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SITE SELECTION FOR NEW NUCLEAR POWER PLANTS

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ABSTRACT

The current methodology for selecting the most advantageous site(s) for nuclear power plant (NPP) development is based on the latest evolution of protocols originally established in the 1990's by the Electric Power Research Institute (EPRI) and others for programs in the USA, and more recently by the International Atomic Energy Agency (IAEA), among others. The methodology includes protocols that account for lessons learned from both the Gen III projects and the catastrophic event at Fukushima, Japan. In general, the approach requires consideration of Exclusionary or "fatal flaw" Criteria first, based on safety as well as significant impact to the environment or human health. Sites must meet all of these Exclusionary Criteria to be considered for NPP development. Next, the remaining sites are evaluated for Avoidance Criteria that affect primarily ease of construction and operations, which allow a ranking of sites best suited for NPP development. Finally, Suitability Criteria are applied to the potential sites to better differentiate between closely ranked sites. Generally, final selection of a Preferred and an Alternate Site will require balancing of factors, expert judgment, and client input, as sites being compared will differ in their scores associated with different Avoidance Criteria and Suitability Criteria.

RIZZO Associates (RIZZO) offers in this paper a modification to this methodology for selecting the site for NPP development, which accords to the categories of Exclusionary, Avoidance and Suitability Criteria strict definitions which can be considered as Absolute Factors, Critical Factors, and Economic Factors for a more focused approach to site selection. Absolute Factors include all of the safety-related Exclusionary Criteria. Critical Factors are those that are difficult to overcome unless extraordinary mitigation measures are implemented; they have a significant impact on the ability of the project to be successful and may cause the affected location to be eliminated if other sites are available. Economic Factors are important for their economic impact on the project and are typically the concern of the proponent rather than the regulator. Application of sensitivity analyses is discussed as a framework to provide more accurate, site-specific and quantitative characterization.

1. INTRODUCTION

Site Selection is the first step in a long process of identifying, qualifying and characterizing a location for the construction and operation of an NPP. The EPRI Siting Guide [1] describes a sequential process for site selection involving reduction of the area under consideration from a Region of Interest to Potential Areas, within which are identified Potential Sites, Candidate Sites, and ultimate identification of a Preferred Site and an Alternate Site. This general process (***Figure 1***) has been recommended by the IAEA [2]. In this process, the relative strength or "fitness" of site suitability factors are identified and importance to site suitability for the project (or weighting factors) are applied. In addition to providing a process for identifying suitable nuclear power plant sites, the approach is designed to satisfy

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environmental and nuclear authority requirements for the consideration of alternative sites to ensure that the selected site is among the most suitable for the project.

