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CAUSE AND EFFECT PATTERNS OF NOXIOUS FACILITY IMPACTS ON PROPERTY VALUES*

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ABSTRACT

Noxious facilities generate different types and levels of impacts that may reduce residential property values. Highly controversial facilities do not consistently cause significant property value impacts while some common, less objectionable facilities do. The research issue is to test which impacts and cause-effect connections result in consistent and significant property value impacts. Typical physical, psychological, and trigger impacts, and local benefits of ten categories of noxious facilities are evaluated based on the consistency of resulting property value impacts. Nuclear power plants, waste facilities, buildings, electrical power plants, and transmission lines cause inconsistent property value impacts. These facilities are characterized by multiple and complex physical and socio-economic impacts, and medium to high perceived risks. Airports, highways, air pollution and visibility impacts, and natural hazards consistently cause significant property value effects. These facilities create single, observable physical impacts and give rise to low risk perceptions. Better descriptions of facilities and impacts must be provided in future studies to identify and mitigate key causal impacts and connections.

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INTRODUCTION

Noxious facilities generate many types of physical and non-physical impacts that can reduce property values. Some relatively benign facilities (such as airports, highways, air pollution, and visibility impacts) cause consistent significant property value impacts while other, highly controversial ones (nuclear power plants, hazardous and municipal waste facilities, and electrical transmission lines) do not [1]. The specific facilities in question generate different impacts and different cause-effect interactions that may result in property value impacts. The discrepancy might also be explained by methodological difference, for example, in measuring property value impacts. The understanding of the impacts and cause-effect connections is essential for environmental managers to accurately assess property value impacts and design effective mitigation measures.

In this article, typical physical and non-physical impacts and local benefits of ten categories of noxious facilities are evaluated and compared with the resulting property value impacts to determine the causal impacts and connections. The results are discussed to identify research needs and to design effective property value mitigation and compensation measures.

THE CAUSAL CONNECTIONS OF NOXIOUS FACILITIES WITH PROPERTY VALUE IMPACTS

Basic Cause-Effect Connections

Residential property value (PV) is an implicit measure of the value of property attributes as surrogates for the expected flow of services to the owner. The value to the owner is generated by the scarcity of properties with specific, desirable attributes (and without undesirable attributes) as: 1) physical characteristics, 2) neighborhood characteristics, 3) accessibility, and 4) amenities. The demand for any type of residential parcel reflects its utility relative to other parcels. The value stems from specific attributes that provide more desirable and less undesirable flows than other parcels for the desired type of land use. Property values are determined in the marketplace by the aggregate demand for certain attributes and change to reflect the locational choices of buyers and sellers in the market. Residential property value differences therefore reflect the differences in the property attributes as surrogates for perceived service flows to the owner that result in different levels of residential enjoyment.

For significant property value impacts to occur, there must exist a complete causal connection between the noxious facility and the attributes of affected properties. The simple cause-effect relationship between a noxious facility and property values consists of three causal components: 1) facility activities including site selection and announcement, construction, operation, emergencies and failure, and decommissioning, 2) the exchange of unwanted outputs and of desired outputs between the facility activities and the environment, as emissions of mass (pollutants), energy as noise, visible light waves, radiation, and of development, money, and employment, 3) impact propagation as transport, dispersion, and fate of outputs, 4) receptor exposure to the propagated mass or energy, and 5) residents' perception and evaluation of the effects on property attributes (see Figure 1). The resulting differences in PVs as the aggregate response of market decision makers (buyers and sellers) are usually expressed as differences in sales prices, consumer surplus, residents' attitudes, price appreciation, or development rates. Impact reduction measures of prevention, control, mitigation, and compensation measures (corresponding to the causal components) can change the levels of causal factors at different points in the cause-effect sequence [2].

Conditions for Property Value Impacts to Occur

Property value impacts will only occur if three conditions governing the interactions of causal elements are present:

1. The facility must produce unwanted outputs that propagate through the environmental media and cause significant exposure of residential properties. The resulting impacts must occur as "localized" disamenities and affect some properties (within a market area) more than others. The cause-effect connection between the facility activities and property values must be correctly selected and specified. Noxious facilities cause a variety of a) objective impacts, as physical and socioeconomic impacts, b) psychological impacts of fear, stigma, and uncertainty, resulting from the perception of risks, and c) local benefits that accrue to the host community and surrounding areas. The first, most direct causal pathway is from the facility activities via the facility's physical and socioeconomic impacts to property values (see Figure 2).

The second pathway is from the facility activities and characteristics through psychological impacts of risk perception as fear, stigma, and uncertainty, to buyers' and sellers' attitude and, hence, to property value judgments [3, 4]. A third pathway is formed by a subset of physical impacts, the trigger impacts, which are obvious nuisance impacts that are connected to underlying subjective beliefs and psychological impacts. These physical impacts have been called "trigger" impacts [5] and include, e.g., odor, noise, and view impacts. For example, although the association of physical health risks and risk perceptions is weak, several studies have shown that some readily perceived nuisance impacts are significantly correlated with residents' beliefs about non-physical impact levels and with their attitude about noxious facilities [5, 6]. These trigger impacts may cause significant psychological impacts (i.e., risk perception) that then affect property values.

The fourth cause-effect path is then from the facility activities to local benefits of increased tax revenues, employment, increased housing demand (and prices),

