Visual Quality/Aesthetics Modeling for Reclamation/Landscape Disturbance Applications [1]

Jon Bryan Burley[2] and Terry J. Brown[3]

Abstract. This paper presents an overview of visual quality quantitative methods for reclamation specialists. Presently, there are a variety of visual quality prediction methods to select for reclamation applications. These models include heuristic models, psycho-physical models, experiential models, and cognitive models. However, many of these methods have low statistical predictability (explain only a small portion of variance), and are thus difficult to defend or require extensive testing. Not all visual quality assessment methods may be readily suitable for reclamation/landscape disturbance applications.

Visual quality models can be combined with geographical information systems (GIS) to study the effects of proposed surface mining projects and reclamation alternatives upon the landscape. In addition, image capture technology can help to translate planning and design alternatives into physical three-dimensional images, useful in public meetings and to study the effects of future landscape treatments. However, current viewshed algorithms in GIS may be theoretically weak and may require substantial modifications; and photographic image capture data may not precisely match three-dimensional wire-frame computer data, causing distortion and undesired variability in the analysis.

This paper documents the types of outputs that can be generated through image capture technology and its application to visual quality analysis in reclamation applications.

Keywords: Landscape planning, site design, computer applications, image capture technology, GIS, viewsheds

Introduction

Landscapes are constantly being modified by natural events and human activities that shape the landscape's physical patterns and affect biological inhabitants. Surface mining is one of these activities that modify landscapes. While scholarly investigations have emphasized understanding the biological/chemical/physical effects that surface mining (and other landscape disturbances) may have upon the landscape and developing techniques for landscape reclamation, there has been comparatively few projects conducted concerning the topic of visual quality issues associated with landscape disturbance, even though major environmental federal legislation/laws in the United States specifically mention the importance of visual quality and in- dicate that visual quality should be ad- dressed. In fact, psychological issues, such as perception are often excluded from visual quality analysis; yet these issues could be the most important factor for a majority of local residents located near a landscape

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[2] Jon Bryan Burley, ASLA is a PhD candidate in Landscape Architecture at the University of Michigan, and an Affiliate Professor in the Recreation Resources and Landscape Architecture Department at Colorado State University.

[3] Terry J. Brown, ASLA, is an Associate Professor of Landscape Architecture at the University of Michigan.

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disturbance project. Investigators in public health sciences and environmental psychology acknowledge the importance of mental health and the negative impacts (stress) that can be generated upon the local population (see Fisher et al 1984:77-80 for an introduction to environmental stress concepts) from possibly the mere suggestion that a project (such as a new surface mine, a new power plant, or a new transportation corridor) is being proposed in their area.[4]

There appear to be several reasons why visual quality has been relatively ignored. First, the study of visual quality adds another layer of environmental uncertainty in an already complex regulation atmosphere. Visual quality issues and associated mental health issues may be ignored because project planners are not willing to add complexity to their often burdensome work schedule.

Second, competency in visual quality issues often requires additional training and study. Usually, environmental psychologists, landscape architects, and recreation resource scientists with advanced graduate training are the only individuals who seem to competently address these topics. While many individuals may claim expertise in visual quality subject-matter, it is usually only those individuals with advanced training in an academic setting that appear to have the necessary educational breadth and scholarly depth to rigorously investigate a visual quality topic. In many respects, there are only a handful of individuals in North America capable of studying visual quality. Therefore, without a broad distribution of numerous, qualified visual quality investigators, there has not been a rapid advancement in the body of knowledge associated with the topic. Thus a body of practical knowledge useful in site development projects may lag behind advances made in other scientific endeavors.

