
- among sites (by simply repeating the single-site analysis at other sites and comparing the results).

The most important VAI-determining variables, in order of descending importance, are:

- nuclear power and pollution control attitude, measured on a 1-to-7 integer scale
- family income
- difference between visual aesthetic scores, assigned to landscape photographs on a 0-to-50 scale
- distance from residence to plant site.

Several assumptions and limitations are associated with the use of the VAI prediction methodology:

- VAI, DVAS, and NPA relationships have not changed appreciably since the data were collected. There may be events which could change the relationships presented in this research. The Three Mile Island

(TMI) incident is a candidate for this type of event. TMI may have altered the way in which nuclear power attitude of the population is determined.

- Uniqueness of site or viewshed was not considered in this study. If the bidding game participants had information that landscapes in the photographs were, for example, of a national wilderness, it is hypothesized that the VAI estimates would be considerably greater, holding other VAI-determining variables constant. Therefore, while the VAI prediction methodology is applicable to the majority of nuclear power plant siting analyses, underestimates of VAI would be produced for some situations.
- Unique site-specific subcultures were not considered in this analysis. Although the methodology captures a broad array of cultural influences, such as urban and rural New England and the rural Southeast, it does not capture things like the VAI of native Americans.
- The VAI from nonresidential population when added to the VAI from expected residential growth at the plant site is negligible. There is sufficient evidence to warrant this assumption.
- Prediction validity test results indicate that using this method results in predictions of the general magnitude of VAI, not a precise estimate.

IMPORTANCE OF VISUAL AESTHETIC IMPACT

The results of several statistical tests support the following conclusions regarding the importance of VAI:

- On the average, using a natural instead of a mechanical draft cooling tower will cause a statistically significant visual aesthetic impact on a community.
- On the average, a tower with a large visible plume, when compared to the same tower with no plume, will cause a statistically significant visual aesthetic impact on a community.

- On the average, willingness to pay for a mechanical instead of a natural draft tower and associated plume ranged from $0 to $10 per month per average household, depending on site-specific conditions such as topography, meteorology, and demographic characteristics.
- Statistical significance does not necessarily imply economic significance. The economic significance of VAI must be determined by a comprehensive analysis of all benefits and costs associated with mechanical draft and natural draft cooling systems.

In addition, the visual aesthetic impact of alternative closed-cycle cooling systems appears to be relatively minor when compared with growth/employment and health/safety issues. This is a tentative conclusion, not based on statistical analyses. However, there is substantial information from this project for its support.

RECOMMENDATIONS

The methodology for predicting VAI of alternative closed-cycle cooling systems for nuclear power plant landscapes is recommended for implementation, primarily because of four features:

- The methodology has been statistically validated and can be used to predict for groups outside the original data set.
- VAI predictions are dollar amounts that communities are willing to pay to avoid visible landscape changes due to closed cycle-cooling systems. As such, the VAI predictions can be directly compared to the expenditures required to substitute one cooling option for another.
- The methodology is relatively inexpensive to implement and maintain.
- In keeping with NEPA directives, the methodology is an advancement in state-of-the-art quantification of amenities and values.

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R. Leber, Ph.D
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American Public Power Association
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Washington, DC 20037

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Portland, OR 97208

C. Kondrat
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P.O. Box 3621
Portland, OR 97208

E. Hall
Chief Sighting Engineer, Planning and Research Department
Pacific Gas and Electric Company
77 Beale Street
San Francisco, CA 94106

W. June
Vice President
Portland General Electric
121 Southwest Salmon Street
Portland, OR 97204

D. Smith
Chief Planning Engineer
Southern California Edison Company
P.O. Box 800
2244 Walnut Grove Ave.
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P. Norman
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U.S. Corps of Engineers
Portland District
P.O. Box 2946
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R. Oliveira
Department of Agricultural
and Resource Economics
Oregon State University
Corvallis, OR 97330

J. Pell
ERD Office of Environmental
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W. Winger
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P.O. Box 25287
Denver, CO 80225

R. Weisz
NRED/ESCS/RSB
500 12th St., S.W.
Washington, DC 20250

ONSITE

51 Pacific Northwest Laboratory

R. C. Adams
T. Bander
A. J. Currie
J. W. Currie (35)
D. E. Deonigi
R. Foster
D. Hessel
J. C. King
T. J. Secrest
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ES - J. W. Currie
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The objective was to produce a validated methodology that can provide timely predictions of the visual aesthetic impact on people viewing alternative closed cycle cooling systems on nuclear power plant landscapes. First, visual aesthetic impact (VAI) measure was defined. The VAI measure chosen was the maximum amount people would be willing to pay (WTP), or the minimum amount they would be willing to accept (WTA) in compensation, for visible changes on nuclear power plant landscapes. The next step was to collect the data required using "bidding game" questionnaires to elicit respondents' WTP and WTA for visible differences between natural and mechanical draft cooling towers and plumes. Data were collected on VAI and other variables at six U.S. sites and analyzed to produce a statistical relationship between visual aesthetic impact and theoretically related variables. The most important VAI-determining variable was nuclear power attitude. Other important variables were family income, landscape characteristics, and distance to plant site. VAI-determining variables cannot be used to develop one general VAI relationship. Using a natural instead of a mechanical draft cooling tower will cause a statistically significant VAI on a community. The VAI relationship can be used to predict the general range of VAI.

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