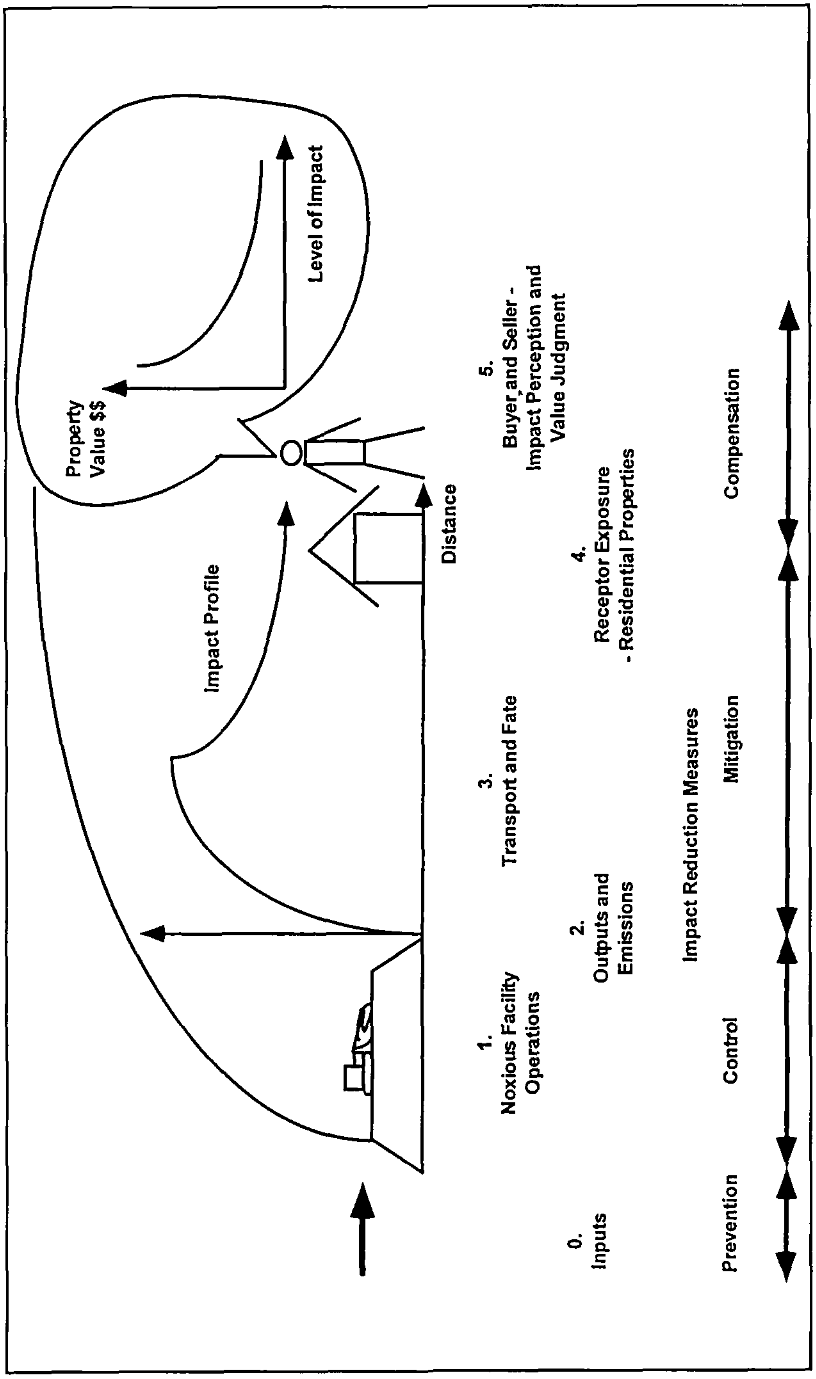

Figure 1. Cause-effect sequence and impact reduction measures for property value impacts.

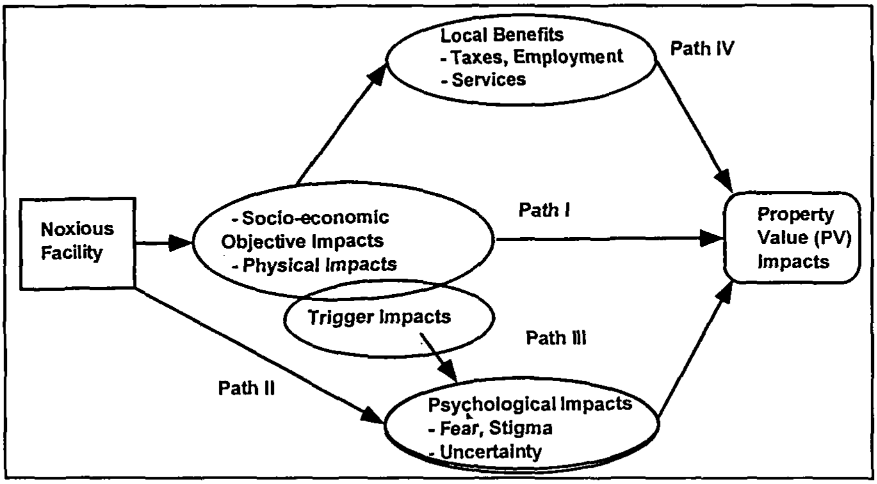

Figure 2. Facility impacts and cause-effect connections to property value impacts.

and improved infrastructure, recreation, and community services on property values (see Figure 2). The resulting PV impacts combine negative impacts and local benefits. Only the correct selection and specification of the types and level of facility impacts and their cause-effect connections will generate accurate and consistent PV impact predictions and assessments.

2. *The resulting increased exposure to unwanted impacts must be perceived* [7] and valued by the aggregate of buyers and sellers in the market. If this logic holds, then buyers would tend to disregard subtle, insidious impacts that are not distinctly attributable to the facility and are only detectable with scientific instruments or special analysis. Facility impacts that are readily observed by human senses are more likely to be considered in risk judgments [8].

Buyers' perceptions may arise from direct observation, say from viewing of affected properties, or from an expectation of the effects based on buyers' beliefs. The beliefs that underlie the expectation may be formed by previous experience with waste facilities, from media reports, word-of-mouth information, or from virtually any source of background beliefs. Therefore, some effects may be expected (and hence perceived) merely because many waste facilities are believed to cause those effects.

The expectations may be worse than the actual effects that occur once the facility is in operation. Hence, the perceptions of facility impacts may be more negative and less accurate during shock periods, when awareness is heightened and perceptions are derived from expectations, than after a noxious facility is operating and perceptions more closely reflect the observed impacts (as shown in

[5]). Shock periods with heightened awareness occur in the facility siting process during the pre-development stage after the site announcement, during facility start-up (depending on the level of public acceptance of the facility), and in conflict resolution stages during facility operation if and when new crises occur or become apparent [9]. During shock periods, temporary PV impacts and higher turnover rates are possible [10]. Some evidence shows that increased numbers of property listings and longer times on the market occur at municipal waste incinerators after site announcement [11]. A closed municipal landfill near Seattle created risks of explosions and health effects from landfill gas migration that led to temporarily lower (by 10 to 15%) property values and significant turnover of residents (over 30%) during a two-year period in a suburban community [12]. These effects are often difficult to test statistically, because typical host communities provide low frequencies of listings and sales [11].