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[4] Over the last century, the public health sciences have evolved from a position of concentrating upon infectious diseases (cholera), to including chronic diseases (smoking), to embracing the concept that any abnormality in human physiology and psychology can be considered a disease. Therefore, the stress placed upon individuals affected by a proposed project, resulting in physiological and behavioral abnormalities means that the proposed project can be considered a type of human related disease that can be studied by employing epidemiological methods. In addition, since changes in visual quality may result in stress, changes in visual quality can be considered an environmental factor contributing to human disease. Theoretically, for a given project, visual quality attributed stress may present a greater health risk to the local population than some traditionally studied factor such as water quality. For example, suppose that the stress attributed to negative visual quality from a particular project resulted in an average loss of 1 day per year of exposure to a person's life span in a local population of 10,000. Such a loss may not seem as absurd as one might believe. Recall that human emotions and stress concerning proposed site developments can be rather extreme for the local residents (just attend one of thousands of public planning meetings/hearings across the United States and Canada each year to observe the intensity of local emotional stress). In this example, over a 20 year period, the loss in human life equal to 547.95 years or the loss of 8.43 people per 200,000 person-years (10,000 days per year * 20 years / [365 days per year * 65 years per person]). This loss rate might be unacceptable if the loss were due to a chemical agent introduced to the water system, but remains relatively "uninvestigated" if the loss may be attributed to visual quality and environmental stress.

Third, even though visual quality issues make "good press" and "good sense" in legislation, and visual quality issues literally affect every site development project, there is relatively little funded investigatory work associated with visual quality. For some reason, funded visual quality investigations do not seem to be highly valued by some research funding agencies; even though to humans it may be one of the most fundamental issues for interacting, comprehending and coping with the environment.

Finally, visual quality has proven to be a difficult topic to study, but not impossible. Developing wildlife habitat models, creating predictive vegetation growth models, and measuring the impacts of site disturbance to watershed hydrology are relatively deep in quantitative history when compared to measuring visual quality. Consequently in some surface mining environmental assessment studies, a lone artist may be selected to assess visual quality; while an esteemed team of investigators may be organized to study a relatively less complex environmental topic.[5]

Despite these impediments to assessing visual quality and advancing visual quality science, there has been some progress achieved over the last twenty-five years in the topic of visual quality. Surface mine operators and reclamation specialists should be acquainted with the fundamental issues associated with visual quality so that they can make informed decisions about techniques and tools that may be employed in future visual quality studies.

[5] Without trying to appear "heavy-handed" about employing a lone artist to conduct a visual quality assessment (because an artist could be a valuable member of an interdisciplinary team), one could consider the choice of an artist to conduct the study as being similar to selecting a canoeist to evaluate water quality and site hydrology, or a "big-game" hunter to perform habitat modeling and assess wildlife impacts.

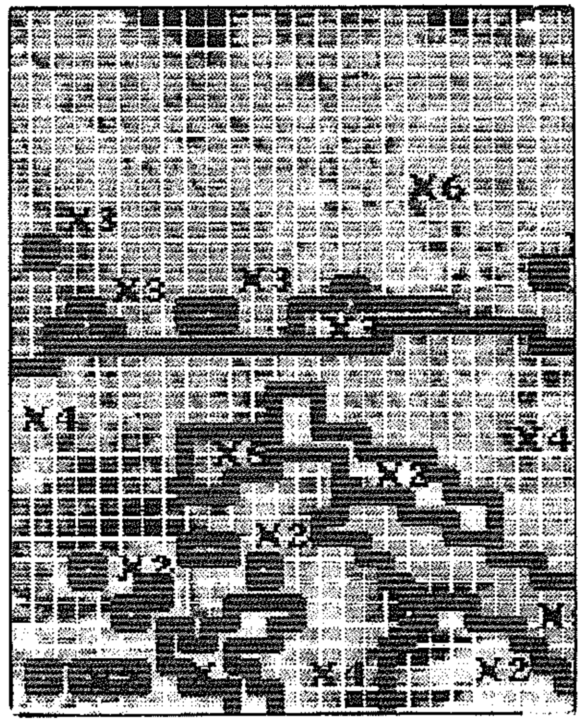

Figure 1. This image depicts the approach employed to calculated the Shafer Visual Preference Score. A grid is place over a photograph and the six Shafer variables are computed with the grid.

Visual Quality Methods

Visual quality can be measured by a variety of methods (see Smardon, Palmer and Felleman 1986 for an overview of the subject) that can evaluate the landscape character based upon landscape features such as vegetation, exposed substrate, and open water composition, meaning changes in landscape content and composition. However, investigators are not in agreement concerning which assessment method is the most appropriate method to employ. These disagreements make visual quality assessment a defensibly difficult task.

The Shafer Equation Example

To illustrate this point, suppose an investigator chose the Shafer Landscape Visual Preference Rating (Brush and Shafer 1975) and applied the procedure to evaluating landscape images from a proposed surface mine project (Figure 1).

