FINAL REPORT

Life Cycle Impact Assessment (LCIA) of Renewable Electrical Generation Technologies Compared to the WECC Baseline

Conducted in accordance with ISO 14044 LCIA Framework and the Draft SCS-002/ANSI Life Cycle Metrics Standard, "Type III Life-Cycle Impact Profile Declarations for Materials, Products, Services and Systems"

Prepared for the Western Area Power Administration
and
Tri-State Generation and Transmission Association, Inc.

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SCIENTIFIC CERTIFICATION SYSTEMS

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Main Report

Life Cycle Impact Assessment of Renewable Elcctrical Generation Technologies Compared to the WECC Baseline

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EXECUTIVE SUMMARY

For this report, SCS conducted a life-cycle impact assessments (LCIA) of two renewable electrical technologies: the Glen Canyon Hydropower Station in Arizona and the Stateline Wind Power Generation System on the border of Washington and Oregon. SCS then compared these results to impact levels calculated for the WECC NERC Region. As prescribed in the ISO 14044 Standard and Draft Standard (SCS-002), the study assessed and compared the LCIA results of these renewable electrical generating plants to those of the WECC across the full range of environmental and human health that have been shown to be environmentally relevant to electricity production within the Western region of the United States.

The report contains the following information:

- a description of the Glen Canyon Hydropower System;
- a description of the Stateline Wind Power Generation System;
- a description of the WECC regional power pool;
- a description of the data utilized for the assessment;
- a discussion of key assumptions;
- a summary of life cycle inventory results;
- a summary of life cycle impact assessment results; and
- a discussion of results.

Upon request of WAPA, this report underwent peer review by individuals from Argonne National Laboratory.

The LCIA results from this study are reported in the format specified in the SCS-002 Committee Draft in order to facilitate use of the findings by policy makers and other stakeholders. Two different Life Cycle Impact Declarations are presented for the Glen Canyon Project based on different sets of assumptions that reflect different operating scenarios for the dam. One scenario assumes that the dam is used for multiple functions, from recreation through water storage, flood control and power generation. In this case, the environmental impacts are allocated across functions in compliance with allocation procedures set forth in ISO 14044. In the second case, all environmental impacts resulting from the Glen Canyon project are assigned to a single function, power generation. For the Stateline Wind Power Project a Life Cycle Impact Declaration of the Wind System with No Added Backup power is presented.

Supplemental Report on Thermal Technologies

Included under this document's cover is a supplemental report. As part of the commission of this study by Western Area Power Administration, SCS gathered data on two thermal electrical generating units; the Colstrip Generating Powerplant in Montana and two generic types of natural gas-fired electrical generators. The detailed data that would be required to perform a Life Cycle Impact Assessment and prepare a Life Cycle Impact Declaration were not available for these two case studies. Instead, publicly available data were used. Where no data existed, SCS substituted data from other sources in order to provide a complete – albeit conceptual data set.

The goals of this supplemental report are (1) to demonstrate how an LCIA method might be used in the case of a thermal generator and (2) to identify problems that might arise in a complete LCIA analysis of power plants similar to those chosen for this demonstration project.

Significant insights have been gained in studying an LCIA method approach to examining the environmental footprint of these two thermal technologies. With these new insights, a complete and cogent LCIA analysis and Life Cycle Impact Declaration could be completed if a complete data set were used.

Significant Findings

1. The WECC has the lowest greenhouse gas loading per 1,000 GWh of any NERC region in the US solely because of the large fraction of hydropower constituting the overall power mix (28 percent).

2. If sited properly, the environmental performance of wind generation facilities is excellent when wind is a small fraction of the total energy available in a power pool. However, performance can degrade significantly with increasing levels of wind energy production. Because wind energy is not dispatchable, at higher levels of wind energy production its environmental performance approaches that of the power used to back it up.

3. Hydropower capacity offers the best backup source to preserve wind power's environmental performance while allowing higher system penetration levels for wind.

4. The environmental performance of coal-fired power plants vary quite widely, but can exceed that of even the WECC, depending upon: 1) the assay of coal inputs; 2) the method of mining; 3) the type and efficiency of energy generation; 4) the type of pollution control technologies employed; and 5) the location of the mine and power plant relative to areas of high population density and areas susceptible to exceedance of environmental thresholds.

5. On balance, natural gas-fired combined cycle power plants can perform better than the WECC average, though their performance is sensitive to location. Their energy resource-depletion ratings are worse than the WECC due to the relatively small reserves of natural gas.

6. The LCIA methodology can provide accurate, credible and relevant environmental performance results for all energy production systems studied. The ability to compare environmental performance among energy production alternatives and to a power-pool baseline can be especially useful for decision-makers.

7. Unavailability of detailed proprietary data for power plant operations can be a significant obstacle to using the LCIA methodology to study those power plants.

Environmental Impact Profiles

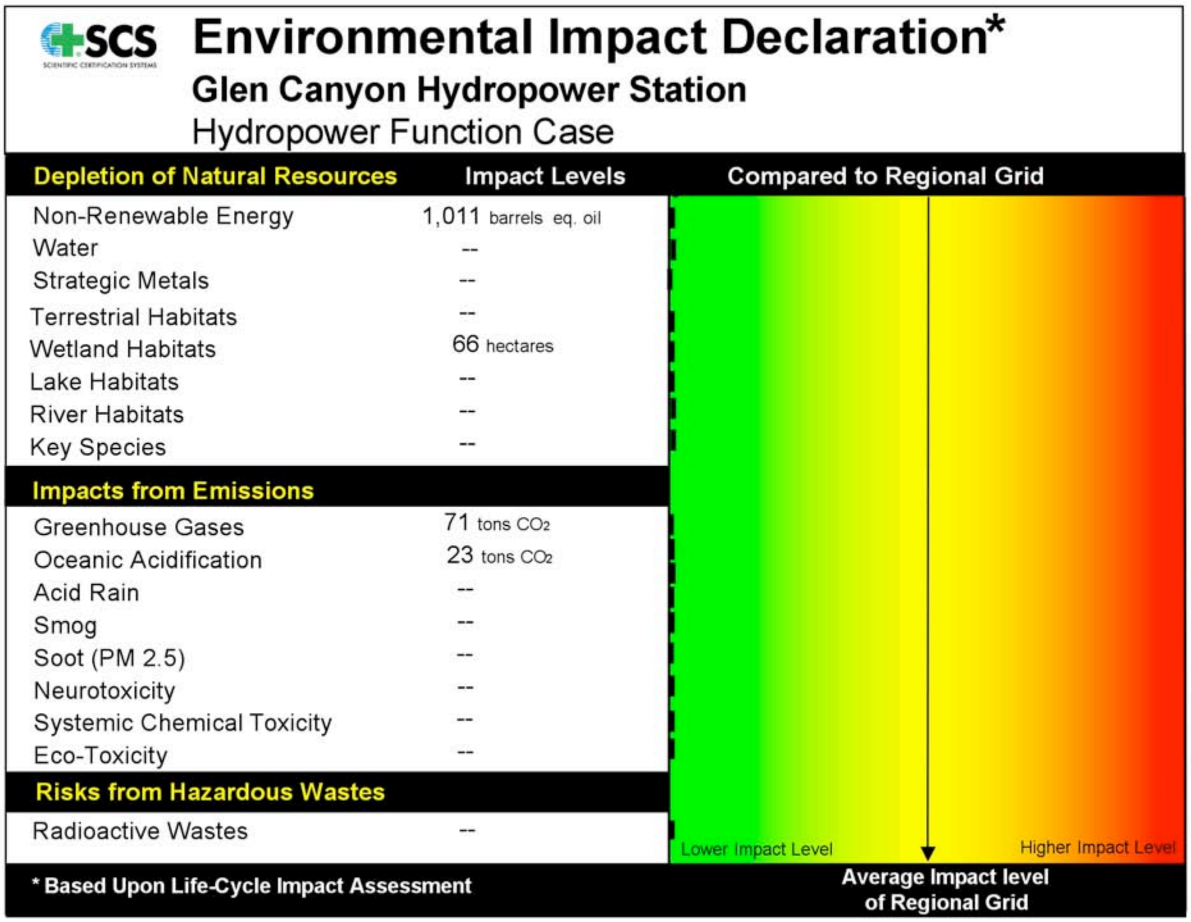


Figure 1. Environmental Impact Profile of Glen Canyon Hydropower Generation System, Hydropower Function case, relative to the WECC baseline per 1,000 GWh.

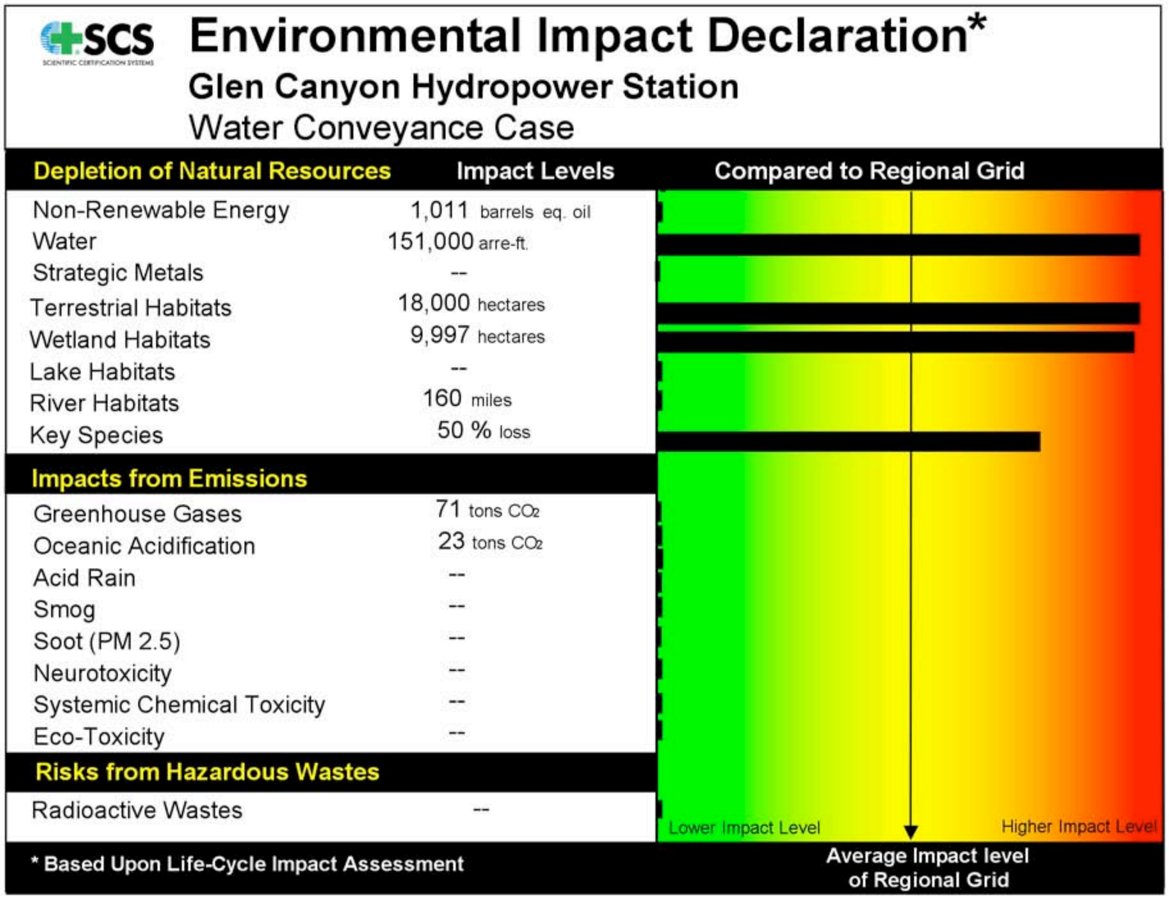


Figure 2. Environmental Impact Profile of Glen Canyon Hydropower Generation System, Water Conveyance Case, relative to the WECC baseline per 1,000 GWh.

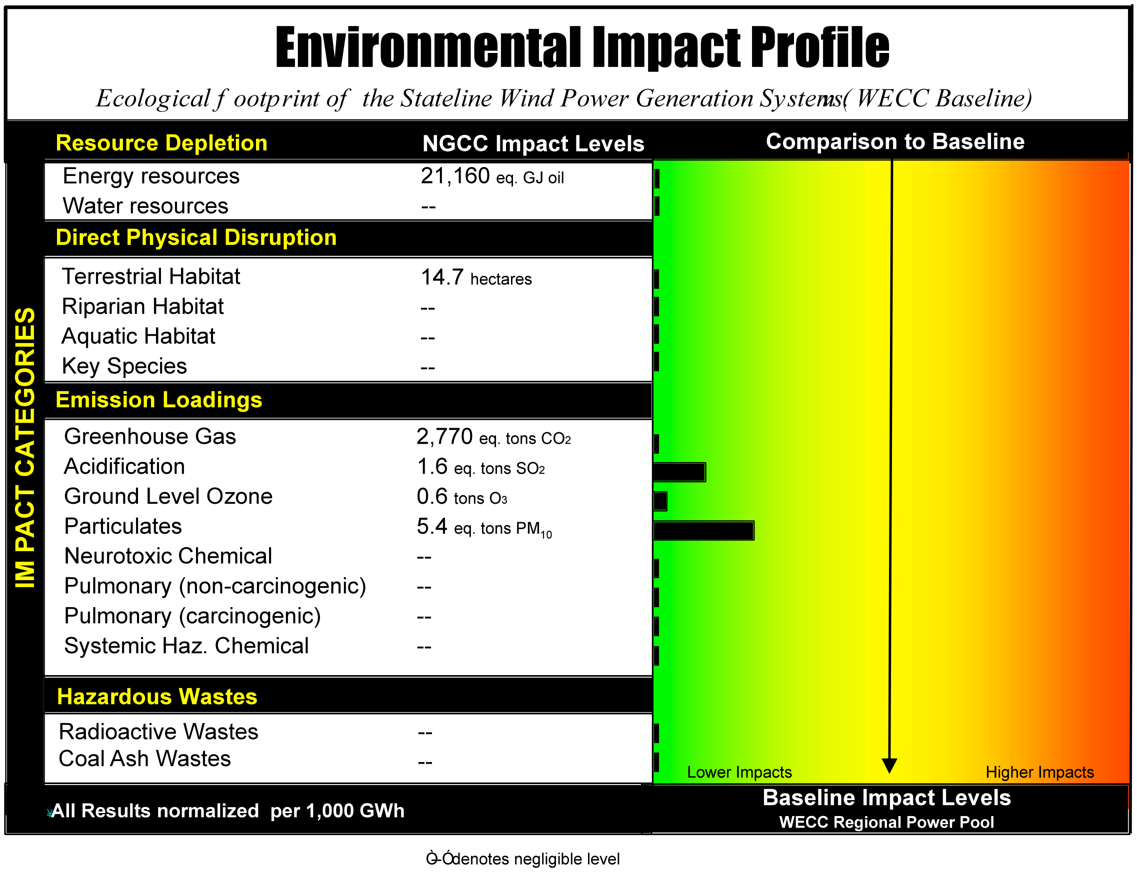


Figure 3. Environmental Impact Profile of Stateline Wind System, Scenario 1.

TERMS AND DEFINITIONS

I. Terms and Definitions Used in This Report

- *Baseline* —The reference case against which a material, product, service, or system is compared, where the indicator results represent the typical or predominant material, product, service or system for the sector, a prior version of the same product, service or system, or another identified product, service or system. All environmentally relevant impact categories for the sector must be included in the baseline comparison.
- *Biobased Resource* — commercial or industrial product (other than food or feed) that is composed, in whole or in significant part, of biological products or renewable domestic agricultural materials (including plant, animal, and marine materials) or forestry materials.[1]
- *Category Indicator* — The selected node for use in reporting the lifecycle impact assessment (LCIA) result. The indicator is often a quantifiable midpoint node within a given stressor-effect network that is selected to represent the impact category because it can be linked both to the initial stressor value and to the endpoint impact.
- *Effect* — A measurable, adverse change to human health or the environment. Also referred to as an "impact" (as in "impact category")
- *Emission Loading* – The amount of emissions released into an environment that deposits into or resides in areas that exceed identified thresholds. This emission loading incorporates relative potency, fate and transport of the emission(s), as well as spatial and temporal characteristics of the identified endpoints.
- *Environmental Characterization Factor (ECF)* —A mathematical expression derived from the quantitative characterization of the relative degree to which a particular stressor affects the environment or human health within a specific impact category.
- *Environmental Data* — Data used to characterize the condition of providing and receiving environments.
- *Environmental Impact Profile (abbreviated as "Impact Profile")* — The cumulative summary of life-cycle impact assessment (LCIA) category indicator results representing the environmental performance of a material, product, service or systems, adjusted to a specific functional unit.
- *Environmental Mechanism* — A distinct and measurable physical, chemical, radiological or biological process(es) that links stressor(s) to effects of human health or the environment.
- *Environmentally Preferable* — A material, product, service or system that has lower environmental impacts than the current reference baseline across the life-cycle, without environmental trade-offs in any category indicators.

[1] Farm Security and Rural Investment Act of 2002 (Public Law 107-17), ("2002 Farm Bill"), Section 9002.

- *Habitat Baseline* — The condition of the habitat in a given area prior to the establishment of the production infrastructure associated with the material, product, service or system.
- *Impact* — A measurable, adverse change to the human health or the environment. Also referred to as an effect (as in "stressor-effect network").
- *Impact Category* — An issue of environmental or human health concern (e.g., climate change, acid rain) that represents a distinct or linked environmental mechanism(s).
- *Impact Endpoint* — An identifiable impact on the natural environment, human health or natural resource reserves that can be linked back to a stressor(s) through a defined environmental mechanism. Also referred to simply as "endpoint."
- *Impact Group* — Impact categories with common or similar midpoints/endpoints.
- *Impact Profile* – See Environmental Impact Profile.
- *Life Cycle Assessment (LCA)* — Assessment that in includes determination of appropriate scope and boundary conditions, a complete life-cycle inventory, and a complete life-cycle impact assessment.
- *Life Cycle Impact Profile Declaration (or simply, Life Cycle Impact Declaration)* – A report summarizing the environmental impact profile derived from the use of the LCSEA as referenced in this Standard. There are three types of declarations: 1) basic declaration of impacts; 2) reduced impact declaration; and 3) declarations of environmental preferability.
- *LCIA Functional Unit (or simply, functional unit)*— A common unit of output (e.g., 1000 GWh for electricity) to which category indicator results are normalized.
- *Life Cycle Impact Assessment (LCIA)* — The phase of life cycle assessment that converts life cycle inventory results (both inputs and outputs) into life cycle category indicator results by calculating the magnitude and environmental relevance of the resultant environmental/human health impacts.
- *Life Cycle Inventory (LCI)* — The phase of life cycle assessment involving the identification, compilation and quantification of inputs and outputs associated with a given material, product, service or system throughout its life cycle.
- *Midpoint Node* —Any distinct, measurable intermediate chemical or biological or physical process along the stressor-effect network between the stressor point (e.g., emission, extraction) and the endpoint.
- *Node* — Any chemical or biological or physical process along a stressor-effect network model of an environmental mechanism.
- *Providing environment* — The natural resource reserves from which resources are extracted.
- *Receiving environment* — The air, water, soil, and habitats into which emissions are deposited or in which they reside.
- *Reserve base* — The quantification of the natural repositories of a given natural resource that is economically or technically recoverable.
- *Resource depletion factor (RDF)* — The characterization factor that reflects the rate of resource depletion against its reserve base.
- *Stressor* — Any input, output, and direct physical disruption activity associated with a material, product, service or system that can be linked to an effect.

- *Stressor Characterization Factor (SCF)* — A mathematical expression used to aggregate related stressors based on their relative potency with respect to a specific impact category.
- *Stressor-Effect Network* — A model used to represent an environmental mechanism, in which a chain of events are shown to link the inputs, outputs, and direct physical disruption activities associated with a material, product, service or system to impact endpoints. Also referred to as "impact chains" or "impact-effects networks."
- *Threshold* — An environmental condition that, when exceeded, is linked to adverse environmental or human health effects
- *Unit operations* – Distinct processes associated with industrial process associated a material, product, service or system across the scope of the assessment.

II. Abbreviations Used in This Report

Ac	acre
Asl	Above sea level
BPA	Bonneville Power Administration
Bq	Becquerel (a measure of radioactivity, where 1 Bq equals 1 disintegration per second (compared to 1 curie = 3.7 x 10^{10} disintegrations per second).
CANDU	Canada Deuterium Uranium (heavy water reactor technology)
CEA	Canadian Electricity Association
CRSP	Colorado River Storage Project
ECF	Environmental Characterization Factor
EGRID	Emissions & Generation Resource Integrated Database
EIA	Energy Information Administration
EPI	Environmental Performance Index
Eq.	Equivalent
GCMRC	Grand Canyon Monitoring and Research Center
GWh	Gigawatt Hour (=1,000,000 kilowatt hours)
GWP	Global Warming Potential
GLO	Ground Level Ozone
Ha.	Hectare
HEC	Human Exposure Coefficient
HEF	Human Exposure Factor
HF	Hydrofluoric Acid
HRC	Human Reference Concentration
HWR	Heavy Water Reactor
IGCC	Integrated Gasification Combined Cycle
ISO	International Organization for Standardization; also, Independent System Operator
Kg	Kilogram
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory Analysis
LCIA	Life Cycle Impact Assessment
LCSEA	Life Cycle Stressor Effects Assessment

LWR	Light water reactor
LBWR	Light boiler water reactor
MAF	Million acre-feet
MWh	Megawatt hour
NAAQS	National Ambient Air Quality Standards
NAAIB	North American Association of Issuing Bodies
NERC	North American Electric Reliability Council
NOAEL	No Observed Adverse Effects Limit
NOx	Nitrogen Oxides
NRC	Nuclear Regulatory Commission
NPRI	National Pollutant Release Inventory (Canada)
ODP	Ozone Depletion Potential
ODS	Stratospheric Ozone Depleting Substances
PM	Particulate Matter
RAINS	Regional Air Pollution Information and Simulation model
RCRA	Resource Conservation and Recovery Act
RDF	Resource Depletion Factor
RfC	Human Reference Concentration
RfD	Human Reference Dose
RIVM	Rijksinstituut Voor Volksgezondheid en Milieu (National Institute of Public Health and the Environment), Coordination Center for Effects[2]
ROW	Right of Way
RNP	Renewable Northwest Power
RPP	Regional Power Pool
RTO	Regional Transmission Organization
SARA	Superfund Amendments and Reauthorization Act
SCF	Stressor Characterization Factor
SCS	Scientific Certification Systems, Inc.
SOx	Sulfur Oxides
Sv	Sieverts
t	Tonne (metric)
TBq	Tera Becquerel (1 Bq x 10^{12})
TCDD	Tetrachlorodibenzodioxin
TCLP	Toxicity Characteristic Leachate Procedure
TRI	Toxic Release Inventory (USA)
WECC	Western Electricity Coordinating Council

[2] The CCE is the Data Center of the International Cooperative Programme on Modeling and Mapping of Critical Levels and Loads and Air Pollution Effects, Risks and Trends (ICP Modeling and Mapping, ICP M&M) and supports the work of the Convention on Long-range Transboundary Air Pollution (LRTAP) of the United Nations Economic Commission for Europe (UNECE).

Section 1.
STUDY OVERVIEW

1.1. Study Background

In 2002, the Western Area Power Administration (Western) contracted Scientific Certification Systems (SCS) to demonstrate the use of Life-Cycle Stressor Effects Assessment (LCSEA), a site-dependent life-cycle impact assessment (LCIA) approach, as a tool for establishing the environmental impact profiles of electric power generation systems in the western U.S. The study now consists of two reports. The first is an LCIA case study of two renewable electrical productions facilities: the Glen Canyon Hydropower System and the Stateline Wind Power Station. In a supplemental report, the concept of an LCIA approach, using publicly identifiable data and surrogate data, is applied to two thermal power plants: Colstrip Coal Power System and two natural gas-fired technologies. The latter analyses were completed as a demonstration of what the opportunities and difficulties of applying this approach to thermal units.

During the course of the project, Tri-State joined Western as an additional interested party and study sponsor.

1.2. Study Goals

The goals of this renewable energy study were as follows:

- to demonstrate the use of the LCSEA methodology in establishing the environmental impact profile of selected electric power generation systems;
- to establish the impact profile of the WECC regional power pool to be used as a baseline against which the impact profiles of specific power generation systems can be measured and scaled (environmental efficiency analysis);
- to establish the Life-Cycle Impact Profile of the Glen Canyon Hydropower System as compared to the WECC regional power pool;
- to establish the Life-Cycle Impact Profile of the Stateline Wind Power System as compared to the WECC regional power pool;
- to demonstrate the degree to which the results of such a study can be used to support informed science-based energy policy discussions, to guide energy company decision-making and investments, and to support energy purchasing.

1.3. Scope of Work

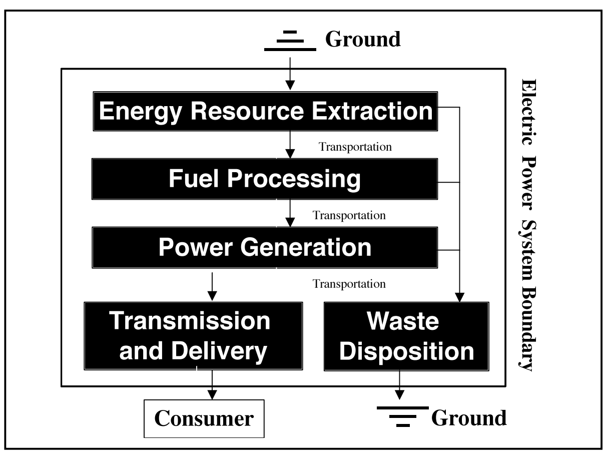
The study utilized life-cycle impact assessment to:

- **Establish the WECC (US) Impact Profile Baseline**
  The WECC regional power pool consists of a wide diversity of power types, and extends over a vast section of the western US and Canada. In this study, the assessment was confined to power generation in the eleven US states included in the WECC.

- **Determine the Impact Profile of a sample of renewable electrical energy generations systems: a Hydroelectric Generation System and a Wind Power Generation System**
  This project involved the establishment of the Life-Cycle Impact – LCIA study and a Life Cycle Declaration of the Glen Canyon Dam hydroelectric power generation system in the state of Arizona. Additionally, a Life-Cycle Impact study – LCIA was completed for the Stateline Wind Power generation system on the boarder of Washington and Oregon. No Life-cycle Declaration was made for this generation system.

The scope of assessment under LCSEA is cradle-to-grave, consistent with internationally recognized life-cycle assessment principles. For electric power generation systems, this scope typically includes: energy resource (and ancillary resource) extraction, raw material transport, fuel processing, fuel transport, power plant construction and operations, power transmission and distribution, waste disposal and treatment, and power plant decommissioning (Figure 1.1).