Two underlying assumptions are related to the perception and valuation of facility impacts on (i.e., the changes to) property attributes in the formation of buyers' attitude toward the property [13]. First, buyers' accurate perception of the facility impacts and perfect knowledge of the real estate market are required for PV impacts to accurately and reliably reflect value. This assumption seems questionable because it is unlikely that buyers can accurately characterize and evaluate all the facility impacts and compare the resulting levels of affected properties' attributes with those of comparable unaffected properties on the market to establish their purchase price. No specific results to document this assumption have been found to date. Second, different sensitivities between sellers and buyers and among buyers can still affect PVs. Experienced real estate agents often qualify buyers and screen properties to obtain a good fit between buyers' wants and property attributes. Thus, sensitive buyers may not be shown properties affected by noxious facilities as frequently as insensitive buyers. If there are enough insensitive buyers in the market to purchase all impacted parcels and real estate agents are efficient, then no PV impacts will occur, although the aggregate value difference placed on facility impacts by all buyers may be negative [11].

PV impacts can be measured only if the magnitude of the causal effects and the intensity of the interactions can be quantified. The levels of the facility impacts must be measurable and predictable as concentrations, exposure levels, intake rates, etc. throughout the affected study area to accurately reflect the differences in impact level on residential properties. Proper indicator scales must accurately reflect the type and level of facility impacts as perceived by sellers and buyers. The impacts can be described with impact profile curves showing the levels of impacts with distance and direction from the facility. The combination of all impact profiles can be compiled into a facility footprint for each phase of the facility activity. The influence of the facility effects must, however, be separated from other independent variables, such as physical housing and parcel characteristics, neighborhood characteristics, accessibility and amenities, and the effects of other noxious facilities. The conditions for property value impacts to occur are simple, but require accurate specification of causal impacts and their cause-effect connections related to buyers' and sellers' perception of facility impacts, perfect knowledge of facility impacts and the real estate market, equal seller and buyer sensitivity to the impacts, and the absence of selective purchases by insensitive buyers. The following analysis attempts to identify the types of impacts and causal connections that lead to significant and consistent property value impacts.

RESEARCH METHODOLOGY

The approach adopted here was to conduct literature research and content analysis of published studies of residential property value impacts from noxious facilities. This approach was deemed superior to yet another assessment of PV impacts at a single facility site, because the analysis of numerous PV studies permits the comparison of impacts over a range of facilities, impacts, and locations to determine consistency of results and reasons for differences.

A thorough literature search was conducted of data bases (EconoLit, Enviroline, Environmental Periodicals Bibliography, NTIS, and WasteInfo), relevant journals from 1988 to 1995, a review of all reference lists, and a search of the Scientific Citation Index for references to authors of relevant articles from 1985 to 1995. Sixty-nine PV impact articles and studies were found (see the complete reference and summary lists in [1]). These studies were analyzed to identify noxious facility categories. Then, the objective impacts, psychological impacts, trigger impacts, and local benefits of each facility category and their magnitude, predictability, and perception were identified from the environmental impact assessment and risk perception literature. The PV impact studies were then analyzed and the following results were extracted:

1. the consistency and magnitude of significant negative PV impacts, for each type of noxious facility and for time periods during the development process, and
2. the significance of objective, psychological, trigger impacts and local benefits and their cause-effect connection with PVs.

The results were compared to determine the types of facilities and impacts that are likely to cause significant property value impacts. Based on these results, further PV impact research and mitigation measures are recommended.

ANALYSIS AND RESULTS

Noxious facility types and impacts are identified and described. Then, the findings of PV impacts are summarized and discussed to answer the three study questions of 1) consistency causal impacts and cause-effect connections to PV impacts, 2) the time period of PV impacts in relation to the facility siting and development, and 3) the consequences for PV impact assessment and mitigation.

Noxious Facility Types and Impacts

The research found PV studies for ten types of noxious facilities and effects, including A—nuclear power plants and radioactive waste facilities, B—solid and hazardous waste management facilities, C—airports, D—transportation facilities (roads, highways and railroads), E—air pollution, F—water pollution, G—visibility, H—buildings and developments, I—natural hazards (landslide, earthquake, and flood zones), and H—conventional electrical power plants and transmission lines (see Table 1, after 1). The objective physical and community impacts, psychological impacts of fear, stigma and uncertainty, trigger impacts, and local benefits are generically identified and discussed to determine possible causal impacts on property values.

Objective Impacts—Physical and Community Impacts

Physical impacts can be classified into three categories for the purpose of this discussion: 1) *Health impacts on humans,* 2) *Environmental quality impacts on* water quality, air quality and soils, and on fauna and flora, including ecosystem health, and 3) Nuisance impacts, such as noise, odor, view disamenity. Community impacts include socioeconomic impacts of population growth, demographic changes, infrastructure, housing, and service effects.

Different types of noxious facilities generate very different types and levels of negative physical and non-physical impacts (see Table 1):

- Nuclear power plants and radioactive waste facilities and sites are among the largest of noxious facilities. They create low impacts on human health due to long-term, low releases of radioactive material and very low probability-high consequence hazards from accidents and catastrophic events as compared with numbers of fatalities from other technological and natural hazards [14]. Similarly, the overall impacts on environmental quality are low. As most large facilities, they generate nuisances as view noise and impacts close to the facility (see Table 1 [15, 16]). Their community impacts are usually large during construction and continue during operation because of the attraction of workers and their families. Thus, housing, infrastructure, and community services are affected. Property values are expected to increase in response to added demand for housing. These socio-economic effects may occur after accidents due to the influx of cleanup crews [17].
- Hazardous waste and municipal solid waste (MSW) facilities' health effects from leachate, gas, and dust emissions have been documented as low to moderate (at risk levels of 10^{-5} to 10^{-7} excess cancer deaths, see [18]). Further impacts on air and surface and groundwater quality have been

documented [19, 20]. These facilities are considered sources of nuisances because of odor, visual unsightliness, and noise [19]. Their community impacts are usually low due to small numbers of employees although some infrastructure demands (access roads, wastewater treatment) are evident.

- Airports cause large impacts from noise and access traffic, and some air quality, water quality, and land use impacts [21]. They generate large socio-economic impacts from population growth due to employment and business growth near the facility [16].
- Roads, highways, and railroads create predominantly noise and view impacts, with low air quality, human health, and environmental effects, except on sensitive land uses, such as habitat [16, 21, 22]. Community impacts include severance of land uses, some loss of land, and dislocation of businesses and residences.
- Air pollution, water pollution, and visibility generically cause physical impacts and may affect human health and environmental quality. Socio-economic impacts may occur, but are difficult to characterize without considering the specific sources.
- Certain types of buildings, such as shopping centers, high-rises, and public housing developments, cause physical impacts as view, traffic, and noise effects, along with minor air quality effects. Many effects stem from the traffic of the users. Socioeconomic effects as increased crime, infrastructure, and service requirements may result, depending on the size.
- Natural hazards of landslide, flood, and earthquake zones create physical risks to human safety, health, and environmental quality, as well as socio-economic impacts due to disruption and damage losses.
- Conventional electrical power plants and transmission lines generate radiation risks and induced electro-magnetic fields from transmission lines, air pollution impacts from stacks, and view impacts due to tall stacks and towers [21, 22]. The community impacts from population growth are low, except during construction. However, the effect on community image can be substantial [5].