This visual quality measuring tool was a scholarly contribution developed during the late 1960s, when Elwood Shafer and colleagues derived a predictive equation to measure the content of an image and then numerically compute the relative preference that individuals may have for the image (see Shafer et al 1969, Shafer 1969, and Brush and Shafer 1975). Essentially, Shafer divided photographs (black and white photographs taken from eye level without a telephoto lens) of eastern and western United States landscapes, into a grid 38 squares by 32 squares and measured the spatial content of each square (recording areas and perimeters of specific variables) -- the independent variables. He then had respondents express their visual preference for the photographs (dependent variables). Using factor analysis techniques, he developed an equation that predicted visual preference (Shafer et al 1969). In his equation, the lower the value, the more preferred the image; and the higher the value, the less preferred the image. The variables employed in his equation are:

A. perimeter of immediate vegetation -- section of the photo where characteristics of individual leaves and bark of trees and shrubs (not including grass and forbs in measurement of vegetation perimeter) are easily distinguishable,

B. perimeter of intermediate nonvegetation -- section of the photo where prominent features of nonvegetation (including grass, soil and rock, but excluding water) are visible, but not in the fine detail found in the immediate zone,

C. perimeter of distant vegetation -- section of photo where only the broad outlines of vegetation shapes are distinguishable, but no details are visible,

D. area of intermediate vegetation -- section of photo where vegetation is visible but not in fine detail found in the immediate vegetation zone,

E. area of any kind of water -- section of photo that includes water,

F. area of distant nonvegetation -- section of photo where shapes of nonvegetation cannot be distinguished.

These variables are brought together in an equation (Equation 1) to form the predictive model.

$$
\begin{aligned}
Y = \; & 184.8 - (0.5436 * X1) \\
& -(0.09298 * X2) \\
& +(0.002069 * X1 * X2) \\
& +(0.0005538 * X1 * X4) \\
& -(0.002596 * X3 * X5) \\
& +(0.001634 * X2 * X6) \\
& -(0.008441 * X4 * X6) \\
& -(0.0004131 * X4 * X5) \\
& +(0.0006666 * X1 * X1) \\
& +(0.0001327 * X5 * X5) \qquad \text{(Eq.1)}
\end{aligned}
$$

Where:

Y = Visual Preference Prediction
X1 = perimeter of immediate vegetation
X2 = perimeter of intermediate nonvegetation
X3 = perimeter of distant vegetation
X4 = area of intermediate vegetation
X5 = area of any kind of water
X6 = area of distant nonvegetation

The respondents employed in the original Shafer study were campers in the Adirondacks, surveyed during the summer of 1967 (Shafer et al 1969). The equation later concurred with similar responses for respondents in Scotland (Shafer and Tooby 1973). In addition, investigators have determined that black and white photographs, color photographs and slides are reasonable representations of real landscapes. In other words, people have no problem equating the black and white photograph with the real landscape image and can rate black and white photographs with no significant differences from ratings of real landscapes (see Smardon et al 1986, Boster and Daniel 1972, and Zube 1974). However, it has been discovered that people's perception of drawings (a rendering of a proposed action) may not covary with the perceptions of real landscapes that the drawings represent (see Smardon et al 1986).

As one can imagine, numerous investigators have discussed the values of the Shafer method. Some argue that the variables in the Shafer method are meaningless to the landscape manager. The physical environmental attributes that are most readily measurable and easily obtained from spatial data are not necessarily the most useful in assessing the landscape to achieve one's management purposes (see Kaplan, Kaplan and Brown 1989). For example, Fisher et al (1984:39) in an evaluation of physical predictive equations, note, "What good does it do one, for example, to know that the diameter of trees times area of water to the third power predicts scenic value?" Therefore, it has been claimed that the Shafer equation is very difficult to easily apply in management situations for a landscape setting. Others argue that the physical, "photo-based" equations have no theoretical explanation (see Fisher et al 1984:39). In addition, Daniel and Boster (1976:14) state, "Some progress has been made in identifying scenically relevant physical features (Shafer, Hamilton, and Schmidt, 1969, ...) but neither the features nor the "rules" by which perceptual effect combine can yet be accurately specified." In contrast others counter-argue that the Shafer equation is purely an empirical equation and was not intended to advance theory, but was strictly intended to predict visual quality. Nevertheless, the Shafer equation illustrates the scholarly debates associated with visual quality investigations.