Figure 1.1. Simplified schematic of the life cycle of an electric power generation system



1.4. Limitations

The following limitations in scope should be noted:

- The study did not address end-of-life issues (e.g., decommissioning of plants) associated with the electric power generation systems examined, even though this is within the normal scope of LCSEA, except as otherwise noted.

- The study did not address one-time or non-recurring accidental releases from any of the electric power generation systems.

- The study addressed power quality or reliability concerns only to a limited degree, and did not address the security of the electric power generation systems examined.

- The study did not address possible worker safety concerns associated with electric power generation systems examined.

- The study did not calculate environmental category indicators associated with noise, visual impact, or aesthetics.

In terms of the assessments conducted, the study was limited in two additional respects: 1) certain inventory data and environmental characterization data were unavailable or unattainable by SCS within the agreed-upon budgets and timelines; and 2) while the study sought to demonstrate the methodology using certain baseline cases for comparison, other baseline cases might have been selected and thereby provided additional insights into the study findings.

Section 2.
OVERVIEW OF LCSEA FRAMEWORK

2.1. Historical Perspective

The field of life-cycle assessment first began development in the 1960s in response to fuel and energy shortages. By the 1970s, analytical methods were proposed to conduct an analysis of fuel and raw material uses in the energy sector and in various industrial systems. These analyses were first referred to as Resource and Environmental Profile Analyses (REPA). In the late 1970s, the seminal text on conducting REPAs was published by Boustead and Hancock (1979) entitled *Handbook of Industrial Energy Analysis*. Between 1979 and 1990, additional environmental factors were added to REPAs, such as air emissions, water effluents, and solid wastes. REPA studies were considered to be useful inventories of the environmental inputs and outputs of industrial systems, and as such, were described as "Life Cycle Inventories" (LCI). Starting in the late 1980s and early 1990s, a number of software tools were developed to help interested companies conduct LCIs for their own industrial systems.

In 1990, the Society of Environmental Toxicology and Chemistry (SETAC) sponsored a conference in Vermont (USA), at which the term "Life Cycle Assessment" was used to describe studies in which factors associated with each life-cycle phase, including raw material use, energy use, emissions to air and water, and solid wastes were reviewed for an entire industrial system. In the Vermont conference, participants described Life Cycle Assessment (LCA) as having three parts: a) the Life Cycle Inventory (LCI), b) Life Cycle Interpretation, and c) Life Cycle Improvement. During this time, discussions among LCA practitioners focused on identifying better ways to use LCA for environmental decision-making purposes. The need for a methodology capable of linking system inputs and outputs to environmental effects thus became apparent, leading to the development of *life-cycle impact assessment* (LCIA) from what was originally called life cycle interpretation, and ultimately, to the publication of an international standard (ISO-14044) in 2000.[3]

ISO-14044 was the product of six years of negotiation among delegates representing more than 100 countries. This standard established a common framework whereby the LCI results could be further classified and characterized in order to determine their relative impacts on the environment, then aggregated into a set of environmentally relevant impact category indicators. The main objective was to convert the LCI data into environmentally relevant category indicator results. The ISO 14044 standard is a

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[3] ISO-14042 was drafted under the auspices of the ISO Technical Committee on Environmental Management (TC-207). A number of collaborative publications contributed toward the development of the LCIA standard. Among the most prominent of these were the *Nordic Guidelines on Life-Cycle Assessment* (1995), including the LCA-Nordic Technical Reports 1-10, and the Society for Environmental Toxicology and Chemistry (SETAC) publications *A Conceptual Framework for Life-Cycle Impact Assessment* (1993) and *Towards a Methodology for Life-Cycle Impact Assessment* (1996).

guidance standard that provides the basic methodological requirements to conduct scoping, the LCI and LCIA phases. At the center of the LCIA guidance is the establishment of the LCIA framework, which requires that impact categories be established in accordance with their identified environmental mechanisms. Such environmental mechanisms are the biophysical impact pathways (stressors, potentials, midpoints, and endpoints) related to the inputs and outputs inventoried during the LCI phase, as well as any biophysical impacts that have identified midpoints/endpoints.

In 1995, the LCSEA methodology was among the first LCIA approaches to formally integrate LCI results with environmental impact assessment (EIA), environmental impact statements (EIS) and other standard environmental impact data sets. The outcome of this development was to transition LCIA modeling from a site-generic approach to a more site-dependent methodology.

Site-dependent LCIA methods for calculating category indicators, especially those associated with regional and local emissions, have continued to be refined, particularly by governments in Europe. The Danish Guideline for LCA, the Nordic Guideline for LCA and others have contributed by integrating dispersion modeling data into an LCIA framework. The United Nations Environment Programme (UNEP) has established a working group to codify LCA practice based on the existing advanced models, including the Danish and Nordic guidelines, and the SCS LCSEA methodology. The European Union (EU) is planning to adopt the UNEP model once it has been codified.

2.2. LCSEA Methodology and Metrics

In LCSEA, the physical, chemical or biological environmental mechanisms that link an industrial input, output or activity (i.e., the "stressor") to an observable impact (i.e., the "effect") are modeled as "stressor-effect networks" (Figure 2.1). The environmental mechanisms used in this model include effects on ecosystems, effects on human health, and the net depletion or accretion of natural resources. LCSEA calculations involve the collection, analysis and integration of two types of data: 1) inventory data (i.e., the energy system's land use, resource and energy inputs, environmental releases and wastes that act as potential stressors), and 2) characterization data that put these inventory data into the perspective with respect to various environmental impacts.[4]

Consistent with standard LCIA practice, the LCSEA methodology contains formal protocols for classification of inventory results and characterization of these results with regard to their respective impacts.

[4] Like all LCIA models, LCSEA is a data integration methodology focused on collecting and analyzing a variety of existing data resources rather than on conducting traditional EIA research.

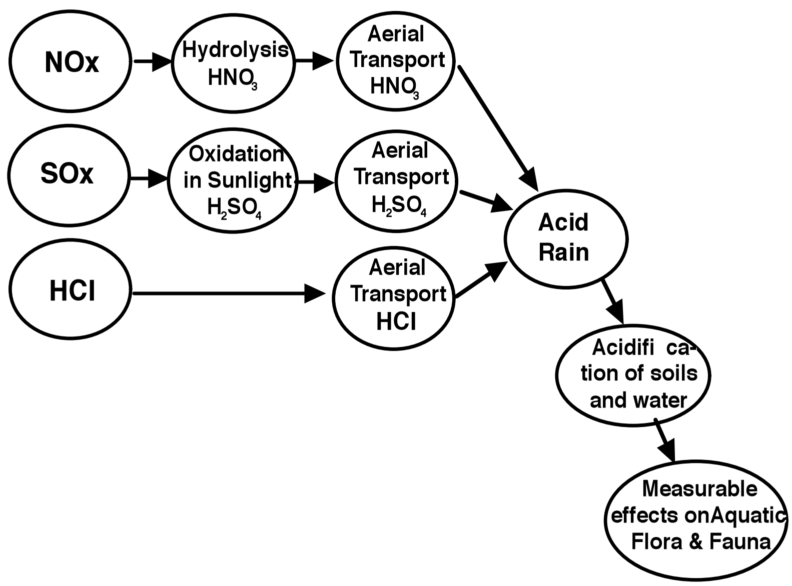

Figure 2.1. Example of a Stressor-Effect Network

2.2.1. Classification Protocols

To start, impact categories are identified that represent distinct stressor-effects networks with defined nodes (Figure 2.1). For each impact category, a category indicator is selected that is representative of a distinct node along the stressor-effect network. "Core" impact categories are then distinguished from categories that are not relevant to a specific region, as described in SCS-002 (Appendix 6). Aggregation of stressor-effect networks with unrelated nodes is not permitted.

Inventory data are then assigned to one or more relevant category indicators. Any inventory data that cannot be assigned to a category indicator must be identified in the inventory, but may be excluded from the final indicator results if sufficient justification is provided.

2.2.2. Characterization Protocols

All category indicators must be characterized using spatial and temporal parameters. Stressor characterization factors (SCFs) and environmental characterization factors (ECFs) or their equivalent must be established before an indicator calculation can be conducted. SCFs characterize the relative potency of various stressors contributing to the same environmental effect. The relative scale used for the SCF is based upon known chemical, biological or physical parameters that are both reproducible and peer reviewed. ECFs characterize the fate and transport of the stressors, including threshold analysis and integration of the relative severity, duration, and reversibility of the measured effect. Threshold analysis involves determining whether a given effect has crossed a defined threshold. To establish an effects threshold, a scientific consensus must exist regarding the threshold level. The relative scale used for the ECF is 0-1. Further discussions of SCFs and ECFs by indicator are found in Section 3 and in Appendix 6.

Meeting the Requirements of Comparative Assertion

LCSEA metrics meet the requirements of the ISO 14044 LCIA framework and the SCS-002 Committee Draft for making "comparative assertions". In this case, Glen Canyon Hydropower Station impact levels (i.e., environmental performance) are compared to the averaged impact levels of the combined power mix that makes up power production of the WECC NERC region. The environmental relevance of the selected impact group, impact categories and related category indicators must be demonstrated in order to be included as a measure of environmental performance.

In this study, the two renewable electrical power systems were compared to the WECC baseline. Consistent with the comparative assertion requirements of ISO 14044 and the SCS-002 Committee Draft, all environmentally relevant impact categories were identified and corresponding category indicator results calculated for both Glen Canyon and Stateline as well for power systems making up the WECC. Whereas standard LCA models do not address the key habitat and species issues that have long been the center of environmental attention of multiple stakeholders concerned about hydropower and wind power projects, LCSEA metrics have been specifically designed to address the complexity and degree of ecological disturbance (impacts on riverine, wetlands, terrestrial, lake and riparian habitats, and loss of key species) associated with power generation systems. LCA studies that have not addressed these key issues have been considered misleading or of little use in making comparisons between fossil generation systems and hydropower and wind generation systems. By addressing the key habitat and species issues in a standard way for all power generation systems, LCSEA metrics provide a more robust comparison between power systems to allow the inherent strengths of each generation technology to be reviewed with greater credibility.

2.3. Steps for Conducting Assessments

The steps for conducting assessments of electric power generation systems consistent with the SCS-002 Committee Draft are summarized below.

2.3.1. Determination of Scope and Boundary Conditions

All projects begin by setting boundary conditions and establishing the scope of a project.

- All relevant unit processes are identified for the electric power generation system, and for the baseline against which the system is to be compared.
- Study boundaries are delineated, incorporating relevant spatial (i.e., geographic) and temporal conditions.
- The functional unit is determined for the electric power generation system and for the baseline against which the system is to be compared. Typically, this functional unit is 1,000 gigawatt-hours. Additionally, any line losses due to transmission distance are factored into the LCIA calculations.
- Scoping must account for spinning or other reserves that are necessary due to intermittency of a particular generation source (e.g., wind, solar) or FERC-mandated minimum flow requirements (i.e., hydro), or any other changes to specific power generation systems that could alter the power mix in the regional power pool.

2.3.2. Life Cycle Inventory Analysis

After setting the boundary conditions and scope of the study, a life cycle inventory is conducted.

- Data related to system inputs and outputs for each unit process are collected. (Only those data that are relevant to the calculation of category indicator results related to active impact categories are required.)
- Inputs and outputs are calculated by unit process. For this study, SCS used the KCL-ECO LCI model (see Appendix 3).
- Appropriate spatial and temporal characterization is conducted to ensure that unit process data are not improperly aggregated.

2.3.3. Life Cycle Impact Assessment

Once the LCI is completed, the LCIA or impact assessment phase of a project is begun.

- ***Defining Stressor-Effects Networks*** — Stressor-effects networks are identified and properly described before use in calculating category indicator results related to the electric power generation system and the regional baseline under study. Measurable nodes (usually a midpoint node along the stressor-effect network) are identified based on the strength of their linkages to the stressor and the impact endpoint. The node with the strongest link to both the stressor and the impact endpoint is identified as the category indicator for the stressor-effect network. The name of the category indicator reflects the midpoint node or impact endpoint selected.
- ***Classification*** — Inventory data are assigned to impact categories in accordance with LCIA modeling requirements.

- ***Characterization*** — Environmental data are collected for use in characterizing the classified inventory data.[5] These data are integrated into the calculation of characterization factors on a site-specific or site-dependent basis where regional and local effects are an issue, taking into account the following considerations:
  - the current state (i.e., degree of stress) of the receiving or providing environment at the midpoint node or impact endpoint;
  - the spatial attributes, such as geographic area and scale of the respective receiving/providing environments.
  - the temporal aspects, such as duration, residence time, persistence, timing, and the reversibility of the environmental mechanism.
- Inventory data are characterized.
- Data are also collected to account for any impacts to habitats or key species resulting from direct physical disruption of terrestrial, aquatic, or riparian habitats.
- ***Aggregation*** — Once the classified inventory data are characterized by unit process, these data are aggregated to calculate the category indicator results.[6]
- ***Environmental Impact Profile*** — Together, these indicator results form the Environmental Impact Profile. Sensitivity analyses are conducted as needed to confirm results.
- ***Life Cycle Impact Declaration*** — The impact profile of a given power generation system is compared to the impact profile of a baseline case on an indicator-by-indicator basis to generate the Life Cycle Impact Declaration.

2.4. Impact Groups, Impact Categories and Category Indicators

As noted above, according to ISO 14044 and the SCS-002 Committee Draft, all impact categories must first be reviewed for their environmental relevance to the sector represented by the material, product, service or system. Table 2.1 provides the list of all impact categories that must be reviewed. To exclude any of these impact categories, a justification must be provided that illustrates why the category is not relevant to the study. Similarly, additional impact categories may be considered if justification can be provided that they are required based on characterization of active midpoints. SCS-002 Annex A, included here as Appendix 6, provides the required algorithms, specific assumptions, data requirements, characterization models and background information related to each group, impact category and category indicators.

Within the scope of this study, those impact categories and category indicators in the final column of Table 2.1 were found to be environmentally relevant. The process for

[5] Environmental data may come from a variety of sources, including governmental, academic, industry and stakeholder publications, as well as privately held databases. Examples of data sources related to energy resource depletion include environmental impact assessments (EIA), the US Geological Survey, National Energy Board (NEB) of Canada, World Energy Institute, and British Petroleum. Examples of data sources related to the direct physical disruption indicators include Federal Energy Relicensing Commission (FERC) reports and LANDSAT data. Examples of data sources related to emission loadings include US Environmental Protection Agency Toxic Release Inventory (TRI) data, monitoring records, and sampling records.

[6] Data aggregation under an impact indicator takes place only if such aggregation does not reduce the overall accuracy of the indicator result.

determining environmental relevance followed protocols is described in Appendix 6. Justification for the exclusion of impact categories is provided in Appendix 7.

Table 2.1. LCSEA Impact Groups, Categories and Category Indicators

LCSEA Impact Groups and Category Indicators	Required Node for Category Indicator	Core Impact Categories for this study, based on environmental relevance
Abiotic/Biotic Resource Depletion Group		
Non-renewable Energy Resource Depletion	Midpoint Node 2	Core
Water Resources Depletion	Midpoint Node 2	Core
Biobased Resource Depletion	Midpoint Node 2	
Strategic Metals Resource Depletion	Midpoint Node 2	
Landscape Disruption Group		
Terrestrial Habitat Disruption	Midpoint Node 2	Core
Aquatic (Lake) Habitat Disruption	Midpoint Node 2	
Aquatic (River) Habitat Disruption	Midpoint Node 2	Core
Riparian/Wetland Habitat Disruption	Midpoint Node 2	Core
Loss of Key Species	Midpoint Node 3	Core
Climate Change Emissions Group		
Accumulated GHG Radiative Force Loading[7]	Midpoint Node 4	Core
Radiative Force Loading - Well-Mixed Greenhouse Gases - Tropospheric Ozone[8] - Soot (Carbon Black)[9]	Midpoint Node 3	
Aerosol Force Cooling[10]	Midpoint Node 3	
Environmental Effects Emissions Group[11]		
Acidification Loading (Oceanic)	Midpoint Node 3	Core
Acidification Loading (Regional)	Midpoint Node 3	Core
Stratospheric Ozone Depleting Chemical Loading	Midpoint Node 2	
Ecotoxic Chemical Loading	Midpoint Node 2	Core
Eutrophication Loading (Regional)	Midpoint Node 2	
Human Health Effects Emissions Group		
Ground Level Ozone Exposures	Midpoint Node 3	Core
Particulate (PM 2.5 equivalent) Exposures	Midpoint Node 3	Core
Pulmonary Toxic Chemical Exposures	Midpoint Node 3	Core
Systemic Toxic Chemical Loading	Midpoint Node 2	Core
Neurotoxic Chemical Loading	Midpoint Node 2	Core
Indoor Inhalation Hazard Loading	Midpoint Node 2	
Noise Exposures[12]	Midpoint Node 2	
Untreated Hazardous Wastes Group		
Specific Untreated Hazardous Waste Risks	Potential Node 1	Core[13]

Eq. is equivalent, t is metric tons, kg is kilograms, ha is hectare

[7] Normalized to GMT_{2040} EOT
[8] By justified regional midpoints
[9] By justified regional midpoints
[10] By regional cooling zone, where appropriate
[11] Materials and products are not required to calculate cumulative loadings; rather, environmental loadings are calculated based on the functional unit.
[12] Accounts for noise in exceedance of a 60 Decibel threshold.
[13] In this study, untreated radioactive waste risks, measured as Equivalent GBq Pu-239

Section 3.

STUDY CONVENTIONS, ASSUMPTIONS AND CONSIDERATIONS

This Section addresses key conventions, as well as assumptions made in calculating LCI and LCIA results for regional and local emissions addressed in this study. Additional assumptions and considerations related to the LCSEA framework are described in Appendix 6, while further assumptions specific to the assessment of the WECC and Glen Canyon Hydropower Station and Stateline Wind Power Station are described in Sections 4 and 5 and 6.

3.1. LCI Conventions and Assumptions

The following conventions and assumptions were applied during the LCI phase of data collection and processing.

3.1.1. Raw Materials

Raw materials and fuels extracted from the earth were burdened with their inherent feedstock value and, in addition, were burdened with the resources, energy, direct physical disruption, emissions, and wastes associated with extraction, refining and transportation.

3.1.2. By-Products

By-products, such as fly ash and gypsum associated with power production from coal, were recorded as output amounts, but subsequent processing or use of such byproducts were outside the study boundaries.

3.1.3. Fuel Inputs and Outputs

Fuel inputs included the total amount of fuel inputs from all sources in the defined electric power generation system, including fuels used for transportation and processing, as well as in power generation and delivery. The calculations for electricity used in different processes, such as oil refining, were performed according to the relevant KCL ECO Model unit operations for grid electricity, based upon statistical values for grid electricity. The KCL ECO Model was also the source of data for production of fuels for truck and ship transport, based on unit operations for oil refining.

Transportation data were recorded in terms of the type of vehicle and the distance involved, including whether a trip was one-way or round-trip. These data were then converted into units of vehicle-kilometers, and according to the corresponding unit operations in the KCL ECO Model converted into quantities of resources and fuel consumed and emissions and wastes generated.

3.1.4. Emissions to Air

Air emissions speciated by chemical and recorded in mass flow (mass per volume per unit of time) represent discharges into the atmosphere after passing through emission control devices. Air emissions were calculated for all system processes, including operations associated with the generation of electricity, process emissions, and emissions resulting from the production and combustion of fuels for process or transportation energy. All such emissions were left unaggregated and unallocated.

3.1.5. Emissions to Water

In this study, there were no reported emissions to water. It was not within the scope of this demonstration study for SCS to perform due diligence on the data provided.

3.1.6. Solid Wastes

Solid wastes, recorded in units of mass, represent all emissions to ground from unit operations within the systems studied. While solid waste inventory values are provided for the completeness of the study, solid waste is, in fact, an input to a final unit operation, solid waste management (i.e., landfill, incineration, etc.).

Within the LCSEA methodology, the accounting of resource wastes occurs under the net resource use calculations. Air emissions generated by incineration are accounted for under their respective category indicators (e.g., particulate loading).

3.1.7. Line Losses

For this study, it was assumed that there is a 2% loss of delivered power due to line losses in transmission, based on the statistical average for the transmission distances involved.[14]

3.2. Site-Dependent Factors Used to Calculate Regional Emissions

The following discussion describes the key assumptions, data and considerations used to calculate the category indicators associated with regional and local emission loadings in this study. Specific assumptions related to Glen Canyon, Stateline and the WECC baseline is described greater detail in their specific sections.

3.2.1. Regional Acidification Loading Assumptions

In this study, SCS assumed that the emissions dispersed within concentric plumes around the plants over long averaging periods. This assumption is supported by a number of modeling exercises using the RAINS model under varied meteorological and stack conditions (Figure 3.1).

[14] The 2% line loss value is corroborated in a number of sources, including Vattenfall Generation's Certified Environmental Product Declaration of Electricity from Forsmarks Kraftgrupp AB (FKA), S-P-00021; 2001.

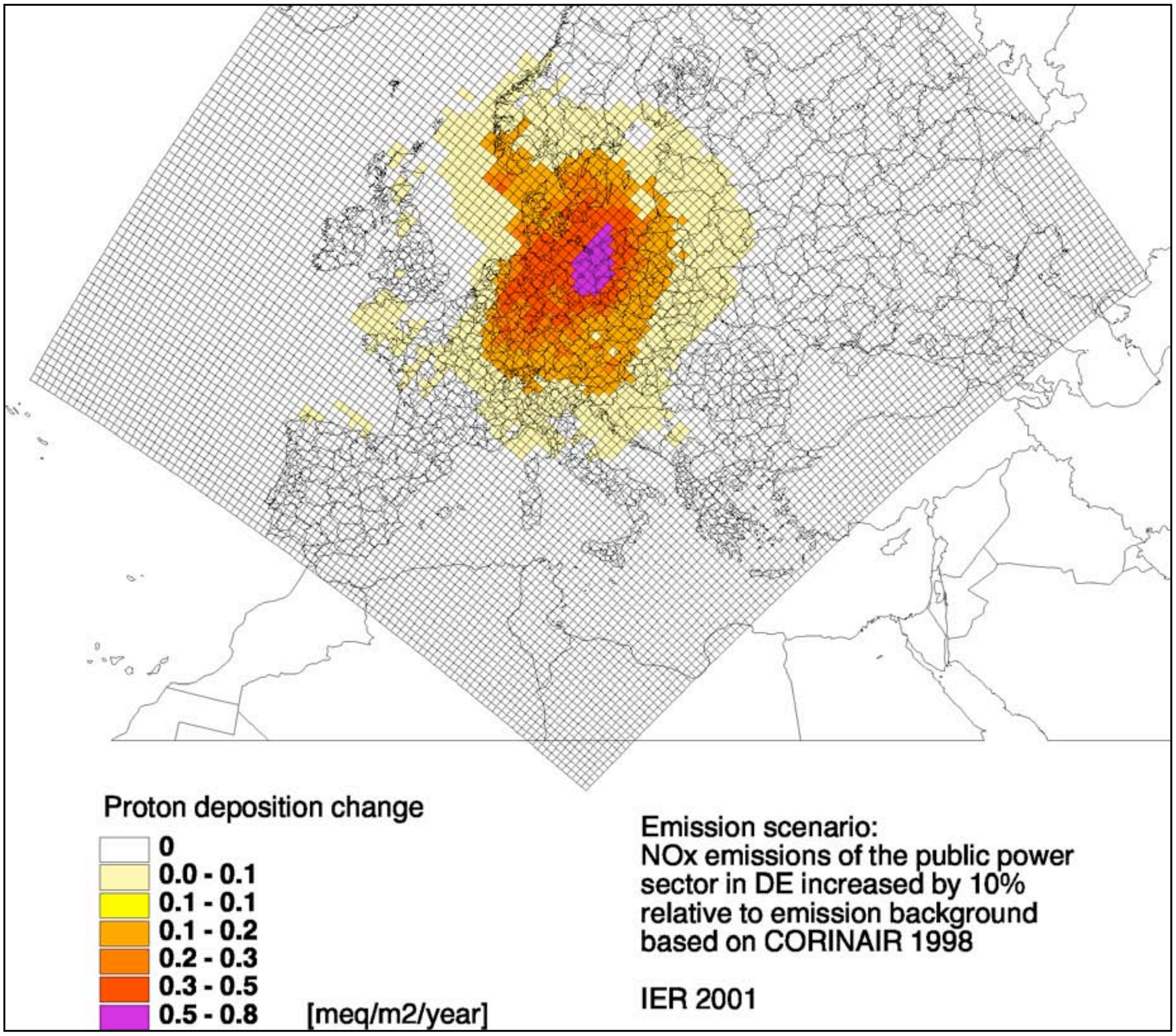

Figure 3.1. Acidification Dispersion Modeling in Europe
Source: Institute of Energy Research (IER), Stuttgart University.
CORINAIR is the database for emissions in Europe.

The calculation shown in this figure was performed to determine acidification deposition, but is also representative of NO_x dispersion.
Scale: Size of total affected region equals about 2000 km from edge to edge.

The geographical distribution of critical acidification load exceedance is based upon the UNEP/RIVM (1999) global acidification report, where exceedance maps for 1992 are given together with estimates for 2015. An overview map from the UNEP report is shown below (Figure 3.2). The UNEP report also provides an exceedance map forecast for 2015, essentially showing the same exceedances.