Generally, the cause-effect relationships for physical impacts are relatively well understood and predictable. The types and rates of emissions for many scientifically measured air and water quality parameters can be determined, there are many models for the prediction of air quality, water quality, and soil quality impacts (see, for example [22]), and the results are quantifiable and measurable. The impact level profiles can be predicted over space (distance and direction) and time.

The types of emissions, transport and dispersion mechanisms, the resulting spatial and temporal impact patterns, and, most importantly, the level and spatial profiles of the impacts vary between types of noxious facility. Impact

Table 1. Noxious Facility Impacts and Local Benefits

Facility Type and Objective Impacts	Psychological Impacts	Trigger Impacts	Local Benefits
A — Nuclear Power and Radioactive Waste			
Low — due to low human health and environmental quality effects from normal operations, low probability–catastrophic events, and visual impacts, some high community impacts as population and service impacts	Large — due to high dread catastrophe impacts and high uncertainty from scientific and personal lack of familiarity and controllability	Medium — visual impacts of cooling towers and stream plumes	Large — due to tax income, employment, economic development, infrastructure and recreational facility development during construction and operation, damage compensation to home owners, and clean up activities may generate employment and business
B — Waste Disposal Facilities			
Moderate — low human health impacts, medium environmental quality impacts from air and water emissions, moderate view, odor, and noise impacts, low community impacts	Medium high — due to medium dread and medium uncertainty and controllability	Medium — due to view, odor and noise impacts in the immediate vicinity up to 500 m (1,500 feet)	Small — due to moderate taxes, low employment, and infrastructure development
C — Airports			
Large — due to noise impacts, and traffic, socioeconomic impacts from population and business growth, low air pollution, water quality, and resource use impacts	Low — due to low dread and high familiarity	Low — due to lack of underlying health or stigma impacts	Large — due to business, tax, and employment benefits
D — Roads, Highways and Railroads			
Medium to high — due to noise, view, and air pollution impacts, some impacts on access, separation of land uses, low water quality, and wildlife impacts, and some socioeconomic impacts as loss of land, severance of ties, and dislocation of residences and businesses	Low — due to low dread of and high familiarity with traffic activities	Low — view may trigger noise and air quality impact perceptions	Low to moderate — indirect business and employment benefits after direct temporary construction benefits

E — Air Pollution and F — Water Pollution			
Moderate to high — direct effects on human health are low, moderate on environmental quality at allowed levels, some observable effects as odor and view	Moderate — due to moderate dread and high familiarity	Moderate — some view and odor impacts indicate health and environmental quality impacts	Unknown — most air pollution emitting activities generate benefits, but these are not connected to local benefits
G — Visibility			
Medium to high — direct impacts	Unknown and variable	Low — other nuisances as noise and odor may trigger view concerns	Unknown — depends on the specific source activities
H — Buildings and Developments			
Low — as view, noise, traffic, small air emissions, socioeconomic impacts as crime and service requirements	Moderate to high — depending on the nature of the building, public housing, prisons, and halfway housing carry social stigma	Low to moderate — as view, noise	Moderate to high — as tax income, employment, access to services
I — Landslide, Earthquake and Flood Zones			
High — immediate safety impacts on human health, environmental quality, and on property and community	Low uncertainty, medium to high dread	Low — noise and view may have limited trigger effects	Low — damage compensation to home owners and clean up activities may generate employment and business
J — Electrical Power Plants and Transmission Lines			
Moderate — air quality from particulate and SO_2 emissions, water quality effects on environmental quality and ecosystem effects, nuisances as view of stacks and plumes, noise, socioeconomic effects on land use, housing, and services during construction	Medium to high — medium dread, but high uncertainty, particularly related to electromagnetic radiation	Moderately high — view of stacks and plumes, noise	Low — after construction, medium tax and low employment benefits

footprints for similar facilities vary (see [19]). Different types of noxious facilities create different sets, levels, and profiles of physical and non-physical impacts. As a result, their property value impacts are expected to vary significantly.

This means that different types of noxious facilities will create different levels of impact so that PV impacts must be analyzed and compared for very specifically defined facilities, impacts, and impact levels. Impact levels do not decline as simple, linear functions with distance in predominant transport directions. As a corollary, the simple linear distance from a noxious facility or dummy variables to indicate distance zones or location in a study area will not accurately indicate the level of facility impacts.

Health risks from a specific facility are predictable, but are not easily measured and separated from other risks. The magnitude of familiar health risks are assessed correctly by publics, while low probability-high consequence risks are overestimated and common, high common risks are underestimated. Conversely, air and water quality impacts are perceived by a limited number of readily observable parameters (debris, color, turbidity) that do not necessarily reflect scientific air and water quality [8]. Nuisance impacts (noise, odor, view) are readily perceived by residents; except for noise levels, nuisances are difficult to measure and quantify objectively, particularly the relationship of nuisance level and character with attitude.

Psychological Impacts as Risk Perceptions

Psychological impacts as defined here include fear, stigma, and uncertainty as determined by risk perception characteristics.