Other Visual Quality Equations

Some visual quality authorities consider the Shafer approach as an example of a supposedly universal psychophysical visual quality regression/factor analysis/ multi-dimensional scaling models. These investigatory approaches attempt to measure the physical attributes of a landscape image and statistically associate those attributes to human preference responses of the image. Since Shafer's equation, only a few other equations models have been developed. Buhyoff et al (1982) describe a regression equation to predict scenic quality based upon pine beetle and spruce budworm damage (Equation 2).

$$
\begin{aligned}
Y = & (10.83 * X1) \\
& -(0.59 * X1 * X1) \\
& +(1.57 * X2) \\
& -(8.60 * X3) \\
& -(64.59 * X4) \\
& +(0.97 * X5)
\end{aligned}
\qquad \text{(Eq. 2)}
$$

Where:

Y = Landscape Preference
X1 = Area in Sharp Mountains
X2 = Area in Distant Forest
X3 = Middle Ground Area of Insect-Damaged Trees
X4 = Proportion of Forested Area
X5 = Area in Flat Topography

Vining and Stevens (1986:182) describe several other physical attribute models for special resource applications: Latimer, Hogo and Daniel (1981) and Malm et al (1981) developed models for particulate air pollution and Arthur (1977) and Daniel and Schroeder (1979) evaluated physical forest attributes, noting "... large trees, large amounts of ground cover and shrubs, and small amounts of downed wood and small trees were associated with high perceived scenic quality." (Vining and Stevens 1986:182). Considering the number of possible attributes that could be studied with substantial publishable results (such as water clarity, presence of wildlife, area of foreground herbaceous vegetation, area of pavement, area of wildflowers) there are surprisingly few multiple regression/ modeling studies presented in the literature, testing physical landscape attributes. If visual quality research were as aggressively pursued as wildlife habitat modeling, or hydrological modeling, there would be hundreds of equations to select from. Yet, in many respects, only the Shafer model seems quantitatively applicable for general visual quality assessment of North American landscape types and may be presently the most appropriate model for assessing landscape disturbances and proposed reclamation projects.

Fisher et al (1984:38-39) state in a general evaluation of these "physical-perceptual" approaches (like the Shafer equation), "... physical-perceptual approach does have scientific merit. ... physical-perceptual approaches show cross-cultural agreement (Zube & Mills, 1976) and consistency within culture (Anderson, Zube, & MacConnell, 1976) ... Moreover, physical-perceptual approaches do a very respectable job of predicting assessments of scenes (Pitt & Zube, 1979)."

Scenic Beauty Estimate

There are other physical perceptual approaches employed in visual quality assessment. One notable example is the scenic beauty estimate approach. Daniel and Boster (1976) present a scenic beauty estimation method for correlating on-site evaluations and photographic slide judgements. This approach can be very helpful in establishing the relative scenic beauty estimate (SBE) of landscapes by employing a workshop procedure for participants, such as special interest groups working together upon a specific project. However, this approach may not lead to any quick predictive equations applicable for other investigators unless the investigator is willing to follow the methodology and derive an SBE for their specific project. Nevertheless, the SBE can be very useful, providing the investigator is willing to conduct a mini- physical-perceptual study, to derive a measure of scenic beauty for the landscapes of interest. This approach can greatly increase the cost of an investigation and relies upon the cooperation of vested interests. If these participating parties require renumeration for their time, travel and input, the cost of the scenic beauty investigation can be ten times greater than the employment of a simple, previously tested equation. Therefore, in many circumstances the SBE methodology has been prohibitively costly to employ. However, given the serious nature of some landscape disturbance projects, a SBE study may become a necessity, often leading to important and defensible findings that allow amenable compromises between differing interests.