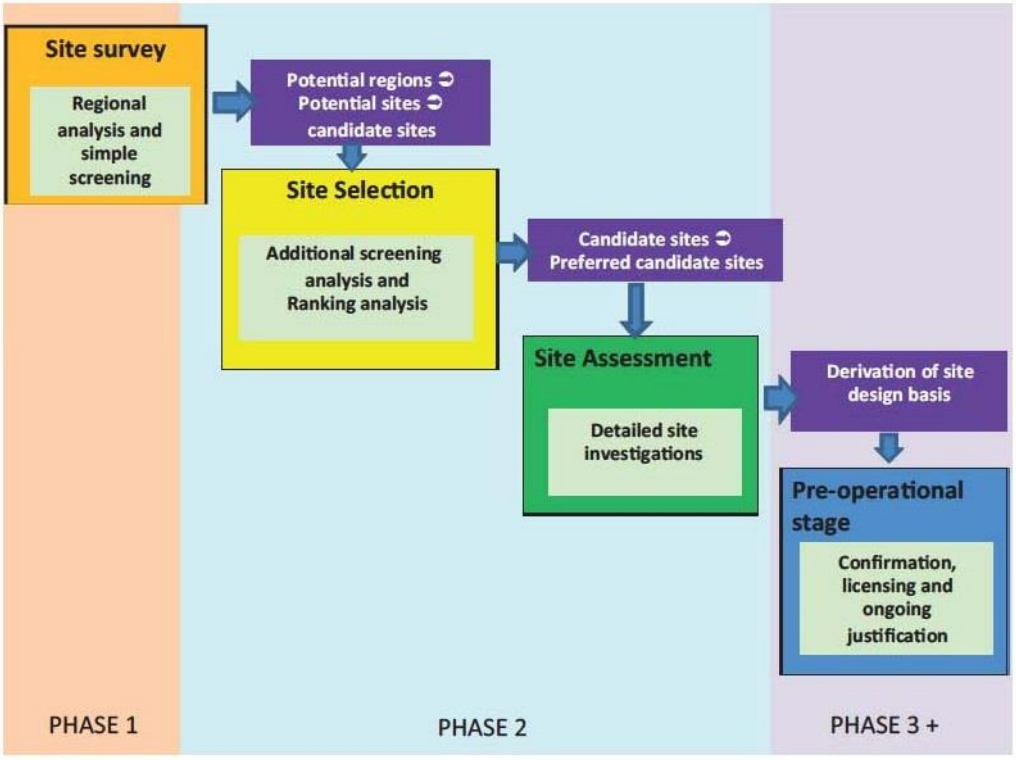

Figure 1. Siting and site evaluation of a nuclear project. [2]

The siting criteria are tailored to the geographic region and regulatory framework applicable to the new plant and address the full range of considerations important in nuclear power facility siting, including health and safety, ecological, socioeconomic, engineering and cost aspects. The criteria must be valid for the entire plant life cycle, including construction, operation, transportation, and accident conditions.

Since the guidance documents acknowledge that the specific criteria used for Avoidance and Suitability Criteria should be selected based on local considerations, RIZZO recommends a modification to the conventional methodology for selecting the site for NPP development. This methodology involves assigning strict definitions to the site selection criteria within the categories of Exclusionary, Avoidance and Suitability Criteria, which can be considered as Absolute Factors, Critical Factors, and Economic Factors, respectively, for a more focused approach to site selection. Absolute Factors are equivalent to the safety-related Exclusionary Criteria and recognize that there is no compromise in evaluating a site for safety of NPP operations and safe shut-down. Critical Factors affect constructability on the site or the ability of the project to be permitted by regulatory authorities, including environmental and human population concerns. Economic Factors include those that affect the overall cost of the project.

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RIZZO's current methodology meets or exceeds international guidance, and is flexible to allow focus on the issues of most potential impact to the country under consideration. It demonstrates how sensitivity analysis can be applied to validate siting decisions. The methodology allows for strategic (non-safety related) factors to be applied, such as to align with the country's strategic plan for development or to address public concerns. This approach is valid for newcomer countries as well as those with mature existing programs, and can be applied (perhaps is best applied) early in the country's overall power development program.

2. METHODOLOGY

The site selection process begins with the identification of the largest area under consideration for plant siting, called the Region of Interest (ROI). All available desktop information about the ROI is collected and evaluated to gain a broad understanding of the ROI with respect to issues and attributes important in the siting, construction, and operation of an NPP. These include aspects related to plant safety as well as impacts on surrounding populations and the environment. Information is collected and evaluated with respect to a broad range of seismic, geological/hydrogeological, environmental, cultural resources, and socioeconomic aspects of the ROI. Typically, because of the expense or intrusive nature of the work, site specific studies are deferred until one or two preferred sites are selected.

The result of the initial desktop information analysis is the identification of areas within the ROI that seem acceptable for an NPP site. Site reconnaissance is performed to validate the literature information about specific sites. A number of specific sites within those broad areas are identified, and then they are numerically ranked in order of attractiveness using criteria established on the basis of safety, environmental or socioeconomic impact, cost, and project strategic interests. ***Figure 2*** illustrates the variability in use of desktop information vs. site specific data collection in quantifying a subset of the various criteria used in site selection.