- Nuclear power plants and weapons storage arsenals are the most dreaded and least understood facilities (see [23]). They create large fear and stigma impacts and are consistently located in the upper right quadrant of the risk perception factor analysis charts (see Figure 3 and Table 2);
- Hazardous waste and municipal solid waste (MSW) facilities are perceived as moderately risky; significant levels of fear and stigma are associated with waste facilities [5, 24]. Hazardous wastes and materials are found to the right of the middle point of dread and halfway between the neutral point and the top end of the "unknown/uncertain" scale (see Figure 3, after [23]).
- Other types of facilities and environmental impacts are associated with risk perceptions (see Figure 3 and Table 2). Airport and road and railroad transport activities are rated as moderate to low on the dread and on the unknown/uncertain risk perception scales, except for airplane accidents which rate high on the dread scale. Air pollution risks are rated moderate on the dread risk and neutral on the unknown scale. Natural hazards are rated moderately high on the dread and catastrophic scales, but low on the unknown/uncertainty scale placing them in the lower right quadrant of

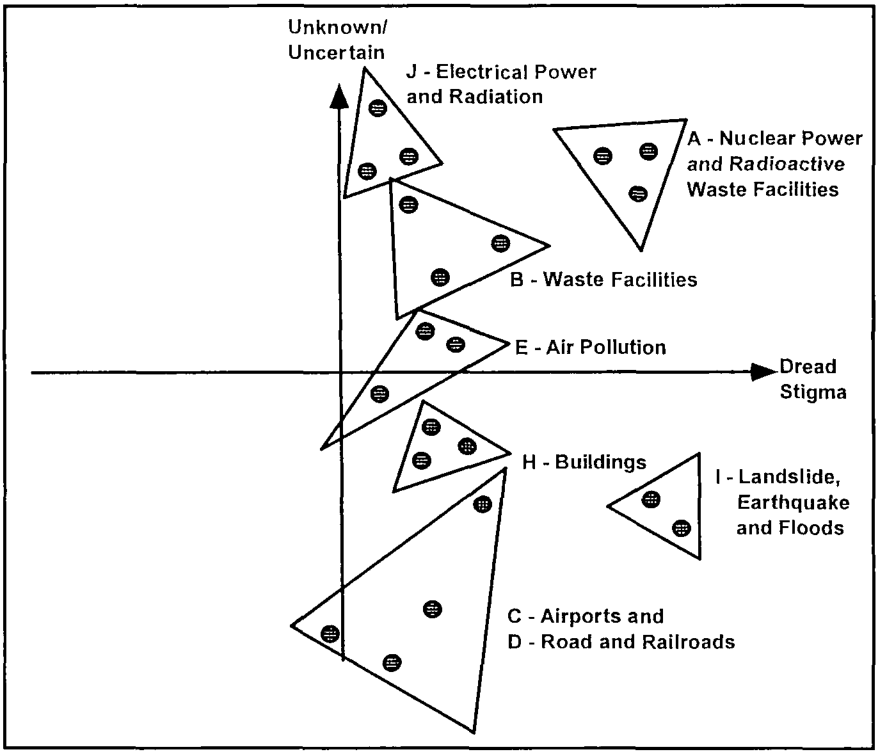

Figure 3. Hazard location on a two-factor plane of risk perception.

risk space [25]. Electrical power generation and electrical radiation (from transmission) lines are rated moderate on the dread scale and high on the unknown/uncertain scales [23].

There are no established quantified measures nor predictive models for these impacts. They are therefore poorly predictable. The measurements to date have been conducted with psychometric scales and the results are descriptive. In part this is because the perceived characteristics ("dread," "uncontrollable," "global catastrophic," "inequitable," etc.) are qualitative. Moreover, the perception and evaluation are measured subjectively and the results are fraught with large interpersonal variation. The levels of risk perception, fear, and stigma impacts over distance, direction, and time are therefore not predictable. These impacts can only be described for general categories of facilities and activities, but to establish spatial and temporal profiles, they must be measured for each facility and community specifically. This requires a specific survey of community risk, fear,

Table 2. Psychological Impacts as Risk Perception Ratings of Dread and Uncertainty

Facility Category	Associated Hazards in Psychrometric Studies	Location on Risk Perception Factor Chart and Rating of Dread and Unknown Risks
A — Nuclear power and radioactive waste facilities	Nuclear power, nuclear reactor accidents, radioactive waste	Extreme upper right quadrant High dread / high unknown risk
B — Hazardous wastes and waste disposal facilities	PCBs, trichloroethylene, pesticides, mercury, DDT, asbestos	Upper-middle right quadrant Moderate dread / moderately high unknown risk
C — Airports and D — Roads, highways, and railroads	General and commercial aviation, jumbo jets, motor vehicles, auto accidents, bridges, railroads, railroad collisions	Lower right quadrant Moderate to low dread / low uncertainty
E — Air pollution and F — Water quality	Coal burning, auto exhaust, fossil fuels	Lower middle right quadrant Low to moderate dread / neutral uncertainty
G — Visibility	None identifiable	Unknown
H — Buildings and developments	Skyscrapers, skyscraper fires, bridges, dams	Lower middle right quadrant Low to moderate dread / Low uncertainty
I — Landslide, flood, and earthquake zones	Tornadoes, earthquakes	Lower right quadrant Moderate to high dread (catastrophic consequences) / Low uncertainty
J — Electrical power plants and transmission lines	Non-nuclear electric power, hydroelectric power, electricity radiation	Upper middle right quadrant Moderate dread / High uncertainty

and stigma perceptions and attitude (see e.g., [5] and [24]). Thus, to date, the specification of psychological impacts for PV studies has been qualitative; these impacts are usually indicated either by a dummy variable for the presence of a noxious facility or by distance. Neither of these measures ensures accuracy of the "objective" impact level, nor of a reliable correlation with residents' attitude. In summary, risk perception, fear, and stigma are poorly predictable and measurable. The perceptions of these impacts may be significant, but there may be strong variation among the sellers and buyers.

Psychological impacts as fear and uncertainty are readily perceived but difficult to measure with psychological and social survey methods. Furthermore, these impacts are not necessarily connected to any physical effects and may not vary spatially across the affected community. Stigma, for example, may be connected to the community name and apply to the entire community equally. Further, the risk perception of nuclear power is strongly affected by the publics' judgment of worst-case consequences, while motor vehicle and other, more familiar hazards are judged by the level of personal benefits [26]. Publics' judgments of risk were shown to split into two groups: risks are either overestimated and the risk is considered significant, or the risks are underweighted and the risks are considered negligible [27]. As a result, risk perception, fear, and stigma levels may not coincide with the profiles of physical impacts. The lack of valid quantified measurement techniques and indicator scales remains a principal difficulty with determining non-physical impacts on property values.

It is often suggested, however, that property value impacts will respond to the levels of fear and stigma rather than to physical impacts and risks [3]. The risk perception research would suggest that facilities that rate high on the dread and unknown scales (i.e., nuclear and radioactive waste facilities) will show significant property value effects, while the facilities that are perceived to be less risky cause less fear, stigma, and uncertainty and, therefore, less significant property value impacts.