In a typical SBE approach, homogeneous landscape types are sampled photographically. The intent is to discover statistical visual quality differences between landscape types. The photographs are presented to respondents to rate the visual quality of the photographs. Each respondent's scores are internally standardized to reduce "observer criterion differences" and the effects of rating scales (see Daniel and Boster 1976:16-21 and Vining and Stevens 1986:175- 178). Then landscape types can be compared for differences in preference. Daniel and Boster (1976) note, "Our major research effort is presently in the area of "Feature Analysis": the prediction of scenic quality from scaled landscape features. We have concentrated on the manageable features or characteristics such as tree density and downed wood. Several researchers --most notable Shafer and his colleagues -- have related scenic beauty to landscape features. They have, however often focused on the variables over which management has little control." For

Table 1. This table is a matrix of the criteria employed by the BLM to evaluate landscapes (for more information see BLM 1980). This table has no statistical/empirical basis.

Visual Sensitivity Level		H			M			L
Special Areas		1	1	1	1	1	1	1
Scenic Quality	Class A	2	2	2	2	2	2	2
	Class B	2	3	3	3	4	4	4
	Class C	3	4	4	4	4	4	4
Distance Zones		FG MG	BG	SS	FG MG	BG	SS	SS

Where: Visual Sensitivity Level is defined by a "Sensitivity Level Matrix" (BLM 1980:20-12) H=High, M=Moderate, L=Low; Scenic Quality Areas are divided into classes based upon "Inventory/Evaluation Rating Criteria" (BLM 1980:18-19) A=19-33 points, B=12-18 points, and C=0-11 points; Distance Zones are FG=Foreground, MG=Middleground, BG=Background, SS=Seldom-Seen (BLM 1980:22-23). The matrix number defines the management class, 1=Wilderness Related, 2=Human Management Subtle, 3=Management Evident, 4=Human/Nature Contrasts Evident, 5=Requires Rehabilitation (not in matrix). Proposals can then be evaluated according to management class, and a "Contrast Rating" (BLM 1980:30-31) to assess the visual impact of proposals.

example their work describes landscape attributes such as the amount of downed wood, average tree diameter, tree density, distribution of downed wood, and crown cover canopy that are landscape features directly related to management options (Daniel and Boster 1976:56). They (Daniel and Boster 1976:57) also state, "The evidence is clear that predictive models [whether Shafer's equation, the SBE approach or other equations] are feasible. Conceptually, such predictive models are not unlike other resource response models (hydrological response models for instance) used to predict consequences (responses) of management options.

Expert Visual Quality Approaches

In contrast to the psychophysical model, several other visual quality estimation methods have been proposed (see Zube 1984). Possibly the most widely applied method is the expert approach. Both the BLM and the USFS employ the expert approach (see BLM 1980, USDA 1973, USDA 1974). Both approaches employ a set of experts to develop a purely synthetic evaluation process to quantify visual quality (Table 1). The numerical values developed in these processes are strictly ordinal and have no interval basis or confidence limits between scores. In other words, scores derived for two landscape images may have no statistical difference even though the BLM and USFS methods state that the two images are supposed to be different.

What seems to make these approaches defensible is that they have been agreed upon by participating agencies and parties as the method of choice, thereby binding the parties to the outcomes of the procedures; however, from a quantitative scientific base, these methods appear to be indefensible and nothing more than a best guess about perceived visual quality. Therefore, the BLM and USFS methods appear to be unsuitable for serious landscape visual quality assessment. However, the BLM and USFS continue to employ these methods. They seem to also be relying upon the idea that precedent is important. If the method has been used in the past, a precedent has been established that this visual quality assessment approach is acceptable. These agencies also seem to rely upon such statements as 'The last time we used our visual quality approach, everyone was happy and liked the method.' implying that the method must be good. However, the BLM and USFS approaches are not "good science."

Cognitive and Experiential Approaches

Another set of methods useful in visual quality analysis are classified as the experiential and cognitive approaches. These methods recently have been reviewed by Kaplan and Kaplan (1989), two of the best known investigators of the cognitive methods. Research by the Kaplans has led to some interesting ideas about landscape legibility, coherence, and related topics. The work has led to interpretations of photographs, with strong statistical evidence to support their work. However, the approach seems best suited at this time to understanding, in a conceptual framework, the composition and content of landscape images. Their approach has not yet tried to generate predictive equations suitable for other investigators to employ in landscape evaluations. Taylor et al (1987:387) note, "The cognitive and especially the experiential paradigms, which have been of less interest to environmental managers, have tended to resist translation into landscape design or management. How does one, for example, design for mystery or transcendent experience?"