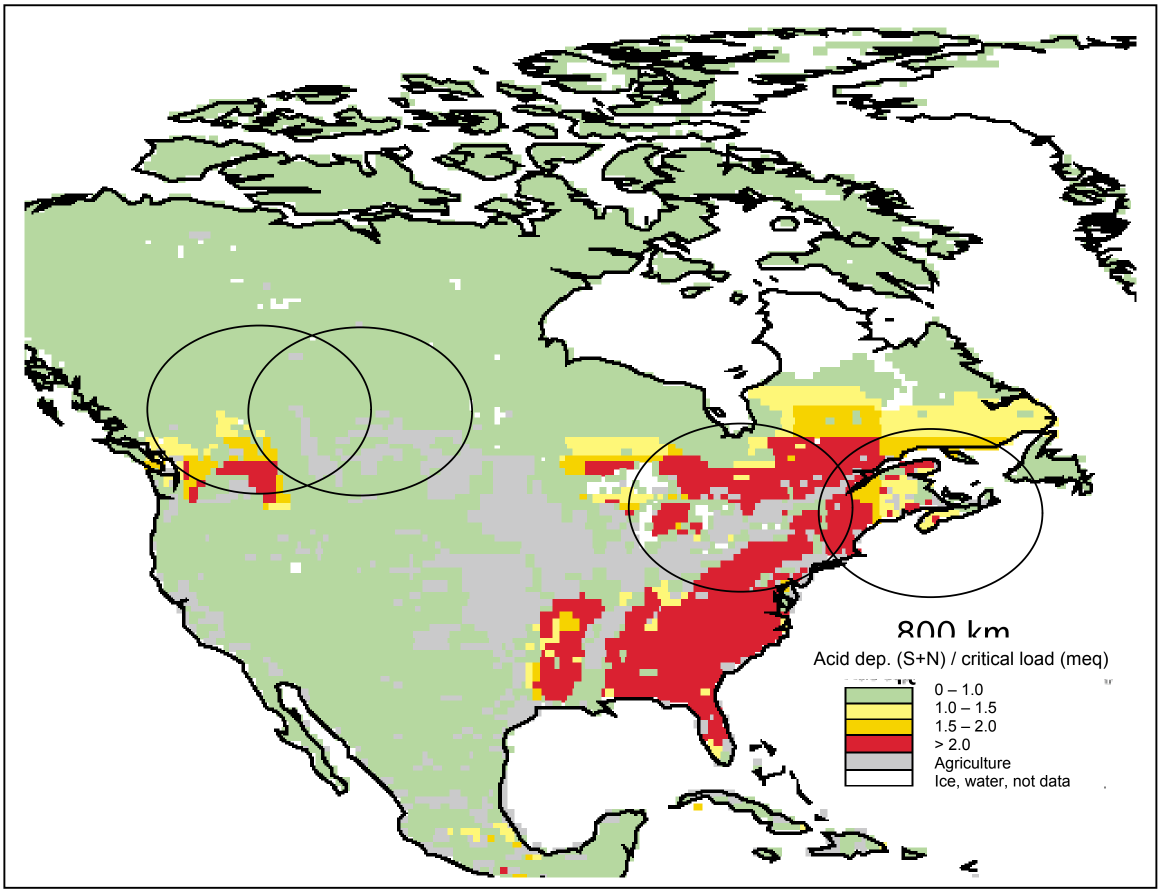

Figure 3.2. Exceedance areas for acidification in North America in 1992
The map grid is 1° by 1°. All areas with a deposition/critical ratio over 1 (yellow to red) are exceedance areas. The ovals indicate areas of 800-km radius.
Source: UNEP (1997).

To obtain the acidification ECF for North American locations, the following method has been used. Acidifying substances were assumed to be dispersed according to the EcoSense function, shown in the figure as concentric segments around the point of emissions. These segments were placed on the map showing the exceedance grid according to UNEP/RIVM (1999), and then the exceedance percentage of every segment area was estimated. (See example for Washington State, Figure 3.3).

Washington Estimating ECF		
Concentric element*	Land in exceedance	Weighted exceedance
0 - 10%	15%	2%
10 - 20%	10%	1%
20 - 50%	5%	2%
50 - 80%	10%	3%
80-100%	0%	0%
Total		7%

* denotes percent of total cumulative acidifying deposition that deposits within the segment area

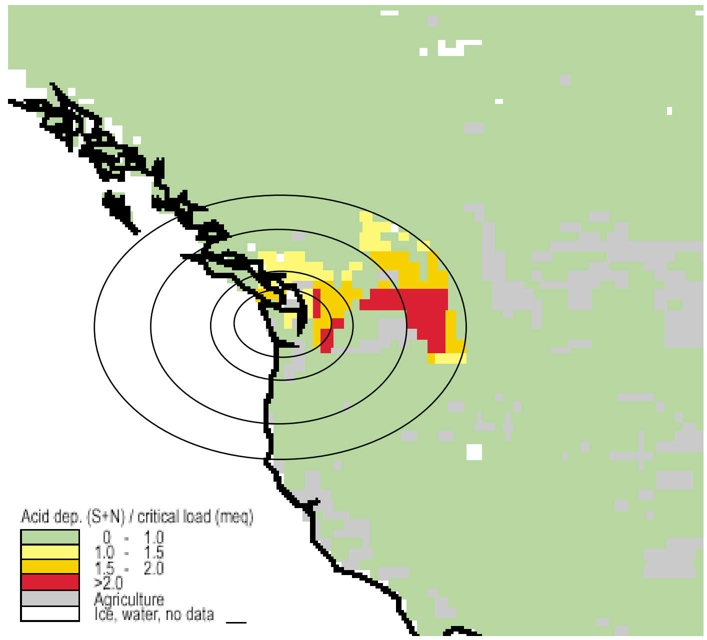

Figure 3.3. Example of Acidification Exceedance Mapping from a Point Source in Washington State
Source: RIVM/UNEP - Global assessment of acidification and eutrophication of natural ecosystems (1999)

The ECF value calculation results are presented in Table 3.1 for the geographical regions relevant for the study.

Table 3.1. Composite Acidification ECF values calculated by State

Emission region	Acidification ECF
Washington	0.07
Montana	0.07
Oregon	0.06
Idaho	0.06
Wyoming	0.02
California	0
Nevada	0
Utah	0
Colorado	0
Arizona	0
New Mexico	0

The above results would be possible to verify using long-range Lagrangian dispersion/deposition modeling for the actual geographical locations in question, and by superimposing the deposition results on the exceedance map.[15] This kind of ECF

[15] The Lagrangian derivative is the change over time of an air parcel's velocity or concentration as measured from the perspective of the parcel itself. It is the sum of the instantaneous change at a fixed location and the convective change (or change due to the movement of the parcel through a field of velocity or background concentrations). Integration of

assessment, however, was not possible within the resources allocated to this project. Earlier work performed in Europe has shown that results from the simplified approach used here is in good agreement with results from more elaborate dispersion/deposition modeling methods.

3.2.2. Ground Level Ozone

3.2.2.1. Human Health and Vegetative Impacts

In the LCSEA methodology, two indicator values can be calculated for ground level ozone: a human health indicator and a vegetation category indicator. Each indicator has its own threshold of critical exceedance. The World Health Organization (WHO) established the threshold for the onset of human health effects to be an exposure to 60 parts per billion (ppb) of ground level ozone over a period of 8 hours, while the threshold for the onset of damage to sensitive crops is 40 ppb based on a cumulative exposure of 3000 ppb-hours. The 60-ppb/8-hour limit has been used as the basis for establishing regulations to protect human health. However, in the case of vegetative damage, the data are more complex, and the linkage between the 40 ppb exposure level and the duration of exposure to specific vegetative damage is less clear. As a result, no regulatory limits have been set based on this threshold. For this study, only the human health indicator was calculated.

The indicator results are calculated using the following equation, and reported in cumulative exposure units of measure (persons * ppm O_3 * hours).

Ground Level Ozone Exposures = $\sum_i [\sum_n (NO_x \text{ emissions x } SCF_{region} \text{ x ECEC})]$

Where:
- *The loading represents the cumulative exposure over threshold (AOT 60), delineated by isopleth, of NO_x-equivalent emissions.*
- *i represents the total number of unit processes.*
- *n represents the total number of ozone precursors emitted by a unit process.*
- *SCF is the specific conversion rate of NO_x and other precursors to NO_x equivalence based on background concentrations of VOCs and NO_x in a given region*
- *ECEC is the product of the cumulative exposure as determined by AOT 60 mapping by isopleth, and the corresponding population density within the dispersion domain.*

3.2.2.2. Considerations in Establishing SCFs and ECFs

Establishment of the SCFs and ECFs used to calculate the ground level ozone indicator involves the correlation of threshold concentrations to point source emissions and the resultant cumulative human exposure.

this function gives the trajectory of the parcel, which is the change of the parcel's position or concentration over time. This trajectory is used to determine the horizontal and vertical extent of the contaminant plume over a given area, which is used to calculate cumulative concentrations.

3.2.2.2.1. Establishing SCFs

The SCF for ground level ozone is based on the establishment of conversion rates for kg of O_3 formed per kg of NO_x or VOCs emitted.

- The following atmospheric reactions are used to estimate the range of conversion rates:
  - Intermediate alkyl-hydroxyl free radicals (ROO·) are formed from VOCs, CO or hydroxyl radical (OH·) and NO_x.
  - The peroxy radicals and ozone (O_3) oxidize nitrous oxide free radicals (NO·) to form nitrogen dioxide (NO_2).
  - NO_2 is split by ultraviolet radiation (UV), leading to the formation of NO· and the release of oxygen free radicals (O·).
  - Oxygen free radicals then react with oxygen (O_2) to form O_3.

- Conversion rates are also dependent upon meteorological conditions and the background concentrations of both VOCs and NO_x.

- Secondary SCFs may be required to establish the specific conversion rate for a given region of the various compounds that comprise the aggregated VOC release. Either the maximum incremental reactivity (MIR) or photo-oxidative chemical potential (POCP) reactivity ranking may be used to determine this secondary SCF.[16]

The ratios of conversion from NOx to ozone can vary significantly — for instance, from 0.2 to 1.3 kg O_3 per kg of NOx released — depending upon the regional background concentrations of VOCs and how limited the NOx concentrations are within that region (Table 3.2).[17]

Table 3.2. SCF values for four different areas within Europe

Area	SCFs ($kgO_3/kgNOx$)
N Lappland, Finland	1.232
E Svealand, Sweden	0.957
SE England	0.228
C Germany	0.276

Additionally, a difference between initial concentrations of nitric oxide free radicals (NO•) has been observed between urban and rural environments. A British government study of rural and urban areas found that the 97th percentile seasonal average for ozone was 52 ppb in rural areas and 43 ppb in

[16] MIRs are established by the California Air Resources Board; POCPs are published in the Nordic Guidelines.
[17] LCSEA Practitioner's Manual, Scientific Certification Systems, the Swedish Environmental Research Institute (IVL) and Soil and Water, 1997.

urban centers.[18] The lower values for urban areas were attributed to the removal reaction of NO• with O_3, resulting in lower levels of ozone formation in urban centers due to higher mobile source emissions. The British study results suggest that the same level of NOx emissions in urban centers forms 20% less O_3 than in rural areas. The SCFs for rural areas in the vicinity of large urban areas are likely to be in the range of 1.2, while in urban areas, the value is likely to be approximately 0.8. For isolated rural areas, much lower SCF values are expected.

In the current study, an SCF of 1.0 was assumed, which is the equivalent of one kilogram of O_3 forming for each kilogram of NOx emitted. For VOCs, the corresponding factor, based on European correlations in the Danish Guideline, was assumed as 0.55 kg O_3/kg VOC.

3.2.2.2.2. Establishing the ECF based upon the AOT-60 Exposure Framework

In order to establish the ECF for ground level ozone, an exceedance threshold must be identified. No absolute scientific consensus has been reached for determining the threshold for chronic human health effects from exposure to ground level ozone. The World Health Organization's (WHO) Air Quality Guidelines use a threshold of 60 ppb averaged over an 8-hour period (i.e., where the concentration level is calculated from running eight-hour averages of the one-hour mean concentrations).[19] In this study, SCS used the WHO threshold, based on its compatibility with the European Union's AOT-60 ("accumulated concentration over threshold") Framework. Several publications and websites present the scientific underpinnings of the AOT-60 approach and integrate these data sets into the regulatory framework to address trans-boundary pollution.[20]

The AOT-60 Framework allows for the establishment of an ECF based upon: 1) the relative population densities of different regions that exceed the 60-ppb/8-hr. threshold; or alternatively 2) the relationship of these population densities to the overall percentage of total NOx emissions contributing to the cumulative annual exposure. The AOT-60 threshold is expressed as the number of people exposed, multiplied by hours of annual cumulative ozone exposure above 60 ppb. The Human Exposure Factor (HEF) is expressed per gram of NOx or equivalent VOC emitted as "person * ppm O_3 * hours / g NO_x", and represents a unit of cumulative exposure for a given region. The HEFs for 41 regions or countries in Europe have been determined with the

[18] Derwent, D., "Ozone Trends in the British Isles and their European Policy Context, Climate Research Division," Meteorological Office, Bracknell, UK [EPG1/3/164], 2002.
[19] World Health Organization (WHO) Air Quality Guidelines for Europe, 2nd Edition, 2000.
[20] Readers interested in this framework are directed to the general website of the Coordination Center for Effects in Holland, CCE, RIVM. http://arch.rivm.nl/cce.

RAINS model (Hauschild et al. 2000) based upon population densities and areas of exceedance of 60 ppb, as shown for 17 countries in Table 3.3.[21]

Table 3.3. Data required for establishing a site-dependent ECF for ground level ozone

Country	Area, km^2	Area, km x km *	Persons per km^2	HEF: pers·ppm·hours/ g NO_x[22]
Austria	83 845	290	96	7.0E-05
Belgium	30 518	175	330	3.8E-04
Denmark	43 094	208	121	3.4E-05
Finland	338 145	582	15	8.5E-07
France	543 965	738	106	2.2E-04
Germany	356 974	597	228	1.7E-04
Greece	131 957	363	79	1.9E-05
Ireland	70 284	265	51	1.2E-05
Italy	301 303	549	190	2.0E-04
Luxembourg	2 586	51	156	1.1E-04
Netherlands	41 526	204	370	2.3E-04
Norway	323 877	569	13	2.1E-06
Poland	323 250	569	119	1.1E-04
Portugal	92 389	304	106	1.3E-04
Spain	504 790	710	78	4.6E-05
Sweden	449 964	671	20	1.2E-05
Switzerland	41 293	203	169	9.8E-05
United Kingdom	244 100	494	238	9.9E-05

* Approximate square root of the column to the left

The data in Table 3.3 can be used to calculate the Human Exposure Coefficient (HEC), representing the rate at which cumulative exposure varies by population density. The slope value is determined by linear regression analysis (Figure 3.4). The product of the HEC and the average population density of any region within a known dispersion domain is the site-dependent ECF. If the highest exposure value given for the regions in Table 3.3 (3.8E-4) were set at an ECF of 1, then the HEC would be calculated to be 0.0022. The ECF value would then be calculated as:

$$\mathbf{ECF_{Ground\ Level\ Ozone} = 0.0022 * PD}$$

[21] Hauschild M. and Potting J. (2002), *Danish Guideline: Spatial differentiation in life cycle impact assessment - the EDIP2000 methodology*. Institute for Product Development, Technical University of Denmark. Guidelines from the Danish Environmental Protection Agency, 2000.
[22] Source: Danish Guideline.

where PD is the average population density within a 300-kilometer distance from the emission source point (i.e., the assumed dispersion domain).

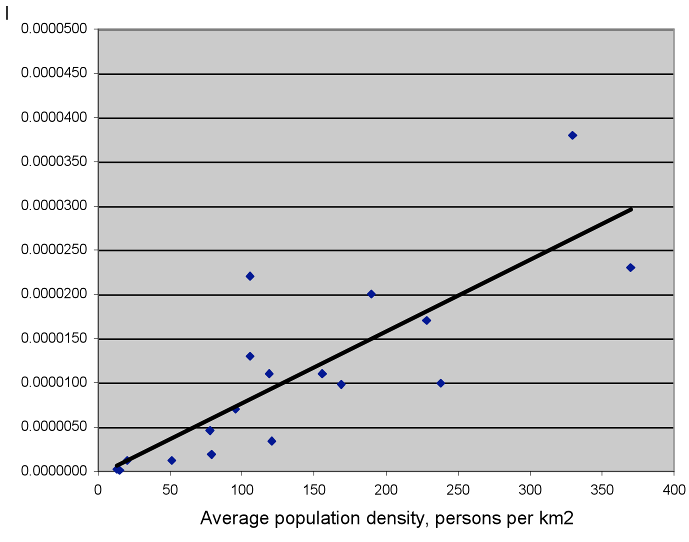

Figure 3.4. Determining the Human Exposure Coefficient for Ground Level Ozone pers·ppm·hours/g NO_x

Given the equation for calculating ECFs, and assuming the concentric plume pattern, then all that remains is to estimate the population density for the regions within the current study. Population density data for the US is shown in Figure 3.5.

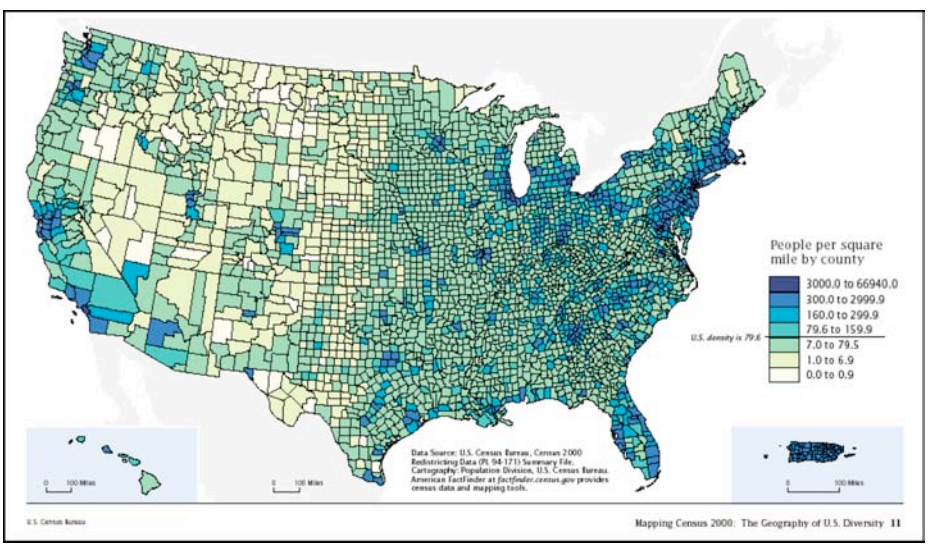

Figure 3.5. Population density of the United States in year 2000
Convert to people per square km by multiplying with 0.3861

The estimated population densities for the dispersion domains (i.e., the receiving environments) relevant to the projects (both power generation systems and baselines) are shown in Table 3.4, together with the corresponding ECFs.

Table 3.4. Composite Ground Level Ozone ECF Values for WECC States, Calculated According to the ECF Approximation Method

Emission location	Population density* Persons / $(km)^2$	Ground level ozone ECF
Washington	28.2	0.062
Montana	2.1	0.005
Oregon	11.4	0.025
Idaho	4.7	0.010
Wyoming	1.8	0.004
California	73.7	0.162
Nevada	4.2	0.009
Utah	8.1	0.018
Colorado	12.3	0.027
Arizona	12.5	0.027
New Mexico	4.8	0.011

* within 300 km distance from the point of emission

While specific domains within each state varied from region to region, Table 3.4 shows the composite ECF values by state for those states serviced by the WECC. For the WECC baseline impact profile, the ECF values for specific generation systems were calculated in accordance with standard LCSEA protocols for several key generation systems. Sensitivity analysis demonstrated that the composite statewide ECFs provide approximately the same overall indicator loadings for ground level ozone as the more site-dependent ECFs. As such, the composite values are the only ECFs provided in this study report. The low value ECF factors in Wyoming and Montana are due to low population density per the equation in page 3-9,

3.2.3. Particulate Loading

3.2.3.1. Establishing the SCF

The assumptions in this study for calculating the SCFs for particulates are consistent with the approach described in Danish Guideline, Appendix 8.1 (Hauschild & Wenzel 1998), in which relative potency characterization factors are established using ambient air quality standards based on the human reference concentrations (HRC, or RfC) for particulate matter.[23]

[23] The abbreviation, HRC, is used in Europe, while the abbreviation, RfC, is used in the U.S.

The Danish Guideline provides example values for relevant ambient particulate concentrations. For example, the recommended 24-hour limit value for the United Kingdom is 50 $\mu g/m^3$.[24] The regulatory thresholds set for annual national ambient air quality by the US Environmental Protection Agency are 50 $\mu g/m^3$ for PM-10, and 15 $\mu g/m^3$ for PM-2.5. Using 50 $\mu g/m^3$ as the HRC value for PM-10, the relative potency would be calculated by the Danish Guideline as 1/HRC = 2E+4 m^3/g, while for PM-2.5, the relative potency would be 1/HRC = 6.7E+4 m^3/g. The SCF values for the indirect formation of aerosols and for SO_2 have been derived as averages from the European health damage factors published in Krewitt et al. (2001), relative to PM-10 damage factors.

Table 3.5. SCF values as PM-10 equivalents

PM Fractions	Potency factors (1/HRC) m3/g	PM-10 eq. SCF (t PM-10eq/t)
Particles – as PM-10 µm fraction	2.0E+04	1.00
Particles – as PM< 2.5 µm fraction	6.7 E+04	3.33
Particles - indirect sulfates per emitted SO2	3.0E+04	1.5
Particles - indirect nitrates per emitted NOx	2.0E+04	1.0
Sulfur dioxide (SO2)	6.8E+02	0.034

3.2.3.2. Establishing the ECFs

The ECFs reflect the cumulative annual human exposure associated with a given amount of release. The region-dependent ECF is established in much the same way as the ground level ozone ECF in that it is dependent upon the atmospheric residence time of the various PM fractions, the release height, meteorologically dependent dispersion and deposition patterns, and the population density in the dispersion domain.

3.2.3.2.1. No Threshold Exposure Modeling

The complexity of the various PM fractions, plus the uncertainty surrounding the composition of the various fractions, complicates the establishment of background thresholds. For example, depending on the assay of a given coal source, there can be a wide distribution of constituents in a PM fraction. Consequently, the resulting variation in health effects from various fractions

[24] Danish Guideline: Spatial differentiation in life cycle impact assessment - the EDIP2000 methodology. Hauschild M. and Potting J., Institute for Product Development, Technical University of Denmark. Guidelines from the Danish Environmental Protection Agency, 2002, Appendix 8.

of PM emissions and a multitude of other emission sources creates levels of uncertainty that preclude the establishment of a threshold concentration. Since the indicator is derived strictly on a basis of cumulative exposure, the indicator has been calculated instead on an absolute basis without use of a threshold concentration.

3.2.3.2.2. Establishing the Human Exposure Factors

The dispersion model used must cover distances up to one thousand kilometers in order to account for potential mobility and residence time contributing to the cumulative exposure for some of the PM fractions (Figure 3.6).

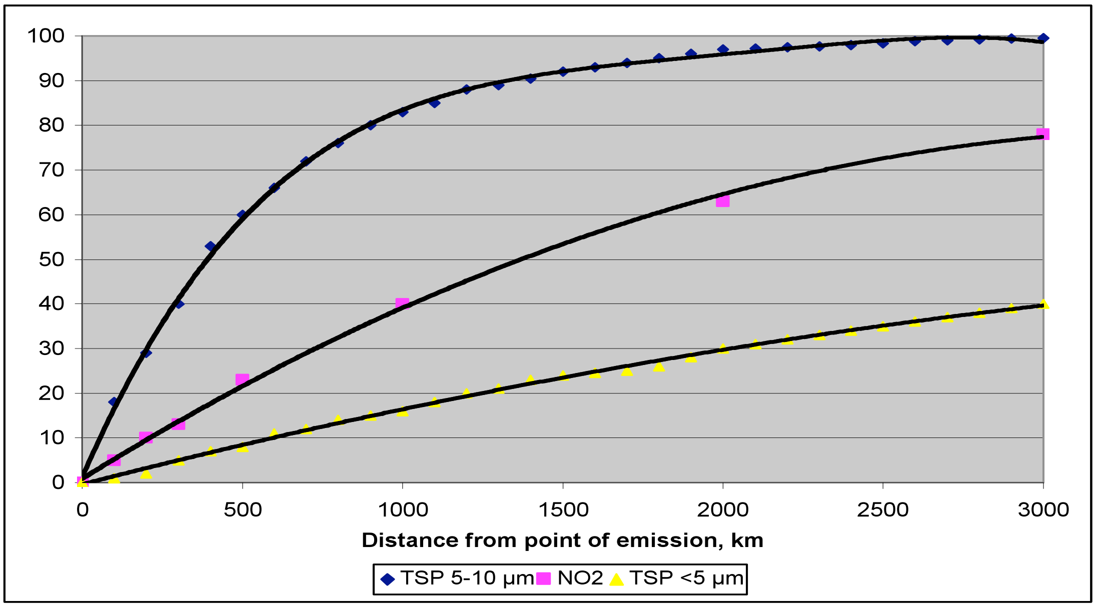

Figure 3.6. Cumulative exposure as percent of total according to dispersion models
Sources: TSP and NO2 examples from European Commission (1998)[25]

Modeling by Krewitt et. al. (2001) calculated the cumulative exposure for the PM fractions covering a region of 5500 x 5100 km that was divided into 150 x 150 km grid cells. Krewitt et. al. 2001 determined the HEFs from one metric ton per annual emissions of SO_2, sulfate aerosols, nitrate aerosols and PM-10 as calculated with the EcoSense model for 14 European countries at 1990 and projected 2010 conditions. In Table 3.6 below, the results have been converted to an emission rate of 1 gram/second (g/s) of the substance, where the HEF is represented in units of person * (μg / m^3) * $(g/s)^{-1}$ of emitted substance.

[25] European Commission Directorate-General XII 1999: ExternE; Externalities of Energy. Volume 7: Methodology 1998 Update, p.63.

Table 3.6. Examples of human exposure factors in Europe 1990
***Source: Krewitt et al. 2001*[26]**

Point of emission	Population density *	Exposure factor, person * (µg / m³)			
1 g/s, 31.5 t/year	Persons/(km)^2	SO2 emission	Sulfate aerosol from SO2	Nitrate aerosol from NOx	PM-10 emission
The Netherlands	106	16 777	11 638	8 782	12 236
Austria	108	12 268	12 239	14 312	11 384
Italy	64	8 925	8 935	11 013	9 650
Finland	10	1 829	2 027	2 377	1 230

* The population density values have been estimated roughly from statistical data for surrounding areas/countries within 300 km radius (the km^2 include also sea and other uninhabited areas).

As in the case of establishing the ECFs for ground level ozone, the establishment of a site-dependent ECF for PM fractions requires that HEFs be plotted against the relevant population densities within the dispersion area domain. The data in Table 3.6 can be used to calculate the HEC (i.e., the slope determined by linear regression) that represents the rate that cumulative exposure varies by population density (Figure 3.7).