Trigger Impacts

Some readily observable physical impacts are associated with underlying beliefs about unobservable, intangible, or psychological impacts. Although the association of physical health risks and risk perceptions is weak, several studies have shown that some readily perceived nuisance impacts are significantly correlated with residents' beliefs about non-physical impact levels and with their attitude about noxious facilities [5, 6]. These observable impacts have been called "trigger" impacts:

- Nuclear power plants exhibit a medium to strong trigger impact of view of the reactor building, cooling towers, and plumes [22]. While noise may occur close to the plant, this impact is not significant outside the offset distance, and, hence will not function as a trigger impact.
- Waste facilities can create several types of trigger impacts as view, noise, and odor up to distances of 500 m [5]. These impacts are linked to underlying beliefs about health risks, stigma, and loss of control and to more negative attitudes about the facilities.
- Airports and transportation lines have low levels of trigger impacts, possibly as view that triggers concerns about noise and air quality [21, 22].

- Air and water pollution impacts may be triggered by obvious visual impacts of plumes and color, debris, flotsam, and other obvious indicators. These are not always present and not necessarily correlated with scientific air and water quality impacts [8].
- Visibility as a primary impact does not generically have trigger impacts associated with it.
- Buildings and Developments may have moderate triggers of view, noise, and traffic.
- Landslide, earthquake, and flood zones may cause low levels of noise and view stimuli as indicators of the underlying impacts.
- Electrical power plants and transmission lines create view impacts of stacks and towers, low impacts of transformer noise close to the facilities [16, 21].

Trigger impacts are moderately well predictable, quantifiable, and measurable (see comments above about nuisance impacts). They are easily perceived and well related to the residents' attitude. As a result, it is expected that these types of impacts will be causally related to property value differences.

In summary, facilities with significant trigger impacts are predicted to cause significant property value impacts. Conversely, facilities without clear triggers for undetectable physical impacts, or for fear, stigma, and uncertainty are expected to show inconsistent and possibly insignificant property value impacts. This prediction may contradict the findings of the psychometric risk perception research, whereby insidious, long term, unobservable, uncertain, in short, the "dreaded" and"unknown," effects, are perceived as more risky and, hence, less desirable.

Local Benefits and Net Facility Impact Footprints

Local benefits may accrue to the residential property owners near the noxious facility as some of the facility's primary products or services (such as improved access to waste disposal). As well, coincidental facility benefits (employment, environmental quality improvements, improved infrastructure, or recreational services) may accrue to the affected community and may offset negative facility impacts on property value. In essence, the net effect of local benefits and negative impacts are combined in the judgment of property value differentials (see Table 1).

- Nuclear power plants produce large local benefits from taxes, employment, business growth, infrastructure, and property value increases from housing demand. Some of these components may be considered negative socioeconomic impacts, but from the perspective of residential property values generally create benefits that are low close to the plant, increase to a moderate (desirable) distance, and then decrease with increasing distance from the site. The net facility impact footprint is determined by high fear and uncertainty, medium to high view trigger impacts, and high offsetting local benefits. The resulting PV impacts are therefore likely to be moderate and inconsistent.

- Waste disposal facilities generate low local benefits as taxes, minor employment (usually in the range of 20 to 50 positions), and some business activity. Many types of physical impacts combine into a complex footprint. The fear, stigma, and uncertainty impacts are notable, as are the trigger impacts. The combination of the effects is complex and not linearly declining with distance. Some PV impacts close to the facility are expected, but the causal connections are vague.
- Airports create large local benefits, predominantly from employment and business growth. The predominant noise and traffic impacts are large and observable, but possibly offset by the large local benefits.
- Roads create local benefits as improved access, and some indirect business and employment, but these effects are often concentrated at intersections and may be very low during operation. The noise impacts are large, readily observed and not completely offset by the local benefits.
- Air and water pollution and visibility impacts do not create local benefits, although specific sources may. The net impacts are unclear, unless specified for specific facilities.
- Buildings may generate moderate local benefits as tax income, employment, access to services, etc., but the benefits vary and can be spatially limited. The physical impacts are small and confined to the immediate vicinity of the site. Fear and stigma can be significant, but vary with the type of development.
- Landslide, earthquake, and flood zones create local benefits as damage compensation, employment, and business after the events. These benefits are minor compared with the impacts of the events. The immediate impacts on human safety are large and significant and dominate the footprint. Fear, stigma, and uncertainty are low.
- Electrical power plants and transmission lines create large local benefits during construction, but low benefits during operation due to low employment, and some taxes. Some physical impacts, such as air pollution and electrical radiation are significant, but electrical facilities are fraught with high uncertainty and strong view trigger impacts. Local benefits are small.

Local benefits are usually difficult to predict accurately and do not follow a strict distance-decay relationship with an origin at the site. As a result, the net effect of negative facility impacts and local benefits on property values is difficult to predict. Similarly, local benefits may not be clearly perceived and valued in terms of property value, because many are intangible public goods (access). Some, however, clearly and directly improve residential property values, such as increased local employment from nuclear power plants and airports.

Property Value Impacts and Causes

In this section, the property value impacts of the ten noxious facility and effect categories are determined to answer the study question: What types of impacts cause significant PV impacts and during what period of the facility development?

The majority of A—nuclear and radioactive facilities and B—solid and hazardous waste facilities exhibit insignificant or inconsistent PV results at 80 percent of nuclear plants and at 65 percent of waste facilities. The levels of PV impacts at the sites with significant negative impacts amount to minus 10 percent PV at nuclear sites and minus 1.3 percent to 19 percent increase per mile distance up to three miles from waste facilities. The PV impact results are inconsistent.

At most sites (approximately 90%), the facility impacts were not specified beyond a general listing of presumed effects. Only at four waste facility sites were the impact levels actually quantified. At one site, the psychological impacts were quantified as the perceived risk levels among residents [29] and showed significant association with PV impacts, although odor and distance did not. However, odor impacts were associated with the risk perceptions and could have functioned as a trigger impact. At three other sites, the facility impacts were quantified as physical impacts including air quality, water quality, and nuisance impacts in addition to distance [5, 28], and showed no significant correlation with PV impacts.

The effects of shock periods on PVs were also tested by identifying significant and insignificant effects by time periods (see Table 3). This analysis is somewhat limited by the scarcity of studies that tested PVs during shock periods. Most studies were conducted during operation.