Even though it has been 22 years since the Shafer method was first reported, and even though scholarly advances in visual quality assessment are constantly being made, no actual "breakthrough" research has occurred towards generating a general predictive equation that is better than the Shafer method for detecting quantitative changes in visual quality. While it may be possible to develop an equation that considers experiential factors, cognitive factors, and physical factors not contained or examined during Shafer's investigations, no one has reported or supported research to find a better general predictive equation than Shafer's method, an equation that explains only 66% (r-squared of 0.66) of the variance in the data.

To provide insight for the visual quality assessment arena, just briefly discussed, Taylor et al (1987) and Zube (1984) describe and categorize various visual quality landscape assessment approaches. Although, some visual quality authorities do not necessarily agree with these classifications, they are useful categories: expert (heuristic), physical-perceptual (empirical), experiential and cognitive (theoretical). Presently, visual quality in-investigators are left with few useful, empirically based, quantitative, predictive methods that are relatively inexpensive to conduct.

Visual Quality Tools

While the methods employed in measuring visual quality may not provide a single numerical approach, significant advances have been made in the last 20 years concerning technological develop ments that may make visual quality assessment less painful to conduct.

Image Capture Technology

Using current technology, one can capture video/slide images of landscapes (photo-points) and edit these images to reflect proposed changes in the landscape (Figure 2). The images can be very realistically rendered. However, this image editing technique can be a complex and tedious task. In addition, proposed changes to the images need to be based upon the predictions of other investigators who can predict the future approximate substrate composition, vegetation distribution, and site hydrology of the landscape. These predictions can be employed to reflect general changes to the landscape. Once the general changes have been visually created, one could employ a visual quality rating technique (the Shafer Equation or other preferred visual quality assessment method) to evaluate the edited image and compare existing landscape images to proposed conditions.

The visual quality investigator must be careful in selecting the appropriate statistical procedure for comparing images. Since very little work has been conducted to identify the structural distribution of visual

Figure 2. The top photograph is an oblique aerial depicting the existing conditions of a proposed site for a sand and gravel mining operation. The bottom image illustrates the proposed configuration of the post-mining reclaimed landscape.