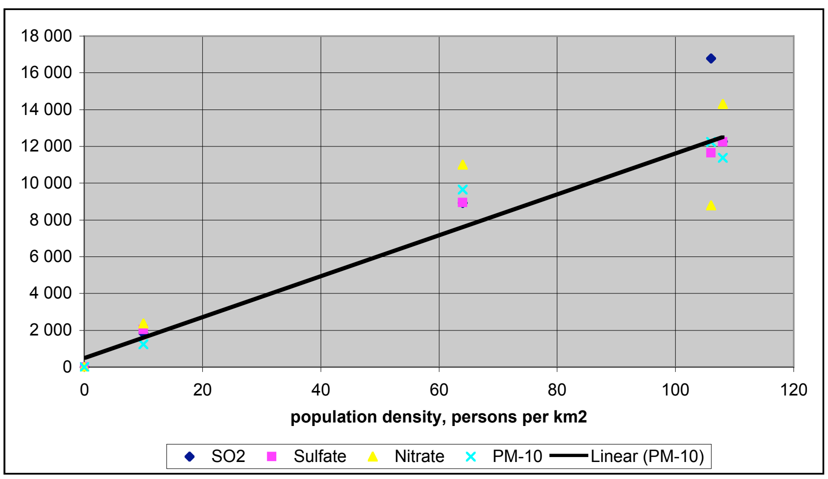

Figure 3.7. Determining the Human Exposure Coefficient for PM Loading
person * (µg / m^3) * (g/s)$^{-1}$

If the highest exposure value in Table 3.6 is defined as ECF=1, the "best-fit" HEC (i.e., the linear regression slope with the least uncertainty) for all fractions is calculated to be 0.007. This HEC multiplied by the population density yields the site-dependent ECF for each project using the following equation:

[26] Krewitt, W., Trukenmüller, A., Bachmann, T. and Heck, T. *Country-specific Damage Factors for Air Pollutants – A Step Towards Site Dependent Life Cycle Impact Assessment.* Int. J. LCA 6(4) pp199 – 210 (2001).

$$ECF_{PM} = 0.007 * PD//(\text{persons per km}^2)$$

where PD is the average population density within a 300-kilometer distance from the emission source point (i.e., the assumed dispersion domain). The ECFs for the current study are shown in Table 3.7.

Table 3.7. Composite PM Loading ECF values for WECC states

Emission location	Population density (Persons/km2)	PM Loading ECF
Washington	28.2	0.020
Montana	2.1	0.001
Oregon	11.4	0.008
Idaho	4.7	0.003
Wyoming	1.8	0.001
California	73.7	0.052
Nevada	4.2	0.003
Utah	8.1	0.006
Colorado	12.3	0.009
Arizona	12.5	0.009
New Mexico	4.8	0.003

3.2.4. Chronic Hazardous Chemical Loadings

Stack emissions data from previous SCS studies have been used to confirm the validity of calculated emissions factor.

3.2.4.1. Classification Issues

3.2.4.1.1. Determining the Chemicals in this Group of Indicators

Although coal systems and typical light water nuclear reactor systems within the WECC generate a wide range of radiological and non-radiological releases, these releases were grouped based on common endpoints and routes of exposure into the same sets of category indicators.

3.2.4.1.2. Classification by Specific Health Effects Endpoints

Within LCIA practice, a sharp division exists over the appropriate approach for classifying hazardous chemical loadings. On the one hand, the Danish Guideline recommends that all chemicals within this group be aggregated into one indicator. The Guideline reflects a largely European assumption that as long as the chemicals are classified generically by governments as toxic and/or hazardous, no further sub-classification is required. Both the International Life Sciences Institute (ILSI) and SETAC (North America) have rejected the European assumption as an oversimplification of the variety of endpoints possible for hazardous chemical exposure, and have proposed a classification step that leverages existing toxicological methods and data. This growing consensus position proposes that these chemicals be classified according to their specific non-cancer and carcinogenic endpoints. SCS adopted the SETAC position for this study.

While SETAC has proposed this classification outline, no published studies (prior to this study) to date have used this classification approach. Several methodological issues have arisen while applying this classification approach. For example, it was necessary to conduct the assessment by using the classification and characterization steps in an iterative manner. Typically, these steps are applied sequentially: first, establishing and defining the impact category, then characterizing the impacts. However, due to the complexity of the environmental mechanisms associated with this grouping, it was necessary not only to identify specific health endpoints, but also, to include the routes of exposure as part of the sub-classification of indicators. TCDD and related compounds provide a good case example of why the classification/characterization process must be iterative. While the routes of exposure for these compounds routinely include inhalation as well as indirect uptake from soils through the food chain, additional routes of exposure exist (e.g., bioaccumulative potential from the recirculation of these compounds in the environment). Furthermore, unlike many of the compounds associated with these endpoints, these chemicals tend to bio-magnify in the body. As a result, even though the entire class of compounds has similar endpoints, their mechanisms differ sufficiently to necessitate the use of separate indicators to be consistent with the SETAC framework.

3.2.4.2. Characterization Issues

In both coal and nuclear power generation systems, the only chemicals in this group of indicators with potentially active human health or environmental endpoints are those associated with direct inhalation routes of exposure, and indirect exposure through uptake of heavy metals through soils and water into the food chain. Characterization of indicators associated with direct inhalation exposure was conducted in a manner consistent with the approaches described above for ground level ozone and particulates. The characterization of indicators that involve indirect exposure requires site-specific dispersion modeling and analysis. For this study, SCS drew upon information reported in an analysis conducted by Cantox Environmental under a separate series of studies regarding chemicals involved in secondary routes of exposure.[27]

3.2.4.2.1. Establishing SCFs

For non-radiological compounds, the SCFs (i.e., human toxicity factors) were obtained from the human reference concentrations listed for hazardous chemicals in the Danish Guideline, Appendix 8.1. For radiological compounds, the HRC is derived from national emission standards and dose coefficients for various radionuclides and their daughter decay nuclides, as

[27] Cantox Environmental. Report to EPCOR, Appendix A. June 6, 2001.

described, for example, in USEPA (1993)[28]. According to US national emission standards, the emission standard threshold value for radionuclides is defined as follows: "Emissions to the ambient air shall not exceed those amounts that would cause any member of the public to receive in any year an effective dose equivalent of 10 mREM/year." In scientific notation, the corresponding dose value is 0.1 mSv/a (milliSievert per annum). This is also an accepted international standard worldwide.

The dose coefficient for each radionuclide depends on the type and intensity of the radiation emitted; the half-life time of the decay is also relevant. Radionuclides are characterized by the US EPA (1993) using effective dose coefficients for humans submerged in air in (Sv/s)/(Bq/m3) for each nuclide, as shown in Table 3.8. The SCF value is calculated from the dose coefficients as Rn-222 equivalents, by dividing the values in column 2 with the value for Rn-222. From the dose coefficient values and the dose standard of 0.1 mSv/a, HRC values also have been calculated.

Table 3.8. Potency Factors (SCFs) and Human Reference Concentrations (HRC) for Selected Radionuclides

Nuclide + daughters	Dose coefficient for submersion in air, (Sv/s)/(Bq/m3)	Equivalent dose coefficient **SCF**, Bq Rn-222 eq / Bq (nuclide)	HRC, Bq/m3
H-3	3.31E-19	3.74E-06	9.58E+06
C-14	2.24E-19	2.53E-06	1.42E+07
Kr-85	7.60E-15	8.60E-02	417.2
Kr-88	1.02E-13	1.15E+00	31.1
Xe-133	1.56E-15	1.76E-02	2032.7
Xe-135	1.19E-14	1.35E-01	266.5
Rn-220	1.13E-13	1.28E+00	28.1
Rn-222	8.84E-14	1.00E+00	35.9[29]
Pb-210	8.97E-17	1.01E-03	3.54E+04
Po-210	4.16E-19	4.71E-06	7.62E+06

[28] USEPA (1993): External Exposure to Radionuclides in Air, Water, and Soil. Federal Guidance Report EPA-402-R-93-081.

[29] Rn-222 is a major contributor to the natural background dose for humans. A check of the above calculation can easily be found in the literature. In the UNSCEAR 2000 annual report, the annual effective dose at a typical natural background radon concentration of 10 Bq/m3 from outdoor exposure during 1760 h/a is given as 0.095 mSv/a. Calculating backwards, the HRC for a 0.1 mSv/a dose at 8760 hours of exposure requires 2.1 Bq/m3. This value is obviously much more cautious than earlier tabulations, such as those in USEPA 1993. On the other hand, German radiation protection authorities allow 80 Bq/m3 radon in urban areas (Frischknecht *et. al.* 1996), which is 8 - 40 times above the values calculated from the UNSCEAR report. The value in this table (35.9 Bq/m3) then is within the range of these three values from the literature.

3.2.4.2.2. Establishing ECFs

The ECFs reflect the cumulative annual human exposure associated with a given amount of chemical release from a given point source. As in the case of ground level ozone and PM, the region-dependent ECF is dependent upon the atmospheric residence time of the emitted chemicals, the release height, meteorologically dependent dispersion and deposition patterns, and the population density in the dispersion domains. Figure 3.8 shows examples of the cumulative exposure as a function of distance from the source of emission.

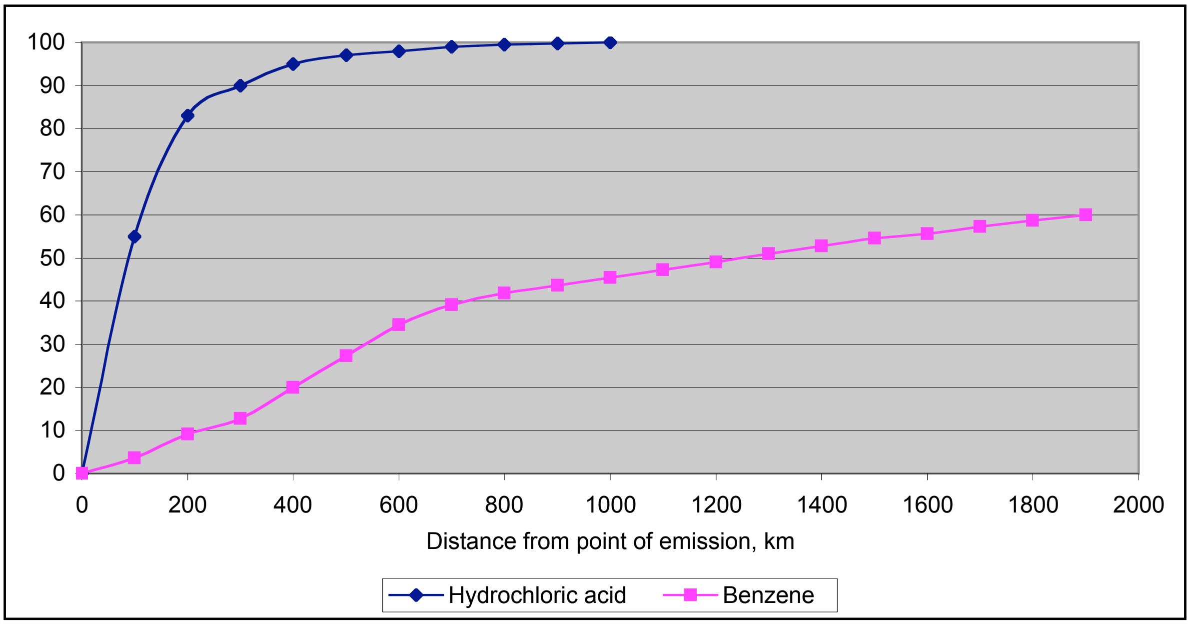

Figure 3.8. Cumulative exposure as percent of total according to dispersion models[30]
Source: Potting et. al. (2000).

The study results from Potting *et. al.* (2000) can be used to establish cumulative HEFs. In the study, two different models were used for the exposure calculations: the EUTREND[31] Gaussian plume type model for short distances (up to about 10 km), and the WMI trajectory model for regional distances (up to over 2500 km distance).[32] For these models, two substances were investigated: benzene, which has an atmospheric residence time of seven

[30] References: European Commission (1998), ExternE: Externalities of Energy, Volume 7, Methodology 1998 Update, Chapter 4: Models for Air Pollution Analysis. Potting, J., Trukenmüller, A., van Jaarsveld, H. and Hauschild, M. (2000); Site dependent assessment of human exposure from air emissions in life cycle assessment. In: Potting, J. (2000): Spatial differentiation in life cycle impact assessment, Doctoral thesis, Utrecht University, March 2000.
[31] Van Jaarsveld J.A., W.A.J. van Pul and F.A.A.M. de Leeuw: Modelling transport and deposition of persistent organic pollutants in the European region. Atmospheric Environment, Vol. 1997, Issue 31, pp 1011 – 1024.
[32] Krewitt W., P.Mayerhofer, R.Friedrich, A. Trukenmüller, T. Heck, A.Gressmann, F. Raptis, F. Kaspar, J. Sachau, K. Rennings, J. Diekmann, B. Praetorius. ExternE – Externalities of energy. National implementation in Germany (EUR 18271). Directorate-General XII for Science, Research and Development of the European Commission, 1997.

days, and hydrochloric acid, with a corresponding residence time of seven hours. These two substances were used as surrogates for emissions of substances with similar chemical and physical properties, including atmospheric residence times. A whole class of low boiling point organic compounds emitted from coal operations would have exposure factors similar to benzene. Likewise, some compounds that are susceptible to wet deposition would have exposure factors similar to hydrochloric acid. In the case of radioactive substances, the radioactive decay half-life also must be considered when establishing the ECF.

To calculate the HEF, the Potting study used the EMEP grid in Europe for a region of 5500 x 5100 km divided into 150 x 150 km grid cells.[33] When an emission of one gram per second (1 g/s) of the substance was located in any of the grid cells, the HEF, expressed as "person * (µg / m^3)", was obtained as a result.

The HEF was calculated for various release heights and meteorological/climatic conditions (e.g., maritime, central, South Europe and northern locations). In the case of hydrochloric acid, the average HEF was 2460 person * (µg / m^3) per g/s. In the case of a longer-lived substance, benzene, the average HEF was 50,000 person * (µg / m^3). Depending on the point of emission the HEF values varied as shown below in Table 3.9.

Table 3.9. Data required for establishing a site-dependent ECF for chronic hazardous chemical loadings – direct inhalation only
Source: Potting et al., 2000

Point of emission	Exposure factor, person * (µg/m^3)		Population Density*
1 g/s	Benzene type substance	Hydrochloric acid type substance	Persons/(km)2
The Netherlands	71 700	11 280	106
Austria	67 460	4 320	108
Italy	54 280	5 050	64
Finland	11 020	570	10

* This value was not given in Potting (2000). The values have been estimated roughly from statistical data for surrounding areas/countries within 300 km radius (the km2 includes sea and other uninhabited areas).

The data in Table 3.9 can be used to calculate the HEC (the slope calculated through linear regression), which represents the rate that cumulative exposure varies by population density for hydrochloric acid-type chemicals and benzene type chemicals (Fig. 3.8). The product of the HEC and the average population density of any region within a known dispersion domain is the site-dependent ECF. Using the above data, and assuming an ECF = 1 for the highest values in the two columns, the regression analysis yielded the

[33] EMEP, 1998.Transboundary acidifying air pollution in Europe. MSC-W status report 1998 – Parts 1 and 2. EMEP/MSC-W Report 1/98, Norwegian Meteorological Institute, Oslo, Norway.

following HECs for long-range chemicals and short-range chemicals within a given indicator group.

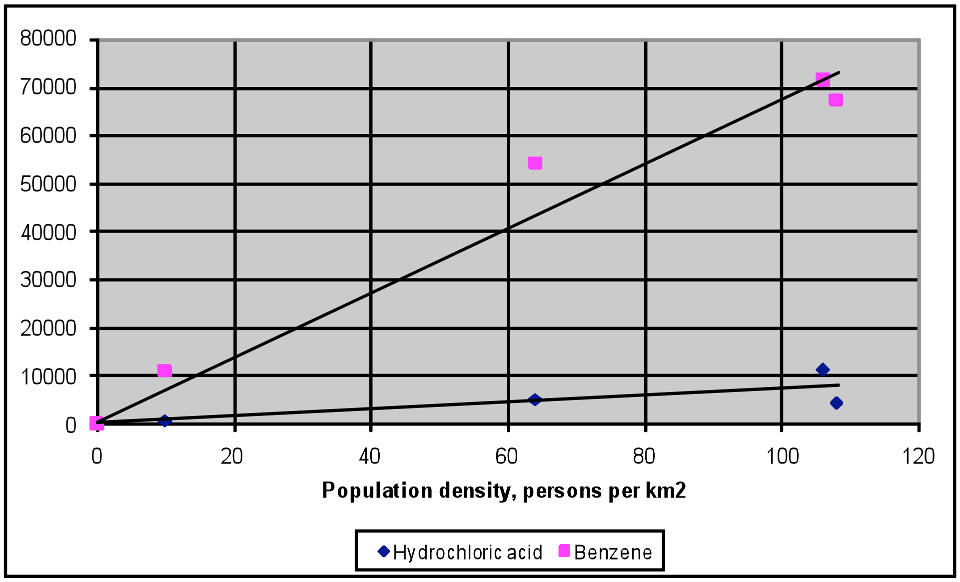

Figure 3.9. Determining the Human Exposure Coefficient for Chronic Hazardous Chemical Loadings, person * (μg / m^3) * (g/s)$^{-1}$

The ECF values, therefore, were:

$$\textbf{ECFs}_{\text{short-range compounds}} = 0.0011 * \text{PD/(persons per km}^2)$$
$$\textbf{ECFs}_{\text{long-range compounds}} = 0.0094 * \text{PD/(persons per km}^2)$$

Table 3.10 shows the ECF values for the regions relevant to the projects and baseline cases included in this study report.

Table 3.10. ECF Values for WECC states Chronic Hazardous Chemical Loadings

Emission location	Population density (Persons/km2)	ECF short-range	ECF long-range
Washington	28.2	0.031	0.265
Montana	2.1	0.002	0.020
Oregon	11.4	0.013	0.107
Idaho	4.7	0.005	0.044
Wyoming	1.8	0.002	0.017
California	73.7	0.081	0.693
Nevada	4.2	0.005	0.039
Utah	8.1	0.009	0.076
Colorado	12.3	0.014	0.116
Arizona	12.5	0.014	0.118
New Mexico	4.8	0.005	0.045

The classification of radionuclides into short-range or long-range substances can be checked against the radioactive decay half-lives shown in Table 3.11. The nuclides Kr-85, Kr-88, Xe-135 and Rn-220 have decay half-lives below 10 hours, and therefore must be classified as short-range substances. However, given the non-ionic nature of these noble gases, the atmospheric velocity of transport may warrant a longer-range classification, pending further research. The nuclides H-3 and C-14, on the contrary, have a short atmospheric lifetime, despite the radioactive decay that is measured in years.

Table 3.11. Radioactive Decay Half-Life for Selected Nuclides

Nuclide + daughters	Dominant nuclide half life
C-14	5730 years
Pb-210	22.3 years
H-3	12.4 years
Po-210	138 days
Xe-133	5.2 days
Rn-222	3.8 days
Rn-220	10.6 hours
Xe-135	9.1 hours
Kr-85	4.5 hours
Kr-88	2.84 hours

Section 4.
The WECC (US) REGIONAL POWER BASELINE

4.1. Project Description and Background

4.1.1. Project Description

Under this project, SCS calculated the impact profile of the Western Electricity Coordinating Council (WECC) electric power generation system, which served as the baseline for comparison in this study. A baseline impact profile represents the averaged level of impact by indicator of all power generation systems that make up the total mix of power in a regional power pool. In this study, the assessment was confined to power generation in the eleven US states included in the WECC.

4.1.2. Project Background

The WECC baseline impact profile provides a common point of reference against which individual power generation systems contributing to the power pool can be compared, and against which improvement efficiencies can be measured. The calculation of the regional power pool impact profile involves a survey and analysis of the full spectrum of power generation sources comprising the power pool, summarized below. The full list of power plants that make up the WECC and their related datasets is provided in Appendix 4.

4.2. WECC Regional Power Baseline

4.2.1. General Description

As described by the North American Electric Reliability Council (NERC), the Western Electricity Coordinating Council, or WECC, "comprises the entire Western Interconnection. With a footprint of 1.8 million square miles and members operating in 14 states in the Western US, two Canadian provinces, and Baja Norte, Mexico, the WECC is the largest geographically of the ten NERC regions. WECC members represent the entire spectrum of bulk electricity users and are divided into five member classes: large transmission owners, small transmission owners, electric line of business entities that do no operate transmission, end users, and state and provincial regulators."[34] The WECC is part of a national NERC regional system with specific control centers in each region as shown in Figure 4.1.

[34] http://www.nerc.com/regional/wecc.html

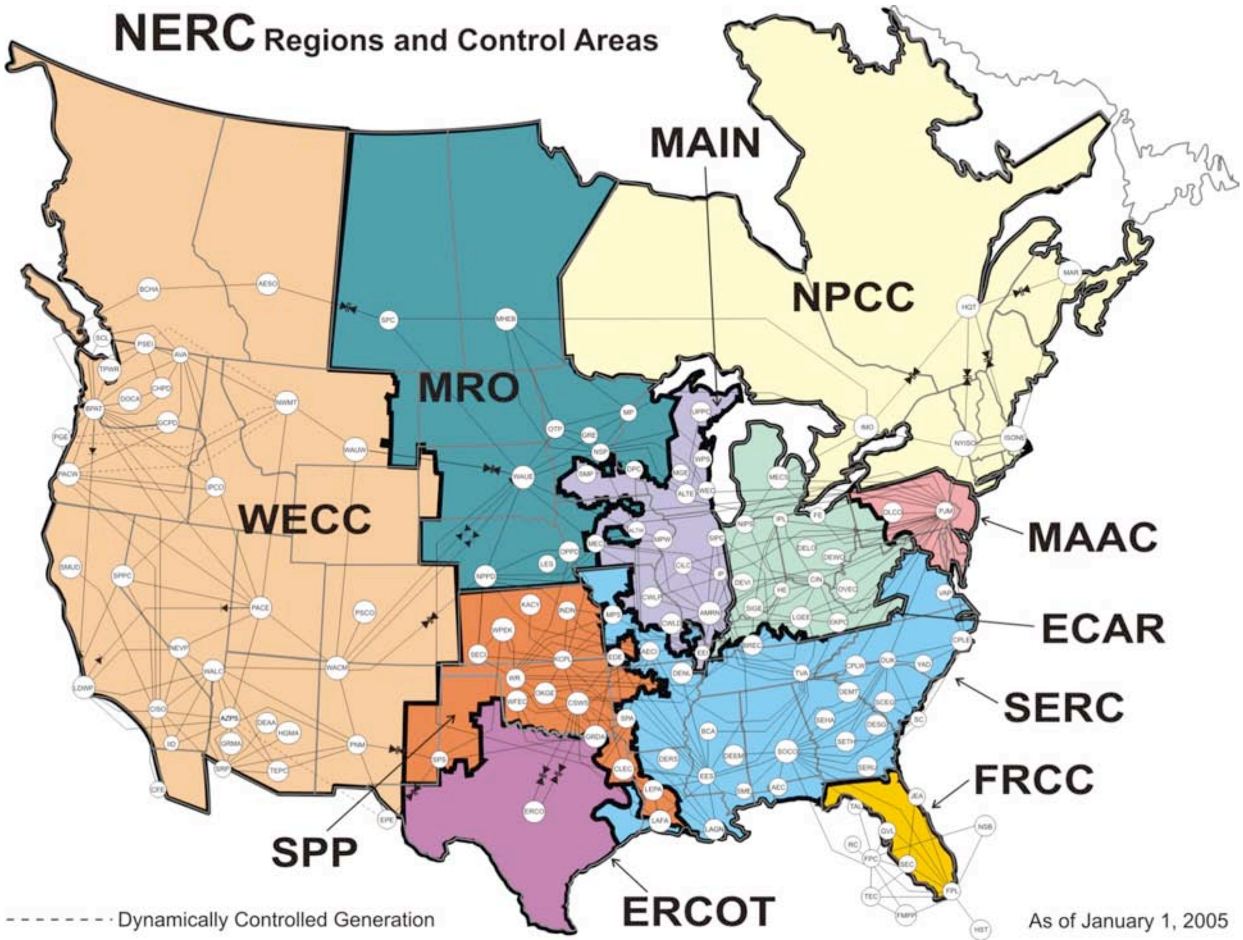

Figure 4.1. Control Areas within WECC and other NERC Regional Power Pools

4.2.2. Sub-NERC Regional Baselines

The data used to established the overall WECC baseline can also be aggregated within either the subregions of the various NERC regions or at the ISO levels as described below. However, the complexity of transactions related to import/export of power exchanges in sub-NERCs make them less than ideal as LCIA baselines.

- **Subregions** — Within the NERC regions, specific subregions have been identified, as shown in Table 4.1. These subregions are defined by EPA, and as such, are lined up with existing EPA environmental data.

Table 4.1. NERC Subregions
Source: EGRID 2002

eGRID subregion name	States involved
ASCC Alaska Grid	
ASCC Miscellaneous	AK
ECAR Michigan	MI
ECAR Ohio Valley	IN,KY,MD,MI,OH,PA,TN,VA,WV
ERCOT All	TX
FRCC All	FL
HICC Miscellaneous	HI
HICC Oahu	HI
MAAC All	DC,DE,MD,NJ,PA,VA
MAIN North	MI,WI
MAIN South	IA,IL,IN,MN,MO
MAPP All	IA,IL,MI,MN,MT,ND,NE,SD,WI,WY
NPCC New England	CT,IL,MA,ME,NH,RI,VT
NPCC NYC/Westchester	NY
NPCC Long Island	NY
NPCC Upstate NY	NY,PA
SPP North	KS,MO
SPP South	AR,LA,MO,NM,OK,TX
SERC Mississippi Valley	AR,IA,LA,MO,MS,OK,TX
SERC South	AL,FL,GA,MS
SERC Tennessee Valley	AL,GA,KY,MS,NC,TN
SERC Virginia/Carolina	GA,NC,SC,VA
WECC California	CA,NV,UT
WECC Great Basin	CA,ID,MT,NV,OR,UT,WA,WY
WECC Pacific Northwest	CA,ID,MT,OR,WA,WY
WECC Rockies	AZ,CO,MT,NE,NM,SD,UT,WY,
WECC Southwest	AZ,CA,NM,NV,TX

- **ISO Regions** — The regions controlled by the Independent System Operators (ISOs) provide an even greater degree of regional differentiation. The selection of ISO-controlled regions has several potential advantages: 1) the ISOs control much of the data needed for the assessments; 2) the ISOs are making the direct dispatch decisions that must be taken into consideration for the assessments; and 3) the ISOs are involved in reviewing and integrating new source generation. Depending on size and breadth, one ISO or a group of ISOs could be considered an appropriate baseline. The California ISO, for instance, is large enough to serve as a discrete baseline.

4.2.3. Scope of WECC Baseline Assessment

For this study, the WECC power pool was defined as the total electricity generation from the utility and non-utility power plants operating within the US part of the

WECC region. The functional unit for the study was derived from data associated with net annual generated electricity, normalized to 1,000 GWh.

The total energy produced in the WECC in 2000 was 667,640 GWh. Table 4.2 provides an overview of the WECC total generation by plant primary fuel, as reported in EGRID 2002. The category, “other”, which represents 4.6% of total generation, includes wind, geothermal, biomass, solar, waste fuel, and other minor plant contributions.

Table 4.2. WECC Electricity Generation in the Year 2000 by Main Primary Fuel
Source: EGRID2002.

Fuel	Total WECC	
	GWh	%
Coal	217,013	32.5%
Hydro	188,382	28.2%
Gas	105,672	23.3%
Nuclear	74,164	11.1%
Oil	1,917	0.3%
Other	30,490	4.6%
Total generation	667,640	100.0%

The full electric power generation system includes not only the power plants, but also the “upstream” unit processes involved in the extraction, processing and delivery of fuels, such as coal mining, primary oil and gas extraction, processing and distribution, lime production and transport. As noted in Section 1, impacts associated with end-of-life dismantling of plants were not assessed for the full WECC. Such impacts are typically insignificant relative to the impacts associated with the operation lifetime.