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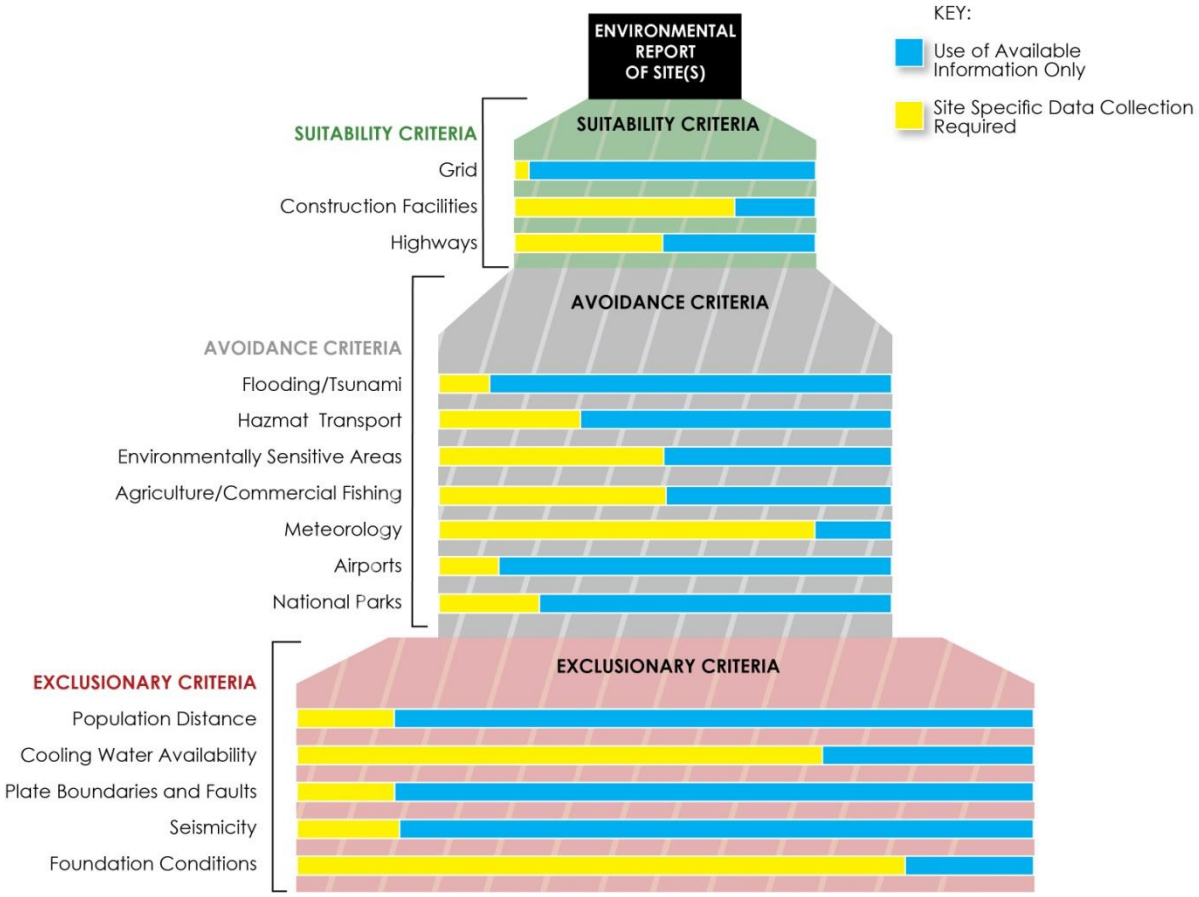

Figure 2. Example screening criteria showing a typical contrast between historical information available in the literature and the need for site specific studies.

A structured methodology, consisting of applying weighting factors and values to the specific criteria, provides an objective basis on which to compare the sites. Briefly, the following steps are typically implemented in site selection:

Application of Exclusionary Criteria

1. A limited number of Exclusionary Criteria, those criteria which must be satisfied or the area must be eliminated from further consideration, are applied to the ROI; remaining areas not affected by the Exclusionary Criteria are termed Candidate Areas and are retained for further investigation. ***Figure 2*** identifies the Absolute Factors that are appropriate as the Exclusionary Criteria using the RIZZO approach.

2. There is no ranking for Exclusionary Criteria. If the area does not pass any single one of the Exclusionary Criteria, it cannot be considered further for an NPP project.

3. In consultation with the project proponent, Potential Sites are identified within the Candidate Areas. Potential Sites are discrete parcels of land that could be acquired and developed for the NPP project.