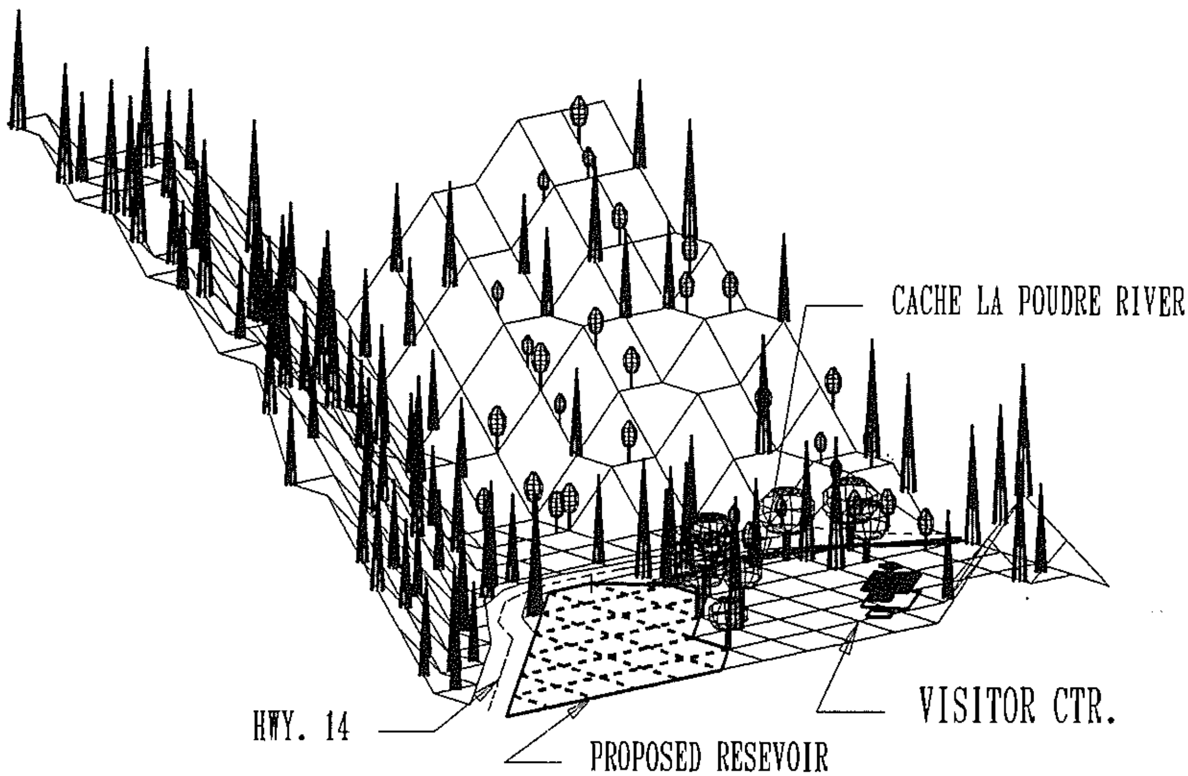

Figure 3. This graphic illustrates a 3-dimensional wire frame image to study the spatial elements of the landscape (in this case, water levels for a proposed reservoir).

quality parameters, statistical techniques based upon "normal-distribution" may not be appropriate. Instead investigators may have to rely upon non-parametric procedures such as the Friedman's Two Way Analysis of Variance (Daniel 1978) test for significant differences. If the Friedman's test indicates significant results, one can use the Friedman's Multiple Comparison Test (Daniel 1978) to identify which landscape treatment are significantly different. If the Friedman's Two Way analysis of Variance test is not significant, one can test for significant similarity by using the Kendall's Coefficient of Concordance (Daniel 1978) test (there are far too few statistical methods that test for significant similarity).

Over the last decade, image capture technology, a technology that migrated to micro-computers was still a relatively expensive tool. Prices for image capture boards (a computer board that translates "TV monitor like" signals to "computer video signals) seemed to be high in comparison to other boards that could be inserted into computers. However, recently there have been numerous "price reductions" in image editing software and hardware. Nevertheless, users of this technology seemed to have readily accepted this tool without performing some fundamental image capture technology assessment work.

Image capture technology may be susceptible to the same image distortion found in aerial photography. Visual quality investigators have not statistically assessed the differences between raw captured images and rectified images. In addition, visual quality investigators have not assessed the ability of 3-d terrain models, often imported into image capture systems to accurately assess the differences between the actual landscape and wire-frame landscapes (for example, based upon the geomorphology of an area, what spatial resolution is required to produce significant similarities between the actual landscape and a wire-frame model?), (Figure 3).

Figure 4. This graphic is a computer generated viewshed (from GIS technology) for a particular photo-point.

For the reclamation specialist, these issues can be of paramount importance because one may certainly desire some degree of objectivity in the image capture technology and not be placed in a position where one may be accused of inaccurately portraying the image of a proposed project.

Viewshed Technology

Besides image capture technology, the computation of viewsheds has been assisted by the micro-computer and geographical information system (GIS) technology. Today, visual quality investigators can predict the area of landscape seen from a particular location (the "viewshed") by knowing the topography of a landscape, the height of viewer above the ground, and the height of blocking elements above the ground such as trees. The boundaries of the viewshed are determined by using a microcomputer/ minicomputer/ mainframe containing viewshed capabilities in a GIS software program, such as MAP (Map Analysis Package, Tomlin 1985, a PC-DOS computing environment), MAP II (Pazner, Kirby, and Thies 1989, a Macintosh computing environment), or GRASS (U.S. Army Corps of Engineers 19-, a UNIX computing environment) (Figure 4). This type of computer technology can be helpful in allowing decision makers, including local residents the ability to assess the extent of visual quality intrusions.

Viewshed computations can be difficult to calculate manually, especially when there are thousands of photo-positions to employ in determining the extent of a viewshed. However, computing power allows for this computation to occur relatively accurately and quickly. So far, extensive use of viewshed capabilities have been sparingly employed. In the future, examples of viewshed applications may be more extensive and comprehensive.

Summary

While visual quality issues are important to many individual personnel and legislatures, visual quality issues are often inadequately addressed. For reclamation specialists, there exists a wide assortment of visual quality assessment techniques, but no single method is readily acceptable to assess visual quality. Recently, image capture technology and viewshed calculation methods have allowed investigators opportunities to study and predict the effects of landscape disturbances and can aid reclamation specialists in assessing and communicating visual quality issues.

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