4.3. WECC Baseline Power Mix

The generation mix included in the WECC regional baseline was derived from the EGRID database. This generation mix is described in Appendix 4.

4.4. Data Sources

4.4.1. Primary Data Sources

The establishment of the US WECC baseline involved a review of readily available data pertaining to generation plant types, size/capacity, GWh production, locations, ages, technology specs, type and amount of material flows. Data on fuels, emissions, efficiencies and co-generation for both the utility and non-utility power plants were derived primarily from two sources: SCS’s LCSEA database and the EGRID database. Both sources are considered to have excellent data quality.

The SCS LCSEA database integrates data from a variety of published industry, government, and independent reports and life-cycle assessment studies, and in addition, incorporates data collected and analyzed under previous SCS LCSEA studies of power generation in North America and Europe conducted over the past decade.

The EGRID database contains data on emissions and resources associated with electric power plants operating in the United States, integrating data sources on power plants and power companies from three different federal agencies – the Environmental Protection Agency (EPA), the Energy Information Administration (EIA), and the Federal Energy Regulatory Commission (FERC). Its data relate to more than 4,700 power plants and nearly 2,000 generating companies.[35]

Power plant data obtained from the EGRID 2002 database for eleven western states -— Washington, Oregon, California, Arizona, Utah, Wyoming, Colorado, New Mexico, Montana, Idaho, and Nevada — were confirmed by SCS on a plant-by-plant basis (Figure 4.2).

For example, hydropower generation listed in EGRID 2002 was checked by comparing its list of power plants to the list of dams in the National Inventory of Dams (NID) database, which identifies over 71,000 dams in the United States, and the USGS Basins database. This crosscheck was conducted because the EGRID database did not include all of the data needed to develop a framework to calculate the full life-cycle impacts, since it did not have data on size of the impoundments associated with each hydropower plant. EGRID lists the power plants, but not the dams themselves. Moreover, in some cases, a single power plant is associated with more than one dam; likewise, multiple power plants may be associated with a single dam. By overlapping the NID and USGS databases, SCS was able to check on the number of installations in the WECC and subsequently link surface area calculations for major impoundments with specific power gener-

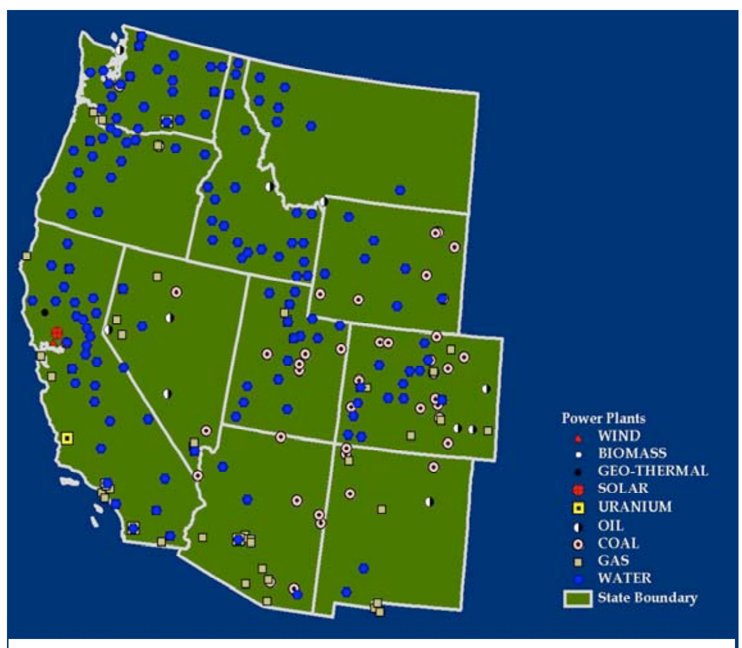

Figure 4.2.
Confirming Major Plant Locations in the US WECC
(Source: EGRID 2000)

[35] EGRID description source: www.epa.gov/cleanenergy/egrid/whatis.htm#what

ation capacity.

The EGRID database was also useful in providing data on a number of other aspects of each plant including (but not limited to) annual fuel use, annual capacity, efficiency, annual net production of electricity, ownership, and location. EGRID also contains annual emission amounts by plant for criteria pollutants: SOx, NOx (annual and ozone season emissions), CO2 and mercury.

4.4.2. Additional Data Sources

In addition to EGRID and the SCS LCSEA database, SCS consulted other published data sources on coal mining and coal quality.[36] For instance, the mass (kg.) of release data for chemicals and metals such as arsenic, cadmium, lead, manganese, nickel compounds and polycyclic aromatics, were taken from a study published by NREL.[37] Radioactive Rn-222 emissions from coal mining and combustion were found in the benchmark Swiss study (Frischknecht et. al. 1996).[38] The US EPA Toxic Release Inventory (TRI) data, though available, were not used as the basis of the calculations. Whereas TRI data are generated for regulatory purposes based on generic EPA emissions factors, LCSEA requires site-specific emissions data in order to accurately assess category indicators.

Additional data for solar, wind, geothermal, and biomass generation were identified through state databases.

4.4.3. Upstream Unit Processes

Generally speaking, upstream unit processes were found not to have significant site-dependent issues; therefore, SCS drew upon data from its energy sector database, including data from North American and European operators. Sensitivity analyses were conducted to confirm that the use of these data was justified, and will be described further in the final study report for peer review.

4.5. Key Project Assumptions and Considerations

Classification and characterization assumptions and considerations pertinent to the WECC power have been discussed in Sections 2 and 3 of this report, and are described more extensively in Appendix 6.

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[36] Hydrogen chloride and hydrogen fluoride emissions were mainly assigned to coal combustion, consistent with earlier SCS studies.

[37] Spath, P., Mann, M., Kerr, D. *Life-Cycle Assessment of Coal-Fired Power Production*. NREL, June, 1999.

[38] Frischknecht, R. et al., *Life cycle inventory of energy systems. Basic methods and data for environmental comparison of energy systems and for the inclusion of energy systems in an environmental assessment of Switzerland* (in German). Swiss Energy Economy Administration (Bundesamt fuer Energiewirtschaft BEW). The Foundation for Projects and Research of the Electricity Industry (Projekt- und Studienfonds der Elektrizitätswirtschaft PSEL). 3rd Edition, July 1996.

During the period over which this study has been conducted, SCS has gradually been able to increase the accuracy of the data sets used to establish category indicators for the baseline impact profile. For example, concurrent to this study, LCSEA algorithms continued to be refined; these refinements now allow captured in the SCS-002 Committee Draft, including refinements for several category indicators involving human health endpoints to be calculated with respect to cumulative annual exposures based upon accurate population density mapping. These advances have made it possible to calculate the WECC air emission loadings with greater accuracy.

Specific considerations and assumptions specific to the establishment of the WECC baseline impact profile are described below:

4.5.1. Characterization of Receiving Environments for Emissions Category Indicators

The establishment of indicator results for category indicators with regional and local impact endpoints required considerable data collection, characterization modeling and key assumptions. For example, the characterization of the various receiving environments for the acidification, ground level ozone, PM, and chronic hazardous chemical loading indicators each required modeling that took into account specific meteorological conditions and airsheds.

LCI and LCIA modeling were completed for significant power systems within the WECC before averaging the entire mix of power systems into the WECC baseline impact profile. Because of the very large area encompassed by the WECC, the receiving environments were prioritized by technology, nameplate capacity and location. By ordering the process in this manner, the larger generation systems were first characterized and the indicator results calculated for the acidification, ground level ozone, particulate, and chronic hazardous chemical loadings. For the remaining smaller units, composite ECFs by state were used.

4.5.2. Water Resource Depletion

SCS researched the issues surrounding depletion of surface water and ground water in the WECC region, looking for evidence of increases rates of evaporation (e.g., in the case of lakes formed from impoundments), and increased rates of aquifer depletion. Although such changes may have historically been a significant factor, SCS did not find sufficient evidence of significant changes in rates of water depletion to warrant the cost of calculating this indicator for the WECC. Even in areas of large water impoundments, such as Lake Powell, conflicting data concerning rates of evaporation made such calculations difficult. An exception was noted in the case of geothermal power, which constitutes only a very small fraction of the total WECC power pool capacity. Here, significant net depletion was observed, related to current efforts to reinject water from aquifers to generate additional steam. However, given the small contribution of geothermal power to the total WECC power pool, this net depletion did not materially influence the average for the power pool.

4.5.3. Key Species Indicator

Impacts calculated under the key species disruption indicator relate to given population of that species at a specific location, and, therefore, are not expressed as a WECC indicator "average" result.

4.5.4. Characterization of Wastes

Mining and plant operation wastes are potentially hazardous due to their high metal content (particularly slags, sludges, slurries and ashes). Dewatering practices from mining can involve re-injection of groundwater and, therefore, can result in contamination. In order to characterize the waste streams from coal power systems, both groundwater and surface water monitoring data are needed to confirm that wastes are fully contained for the duration of their potential to leach into the receiving environment. For the WECC power pool baseline impact profile calculations, SCS assumed that the waste stream management practices of the coal power generation systems do not result in measurable impacts on groundwater quality.

4.5.5. Characterization of Coal Assay to Determine Material Use

For coal systems, the modeling incorporated assumptions based upon published statistics on the type of coal mining (surface or underground) and the sulfur content of coal. From the combination of sulfur content, heat value and SOx emission levels, SCS estimated the degree of flue gas desulfurization based on the age and type of coal generation in the WECC, which in turn yielded input data for lime consumption and associated upstream processes.

4.5.6. LCIA Data for Nuclear Power Systems

After completing several LCIA studies on various light water reactors systems, SCS has found that most light water reactor nuclear systems have very similar impact profiles. The similarities are due to the similar designs of all reactors, similar burn-up rates, central enrichments facilities (only one in the US), identical waste storage requirements, very tight regulations on emissions, and that fact that almost all were built during the same phase of technology development. As a result, SCS modeled the nuclear systems within the WECC without obtaining or using site-dependent data from the actual facilities. Since hydropower does not create any impacts related to nuclear power, this shortcoming in the scope of work was not considered significant to the overall comparative assertion of Glen Canyon to the WECC.

4.6. Summary LCI Results

The LCI results are summarized in Table 4.3.

Table 4.3. Life-Cycle Inventory Results for the WECC Regional Power Pool
Data are normalized to a production of 1,000 GWh.

		WECC Regional Power Pool Average
Inventory	Unit	
Outputs		
Emissions, air		
Arsenic	kg	16
Benzene	kg	6
Cadmium	kg	1
CFC-114	kg	34
CH4	kg	906,170
CO2, fossil	kg	478,383,000
PM-10, TSP	kg	197,030
VOC, HC	kg	29,910
HCl	kg	26,959
HF	kg	683
Mercury	kg	7
Manganese	kg	14
NOx	kg	956,413
Lead	kg	10
Rad. act. Rn-222	GBq	2,910
Rad. act. noble gases	GBq	250
SO2	kg	731,940
Emissions, water		--
Wastes		NA
Energy		
electric power	MWh	1,000,000
Inputs		
Resources		
Coal	kg	200,080,000
Crude oil	kg	3,631,900
Natural gas	kg	48,502,000
Uranium in ore	kg U	3,048
Limestone	kg	3,183,900

-- denotes negligible or zero result
NA denotes data not available or not provided.

4.7. Landscape Disruption Group - Habitats Disrupted

LCSEA includes an assessment of direct habitat disturbance from all power systems operating within the WECC, including effects on species abundance and productivity from power generation facilities as well as from land use functions associated with administration buildings, roads, mines, and right-of-ways (e.g., for transmission lines). Because of the size and complexity of the WECC, the current scope of work did not permit a detailed assessment of various degree and types of habitats disrupted from overall power operations. However, given the focus of this study on the Glen Canyon Hydropower Station and on the Stateline Wind Power Station, key assumptions could be made and still meet the objectives of LCIA assessment. The following assumptions were made:

- The scale of terrestrial habitat disruption per 1000 GWh was established for the WECC baseline. This impact category has significant contributions from transmission line ROWs, coal mining, hydropower operations, natural gas extraction and distribution, and coal transport. ROWs constituted the largest single source of impacts in this category.

- Wetlands/riparian, riverine and lake habitats disruption from Glen Canyon were assumed to be at “worst case” disruption levels relative to the levels of the WECC baseline. For the Stateline Wind Power system, two scenarios were created: a “stand alone” scenario and one that includes a natural gas-fired “backup” generator to compensate for the intermittency of the wind power system. The terrestrial, riparian, riverine habitat disruption levels for the Stateline project differ according to the scenario used. The level of disruption per 1000 GWh for other major generation systems in the WECC was estimated to be an order of magnitude lower than impact levels observed from the Glen Canyon Dam and Stateline operations, as can be seen from the following table.

Table 4.4.
Scale of Disruption of Riparian/Wetlands, Riverine and Lake Habitats within WECC Power Mix

Fuel Type	Percentage of WECC Power Mix	Scale of Habitat Disruption
Coal	32.5%	R/W neg., R neg., L neg
Gas	23.3%	R/W neg., R neg., L neg.
Nuclear	11.1%	R/W neg., R neg., L neg.
Oil	0.3%	Unimportant to Baseline impact levels
Other – including Wind	4.6%	Unimportant to Baseline impact levels
Hydro	28.2%	R/W = 25 to 14,000 h, R = 0 to >600 m, L = > 30 h
Total generation	100.0%	

Riparian/Wetland = R/W, Riverine = R, Lake = L, h= Hectare, m = miles

As can be seen from the Table 4.4, 66.9% of the total power derives from nuclear, coal and natural gas that has negligible levels of impacts of riparian/wetlands, riverine and lake habitats. Hence, hydropower constitutes 99% of the source of these impacts for the WECC baseline values. Due to the sheer size of the Glen Canyon dam and impoundment, its habitat disruption impact levels represent the higher range for all hydropower systems.

4.8. LCSEA Results

Category indicator results are calculated for the entire system, based on the classification and characterization steps described in Sections 2 and 3 and incorporating the special study assumptions and considerations described above. These category indicator results together form the baseline impact profile for the WECC regional power pool system, as summarized in Table 4.5. Tables 4.6 and 4.7 show examples of the LCSEA calculations by indicator category. (Additional detailed data for the other indicator categories will be provided in the final study report for peer review.)

Table 4.5. WECC Impact Profile — Category Indicator Results per 1,000 GWh Production

Key Indicator	Unit	WECC Baseline
Non-renewable Energy Resource Depletion	Eq. GJ of oil	5,207,000
Water Resources Depletion	Acre-feet	NC
Terrestrial Habitat Disruption	Eq. ha. disturbed	1,882[39]
Aquatic (Lake) Habitat Disruption	Eq. ha. disturbed	*Not broken out*
Aquatic (River) Habitat Disruption	Eq. river miles	*Not broken out*
Riparian/Wetland Habitat Disruption	Eq. ha. disturbed	*Not broken out*
Loss of Key Species	% loss key species	NA[40]
Accumulated GHG Radiative Force Loading	Eq. t CO_2	500,000
Acidification Loading (Oceanic)	t CO_2	165,000
Acidification Loading (Regional)	Eq. t SO_2	6.5
Eco-Toxic Chemical Loading	Eq. kg As	NC
Ground Level Ozone Loading*	t O_3	8.9
Particulate Loading*	Eq. t PM_{10}	12.2
Pulmonary Toxic Chemical Loading*	Eq. kg Benzene	5.2
Systemic Toxic Chemical Loading	Eq. kg TCDD	NC
Neurotoxic Chemical Loading	Eq. kg Hg	5.7
Radioactive Waste Loading	Eq. GBq Pu-239	NC

-- denotes negligible or zero result; NC denotes not calculated; NA denotes not applicable.
Results above 10,000 are rounded to the nearest 1,000.

** These category indicators were calculated as loadings at the time that the WECC portion of this study was conducted. Since that time, the algorithms for these three indicators have been converted to exposure calculations. Because Glen Canyon did not result in any emissions associated with these three impact categories, the upgrading of these indicator results to measurements of exposure was deemed unnecessary.*

[39] As noted in Section 2, four habitat disruption indicators have been identified. At the time the current study was initiated, however, habitat disruption calculations were collapsed under a single indicator. The WECC indicator result was calculated with data collected at that time, and hence is presented as a single indicator result.

[40] Not applicable. The baseline for key species is based on pre-system species populations in the same region.

Table 4.6. LCSEA Non-Renewable Energy Resource Depletion Results for the WECC Baseline Case per 1,000 GWh

Energy Resource Depletion	Inventory Resource	Energy Resource Consumed (t)	Stressor Characterization Factor (SCF) (GJ/t)	Equivalent Energy Resource Consumed (GJ)	Resource Depletion Factor (RDF_{25}): Rate of dep / Rate of oil dep	Equivalent Resource Depletion (GJ oil eq.)
WECC baseline	Uranium in ore	3.048	900,000.0	2,743,524	0.51	1,399,197
	Crude oil	3,631	45.6	165,596	1.00	165,596
	Natural gas	48,501	53.4	2,589,937	0.94	2,434,541
	Coal	200,080	21.6	4,313,725	0.28	1,207,843
				9,812,782		**5,207,177**

Table 4.7. LCSEA Accumulated GHG Radiative Force Loading Results for the WECC Baseline Case per 1,000 GWh

Accumulated GHG Radiative Force Loading	Inventory Emission	Life-Cycle Inventory Result (t/a)	Global Warming Potential (t CO_2 eq./t)	Gross Emission Loading (t CO_2 eq.)	Environment Characterization Factor (ECF)	Net Emission Loading (t CO_2 eq.)
WECC baseline	Fossil CO2	478,383	1.0	478,383	1.000	478,383
	CH4	906	23.0	20,842	1.000	20,842
	CFC-11	0.034	9,300.0	741	1.000	741
				499,966		**499,966**

4.9. Summary of Results and Discussion

4.9.1. WECC Baseline

The impact levels observed for the WECC baseline were largely consistent with expectations, given the power mix of the region. Among the results that stand out are the following:

Western Coal Systems — Many of the regional emission concentrations—ground level ozone, particulates, acidification and the HAPS related emissions — resulted in exposures that were quite low on an annual cumulative basis. This level of performance for coal systems reflects the location of these units in isolated regions far from population centers and the fact that the best coal seams were located in these remote regions.

The WECC's Hydropower is making a major contribution to containing the overall Greenhouse Gas Loading of the US — While most NERC regions rely largely on coal and nuclear power generation as the core of their baseload power, the WECC has the unique advantage of having significant hydropower capacity.

Its 188,383 GWh in hydropower generation represents one of the highest hydro production regions in the world.

From the perspective of the accumulated GHG radiative force loading, this factor has a significant effect on the WECC baseline impact profile. Hydropower generation in the region represents an annual displacement of 134 million metric tons of greenhouse gases (from 307 million metric tons to 447 million metric tons) that would otherwise be emitted if the hydropower system was decommissioned and replaced with the average mix of remaining WECC power. This displacement value represents a difference of 43%. Over the lifetime of the current hydropower facilities (40 years), the difference amounts to a displacement of 5.9 gigatons. It should be noted that this displaced tonnage is on a scale that is relevant to international estimates of the expected increase in retained atmospheric greenhouse gases over the same time period (about 170 gigatons).[41]

If drought conditions in the western US persist, the WECC could become a much greater source of greenhouse gas emissions on this scale.

The following section provides an analysis of results by impact category.

4.9.1.1. Analysis of Results by Indicator for the WECC Regional Power Pool

Table 4.8 provides a short discussion of the WECC indicator results.

Table 4.8. Discussion of Net Indicator Results for the WECC per 1000 GWh

Indicator	WECC	Discussion
Energy Resource Depletion	5,207,000 GJ	This indicator is a direct reflection of the power mix that comprises the WECC. For instance, natural gas, constituting a relative high percentage of the mix (26%), has a high RDF. Note in Table 4.6 that the ratio between net and gross energy depletion for the WECC is 0.53.
Terrestrial Habitat Disruption[42]	1,882 Ha	This indicator result is derived from a combination of impacts associated with transmission line ROW, coal mining, and hydropower.
Aquatic (Lake) Habitat Disruption	NC	This indicator could not be calculated within the scope of this study.
Aquatic (River) Habitat Disruption	NC	This indicator could not be calculated within the scope of this study.
Riparian/Wetland Habitat Disruption	NC	This indicator could not be calculated within the scope of this study.
Key Species	NA	There is no regional baseline for this indicator.
Accumulated GHG Radiative Force Loading	500,000 Eq. t CO_2	This result was expected, given the mix of power sources.

[41] International Panel on Climate Change
[42] Aquatic and riparian/wetland habitat disruption were not broken out in the baseline case.

Acidification Loading (Oceanic)	164,891 t CO_2	A midpoint has been identified demonstrating an oceanic acidification exceedance of critical load by isopleth. Exceedance maps are available. The discovery of this exceedance requires the establishment of this impact category and corresponding category indicator. The only inventory value required to meet the calculation is the total carbon dioxide emission, and therefore, no SCF is required. The ECF is represented by the fraction of total CO_2 that deposits in the ocean from the annual gross release of CO_2.
Acidification Loading (Terrestrial / Inland Waterways)	6.5 Eq. t SO_2	The acidification loading for average power generated in the WECC, normalized to 1,000 GWh, is relatively low, due to:1) the significant contribution of nuclear power and hydropower to the WECC baseline; and 2) the low percentage of gross emissions of acidifying gases that deposit in areas of exceedance.
Ecotoxic Chemical Loading (Soil/Water)	NC	This indicator was identified in the LCSEA framework only after the data collection portion of work had been conducted, and as such, could not be calculated within the current study.
Ground Level Ozone Loading	8.9 t O_3	This study's findings indicate that the ground level ozone loading for average power in the WECC, normalized to 1,000 GWh, is relatively low compared to other NERC regions, due to: 1) the significant contribution of nuclear power and hydropower to the WECC baseline; and 2) the low average background concentrations in the overall WECC.
Particulate Loading	12.2 Eq. t PM_{10}	This study's findings indicate that the particulate loading for average power in the WECC, normalized to 1,000 GWh, is relatively low compared to other NERC regions, due to: 1) the significant contribution of nuclear power and hydropower to the WECC baseline; and 2) the relatively low population densities and potential for exposure across the overall WECC region.
Pulmonary Chemical Loading	5 Eq. kg benzene	This study's findings indicate that the pulmonary chemical loading for average power generated in the WECC, normalized to 1,000 GWh, is relatively low compared to other NERC regions, due to: 1) the significant contribution of nuclear power and hydropower to the WECC baseline; and 2) the relatively low population densities and potential for exposure across the overall WECC region.
Systemic Chemical loading (heavy metals)	NC	This indicator could not be calculated within the scope of this study.
Neurotoxic Chemical Loading	6 Eq. kg Hg.	This study's findings indicate that the neurotoxic chemical loading for average power generated in the WECC, normalized to 1,000 GWh, is relatively low compared to other NERC regions, due to: 1) the significant contribution of nuclear power and hydropower to the WECC baseline; and 2) the relatively low population densities and potential for exposure across the overall WECC region.

-- denotes a zero or negligible result; NC denotes that an indicator result was not calculated.

Section 5.
STATELINE 300 MW WIND SYSTEM

5.1. Project Description and Background

5.1.1. Project Description

In this project, SCS assessed the environmental performance of the 300 MW Stateline wind power generation system, then compared the results to the WECC regional power pool baseline.

5.1.2. Project Background

In the case of wind power, the scope of a life-cycle assessment includes not only the impacts from construction, operations/maintenance and end-of-life, but also any indirect impacts that may be associated with back-up power sources used to offset the intermittency of wind as a fuel source. In this study, SCS modeled the Stateline wind power generation system in two different ways – the first scenario assumed that no back-up power was required, while the second scenario assumed that back-up power was needed.

- **Scenario 1: Stateline Wind Power Generation System, Requiring No Additional Back-up Power**
  Under this scenario, SCS established the impact profile for the Stateline system itself, based strictly on the amount of delivered power it produces, normalized to 1,000 GWh. The impacts associated with the life-cycle are those resulting from the construction, routine operations and maintenance of the wind farm; any habitat disruption and impacts on species associated with the installation of the turbines towers and supporting infrastructure, and final dismantling of the wind turbines at the end of their useful life.

- **Scenario 2: Stateline Wind Power Generation System Plus Back-Up Power**
  Under this scenario, SCS established the impact profile, normalized to 1,000 GWh, reflecting: 1) the direct impacts associated with the construction, operation, and dismantling of the Stateline wind power generation system; and 2) indirect impacts associated with back-up sources required to counter the intermittency in the electricity produced by the wind turbines. In this case, the system boundaries have been defined to take into account the full range of industrial processes involved in delivering electricity that meets minimum quality and reliability standards. (See the discussion of "Functional Equivalency" in Section 5.1.3 below.)

The WECC power pool system, which serves as the baseline in this project, consists of base load units (coal, nuclear, hydroelectric and natural gas), reserve units that handle seasonal/daily load demand (produced primarily by coal, dispatches planned over and predictable loads), and peak loading units (mostly natural gas). Wind power does not fit neatly into any of these categories, given the potential problems of low capacity factor, and unpredictable intermittency. Scenario 2 offered an opportunity to examine more closely how the wind farm integrates into the regional power pool system. Certain assumptions were made in this regard, as described below.

5.1.3. Specific Issues Surrounding Functional Equivalency and System Boundaries

Scenario 2 has been included to meet the basic LCA requirement that comparisons between systems incorporate an analysis of "functional equivalence."[43] In order to compare the wind farm to the baseline, the WECC power pool, functional equivalency between the two had to be established. A short discussion of this issue follows.

Generally speaking, functional equivalency means that a product performs the identical (or substantially the same) function as another product to which it is compared. In the case of electricity, the quality of power delivered to the end customer must fall within a defined range of charge parameters to be useful.

Traditional electricity generation technologies that are designed to be dispatched to meet demand loads within a power system deliver electricity that maintains the quality of the charge within these acceptable ranges. In the case of certain passive renewable technologies, however, intermittency in generation affects the quality of the power delivered to users. Examples of such technologies are wind farms, run-of-river hydropower plants and photovoltaic power generation. Of these, wind farms have the greatest degree of generation unpredictability.

To fulfill the life cycle prerequisite to establish functional equivalency before making comparisons, the 300-MW Stateline wind power generation system therefore was analyzed in terms of the generation of equivalent power quality, including any back-up power sources required to achieve this objective. For the Wind System Plus Back-up Power scenario modeled in this project, SCS assumed that for every 850 MW of electricity produced by the wind-farm, 150 MW is required from natural gas units. This assumption and its implications are discussed more fully in the sections that follow. (Reports published by Oakridge National Laboratory indicate that eastern Washington wind power has been integrated through the Bonneville Power Administration (BPA), which is largely hydropower.[44] However, SCS lacked the data needed to model the implications from using hydropower as back-up power.)