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Application of Avoidance Criteria

4. A number of Avoidance Criteria are selected to provide a basis for the evaluation and subsequent ranking of the Potential Sites. Avoidance Criteria are those that degrade the suitability of a site, but are not sufficiently onerous to *prima facie* eliminate a site from consideration. Using the RIZZO approach, Avoidance Criteria are limited to Critical Factors in which the mitigation of negative impacts would be impossible or prohibitively expensive. These include environmental, societal, and land use impacts. In the EPRI (2002) approach, some of these criteria are listed as Exclusionary Criteria.

5. Specific objective values are applied to each of the Avoidance Criteria (i.e., a value of 5 would indicate that the site is not impacted by the specific criterion; a value of 1 would indicate that the site is highly impacted by the criterion). The values provide a quantitative way to assess how well each site displays a favorable attribute of the criterion.

6. A weighting is applied to each of the Avoidance Criteria. The weighting factor (perhaps ranging from 1 to 10) reflects how important each of the Criteria is to the decision-making process regarding site rankings. The higher the number, the more important the criterion is to the decision making process. A particular criterion may be very important to the attractiveness of the site, but there may be so little information available regarding that criterion that it cannot be used to discriminate among sites and therefore may be assigned low weighting factor. However, all of these factors must be considered later when performing a site assessment for the preferred site(s) to assure that the site(s) are adequately characterized for licensing.

7. For each site, the value is multiplied by the weighting for each criterion, and then the total for all criteria are summed to obtain a score for each site for the Avoidance Criteria. Potential Sites are thus ranked after consideration of Avoidance Criteria.

Application of Suitability Criteria

8. In the typical approach, the next step consists of selecting a number of Suitability Criteria to provide a basis for the evaluation of the most highly ranked Potential Sites to determine the best sites from among acceptable sites. Suitability Criteria are those that describe the potential environmental, socioeconomic or strategic attributes of a site, but for which the negative aspects can reasonably be mitigated. ***Figure 3*** provides examples of Exclusionary, Avoidance and Suitability Criteria.

9. Values, weightings, and the summation are performed as for the consideration of the Avoidance Criteria. The Suitability Criteria are applied to identify a smaller number of Candidate Sites. Any of the Candidate Sites are acceptable for a nuclear power project; typically the highest scoring site(s) are selected as the Preferred and Alternate Site(s) unless there is a strategic reason applied by the project proponent.

The RIZZO modification to this approach is discussed in ***Section 3*** below.

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		STEPS			
Section	**Criteria**	**1**	**2**	**3**	**4**
3.1	**Health & Safety Criteria**				
3.1.1	Accident Cause-Related				
3.1.1.1	Geology/Seismology (GEOL)				
3.1.1.1.1	Vibratory Ground Motion	E	E	S	S
3.1.1.1.2	Capable Faults	E & A	E & A	S	S
3.1.1.1.3	Surface Faulting and Deformation	A	A	S	S
3.1.1.1.4	Geologic Hazards	A	A	S	S
3.1.1.1.5	Soil Stability		A	A & S	S
3.1.1.2	Cooling System Requirements				
3.1.1.2.1	Cooling Water Supply (HYDRO)	A	A	S	S
3.1.1.2.2	Ambient Temperature Requirements (MET)	E			
3.1.1.3	Flooding (HYDRO)	E	E	S	S
3.1.1.4	Nearby Hazardous Land Uses (LU, SOCEC)				
3.1.1.4.1	Existing Facilities		A	S	S
3.1.1.4.2	Projected Facilities			S	

Figure 3. Examples of Exclusionary (E), Avoidance (A) and Suitability (S) Criteria. [1]

3. SENSITIVITY ANALYSIS IN SITE SELECTION

The guidance on site selection is broadly written to cover a wide variation in the areas initially considered for new nuclear power. Each project proponent has primary concerns, such as distance to load centers or location where the local community is most interested, that will drive site selection, after certain baseline conditions are satisfied. To accomplish this, the site selection process described above must be iterative.

In most guidance documents, drilling down from the region of interest to the selected site is based on first Exclusionary, then Avoidance, then Suitability Criteria; i.e., a linear process. The reality is that criteria that initially cause a site to be ranked low based on conservative assumptions may need to be revisited with less conservative (although still acceptable) assumptions following a holistic review of all potential sites and siting factors.