Before site announcement, all PV impacts were insignificant. After announcement and during construction, approximately 50 percent to 60 percent were significant; during operation, between 40 percent and 67 percent were significant. During cleanup and after closure up to 50 percent were significant. The percentages of sites with significant impacts during shock periods is not significantly higher than during other periods. As a result, neither the specific causes of PV impacts nor the differences between facilities with significant and insignificant PV impacts can be distinguished. In contrast, C—Airports and D—Roads and Railroads show significant PV impacts at 100 percent of the sites. Their PV impacts are consistently significant at up to 16 percent PV decreases. Most studies specified noise impacts and used measured noise levels as the impact indicator scale. However, even studies with unspecified impacts and distance/dummy indicators showed significant negative impacts. Most studies used hedonic regression; sales comparisons all showed significant results too. General environmental quality effects on E—Air quality, and G—Visibility cause predominantly significant PV impacts, on average at about 88 percent to 100 percent of sites. Water quality effects were studied in three references and showed inconsistent results with 67 percent significant effects. All studies specified the

Table 3. Property Value Impacts in Shock Periods

	Before Announce-ment	After Site Announce-ment	Construction and Startup	Operation	After Closure/ Cleanup
A — Nuclear Power Plants					
Significant PV Impacts	0	1	0	2	0
No PV Impacts	1	3	0	1	1
B — Municipal and Hazardous Waste Facilities					
Significant PV Impacts	0	3	1	8	2
No PV Impacts	6	4	1	12	2
C — Airports					
Significant PV Impacts	0	1 — Shock periods	0	5	0
No PV Impacts	0	0	0	1	0
D — Roads, Highways, and Railroads					
Significant PV Impacts	0	1	1	11	0
No PV Impacts	0	0	0	0	0
E — Air Quality and F — Water Quality Impacts					
Significant PV Impacts	0	0	0	9	0
No PV Impacts	0	0	0	1	0
G — Visibility					
Significant PV Impacts	0	0	0	3	0
No PV Impacts	0	0	0	0	0
H — Buildings					
Significant PV Impacts	0	0	0	2	0
No PV Impacts	0	1	0	0	0
I — Landslide, Earthquake, and Flood Zones					
Significant PV Impacts	1	1	0	2	0
No PV Impacts	0	0	0	0	0
J — Electric Power Plants and Transmission Lines					
Significant PV Impacts	0	0	0	2	0
No PV Impacts	0	0	0	3	0
Summary — Total					
Significant PV Impacts	1	7	2	44	2
No PV Impacts	7	8	1	18	3

physical impacts and used quantified impact scales of pollutant concentrations in air or water and view ratings for visibility impacts. Source characteristics were not specified and, therefore, trigger impacts and local benefits were not identifiable. Nonetheless, these specific single physical impacts cause significant PV impacts at the levels studied.

Certain buildings and developments (category H) showed predominantly insignificant PV impacts, resulting from a study of six public housing sites. The impacts at all sites were only mentioned generally and distance/dummy variables were used. All studies used hedonic regressions. The results are inconsistent and do not support significant impacts on PVs.

Landslide, Earthquake, and Flood zones (category I) showed consistent negative PV impacts, before and after actual natural hazard events. Again, simple physical hazards and impacts appear to produce significant PV impacts.

Electrical power plants and transmission lines (category J) showed mixed results at five sites. The impacts were usually not specified and instead were indicated by distance/dummy variables. Hence, the causal impacts and connections cannot be determined. The impacts that can combine several physical, psychological (uncertainty over electrical radiation effects), and trigger (view) impacts with low local benefits produce inconsistent PV impacts.

DISCUSSION OF THE RESULTS

The compilation of facility type and impact footprint characterization and the results of the PV impact analysis in Table 4 allows a comparison of characteristics related to inconsistent or consistent PV impact findings.

Inconsistent PV impacts were found at A—Nuclear power and radioactive waste facilities, B—Solid and Hazardous Waste Facilities, H—Buildings and Developments, and J—Electrical Power Plants and Transmission Lines. These facilities create low to medium high levels of multiple physical impacts. For nuclear, waste, and electrical facilities, the physical impact profiles are complex and combine several different types of impacts. Conversely, the psychological impacts of this group were all rated as medium to high, either because of high fear of catastrophic consequences (for nuclear power plants and waste facilities), stigma (waste facilities and some buildings), or uncertainty (nuclear plants and electrical transmission lines). Similarly, these facilities all had notable trigger impacts as view, odor, or noise. The PV impact results were, however, inconsistent for all facilities in this group. Large local benefits from the nuclear power plants may contribute to the generally insignificant PV impacts of this type of facility, but other categories (airports) generate high local benefits and show consistent PV effects (see below). For all PV analyses of these categories, the impacts were not specified and distance or dummy variables were used as proxies for impact levels. Thus, the impacts are poorly defined. Most analyses were conducted with hedonic regressions; the few sales comparisons showed less consistent PV impacts. Overall, the characteristics of complex, multiple physical impacts, albeit in the presence of significant psychological and trigger impacts, with poor specific and quantified impact definition show no consistent PV impacts. This result contrasts with the intuitive expectation of PV impacts for these highly controversial facilities.

Consistent PV impacts were detected for C—Airports, D—Roads and Railroads, E—Air quality, G—Visibility, and I—Landslide, earthquake, and flood zones. These facilities and sites are characterized by significant, single (or simple), directly observable physical impacts with low fear, stigma, and uncertainty and low trigger impacts. The obvious physical impacts seem to be clearly reflected in PV impacts at sites with high local benefits (C—Airports) as well as at sites with moderate or low local benefits (I—Landslide, earthquake, and flood zones). The physical impacts for this group were all specified and their levels quantified. Hedonic regression with various functional forms was used in the majority of cases. The results were highly consistent, i.e., over 75 percent of studies in each category showed significant negative PV impacts at the tested levels of noise, air quality, and view. From this comparison, it therefore appears that facilities and sites with single, easily observed physical impacts consistently affect PVs even in the presence of significant local benefits (e.g., airports with employment). Facilities with multiple, complex impacts show inconsistent effects despite significant psychological impacts. The effect of shock events and periods on PV impacts could not be resolved because very few studies specifically analyzed PVs during periods of high awareness. Shock effects are expected to be temporary only.

The identification, specification, and quantification of facility effects that may cause property value differentials appears important for obtaining consistent results. General unspecified or combined impact profiles may mask the variation over space that relates to PV differences. Without this specification, the separation of facility effects from other influences with adequate background variables for housing, neighborhood, access, and other amenities on PVs is difficult. Finally, the use of hedonic regression and the testing of several functional forms is essential to separate the other effects and correctly select an appropriate value curve to represent sellers' and buyers' values.