[43] The term, back-up powering, is related to the more familiar term, co-firing. When coal-fired units introduce a percentage of biomass into the overall fuel mix, such mixes are referred to as co-fired coal/biomass systems. The relative percentage of co-firing is readily determined by analyzing the input amounts. In much the same way, wind power and back-up power sources act together to produce an overall total production of electricity. Such combinations work together in much the same way as co-fired coal/biomass systems, except that the energy production takes place physically at different locations.

[44] Oak Ridge National Laboratory.

5.2. Stateline Power Generation System Description

5.2.1. Wind Farm

The Stateline Wind Energy Center ("Stateline") is a state-of-the-art 300-MW windfarm owned by FPL Energy, Inc., a subsidiary of Florida Power & Light Co. The Stateline facility is the largest commercial wind project in the Northwest U.S.[45]

Stateline's 660-kW Vestas wind turbines straddle the Vansycle Ridge on the Washington-Oregon border, near the towns of Touchet, WA and Pendleton, OR. Operations began in July 2001, and completion of the windfarm is projected to involve expansions on both sides of the border. The turbines are powered by winds averaging 16-18 mph traveling up the Columbia Gorge (Table 5.1). This wind is considered sufficient to generate 30-35% of the windfarm's 300-MW capacity year-round. Power is marketed by Pacific Power Marketing (PPM) Energy to Bonneville Power Administration (BPA) and Seattle City Light.

Figure 5.1. Stateline Wind Energy Center

Stateline is surrounded by agricultural land. In addition, the land between the turbines continues to be used for agricultural purposes, primarily dryland wheat and cattle grazing (Figure 5.1).[46] The proximity of the site to pre-existing transmission lines has been beneficial in reducing the need for new cables and minimizing transmission line losses. The FPL Energy substation is connected to transmission owned by PacifiCorp.

According to the Renewable Northwest Project (RNP) website:

> "The Stateline wind project was planned carefully and underwent extensive review to minimize its environmental impact. Early biological studies indicated that the site receives little use by birds or other vulnerable species. The project uses tubular towers and buried cables in order to avoid adding new perching places for birds. Slower-moving blades and an upwind design further minimize any potential for avian fatality.
>
> Electronic control systems point each turbine into the wind and adjust the pitch of the blades to make the best use of wind at any speed. The turbines can generate power at wind speeds of 7 to 56 mph. At higher speeds the turbines automatically shut down — a feature that allows them to withstand hurricane-force winds."

[45] http://www.rnp.org/Projects/stateline.html, website of the Renewable Northwest Project (RNP), a coalition of public-interest organizations and energy companies.
[46] http://www.ppmenergy.com/cs_stateline.html

Table 5.1. Stateline Wind Turbine Facts
Source: *www.rnp.org/Projects/stateline.htm*

Blade Length:	76 feet
Turbine Height:	166 feet
Peak Output per Turbine:	660,000 watts (660 kW)
Manufacturer:	Vestas American Wind Technology
Operable Wind Speed:	7 to 58 mph
Vansycle Ridge Avg. Wind Speed:	16 to 18 mph
Number of Turbines (Nov. 2002):	454
Total Project Output:	Peak 300 MW

5.2.2. Functional Unit

The functional unit of the modeled system is an annual generation of 1,000 GWh, the same scale of production used to normalize results from other electric power systems included in the current study.

5.3. Baseline Case

The averaged impact profile for power generated in the WECC power pool, per 1,000 GWh, serves as the baseline impact profile for comparison. A detailed description is provided in Section 6 of this report.

5.4. Integrating Wind into the Regional Power Pool System

As discussed above, the key issue surrounding the integration of wind power into a regional power pool system is the need for back-up power to correct for wind's inherent intermittency as a power source. The US National Renewable Energy Laboratory (NREL) has suggested that the problem of intermittency can be overcome by widely dispersing the wind farms so that the cumulative effects of intermittency can be significantly offset by the very localized windforce variability. More accurate windforce forecasts would reduce the need to dispatch more peaker units to maintain stability. A recent study conducted by the Oak Ridge National Laboratory in Tennessee, however, suggests that the intermittency effects within the Bonneville Power Administration (BPA) regional system have resulted in a measurable increase in variability to delivered bulk power. The author of that study also projected that intermittency will be the factor that establishes the upper limits to penetration of wind into a regional power pool system.[47] While not directly analyzed, it could be assumed that Stateline wind power generation system is dispatched through BPA and is contributing to the current increase in variability.

[47] Hirst, Eric, "Integrating Wind Energy with BPA Power System: Preliminary Study," September 2002.

A report commissioned by the California Energy Commission[48] describes experiences in Europe and Japan that indicate that wind power penetration up to 10 to 20 percent does not pose stability problems, provided that sufficient grid connection capacity is provided.

5.5. Data Sources

5.5.1. Materials and Energy Used in Wind Farm Construction, Operations, and Maintenance

For the inventory modeling SCS used proxy data from the ECLIPSE project initiated by the European Union, which has published extensive life-cycle inventory information on renewable energy processes.[49]

The specific ECLIPSE wind power station data used as the proxy for this project is a Vestas 600 kW station with the following characteristics (Table 5.2). Assumptions related to these data are provided in Section 5.6.4 below.

Table 5.2. Vestas V 44 Main Technical Data

Parameter	Specification
Power	600 kW
Number of blades	3
Rotor diameter	44m
Swept area	1521 m2
Tower	tubular
Height of the tower (standard hub height)	estimated 37m (35m)
Variable speed	no
Power control	pitch
System lifetime	20 years
Full load hours	2500 h/y
Transformer losses	1%
Electrical output over the lifetime	2,97E+7 kWh

The main source of the LCI data in the ECLIPSE report is a literature study: *Life-Cycle Value Assessment of a Wind Turbine, Pembina Institute, Alberta, Canada, McCulloch M., Raynolds M., Laurie M., 2000.* The quality of the LCI data is good, since it includes full accounts of construction, operation and dismantling. (See the ECLIPSE fact box in Section 5.5.1 below.)

[48] Julie Blunden, KEMA-XENERGY, June 2004 "Intermittent Wind Generation: Summary Report of Impacts on Grid System Operations". Consultant Report, prepared for the California Energy Commission. http://www.energy.ca.gov/pier/final_project_reports/CEC-500-2004-091.html

[49] Environmental and Ecological Life cycle Inventories for present and future Power Systems in Europe; Synthesis Report 2004, http://www.eclipse-eu.org/

5.5.2. Direct Physical Disruption Associated with the Wind Farm

As described in Section 5.2.1, Stateline is located in an area that spans the Oregon and Washington border and is located predominantly on land that is in use as agricultural land for farming and grazing of cattle.

To calculate the habitat disruption associated with the Stateline system, Western put SCS in touch with the operators, who in turn provided SCS with the bulk of the data needed to calculate the level of habitat disturbance. Data was mostly compiled from reports produced for licensing the facility. In addition, SCS conducted an on-site assessment to determine the status of the agricultural lands in use and the potential for disturbance to unique or special habitats or species, and to review the land used specifically for the wind turbines or the associated facilities.

The specific structures and equipment that have an actual footprint and had to be examined for potential disturbance to habitat and species were:

- Turbine Towers
- Transmission Cables
- Building Facilities
- Roads

Each turbine is anchored to the ground by bolting a steel tower that holds the turbine to a cement pad. Each pad is 16 ft. in diameter and 2.5 ft. deep, using 54 cubic yards of concrete. In addition, an area is cleared around each tower pad to facilitate maintenance of the tower and associated hardware and cable. The area around each tower is approximately 0.5 acres (0.2 hectares). This amounts to a total of around 227 acres (92 hectares) of disturbed land.

Each tower is connected to the system via an underground cable. The area of the underground cable adjacent to the towers does not add significant land use, as the area is already maintained for tower maintenance.

The wind facility is close to existing transmission lines and therefore does not add significantly to habitat disturbance through the lines connecting the wind facility to the existing transmission system. A 115-kV line is located about 6 miles from the project substation, and another 230 kV line is about 3 miles from the project substation. As far as could be determined from the available reports, no significant amount of habitat is disturbed to maintain Right of Ways (ROWs) for the lines connecting the wind facility to the nearby transmission lines.

Buildings are set on previously used agricultural land. Even assuming total habitat loss where buildings are now placed, the amount of land is minimal. Roads provide a similar scenario. Most roads used to maintain facilities for the project are pre-existing structures that are still in use by the landowner for farm/ranch maintenance. According to the reports provided, around 100 acres (40.5 hectares) of additional disturbed habitat can be attributed to the overall facilities and roads.

Neither published reports nor direct on-site examination provided any evidence that aquatic habitats of any note were affected by the project. The same is true for icon species. Although there are some birds in the area, bird use of the area is minimal and bird loss due to the project is almost non-existent. In one year, there were only three reports of birds downed in the area of the wind facility. Regardless of whether these bird interactions were directly caused by the wind facility, the exceedingly low number of incidents provides no evidence that key or icon species are being affected by the project.

The minimal effect on habitats and species is the result of good pre-planning by the wind facility operators. In planning for the project, the operators identified already disturbed lands that are still currently under use for agriculture. This minimizes the amount of disturbance necessary to put up, operate, and maintain the wind facility as the lands are already set up to allow vehicle traffic and native ecosystems are already highly disturbed due to the farming and grazing activities on the land. In addition, the lack of native forests on the land precludes any disturbance due to the wind tower construction, operation, or maintenance. To avoid disturbance to key or icon species, the operators conducted thorough studies of the area to determine if any areas with good wind force for energy generation also were lands used by select species such as key mammals, reptiles, or amphibians, or by mobile or migratory species such as birds or butterflies.[50] The studies identified birds as the major concern, documenting areas of high bird use and low bird use to ensure that towers could be placed in low-use areas. In addition, the operators chose wind tower designs that did not require any additional infrastructure such as guide wires, which have been shown to be detrimental to flying species.

Lastly, SCS identified one other major concern for this life cycle study of a wind farm. SCS examined the potential for the wind farm to significantly disrupt farming activities, such that additional lands would have to be used to provide the same agricultural services. If, in fact, this were true, this could cause a significant impact. The potential impacts to the agricultural lands at Stateline are successfully mitigated by the tower design and placement. The towers are higher than towers used in many previous wind facilities, allowing the blades to be longer yet stay further from the ground. This creates much less disturbance for farming or ranching. Crops are grown within feet of the towers, and the towers are spaced such that the farming equipment can easily move between towers. Cattle are also grazed on some of the lands, and with the higher towers and improved blade design, there is no chance of directly impacting/hitting cattle, and the noise reduction is sufficient that cattle do not seem to be bothered as they can be seen grazing directly adjacent to the towers.

5.5.3. Direct Physical Disruption Associated with Back-Up Power (Scenario 2)

SCS used the habitat disruption data developed for Section 8 of this study to address the back-up power modeled into Scenario 2.

[50] *Citations to be inserted.*

5.6. Key Assumptions

This section summarizes assumptions specific to this project only. Other assumptions and considerations related to the application of the LCSEA model are described in Sections 3 and 4.

5.6.1. Windforce Analysis

The overall quality of the windforce was not analyzed within the scope of this study.

One aspect of the analysis of quality of the windforce is an assessment of ramp rates. The assumption for the wind power generation ramp rate is that there will be at least one hour from full capacity to zero and vice versa (nearly the same as the data in the Xcel study referenced below). During this hour, operators will have time to respond to these fluctuations in energy production by bringing on or by backing off other generating assets as required.

5.6.2. Back-Up Units in Scenario 2

SCS has assumed that natural gas units are brought on-line to serve as back-up power sources. SCS has further assumed that these are the most efficient natural gas units in the system, i.e. combined cycle or single cycle plants. The same gas turbines that run in the present system, supported by the redispatching of some hydropower capacity, suffice to guarantee that partial losses (or gains) in load can also be covered during the day. During off-peak periods, it is assumed that base load coal units would be powered down to accommodate any added production from the wind farm.

5.6.3. Amount of Back-Up Power Required for Scenario 2

In attempting to project the actual amount of make-up power that will be needed, several variables must be considered. Because the analysis required to factor in all of these variables was far too complex for the scope of this study, research conducted by Xcel Energy on the effects of wind power on their power pool system was used as the surrogate for this study.

The Xcel Energy Case

The Xcel Energy research was one of six cases included in a report published by the Utility Wind Interest Group (UWIG 2003), in which the impact of wind farms on power system operating costs were analyzed.[51]. In the Xcel case, the Xcel Energy-North[52] system has a combined capacity of 8,000 MW. By calendar year 2000, Xcel Energy had a nameplate wind generation capacity of about 280 MW in its northern control area, similar in size to the Stateline project. This area includes 75% of the power consumption of Minnesota, plus smaller parts of Michigan, Wisconsin, and North and South Dakota. Xcel's generating resources are predominantly thermal, with the total thermal generating capacities exceeding

[51] UWIG 2003. *Wind Power Impacts on Electric-Power-System Operating Costs; Summary and Perspective on Work Done to Date*, November 2003. http://www.uwig.org/operatingimpacts.html
[52] *Characterizing the Impacts of Significant Wind Generation Facilities on Bulk Power System Operations Planning. Xcel Energy – North Case Study*, Final Report, May 2003. http://www.uwig.org/operatingimpacts.html

7,000 MW. Peaking units fueled by natural gas and oil comprise 20% of this capacity. The remaining 80% of Xcel's thermal capacity is obtained from more economical units fueled by coal, nuclear energy, and wood. The wind power penetration is 3.5%. The most important load following — and wind fluctuation compensation — assets are the three Sherco coal units with 654, 660 and 807 MW capacity. These units have ramp rates of 12, 12, and 15 MW/minute, as compared to a maximum ramp rate for the 280-MW wind farm of 2–4 MW/minute. Import and export exchanges also take part in the load following. The main import source is Manitoba hydropower.

The main conclusions of the Xcel Energy study were as follows:

- Cost of wind generation forecast inaccuracy for day-ahead scheduling: US$0.39/MWh to $1.44/MWh
- Cost of additional load following reserves: no cost
- Cost of intra-hour load following "energy component": US $ 0.41/MWh
- Cost of additional regulation reserves: no cost, however the regulating burden did increase by approximately 4%.

These costs can be compared with an average power generation cost of about US $40/MWh. The Xcel report did not comment on which technologies were used when the wind power cost additions were calculated. The cost increases reported (2-5%), however, would indicate very low additional load following costs or losses due to inaccurate scheduling information.

Assuming that all of the wind power ancillary cost (US $ 0.85 – 1.83 /MWh) is incurred by replacing coal power with gas power, and that the incremental fuel cost for replacement is US $20/MWh (in 2002 the fuel cost of coal electricity was about US $10, and about US $30/MWh for gas), the coal power replacement by gas power generation then would be 4.3 – 9.2% (0.85/20 = 4.3%; 1.83/20 = 9.2 %) of the total wind generation. Based on this analysis, it can be assumed that a 4–9 % additional back-up by natural gas power generation would be needed to meet the functional equivalent power generation. Extrapolating these results to the WECC showed that approximately 15% additional back-up of natural gas to total power produced from the wind farm would be consistent with the Xcel Energy case as long as the energy production penetration does not exceed 5% of the total GWh of the WECC. Thus, under Scenario 2, the power is assumed to be generated as 900 GWh wind power and 159 GWh natural gas power per year, which when normalized to the functional unit of 1,000 GWh, corresponds to 850 GWh wind, 150 MWh natural gas (i.e. 85%/15%).

As the percentage of wind power to total regional system power approaches the 5% level, the Xcel Energy study suggests that the percentage of required back-up power will also increase. Some projections derived from the Xcel study suggest that as much as 30% natural gas to total delivered bulk power from wind power would be required. However, it will be impossible to predict the exact amount of additional dispatch until there is greater experience.

5.6.4. Assumptions Related to Wind Farm Material and Energy Inputs

The data used in calculating ECLIPSE LCI results for the Vestas 600 kW turbine are summarized in the breakout box below ("ECLIPSE Wind Turbine Report"). SCS amended those results in the following ways.

- The estimated lifetime of all parts of the wind power station was extended from 20 years to 50 years, while the lifetime for moving parts (nacelle and rotor blades) was left at 20 years.[53] The lifetime extension was based on arguments made, for example, in the Swiss ETH study (Frischknecht, 1996).[54] The lifetime assumption did not affect the per-kWh operating environmental burdens, but did affect the lifetime allocation of both construction and end-of-life burdens.[55]

- The operating full-load hours were changed from 2,500 to 3,000 hours per annum, according to the capacity utilization given (30 to 35%) for Stateline. The assumed capacity factor was 34.2 %.

- The functional unit was changed from 1 kWh to the 1,000 GWh value used for all of the electric power systems included in this study (which is on the same order of magnitude as the expected annual output of the full-size 300-MW Stateline wind farm operating at maximum capacity, 900 GWh.

- No attempt was made to scale the data up from 600 to 660 kW units.

- Because the original data used by ECLIPSE are somewhat out-of-date, referring to 1995 to 1998 state of technology, the results must be viewed as "worst case." With newer technology, the overall burdens may reduce as much as 20 to 30%. Inclusion of an appropriate recycling rate for steel and copper used in construction would also lower some inventory results.

- In calculating the LCIA results, SCS assumed that the wind turbines were manufactured in heavily industrialized manufacturing regions, based on its research of such activities. This assumption is reflected particularly in the air emission loading calculations, in that emissions were considered more likely to exceed thresholds.

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[53] From a sensitivity analysis standpoint, if the lifetime of the wind power system was assumed to be 30 years instead of 50, the LCI and LCSEA indicator values would increase by a factor of about 1.5.

[54] Frischknecht, R. et al. 1996: *Life cycle inventory of energy systems.* Basic methods and data for environmental comparison of energy systems and for the inclusion of energy systems in an environmental assessment of Switzerland. Swiss Energy Economy Administration (Bundesamt fuer Energiewirtschaft BEW). The Foundation for Projects and Research of the Electricity Industry (Projekt- und Studienfonds der Elektrizitätswirtschaft PSEL). 3rd Edition, July 1996.

[55] As the ECLIPSE results were only available for the whole system, a common lifetime was assumed for all parts. However, since the moving parts (and the associated manufacturing emissions and energy consumption) represent only a small fraction of the total used materials (about 18%), the error in the results from the use of a prolonged lifetime estimate for the moving parts was small. Additionally, since the ECLIPSE model assumes that 15% of the nacelle and rotor blade materials is replaced by new materials during their lifetime, the prolonged life estimate could be accurate given efficient maintenance,

ECLIPSE Wind Turbine Report (adapted from p. 51 of report)

4.1.2 Data source and quality

The data for the material balance is taken from [6]: *Life-Cycle Value Assessment of a Wind Turbine, Pembina Institute, Alberta, Canada, McCulloch M., Raynolds M., Laurie M., 2000.* It is not clear if the data include or not the losses of material during the fabrication step. Strong hypothesis had also to be taken for the operation of the plant and the end-of-life. Data sources:

Materials consumed for the elements of the wind turbine (nacelle, tower, rotor blades):

- The global mass of the elements of the wind turbine (mass of nacelle, rotor blades, tower) are taken from [McCulloch et. al. 2000].[56]
- The upstream processes of current materials like steel, aluminum, or copper were taken from the Eclipse database, and are representative of Europe.

Process of the main elements of the wind turbines:

- The process energy and water for the different elements of the wind turbine (nacelle, tower, blades) is taken from Vestas Environmental statement, such as process emissions and waste.
- The upstream processes of current materials like steel, aluminum, or copper was taken from the Eclipse database.
- The upstream process of glass fiber is taken from Vattenfall (composition based on US manufacturer data, energy based on an estimation from Vattenfall)

Electricity mix:

- The electricity mix is taken from the Eclipse database.

Upstream process of natural gas:

- The upstream process of natural gas is taken from the Eclipse database.

On-site energy:

- The energy necessary for the erection of the wind turbine (combustion of diesel) is assumed to be represented by a building machine (EDF data derived from CIT OEkologik). The quantity on the necessary energy is derived from [9]: Beitrag zum kumulierten Energieaufwand ausgewählter Windenergiekonverter", Pick & Wagner, and supposed to be dependant on the height of the tower and on the weight to lift.

Transport processes:

- Transport, by lorry or cargo ship is taken from the Eclipse database.

Operating data:

- Operation includes the replacement of some of the elements (i.e. material & energy for fabrication process & transport, source for proportion of material replacement: KEMA & EDF expertise), the necessary lubricant.

Transports (source: Techwise [10]):

- The transport for routine visits on the farm (by car, based on a determined distance and number of visits / year).

Recycling processes:

- Only transport is taken into account.

Waste treatment:

- An incineration module and a landfill module are included, based on ETHZ96: "Abfaelle in SAVE" & "Abfaelle in Inertstoffdeponie".

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[56] *Life-Cycle Value Assessment of a Wind Turbine*, Pembina Institute, Alberta, Canada, McCulloch M., Raynolds M., Laurie M., 2000.

5.6.5. Habitat Disruption Assumptions

No assumptions were needed to evaluate land disturbance for the Stateline windfarm. All of the information used was made available either through documents or the SCS on-site visit. Direct measures were made of tower size and associated disturbances from building, operating, and maintaining the project. Since Stateline was constructed on highly modified agricultural lands, and since these lands remain in comparable agricultural use, a minimum ECF of 0.1 was assigned to the calculation of habitat disruption (Table 5.3). This ECF reflects SCS's estimate that continuous farming and ranching on the land has resulted in a 90% reduction in biodiversity from the land's original state. The disturbance attributable to Stateline is therefore accounted for as 10% of the total disturbance of approximately 326 acres (132.4 ha) — i.e., 32.6 acres (13.2 ha) — of equivalent original habitat for the 300-MW facility. When normalized to 1,000 GWh, this result becomes 14.7 hectares (36.3 acres).

Table 5.3. Estimated Habitat Disruption for the 300 MW Wind Power Plant 900 GWh/a System.

Terrestrial	Land Use (ha)	Pre-project Status	Post-project Status	ECF	Hectares Disrupted
a. Turbines					
1. General Habitat	92	Highly modified ag lands	Highly modified ag lands	0.1	9.2
2. Rare/Threatened Habitat	0				
3. Critical Habitat	0				
4. Wetlands Habitat	0				
5. Riparian Habitat	0				
b. Buildings and Roads					
1. General Habitat	40.5	Highly modified ag lands	Highly modified ag lands	0.1	4
2. Rare/Threatened Habitat	0				
3. Critical Habitat	0				
4. Wetlands Habitat	0				
5. Riparian Habitat	0				
c. Transmission Lines					
1. General Habitat	NA				
2. Rare/Threatened Habitat	0				
3. Critical Habitat	0				
4. Wetlands Habitat	0				
5. Riparian Habitat	0				
Aquatic					
a. Turbines					
1. Lacustrine	0				
2. Riverine	0				
b. Buildings and Roads					
1. Lacustrine	0				
2. Riverine	0				
c. Transmission Lines					
1. Lacustrine	0				
2. Riverine	0				
Total Terrestrial					**13.2**
Total Riparian					**0.0**
Total Aquatic					**0.0**

Table 5.4 provides the estimated hectares of habitat disturbance per 1,000 GWh, including estimate assumed for this study. Note that the habitat disruption associated with the Stateline power generation system (Scenario 1), is far lower than the disruption estimates for comparable wind power systems built on previously undisturbed lands.

Table 5.4. Average Estimated Acres of Habitat Disturbed for Various Electric Power Technologies (per 1000 GWh)[57]

Energy Type	Avg. Estimated Hectares Disturbed per 1,000 GWh
Coal (1998)	1882.6
Nuclear (1998)	37.25
Natural Gas (1998)	81
Oil (1998)	81 [58]
Hydro (1998)	445
Wind (2001)	287.5[59]

5.6.6. Natural Gas Back-Up Power Assumptions

The back-up power production system used for Scenario 2 is based on the natural gas single cycle (NGSC) system described in Section 8 of this report.

5.7. Summary LCI Results

The LCI results for the 300 MW Stateline wind power generation system are shown in Table 5.5. LCI results are summarized for: 1) the 300 MW wind system with no additional back-up power (Scenario 1); 2) the back-up powered electric power system based on an assumption of 85 % wind power and 15 % natural gas power (Scenario 2); and 3) the WECC regional power pool. The energy resources, energy inputs, and emissions shown in the table for the wind-farm reflect the construction, transport, installation and maintenance of turbines and other capital equipment, as well as eventual dismantling after 50 years.

[57] Report for Exelon: *Life-Cycle Stressor Effects Assessment of the PJM Regional Power Pool and Selected Exelon Assets Within the PJM,* Scientific Certification Systems, December 2001.
[58] Habitat disruption acreage attributed to natural gas was used as a surrogate value, tested by sensitivity analysis.
[59] This disruption value for wind power represents an upper range value, based on SCS research to date, reflecting the siting of wind farms in areas leading to disturbance of native habitats.

Table 5.5. Main Life-Cycle Inventory Results for the 300 MW Wind Power Plant 900 GWh/a System (Scenario 1), the Back-Up Powered 1,059 GWh/a System (Scenario 2), and the WECC Power Pool (Baseline), based on KCL-ECO LCI Modeling. Data are normalized to a production of 1,000 GWh.

		Scenario 1	Scenario 2	WECC Power Pool Baseline
Inventory	**Unit**			
Outputs				
Emissions, air				
Arsenic	kg	--	--	16
Benzene	kg	--	--	6
Cadmium	kg	--	--	1
CFC-114	kg			34
CH4	kg	2,400	3,432,890	906,170
CO2, fossil	kg	2,713,000	100,584,850	478,383,000
PM10, TSP, dust	kg	2,980	9,140	197,030
HC, VOC	kg	613	520	29,910
HCl	kg	--	--	26,959
HF	kg	--	--	683
Mercury	kg	--	--	7
Manganese	kg	--	--	14
NOx	kg	5,630	198,037	956,413
Lead	kg	--	--	10
Rad. act. Rn-222	GBq	--	--	2,910
Rad. act. noble gases	GBq	--	--	250
SO2	kg	8,580	8,460	731,940
Emissions, water		--	--	--
Energy				
electric power	MWh	1,000,000	1,000,000	1,000,000
Inputs				
Resources				
Coal	kg	633,100	461,200	200,080,000
Lignite	kg	121,900	88,100	
Crude oil	kg	207,067	150,900	3,631,900
Natural gas	kg	172,083	26,325,000	48,502,000
Uranium in ore	kg U	--	--	3,048
Limestone/dolomite	kg	--	--	3,183,900
Hazardous waste				

(--) denotes result of negligible or zero

5.8. LCSEA Results

From the LCI data, the LCSEA indicator results have been calculated, using the appropriate stressor and environmental characterization factors, as discussed in Sections 3 and 4. In Table 5.6, LCSEA indicators are summarized for: 1) the 300 MW wind power generation system with no additional backup power (Scenario 1); 2) the back-up powered electric power system based on an assumption of 85 % wind power and 15 % natural gas power (Scenario 2); and 3) the WECC regional power pool. Tables 5.7 to 5.12 present in more detail the calculation of key indicators.