RIZZO proposes an alternative approach whereby the three categories of siting criteria have distinct roles in the site selection decision making process, as follows:

- Exclusionary Criteria – limited to safety factors that cannot be ignored or mitigated ("Absolute Factors")
- Avoidance Criteria – limited to factors that are so difficult to overcome that an affected location must be eliminated if suitable mitigation measures cannot be implemented ("Critical Factors")
- Suitability Criteria – factors that are important for their economic impact on the project ("Economic Factors")

3.1 Absolute Factors (Exclusionary Criteria)

Absolute Factors establish the feasibility of the site for the new NPP project and therefore must be satisfied very early in the program. Absolute Factors include all of the critical

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safety-related Exclusionary Criteria. If there are no sites that pass the initial screening for the Absolute Factors, then the project cannot go forward. If there are few areas that pass the initial screen, then sometimes the ROI initially considered for the nuclear program can be expanded to encompass more favorable sites. If not, however, then the project will not be feasible.

3.2 Critical Factors (Avoidance Criteria)

RIZZO includes in this approach some factors that are frequently considered as exclusionary within this second category of Critical Factors, such as environmental concerns and flooding potential. We place them here because the initial screening criteria may be overly conservative, or mitigations may be able to be put into place to make these factors acceptable.

It is important to properly identify the necessary Critical Factors before starting the screening analysis, as the overall score is the sum of individual scores and thus is affected by the nature and number of individual criteria included in the analysis. It is recommended to work with subject matter experts to determine the importance of each of the criteria on the area being considered.

The impact of a sensitivity analysis applied to a single criterion is reduced if a great number of criteria are used, a mathematical truism. Therefore, at this point each of the criteria should be evaluated for its importance to the decision making process. If the areas being considered do not differ significantly with respect to a criterion, or if not enough information is known about the site with respect to that criterion, it should not be selected as a Critical Factor. For example, if none of the Candidate Sites are close to commercial agriculture or fishing, then this criterion should not be a Critical Factor. If all of the sites have the same score for a particular criterion, and greater precision in defining the values cannot be obtained with the available information, then the criterion should be deleted from consideration.

When the compilation of Critical Factors is completed, the results may show that the Candidate Sites do not differ significantly in their rankings, and therefore it may be necessary to apply a sensitivity analysis to these factors. Although the summation of the scores may show close results, the particular criteria may differ significantly among sites.

Figure 4 shows an example set of Critical Factors for five sites. Three sites (Numbers 8, 26, and 4 are closely ranked and a change in the scoring for any one factor would change which site is ranked highest. For example, Site 26 is ranked lower for land use impact but ranked highest of the three for sensitive habitat protection concerns. The proponent must determine which site is the best, forcing a value judgment on land use impact *vs.* sensitive habitat protection.

There are two approaches that can be used at this point in the process. The first, traditional approach, assumes that the Avoidance Criteria have been applied to this point and now Suitability Criteria are applied. The Suitability Criteria are used to discriminate between closely ranked sites, and this is a valid method for ranking the sites. However, this approach ignores that while the scores prior to application of Suitability Criteria are the same, the actual sites themselves are very different in their potential for being a viable new NPP project.

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In the second approach, RIZZO's proposed approach, which applies a sensitivity analysis, the Avoidance Criteria (Critical Factors) are analyzed in depth using a more detailed consideration of available data and consideration of the country's own legislation and flexibility in applying mitigation factors. Options for refinement of the analyses include the actual data scores assigned to the site using the original conservative or estimated assumptions, the numerical values used for data ranges, or the weighting which reflects the proponent's view of the importance of the criterion.

In some cases, the potential for negative features can be resolved by legislation or regulatory negotiation. There may be potential for resolving the negative aspects of the site, such as by establishing siting constraints within the potential area (changing the selected site location within the Candidate Areas) or mitigation through engineering solutions.