CONCLUSIONS FOR PROPERTY VALUE PREDICTION AND MITIGATION

Currently, PV assessments only provide consistent results under narrowly defined conditions as for facilities with single or predominant, readily observable physical impacts as noise (airport and roads), the physical effects of air quality and visibility, and landslide, earthquake, and flood zones. Consistent significant negative results occur when facility impacts are specified and their levels are quantified and separated from other PV factors. Hedonic regression analyses

Table 4. Summary of Property Value Impact Results

Facility Type, Impacts and Net Causal Effect on PV Impacts	PV Assessment Methods and Relationship to Results — Approach — Impact Definition — Indicator Variable	Percentage of Sites with Significant Negative PV Impacts and Value of Negative PV Impacts	Consistency of Significant PV Impacts
A — Nuclear Power and Radioactive Waste — Net effect unclear, due to psychological impacts and offsetting benefits			
— Physical-Low — Psychological-High — Trigger-Moderate — Local Benefit-High	— Approach — All hedonic/regression — Impact Definition — general — Indicator Variable — distance and dummy scales	Significant negative PV impacts at 20% of sites Δ PVs of minus 10%	Inconsistent PV impacts
B — Municipal and Hazardous Waste Facilities — Net effect is unclear due to varying facility conditions and physical impacts, combined physical-stigma-trigger impacts			
— Physical-Moderate — Psychological-Notable — Trigger-Notable — Local Benefits-Low	— Approach — hedonic regression and sales comparisons — Impact Definition — most general, three sites with specific impacts — Indicator Variable — most use distance/dummy, few quantified	Significant negative PV impacts at 35% of sites Δ PVs of minus 1.3% to 19%/mile up to 2.0 to 3.5 miles	Inconsistent PV impacts
C — Airports — Net effect stems from observable, direct, single noise impact; low stigma and high local benefits do not interfere with the cause-effect connection			
— Physical-High — Psychological-Low — Trigger-None — Local Benefits-High	— Approach — most use hedonic/regression — Impact Definition — specific, single noise impact — Indicator Variable — noise levels in dBA	Significant negative PV impacts at 100% of sites Δ PVs of minus 0.4 to 0.5 per dBA increase, total Δ PV of 4.5 to 22.5%	Consistent significant PV impacts
D — Roads, Highways, and Railroads — Net effect stems from observable, direct, single physical impact with some local benefits			
— Physical-High — Psychological-Low — Trigger-None — Local Benefits-Low	— Approach — most use hedonic/regression — Impact Definition — specified as noise — Indicator Variable — noise levels, distance/dummy scales show same results	Significant negative PV impacts at 100% of sites Δ PVs of minus 0.08 to 0.48%/ dBA, total 8 to 16%	Consistent significant PV impacts

E — Air Quality and F — Water Quality — Net effect stems from observable physical impacts, with some triggers			
— Physical-Moderate — Psychological-Moderate — Trigger-Notable — Local Benefit-Low	— Approach — all hedonic — Impact Definition — all specified — Indicator Variable — all quantified levels as concentrations or deposition rates	Significant negative PV impacts at 83% of sites Δ PVs of minus $70/microgram-m3 $1,000/microgram-m2-day sulfation, $1613/10 ppm NOx	Fairly consistent significant PV impacts
G — Visibility — Net effect stems from obvious, direct physical impact			
— Physical-Low — Psychological-? — Trigger-None — Local Benefits-?	— Approach — all hedonic — Impact Definition — all specified — Indicator Variable — all numerical view ratings and distance and dummy results are consistent	Significant negative PV impacts at 100% of sites Δ PVs of minus $2,520, or $57 to 82.50/year	Consistent significant PV impacts
H — Buildings and Developments — Net effect stems from unobservable, mixed physical and psychological impacts			
— Physical-Low — Psychological-Notable — Trigger-Low — Local Benefits-Low	— Approach — all hedonic — Impact Definition — all general — Indicator Variable — all distance or dummy or both	Significant negative PV impacts at 25% of sites Δ PVs of minus 15% up to 1,000m, 5% above 1,000m	Inconsistent PV impacts
I — Landslide, Flood, and Earthquakes — Net effect stems from observable, single physical impact events			
— Physical-High — Psychological-Notable — Trigger-Low — Local Benefits-Low	— Approach — all hedonic — Impact Definition — specified risks — Indicator Variable — distance/dummy and quantified levels give consistent results	Significant negative PV impacts at 100% of sites Δ PVs of minus 2.5 to 3.7%	Moderately consistent significant PV impacts
J — Electrical Power and Transmission — Net effect combines physical impacts with trigger and psychological impacts			
— Physical-Low — Psychological-Notable — Trigger-Notable — Local Benefits-Low	— Approach — hedonic and sales comparison studies are inconsistent — Impact Definition — all general — Indicator Variable — all distance or dummy or both	Significant negative PV impacts at 40% of sites Δ PVs of minus 1%/1,150 ft up to 11,500 ft	Inconsistent PV impacts

reflect the variations in impact levels over distance and time and allow for the testing of several functional forms to select the best fitting form of value curves. If these conditions are met, then the assessment of PVs will provide fairly consistent results. Conversely, PV impacts either do not occur, or cannot be accurately determined at nuclear power plants, waste facilities, buildings and electrical power plants and transmission lines. The conclusions for further research can be based on the cause-effect sequence (see Figure 1). First, the facility characteristics that affect impact types and levels must be more accurately described and the resulting physical, trigger, psychological, and socioeconomic impacts and local benefits must be predicted for all facilities, particularly for those with multiple, complex, and interacting impacts. Simple distance or dummy indicators will not accurately reflect the impact levels to which residential properties are exposed. The resulting impact profiles and impact footprints should be established for the pertinent phases of the project, e.g., site selection and preparation, construction, operation, and closure. Finally, the causal connections of the types of impacts with property values can be tested for the individually specified impacts for specific facilities. This step will overcome the generic and vague impact specifications for entire facility categories and will allow specific impact levels to be tested for their effects on property values.

Mitigation of PV impacts is possible through the reduction of direct physical impacts. There is no evidence to support significant causal connections and, hence, the effectiveness of mitigation efforts aimed at psychological impacts or trigger impacts. The presence or provision of local benefits does not show consistent effects on PV impacts.

The mitigation of PVs can be achieved for facilities with consistent results and clear causal impacts by designing impact management measures along the causal sequence, beginning with prevention, control, mitigation, and compensation. Additional verification of the preferred management measures would be useful because compensation may not be the most effective measure to enhance community acceptance. Property value impact mitigation for facilities with inconsistent results currently lacks the rational basis that the results of the recommended research can provide.

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