Table 5.6. Life-Cycle Impact Indicator Results for Scenario 1 (the 300-MW, 900 GWh/a Wind System), Scenario 2 (the Wind + Back-Up Power System, 1059 GWh/a), and the WECC Regional Power Pool, Normalized to 1,000 GWh.[60]

		Impact Profile: Stateline System (Scenario 1) —	Impact Profile: Stateline System (Scenario 2) 85% wind /15% natural gas	WECC Power Pool Baseline Impact Profile
Key Indicator	***Unit***			
Energy Resources Depleted	Eq. GJ of oil	21,000	1,786,000	5,207,000
Water Resources Depleted	Acre-feet	--	--	NC
Terrestrial Habitat Disruption	Eq. Ha disturbed	14.7	14.7	1,880
Riparian Habitat Disruption	Eq. Ha disturbed	--	NC	*Not broken out*
Aquatic Habitat Disruption	Eq. Ha disturbed	--	NC	*Not broken out*
Key Species	% loss of key species	--	NC	NA
Greenhouse Gas Loading	Eq. t CO_2	2,770	112,000	500,000
Acidification Loading	Eq. t SO_2	1.6	5.9	6.5
Ground Level Ozone Loading	t O_3	0.6	3.0	8.9
Particulates	Eq. t PM_{10}	5.4	4.3	12.2
Neurotoxic Chem. Loading	Eq. t Hg.	--	--	0.0057
Pulmonary (non-carc) Chem. Loading	Eq. t HF	--	--	0.5423
Pulmonary (Carc.) Chem. Loading	Eq. t benzene	--	--	0.0041
Systemic Chem. Loading	Eq. t TCDD	--	--	NC
Radioactive Waste Loading	Eq. TBq Pu-239	--	--	NC
Coal Ash Waste Loading		--	--	NC

(--) denotes negligible or zero result. NA is not available, NC is not calculated.
Results above 10,000 are rounded to the nearest 1,000.

[60] It should be noted that the indicators have been slightly modified to conform to the ASTM Draft Standard E06.71.10 since this set of calculations was completed. Specifically, a new oceanic acidification indicator has been added, the pulmonary loading indicators have been collapsed back to one indicator, and the coal ash waste loading is now addressed under the Ecotoxic Chemical Loading (Soil/Water) indicator, as shown in Sections 2 and 6. However, these changes will not have a material effect on the impact profile of Stateline to the baseline. Modifications will be made to this Section before the report is released for peer review.

Table 5.7. Project #5: LCSEA Energy Resource Depletion Results for Stateline Electric Power System (Scenarios 1 and 2), Per 1,000 GWh Production

Energy Resource Depletion	Inventory Resource	Energy Resource Consumed (t)	Stressor Characterization Factor (SCF) (GJ/t)	Equivalent Energy Resource Consumed (GJ)	Resource Depletion Factor (RDF_{25}): Rate of dep / Rate of oil dep	Equivalent Resource Depletion (GJ oil eq.)
Electric Power System: 100% Wind — Scenario 1	Uranium in ore	0.00002	900,000	16	0.510	8
	Crude oil	207	45.6	9,442	1.000	9,442
	Natural gas	172	53.4	9,189	0.940	8,638
	Coal	633	15.5	9,813	0.280	2,748
	Lignite	121	9.5	1,148	0.280	322
				29,608		**21,157**
Electric Power System: 85% Wind / 15% Natural Gas — Scenario 2	Uranium in ore	0.000015	900,000.0	13	0.510	7
	Crude oil	176	45.6	8,026	1.000	8,026
	Natural gas	35,361	53.4	1,888,287	0.940	1,774,989
	Coal	538	15.5	8,341	0.280	2,335
	Lignite	103	9.5	976	0.280	273
				1,905,643		**1,785,631**

Table 5.8. Project #5: LCSEA Greenhouse Gas Loading Results for Stateline Electric Power System (Scenarios 1 and 2), Per 1,000 GWh Production

Greenhouse Gases Loading	Inventory Emission	Life-Cycle Inventory Result (t/a)	Global Warming Potential ($t\ CO_2$ eq./t)	Gross Emission Loading ($t\ CO_2$ eq.)	Environment Characterization Factor (ECF)	Net Emission Loading ($t\ CO_2$ eq.)
Electric Power System: 100% Wind— Scenario 1	Fossil CO2	2,713	1.0	2,713	1.000	2,713
	CH4	2	23.0	55	1.000	55
				2,768		**2,768**
Electric Power System: 85% Wind / 15% Natural Gas — Scenario 2	Fossil CO2	100,585	1.0	100,585	1.00	100,585
	CH4	517	23.0	11,890	1.00	11,890
				112,475		**112,475**

Table 5.9. Project #5: LCSEA Acidification Loading Results for Stateline Electric Power System (Scenarios 1 and 2), Per 1,000 GWh Production

Acidification Loading	Inventory Emission	Life-Cycle Inventory Result (t)	Stressor Characterization Factor ($t\ SO_2$ eq./t)	Gross Emission Loading ($t\ SO_2$ eq.)	Environment Characterization Factor (ECF)	Net Emission Loading ($t\ SO_2$ eq.)
Electric Power System: 100% Wind — Scenario 1	SO2	8.6	1.000	8.6	0.150	1.3
	NOx	5.6	0.700	3.9	0.075	0.3
				12.5		**1.6**
Electric Power System: 85% Wind / 15% Natural Gas — Scenario 2	SO2	16	1.000	16	See Table 5.11	1.63
	NOx	198	0.700	139	See Table 5.11	4.31
				155		**5.94**

Table 5.10. Project #5: LCSEA Ground Level Ozone Loading Results for Stateline Electric Power System (Scenarios 1 and 2), Per 1,000 GWh Production

Ground Level Ozone Loading	Inventory Emission	Life-Cycle Inventory Result (t)	Stressor Characterization Factor (SCF) (t O_3/t)	Gross Emission Loading (t O_3)	Environment Characterization Factor (ECF)	Net Emission Loading (t O_3)
Electric Power System: 100% Wind — Scenario 1	NOx	2.4	1.000	2.4	0.220	0.5
	CH4	1.0	0.010	0.0	0.220	0.0
	VOC, HC	0.3	0.410	0.1	0.220	0.0
				2.5		**0.6**
Electric Power System: 85% Wind / 15% Natural Gas — Scenario 2	NOx	99	1.000	99	See Table 5.11	2.94
	CH4	258	0.010	3	See Table 5.11	0.07
	VOC, HC	0	0.420	0	See Table 5.11	0.02
				102		**3.03**

Table 5.11. Project #5: LCSEA Particulate Loading Results for Stateline Electric Power System (Scenarios 1 and 2), Per 1,000 GWh Production

Particulate Matter Loading	Inventory Emission	Life-Cycle Inventory Result (t)	Stressor Characterization Factor (SCF) (t PM_{10} eq/t)	Gross Emission Loading (t PM_{10} eq)	Environment Characterization Factor (ECF)	Net Emission Loading (t PM_{10} eq)
Electric Power System: 100% Wind — Scenario 1	TSP	3.0	1.00	3.0	0.250	0.7
	SO2	8.6	1.50	12.9	0.250	3.2
	NOx	5.6	1.00	5.6	0.250	1.4
				21.5		**5.4**
Electric Power System: 85% Wind / 15% Natural Gas – Scenario 2	TSP	11.7	1.00	11.7	See Table 5.11	0.7
	SO2	16.3	1.50	24.4	See Table 5.11	2.8
	NOx	96.6	1.00	96.6	See Table 5.11	0.8
				132.7		**4.3**

For the combined wind power - gas system (Scenario 2), the LCSEA spreadsheet calculation from LCI data must be presented as a breakdown in two different operations, as below in Table 5.12, because the manufacturing of wind power equipment takes place in an industrial region where high population density and acidification exceedances give rise to high ECF values. Such calculations are not needed for the indicators, energy resource depletion and greenhouse gas loading, since the environmental characterization is global. For the acidification, ground level ozone loading and particulates loading indicators, the ECF values are completely different for the industrial region where equipment is manufactured, and for the region near the windfarm, where the natural gas electricity production is assumed to take place. In the gas power plant case, the loading from manufacturing is negligible in comparison to operation emissions from power plant flue gas.

Table 5.12. Break-out of Air Emission Loading ECFs Associated with Regional Air Emission Indicators for Scenario 2, per 1000 GWh

	Inventory Emission	Life-Cycle Inventory Result (t)	Stressor Characterization Factor (SCF)	Gross Emission Loading (t SO_2 eq.)	Environment Characterization Factor (ECF)	Net Emission Loading (t SO_2 eq.)
Acidification Loading						
150 MW wind farm production system 850 GWh	SO2	7	1.000	7	0.150	1.09
	NOx	5	0.700	3	0.075	0.25
						1.34
Gas power production system 150 GWh	SO2	9	1.000	9	0.060	0.54
	NOx	193	0.700	135	0.030	4.06
						4.60
Ground Level Ozone Loading						
				(t O_3)		(t O_3)
150 MW wind farm production system 850 GWh	NOx	2	1.000	2	0.22	0.53
	CH4	1	0.010	0	0.22	0.00
	VOC, HC	0	0.420	0	0.22	0.02
				3		0.55
Gas power production system 150 GWh	NOx	97	1.000	97	0.025	2.42
	CH4	257	0.010	3	0.025	0.06
	VOC, HC	0	0.420	0	0.025	0.00
				99		2.48
Particulate Loading						
				(t PM_{10} eq)		(t PM_{10} eq)
150 MW wind farm production system 850 GWh	TSP	2.5	1.00	2.5	0.250	0.6
	SO2	7.3	1.50	10.9	0.250	2.7
	NOx	0.0	1.00	0.0	0.250	0.0
				13.5		3.4
Gas power production system 150 GWh	TSP	9.1	1.00	9.1	0.008	0.1
	SO2	9.0	1.50	13.5	0.008	0.1
	NOx	96.6	1.00	96.6	0.008	0.8
				119.2		1.0

5.9. Discussion of Results

5.9.1. Proper Scoping

The results of this study reinforce the importance of proper scoping in establishing the environmental impact profile of wind power systems. In order to determine the full impact, an analysis should be conducted to assess the possible need for back-up power, including assessment of transmission grid stability and transmission capacities.

5.9.2. Wind System with No Added Back-up Power (Scenario 1)

Consistent with expectations for western wind power systems, the Stateline wind power generation system has one of the smallest impact profiles of any power system measured to date by SCS (Figure 5.2).[61] This outcome reflects the fact that the energy resource depletion and emission loadings were derived only from the manufacturing and maintenance of the turbine equipment and associated infrastructure, and not from the energy generation itself.

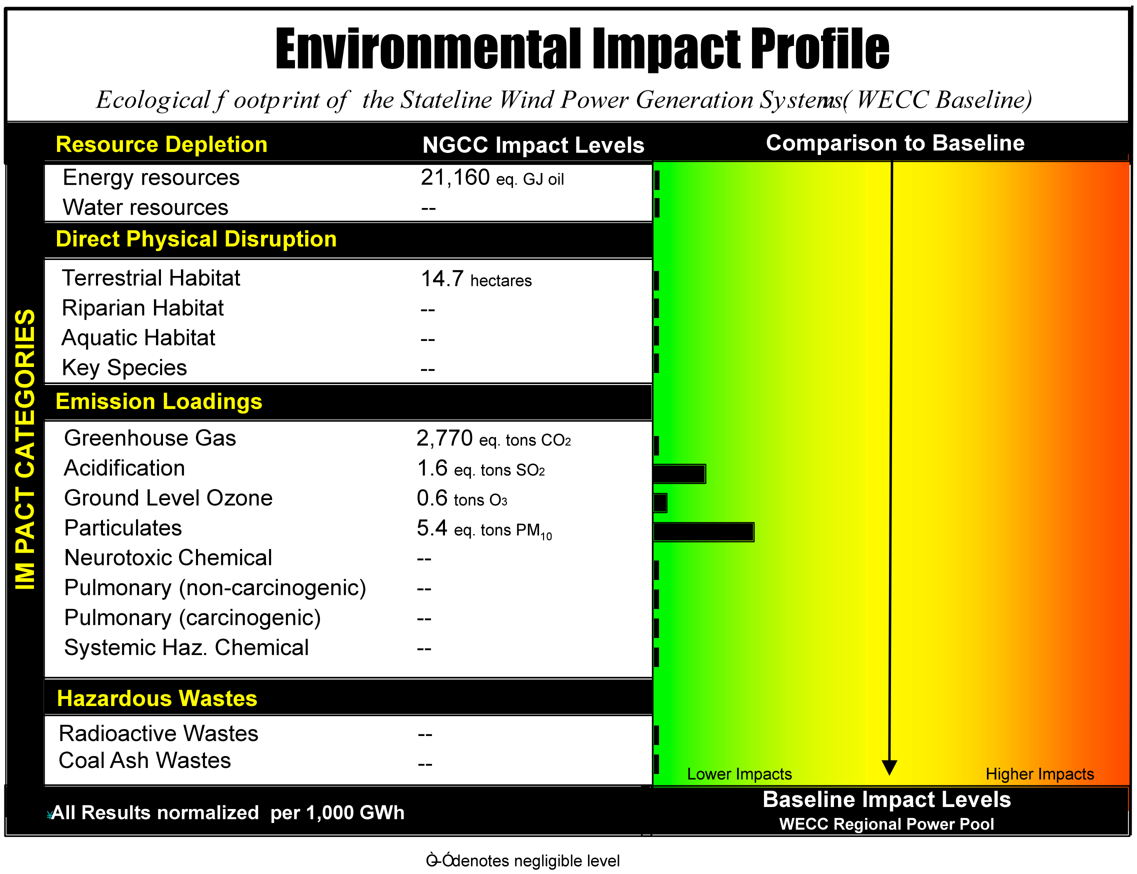

Figure 5.2. Environmental Impact Profile of Stateline Wind System, Scenario 1.

The fact that the land used for the project was already in a highly disturbed state – i.e., significantly altered from its original and pristine condition – was reflected in the application of an ECF of 0.1 to account for the previous disturbance. Had the wind farm been placed on pristine, unaltered land, the habitat disruption would have been considerably higher (326 acres or 132.4 hectares).

[61] SCS has conducted life-cycle research on a variety of electric power systems — including coal, natural gas, nuclear, hydropower, bunker oil, and wind technologies – as well as several regional power pools.

5.9.3. 85% Wind Power / 15% Natural Gas Back-up Power (Scenario 2)

As expected, the addition of natural gas in a back-up powered system increases results in the following impact indicators: energy resource depletion, greenhouse gas loading, acidification loading, ground level ozone loading, and PM loading.

- **Energy Resource Depletion** — While natural gas-generated power constituted only 15% of the system, the energy resource depletion rose from Scenario 1 by 84-fold (Table 5.7). This increase demonstrates how dramatically the impact profile for wind power can be changed when augmented even to a small degree by traditional power technologies.

- **Greenhouse Gas Loading** — Large differences were also noted between Scenario 1 and Scenario 2 in terms of the greenhouse gas loading. In this case, the increase was 41-fold (Table 5.8).

- **Regional Air Emission Loadings (Acidification, Ground Level Ozone, PM) —** In the case of the regional air emission loadings, the net emission loadings were substantially lower than the gross emission loadings, reflecting the low population densities of the region outside of Portland (ground level ozone, particulates).

- **Habitat Disruption** — There was no significant increase in habitat disruption from Scenario 1 to Scenario 2, reflecting the inherently small physical footprint of natural gas units.

5.10. Differences in Scenarios' Performance

The environmental performance of Scenarios 1 and 2 are compared to the WECC power pool in Table 10.13. As can be seen in the table, adding wind power under Scenario 1 to the power pool is essentially an impact free option for increasing the energy supply, as long as wind penetration into the power pool remains relatively low. Under Scenario 2, the anticipated environmental benefits would be reduced in three areas — energy resource depletion, greenhouse gas loading and acidification loading.

As the percentage of wind penetration increases in the WECC, Scenario 2 will become more likely, due to the limitations in availability of BPA hydropower for back-up dispatch.

Table 5.13. Scenario 1 (wind power only) compared to the WECC regional power pool

Indicator	Unit	Stateline Impact Profile Wind power only	Stateline Impact Profile (85 % wind and 15% gas)	WECC Regional Power Pool
Energy Resources Depleted	Eq. GJ of oil	21,000	1,786,000	5,207,000
Water Resources Depleted	Acre-feet	--	--	NC
Terrestrial Habitat Disruption*	Eq. ha disturbed	14.7	14.7	1,882
Aquatic Habitat Disruption	Eq. ha disturbed	--	NC	*Not broken out*
Riparian/Wetland Habitat Disruption	Eq. Ha disturbed	--	NC	*Not broken out*
Key Species	% loss	--	NC	NA
Greenhouse Gases	Eq. t CO_2	2,770	112,000	500,000
Stratospheric Ozone Depletion	Eq. t CFC-11	--	--	0.027
Acidification Loading	Eq. t SO_2	1.6	5.9	6.5
Ground Level Ozone Loading	t O_3	0.6	3	8.9
Particulates Loading	Eq. t PM_{10}	5.4	4.3	12.2
Neurotoxic Chem. Loading	Eq. t Hg.	--	--	0.0057
Pulmonary (non-carc) Chem. Loading	Eq. t HF	--	--	0.5423
Pulmonary (Carc.) Chem. Loading	Eq. t benzene	--	--	0.0041
Systemic Chem. Loading	Eq. t TCDD	--	--	NC
Radioactive Wastes	Eq. TBq Pu-239	--	--	NC
Coal Ash Waste	Eq. t Hg.	--	--	NC

(--) denotes negligible or zero result. NA is not available, NC is not calculated.
Results above 10,000 are rounded to the nearest 1,000.

Section 6.
GLEN CANYON HYDROPOWER GENERATION SYSTEM

6.1. Project Description and Background

6.1.1. Project Description

In this project, SCS established an impact profile for the Glen Canyon Dam hydroelectric power generation system, and compared this impact profile to that of the WECC regional power pool baseline. Additionally, SCS examined the degree to which changes made in hydropower dispatch in order to meet modified low fluctuating flow requirements of the 1996 Record of Decision (ROD) may have resulted in impact trade-offs, due to the flow modifications and the use of alternative load-following power sources.

6.1.2. Project Background

Glen Canyon is one of 58 dams constructed by the US Bureau of Reclamation, delivering electricity to customers throughout the west. Glen Canyon is among the largest hydroelectric facilities in the region, alongside Hoover Dam on the lower Colorado (Arizona), Grand Coulee Dam on the Columbia River (Washington), Shasta Dam on the Sacramento River (California) and Yellowtail Dam on the Bighorn River (Montana).[62] This multi-purpose unit was built not only to generate electricity, but also to store water for municipal and industrial water uses, land reclamation, flood control, and public outdoor recreation. The Glen Canyon facility – the dam, power plant and Lake Powell reservoir – is the centerpiece of the Colorado River Storage Project (CRSP), which includes three additional storage units and 11 participating projects.[63]

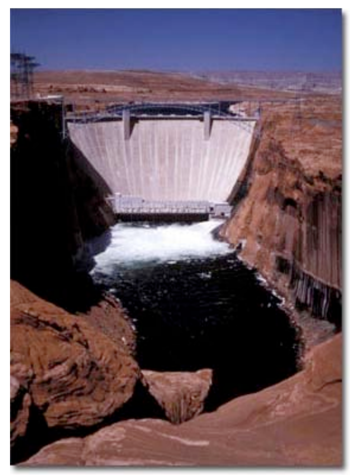

Figure 6.1. Glen Canyon Dam
Photo: National Park Service
Source: Glen Canyon Assn.

Glen Canyon has been the subject of intensive environmental interest and scrutiny since its inception in the late 1950s. The site was originally selected as a compromise to prevent construction of an alternative dam that would have resulted in the flooding of the Dinosaur National Monument area. Since that time, federal, state and tribal agencies, recreational

[62] US Bureau of Reclamation, Dept. of the Interior, Power Resources Office, *Reclamation: Managing Water in the West — Hydroelectric Power.* July 2005.
[63] 43 U.S.C. §§ 620-620o, April 11, 1956, as amended 1962, 1964, 1968 and 1980. The Colorado River Storage Project Act "provides for the comprehensive development of the water resources of the Upper Colorado River Basin to: regulate the flow of the Colorado River; store water for beneficial consumptive use to make it possible for states of the Upper Basin to use the apportionments made to and among them in the Colorado River Compact and the Upper Colorado River Basin Compact, respectively; provide for the reclamation of arid and semiarid land, the control of floods, and the generation of hydroelectric power."

fishermen and boaters, Native American groups and environmental organizations have expressed concerns about the project's impacts on habitats, wildlife and cultural resources. These concerns have centered primarily around two consequences of dam construction and water regulation: changes in seasonal and daily river flow fluctuations, and marked changes in water temperatures downstream.[64]

In 1980, a cost-benefit study being conducted to investigate the potential to add new generators to produce more power was halted in the face of unanswered questions about impacts on key habitats and species, both upstream as a result of inundation, and downstream as a result of changes in water flows.[65] In 1982, the Bureau of Reclamation initiated the Glen Canyon Environmental Studies (GCES) program, a program now encompassed under the mandate of the Grand Canyon Monitoring and Research Center (GCMRC).[66] Evidence gathered by GCES, together with plans to rewind the generators, led to the decision to undertake the preparation of a formal Environmental Impact Statement in November 1989, a process that took six years to complete. During this period, in 1991, an interim regimen of modified flows was instituted, while plans were laid for further study.[67] According to the Bureau of Reclamation, the publication of the Final Environmental Impact Statement (FEIS) in 1995 received "broad and intense interest" from a wide cross-section of public and private stakeholders. The FEIS called attention to a range of impacts, both positive and negative, while raising a number of questions regarding the causes and extent of these impacts.[68] (See further discussion, Section 6.6.)

Based on the findings of the FEIS, a Record of Decision (ROD) was signed by the Secretary of the Interior in October 1996, requiring the dam to be operated within more stringent environmental parameters, including: minimum and maximum flows, limitations in fluctuations, new triggering mechanisms for conducting beach/habitat-building flows, and the establishment of the Glen Canyon Dam Adaptive Management Program (AMP) to continue monitoring environmental evidence and adapting operational requirements accordingly. As described in the Secretary of the Interior's Report to Congress in 2001, "the National Academy of Sciences described the AMP as "a science policy experiment of local, regional, national, and international importance."[69]

Among the most significant changes resulting from the ROD has been the change in dispatch of Glen Canyon generated power. Whereas Glen Canyon was historically used for load following power generation, compliance with the new modified flow regime has altered its power production profile. As a result, other power plants in the region have had to be tapped to fill the gap during peak periods.

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[64] Bureau of Reclamation, U.S. Dept. of the Interior, *Operation of Glen Canyon Dam: Colorado River Storage Project, Arizona. Final Environmental Impact Statement (FEIS)*, March 1995.
[65] *Ibid.*
[66] National Park Service, U.S. Department of the Interior, 2005. Website: http://www.nps.gov/glca/damindx.htm
[67] Dates confirmed in verbal correspondence to SCS by representatives of Western.
[68] Bureau of Reclamation, U.S. Dept. of the Interior, Glen Canyon Adaptive Management Program. Website: http://www.usbr.gov/uc/rm/amp/background.html#background
[69] Secretary of the Interior, *Report to Congress: Operations of Glen Canyon Dam Pursuant to the Grand Canyon Protection Act of 1992, Water Years 1999 – 2001*, May 2002.

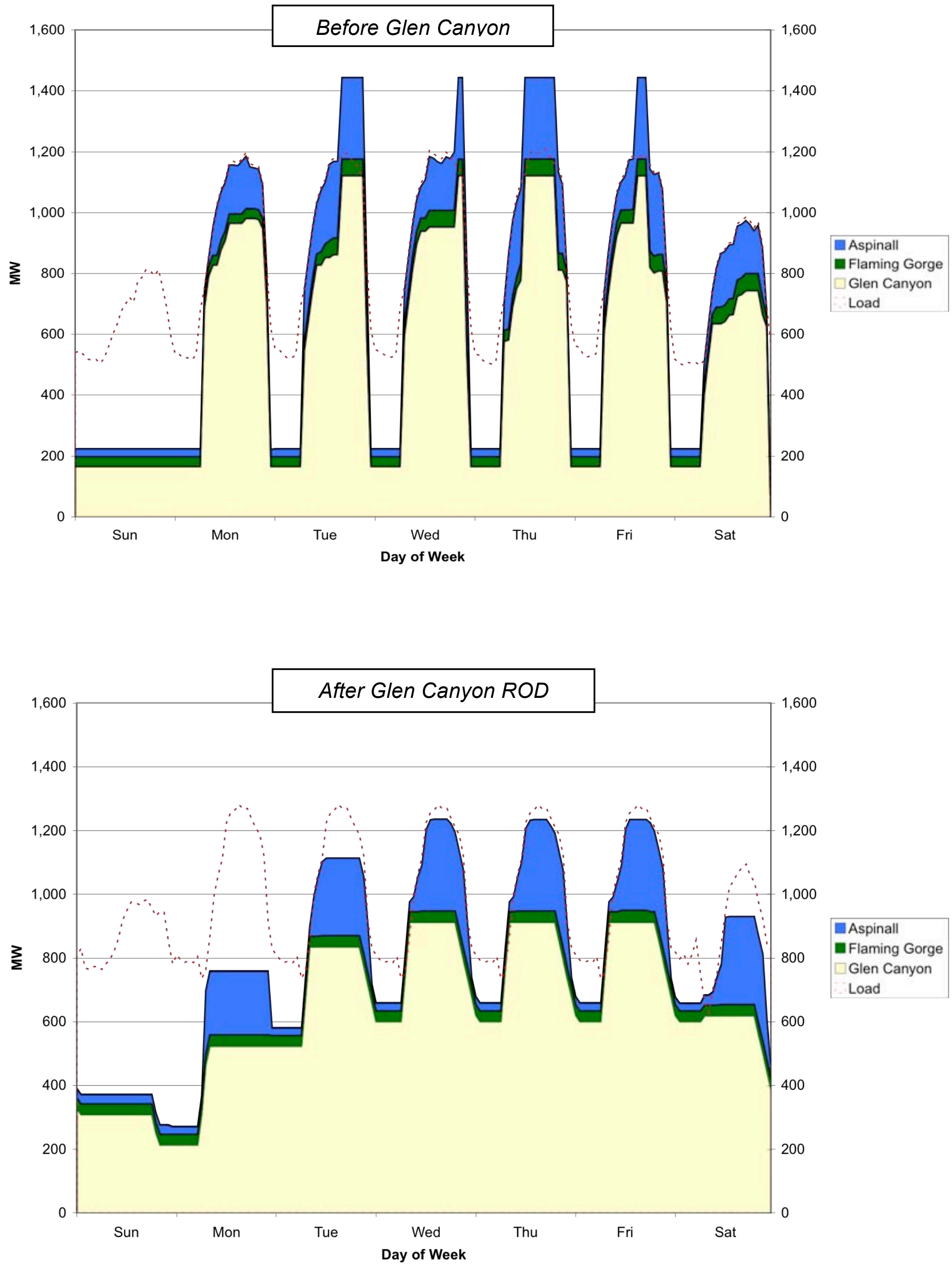
6.2. Power Generation System Description

6.2.1. System Boundaries, Scoping and Specific Unit Processes

The Glen Canyon hydropower generation system includes the power plant and dam complex, upstream processes related to major construction materials (concrete, steel, copper), and power transmission. Along with Aspinall and Flaming Gorge hydropower stations, Glen Canyon generated sufficient power before the ROD to satisfy existing contractual load-following requirements for every day except Sunday (Figure 6.2). After the ROD, the resulting shortfall of dispatchable power (about 25%) led to the use of alternative load-following power sources. Given the type of load demand required for this time of day, make-up power comes from a combined cycle natural gas (NGCC) source.