AVOIDANCE CRITERIA (CRITICAL FACTORS)							Value
Land Use Impact		Site					
		8	26	4	30	19	5 = Sparsely populated and no designated land use purpose
	Data (#/sq km)	87.8	122.7	62.8	46.8	29.1	3 = Moderately populated and future land use identified in regional strategic plans
	Value	5	3	5	5	5	1 = Beneficial land use in place
10	Weighted Value	50	30	50	50	50	
Important Species/Habitats (distance to ecological protected area)		Site					
		8	26	4	30	19	5 = Greater than 5 km from an ecological protected area (proposed area or bird flyway not applicable)
	Data (km)	4.5	7.0	3.0	2.9	1.5	3 = 2 to 5 km from a listed ecological protected area (proposed area or bird flyway not applicable)
	Value	3	5	3	3	1	1 = Within 2 km of a listed ecological protected area (bird flyway not applicable)
9	Weighted Value	27	45	27	27	9	
Soil Stability		Site					
		8	26	4	30	19	5 = Hard rock, Vs > 9,200 ft/sec (2,804 m/sec)
	Data (ft/sec)	2300	3000	3500	2300	2300	3 = Soft rock, Vs > 2,300 ft/sec (701 m/sec)
	Value	3	5	5	3	3	1 = Loose or soft soil < 45 m deep
7	Weighted Value	21	35	35	21	21	
Groundwater Radionuclide Pathway		Site					
		8	26	4	30	19	5 = Surficial geology is shale.
	Data	sandstone	shale	sandstone	k.ls	gravel	3 = Surficial geology is sandstone
	Value	3	5	3	0	0	1 = Suficial geology is limestone
7	Weighted Value	21	35	21	0	0	0 = Surficial geology is karstic limestone or sand/gravel
Topography		Site					
		8	26	4	30	19	5 = Topography is flat and conducive to construction
	Data	na	na	na	na	na	1 = Topography is hilly and difficult to build on
	Value	5	1	1	1	1	0 = Topography is not conducive to construction
6	Weighted Value	30	6	6	6	6	
TOTAL WEIGHTED VALUES		149	151	139	104	86	

Figure 4. Site ranking showing differences within Avoidance Criteria (Critical Factors).

The sensitivity analysis must be performed in close consultation with the proponent, who often has knowledge of how the Avoidance Criteria can be addressed within the country. In the example considered here, the nature of the environmentally sensitive area may have been identified as such by an overly broad area of protection beyond that actually encompassing the sensitive habitat, which could be modified through more detailed analysis of potential impacts on the environmentally sensitive area and discussions with the environmental agency. Alternatively, the impacts on the environment may be mitigated such as by

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controlling construction aspects or by suitable protections allowing the project set-off to be reduced.

Similar analysis is performed for all of the Avoidance Criteria, not just the ones that are initially seen to affect the overall score, as a change in one of the factors may result in another criterion becoming important to the score.

Following the sensitivity analysis and revision of the scoring, values and/or weights for the Avoidance Criteria, the site selection analysis is repeated and the results assessed. After this second iteration, assuming that each of the Avoidance Criteria has been thoroughly analyzed and optimized, the Economic Factors (Suitability Criteria) are evaluated.

3.3 Economic Factors (Suitability Criteria)

Economic Factors include a selection typically assigned to both Avoidance and Suitability Criteria. Economic Factors must be considered together, although traditional practice considers each of the criteria individually. For example, typical Economic Factors include presence of transportation infrastructure, location of major load centers, and impact of existing facilities. Rarely are the potential sites so similar that they rank closely in their Economic Factors. Additionally, at the stage of site selection little is known about the costs to overcome the Economic Factor difficulties.

Since it is the overall cost of the project that is important, not the cost of only one component, it is more useful to consider the total economic cost of the project than any one factor. If the initial assessment of Critical Factors shows clear differentiation among potential sites, then no sensitivity analysis of Economic Factors need be performed. However, when a Preferred Site will be selected on the basis of the Economic Factors analysis, then a sensitivity analysis should be performed to determine which of the Economic Factors are significant to the decision. For these factors only, additional financial and technical information should be collected to better inform the analysis. It is not necessary to apply additional resources to analysis factors that will not affect the final selection of a site.

4. SUMMARY AND CONCLUSION

The general process of site selection has been discussed within guidance manuals for many years. The current paper proposes a new approach developed by RIZZO which goes beyond the standard approach and focuses the resources necessary for data collection and analysis on those criteria which have the greatest impact on the decision making process for site selection. The application of the sensitivity analysis process is particularly useful where the potential sites are closely ranked, or where there are significant discrepancies in the results of the site selection process among potential sites. The sensitivity analysis provides more information to the decision makers regarding the true costs, both economic and in public acceptance.

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