Life-cycle scoping requires assessments on complete systems. The Glen Canyon hydropower station is part of the larger Colorado River hydropower system comprising a network of hydropower plants sited up- and downstream, including the Hoover Dam. Glen Canyon should be considered part of this larger system because it has distinct environmental links in terms of cause and effects to the operations of other hydropower stations along the river. For instance, flow management decisions at Glen Canyon Dam have significant implications for Hoover Dam, Lake Mead, and river flow all the way to the Sea of Cortez in Baja. Although it was beyond the scope of this study to consider the complete hydropower system operating along the full length of the river, SCS would recommend that the study be extended to encompass such facilities in order to develop a more comprehensive understanding of the degree to which the Glen Canyon hydropower station is responsible for indirect impacts along the Colorado River.

Figure 6.2. CRSP Generation Before and After Glen Canyon ROD and Flaming Gorge BO



5.2.2. Plant Location

The Glen Canyon facility is located on the upper Colorado River close to the Utah border, two miles northwest of Page, Arizona, and 15 miles upriver from Lee's Ferry (Figure 6.3). The massive Lake Powell reservoir created behind the dam is primarily within Utah state borders, within an area now designated as the Glen Canyon National Recreation Area.

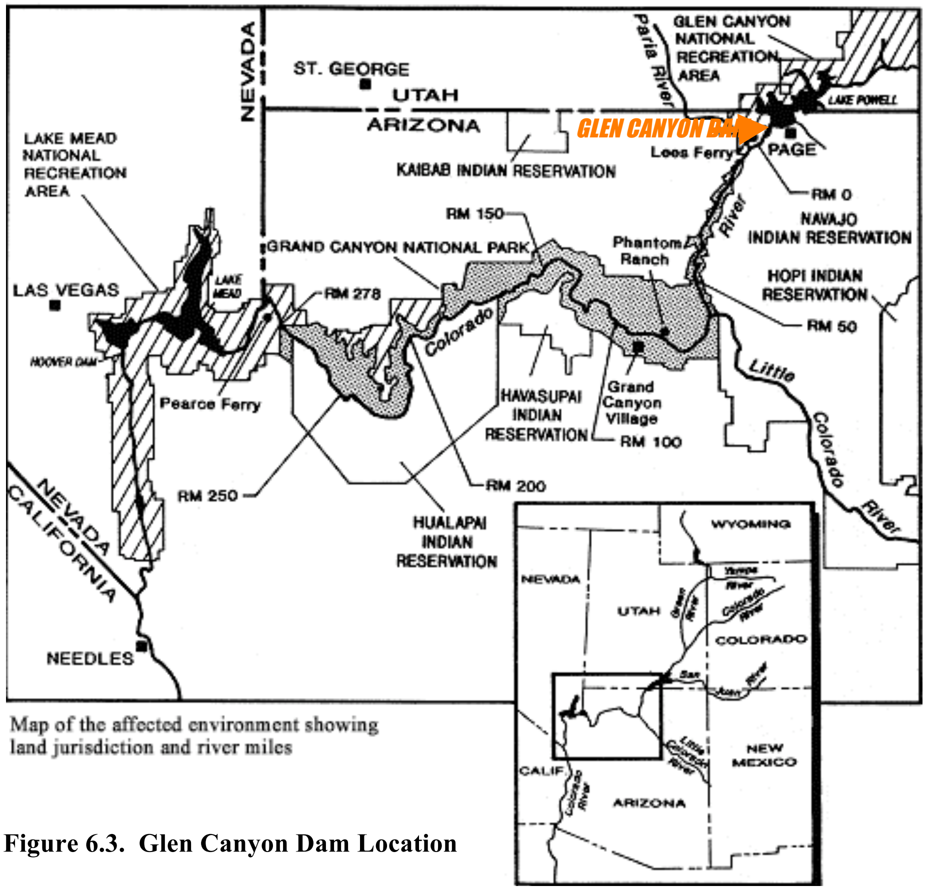


Figure 6.3. Glen Canyon Dam Location

Lake Powell extends up to 186 miles upstream. The total drainage area of the Upper Colorado River basin is approximately 108,355 sq. miles.[70] Major upstream tributaries include the Upper Colorado, Green, Gunnison, and San Juan Rivers.

Below the dam, the river flows for fifteen miles through lower Glen Canyon in the Glen Canyon National Recreation Area, then flows 278 miles through Grand Canyon National Park. The river borders the Navajo Indian Reservation to the east (Glen and Marble Canyons), while the Hopi Indian Reservation is farther to the east. In Grand Canyon National Park, the river flows past the Havasupai Indian and Hualapai Indian Reservations. Downstream tributaries include the Little Colorado and Paria Rivers.

[70] Bureau of Reclamation, U.S. Dept. of the Interior. Website. http://www.usbr.gov/dataweb/dams/az10307.htm

The canyon walls of the Glen Canyon dam site and reservoir are largely formed from medium to fine-grained Navajo sandstone, ubiquitous in the area. Red to buff in color, the sandstone is moderately porous and highly absorptive.[71]

6.2.3. Construction

The construction of Glen Canyon Dam was authorized under the Colorado River Storage Project Act of 1956 (Public Law 84-485):

> " . . . for the purposes, among others, of regulating the flow of the Colorado River, storing water for beneficial consumptive use, making it possible for the States of the Upper Basin to utilize, consistently with the provisions of the Colorado River Compact, the apportionments made to and among them in the Colorado River Compact and the Upper Colorado River Basin Compact, respectively, providing for the reclamation of arid and semiarid land, for the control of floods, and for the generation of hydroelectric power, as an incident of the foregoing purposes . . . . In 1968 Congress enacted the Colorado River Basin Project Act (43 U.S.C. 1501 et. seq.)." [72]

Construction was begun in 1957, and completed in 1963, with power generation commencing in September 1964.[73] Construction of the 710-foot concrete thick arch dam required the use of 4,901,000 cu. yd. of concrete, with an additional 469,000 cu. yd. of concrete used in the construction of the power plant, penstocks, and related infrastructure (Table 6.1).

Table 6.1. Glen Canyon Dam Dimensions

Crest Elevation	3715.0 ft
Structural Height	710 ft
Hydraulic Height	583 ft
Crest Length	1,560 ft
Crest Width	25 ft
Base Width	300 ft

Due to the remote location of the facility, it was also necessary to construct the Glen Canyon bridge to transport construction materials and equipment (Figure 6.4). The 1,271-ft. long steel-arch structure spans the river 865 feet downstream from the dam.[74]

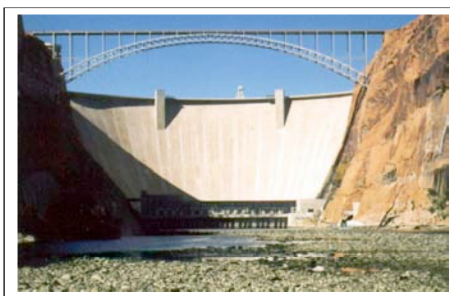


Figure 6.4. Glen Canyon Bridge

6.2.4. Operations and Maintenance

The Glen Canyon facility has been in continuous operation since 1964. Its eight generators were each originally rated at 118,750 kW, for a combined total capacity of 960 MW (Figure 6.5). In 1992, the Bureau of Reclamation completed an environmental

[71] Glen Canyon Association, Website: http://www.glencanyonassociation.org
[72] Secretary of the Interior, *Report to Congress: Operations of Glen Canyon Dam Pursuant to the Grand Canyon Protection Act of 1992, Water Years 1999 – 2001*, May 2002.
[73] Bureau of Reclamation, U.S. Dept. of the Interior. Website. http://www.usbr.gov/dataweb/dams/az10307.htm
[74] Bureau of Reclamation, U.S. Dept. of the Interior, 2005. Website: http://www.usbr.gov/dataweb/html/crsp.html

assessment of the impacts of uprating and rewinding, resulting in a finding of no significant impacts (FONSI). Based on this finding, generators were uprated, starting in the mid-90's (except Unit 7, scheduled for service in 2006-7). As of 2005, seven generators are now rated at 165,000 kW each, while the remaining unit is rated at 157,000 kW each, for a combined capacity of 1,312,000 kW.[75] Unit circuit breakers have been replaced (2000), and the penstocks have been recoated with MC tar.[76]

The reservoir has a total capacity of approximately 27 million acre-feet (maf), with an active capacity of about 24.3 maf. Water can be released from the dam in three ways: 1) through the power plant, with a capacity of 33,200 cfs; 2) through the river outlet works, capable of spilling 15,000 cfs; and 3) through the spillways, with a combined capacity of 208,000 cfs. Since the introduction of modified releases in 1991, releases have generally been held at or below 20,000 cfs, except in rare "floodflow" conditions (Table 6.2).[77]

Figure 6.5. Glen Canyon Generators

Table 6.2. Glen Canyon Floodflow Release History

Year(s)	Amount Released	Reason
1965	NA	Excess water released to balance reservoir
1980	NA	Excess water released to test spillways
1983	Up to 100,000 cfs	Heavy spring run-off; temporary 8-foot retaining wall built to hold back floodwater.
1984, 1985, 1986	40-50,000 cfs / 1 mo./yr	Heavy run-off years.
1990, 1991	NA	Research flows for EIS.
1996	45,000 cfs / 7 days	Controlled flood, evaluating habitat restoration potential.

[75] Correspondence from R. Gattis, Bureau of Reclamation, US Dept. of the Interior, to G. Burton, Western.
[76] Bureau of Reclamation, U.S. Dept. of the Interior, *Operation of Glen Canyon Dam: Colorado River Storage Project, Arizona. Final Environmental Impact Statement (FEIS)*, March 1995.
[77] *US Geological Survey, Western Coastal and Marine Geology, Glen Canyon, Website:* *http://walrus.wr.usgs.gov/grandcan/dam.html*

6.2.5. Power Transmission

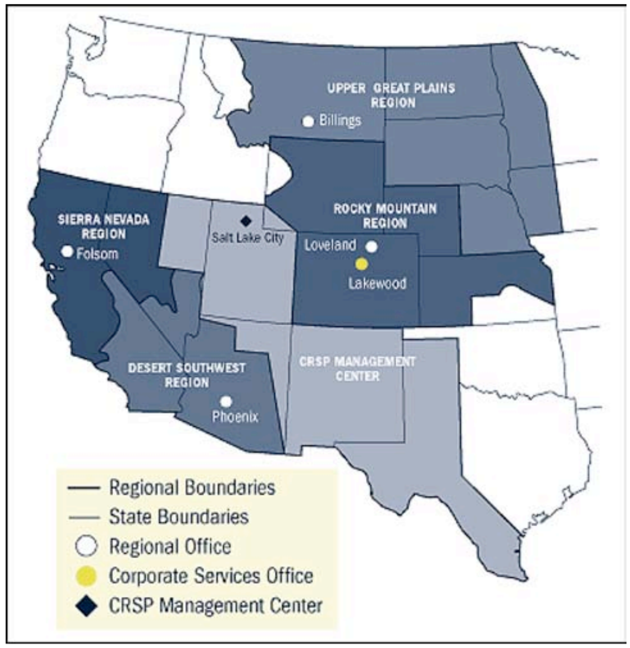


Figure 6.6. CRSP Management Center, with Western's Marketing / Transmission Territory

Power generated at the Glen Canyon power plant is sold to customers in Arizona, Colorado, Utah, Wyoming, New Mexico, and Nevada, supplying the annual electrical needs of about 400,000 households.[78] The transmission system is operated by Western Area Power Administration (Western), and is linked to its larger system of more than 16,800 circuit miles (27,000 kilometers) of transmission lines, 258 substations, and other electric power facilities in a geographic area covering 1.3 million square miles (3.38 million square kilometers) in 15 central and western states.[79] The system transports CRSP power to key load points, and is integrated with preference-user and private-company transmission lines to form the CRSP Interconnected Transmission System (Figure 6.6).[80] The CRSP Customer Service Center (CSC) office in Salt Lake City is a member of the Western Regional Transmission Assn. (WRTA) and Southwest Regional Transmission Assn. (SWRTA), and operates within the Western Electric Coordinating Council (WECC).[81]

From the Glen Canyon switchyard, 2 major transmission lines run due south to the Flagstaff (FLG) switching station, while 1 line runs east to the Navajo (NAV) facility (Figure 6.7).[82] Additionally, two separately owned T-lines tie into the Glen Canyon switchyard complex from the west.

[78] Secretary of the Interior, *Report to Congress: Operations of Glen Canyon Dam Pursuant to the Grand Canyon Protection Act of 1992, Water Years 1999 – 2001*, May 2002.
[79] Western Area Power Administration, *General Requirements for Interconnection*, Dept. of Energy, Sept. 1999.
[80] US Bureau of Reclamation, Dept. of the Interior, 2005, *Attachment K, Authorities And Obligations*. http://www.usbr.gov/dataweb/html/crsp.html
[81] Western Area Power Administration, Website: http;//www.wapa.gov/
[82] GIS maps supplied by Western Area Power Administration.

6.2.6. Function and Functional Unit

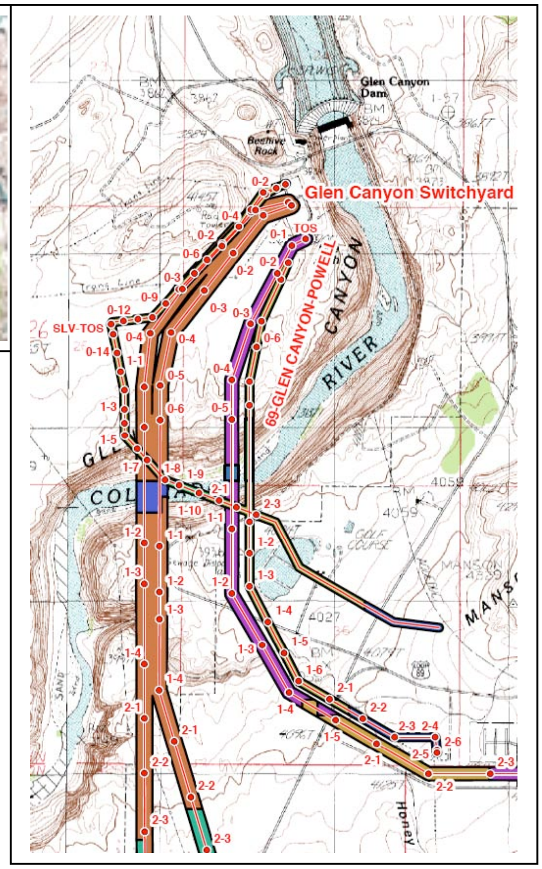


Figure 6.7. Power transmission from Glen Canyon

Above: Northernmost section of transmission system.
Left: Sheet #01 break-out, showing transmission tower (red dots) spaced approximately 500 meters apart. Each GIS sheet provides detailed vegetative cover mapping.

Glen Canyon hydropower station has historically served a load-following function within the WECC, i.e., supplying power as needed to meet changing daily demand. However, under the restrictive flow regimes of the ROD, Glen Canyon can no longer fulfill this function without make-up power from back-up sources. Additional power sources capable of flexible deployment have been needed to fill the gap, at levels between 20 and 30% of the power generated by the hydropower station.

The functional unit for the Glen Canyon is 1,000 GWh of load-following power generation.

6.3. Baseline Case

The averaged impact profile for power generated in the WECC power pool, per 1,000 GWh, serves as the baseline impact profile for comparison. As described in Section 4 of this report, the WECC power pool system consists primarily of base load units (coal, nuclear, hydroelectric and natural gas), reserve units that handle seasonal/daily load demand (produced mainly by coal plants and combined cycle natural gas plants), and peak loading units (mostly natural gas).

6.4. Data Sources and Data Quality

6.4.1. Data Sources

Data utilized for this study were derived from a combination of first-hand and second-hand sources, including published governmental and agency reports (e.g., Report to Congress, Glen Canyon and Electric Power Marketing Environmental Impacts Statements); maps; photographs; satellite-generated images; correspondence; interviews and first-hand observation. In addition, data were used from the Grand Canyon Model, the STARS model, and from various databases (temperature, sediment, flow, etc.) housed at the Grand Canyon Monitoring and Research Center in Arizona.

6.4.2. Data Quality

As already discussed, the Glen Canyon hydropower generation system has been the subject of intensive scrutiny since its initial inception and construction. Much of the data evaluated for this report were extracted from previous reports and publications that have been used to meet a wide variety of regulatory requirements, and have in many cases undergone extensive peer review as well as review from stakeholders and the general public. As such, the accuracy and quality of the data SCS used in this report is considered to be quite high.

The documents provided both a quantitative and qualitative analysis of the flora and fauna both on a regional and a local scale. In addition, the data on dam construction, dam operations, and ongoing mitigation activities was informative and comprehensive.

In areas where SCS utilized data from existing models and databases, the data quality parameters are well known, based on direct measurements and tested extrapolation and modeling methodologies. Extensive internal and external reviews have been conducted on data monitoring, analysis and modeling aspects.[83]

6.5. Key Assumptions and Scoping Considerations

This section summarizes assumptions specific to this project only. Other assumptions and considerations related to the application of the LCSEA methodology are described in Sections 2 and 3, and Appendix 6.

6.5.1. Allocation of Impacts

The Congressional Act that authorized the construction of Glen Canyon Dam, the power plant and Lake Powell, identified electric power production as "incident" to the operation of the dam for purposes related to the development of water in the Colorado River Basin

[83] For instance, the GCMRC Protocol Evaluation Program established a peer-reviewed data evaluation process. http://www.gcmrc.gov/products/pep/pep.htm

states.[84] A task then, for this study, was to determine the proper allocation of impacts to the production of electrical power when much (or all) of the infrastructure of the dam and associated reservoir were built for other purposes.

SCS attempted to uncover an engineering, scientific or political basis for allocating the environmental impacts of the 472-foot-tall dam and the 199-mile lake to the power function alone but was unable to do so. That is, there appears to be no objective method to parse the environmental impacts of the dam and lake into impacts allocated exclusively to the electric power function, apart from the environmental impacts of the water storage and delivery system of these facilities.

Therefore, this study allocated impacts in two different and extreme ways:

- The Gross Impacts Allocation Case, a "worst-case" allocation, assigned all documented environmental impacts from the dam and lake structures to the Glen Canyon hydropower generation system. This case assumes that hydropower generation is a primary and inseparable purpose of the project and is responsible for producing the environmental impacts from the entire Glen Canyon Dam and Lake Powell facility, its operation and effects.

- At the other extreme, the Hydropower Function Case, a "best case" allocation, assigns to the hydropower electrical generation only those effects that are caused because of the existence and operation of a power plant within Glen Canyon Dam. Hourly and daily changes in water releases from the dam caused by changes in generation to follow electricity demand, resulting in hourly and daily stage changes in the Colorado River, are assigned to hydropower. Monthly water releases assigned by Reclamation, lowered river temperature caused by the retention of water in a large impoundment, sediment retention in Lake Powell, disruption of the riverine habitat above the dam, evaporative water loss due to the existence of the lake and other lake-related environmental impacts were not assigned to hydropower because they are artifacts of the existence of the dam and reservoir.

As stated above, the latter case is justified by the Colorado River Storage Project Act of 1956. It is clearly the case, however, that the dam and its large reservoir and the power plant exist together as an integrated facility to meet Congress' overall purpose of water development in the Western U.S. as envisioned in the CRSPA. The two cases – one with environmental impacts associated with the existence of the dam and reservoir and one without – constitute "book ends" for the measurement of environmental impacts associated with power production. They represent the endpoints of the range of possible allocations to power that could be made.

[84] Colorado River Storage Project Act of 1956 (Public Law 84-485)

6.5.2. LCI Model Assumptions

The main assumptions regarding the applied LCA inventory model are as follows:

- Initial construction impacts have been allocated to the functional unit of 1,000 GWh, assuming a lifetime of 100 years and a 3,320,195 MWh annual power generation as reported for FY 2004.
- Data for annual fuel use for plant operation and maintenance were not available, and therefore were approximated as 0.02 kg diesel oil/MWh, or 66,400 kg per year.
- Temporal characterization of CO_2 emissions from manufacturing of construction materials was calculated for 2005, assuming that construction time was 1963 and that the first full year of power generation was 1965.

6.5.3. Biophysical Impact Focus

The Final Environmental Impact Statement prepared for Glen Canyon in 1995 addressed a variety of issues, including biophysical indicators of environmental impacts, as well as economic and social factors such as recreational value, cultural resources and costs of operation (see sidebar below).

Issues addressed in the Glen Canyon FEIS
Source: Final Environmental Impact Statement March 1995.

- How do dam operations affect the amount and quality of water available from Lake Powell at specific times?
- How do dam operations affect sediment resources throughout the study area?
- How do dam operations affect fish – their life cycles, habitat, and ability to spawn?
- How do dam operations affect vegetation in the river corridor?
- How do dam operations affect area wildlife and their habitat?
- How do dam operations affect the populations of endangered and other special status species throughout Glen and Grand Canyons?
- How do dam operations affect other electrical production in the area, including those methods that have impacts on air quality?
- How do dam operations affect the continued existence of cultural resources in the study area?
- How do dam operations affect recreation in the study area?
- How do dam operations affect the ability of Glen Canyon Powerplant to supply hydropower at the lowest possible cost?
- How do changes in Glen Canyon Dam operations affect non-use value?

As described earlier in this study, the scope of LCIA is focused more narrowly on an assessment of biophysical impacts only, using quantitative indicators. Issues related to recreational uses, effects on cultural resources and cost considerations were outside the scope of this project. Data from the Glen Canyon FEIS were utilized along with other data resources to conduct this study, as described under Section 6.4 above.

For the same reasons, issues related to aesthetic concerns are not addressed in this study. Aesthetics are clearly a matter of concern to stakeholders. In the case of Glen Canyon, an active campaign exists to drain the reservoir and restore the canyon to its original state, motivated in large part by the drive to restore the canyon to its original state of natural beauty. However, aesthetics are highly subjective. Others might argue that the beauty of the lake in the middle of an otherwise arid to semi-arid terrain is of at least equal aesthetic value. From a quantitative standpoint, one could assess the degree to which a physical change to a landscape – by means of construction of a dam and reservoir, installation of transmission towers, etc. — has altered the viewshed. But it is not clear that such a measure would provide an adequate or accurate reflection of the complex aesthetic issues to be addressed. As such, there is no attempt in this study to provide indicators of aesthetic impact.

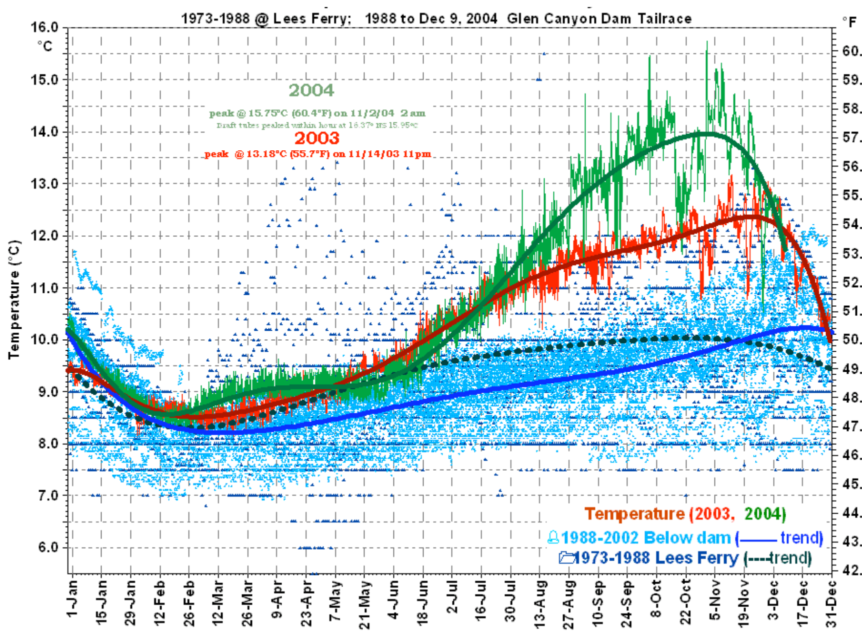
6.5.4. Drought Related Impacts

Since 1999, the Colorado River basin has been experiencing a severe drought. According to a July 2005 update posted on the Bureau of Reclamation website:

> "In the summer of 1999, Lake Powell was essentially full with reservoir storage at 97 percent of capacity. Inflow volumes for 5 consecutive water years were significantly below average. Total unregulated inflow in water years 2000, 2001, 2002, 2003, and 2004 was 62, 59, 25, 51, and 51 percent of average, respectively. Inflow in water year 2002 was the lowest ever observed since the completion of Glen Canyon Dam in 1963. … Lake Powell reached a low elevation on April 8, 2005, at 3,555 feet (145 feet from full pool)."

One notable consequence of the drawdown in lake level has been the marked increase in water temperatures of dam discharges. Historically, water temperatures in the Colorado River downstream of Glen Canyon varied considerably, from lows near freezing to highs of about 85°F, reflecting run-off flows, sediment content, and other seasonal factors. After the construction of the dam, water discharge temperatures stabilized at an average of 45-50°F, with only slight seasonal variations over the course of the year, and downstream temperatures warming only slightly. This change in temperature profile has been cited as a major factor in creating suitable habitat for non-native trout species, and potentially, for impacting the populations of warm water native fish species such as the endangered humpback chub. As a result of the current drought, however, average temperatures have risen markedly by as much as 6-7°F (Figure 6.8).

Figure 8.8. Annual Temperature Patterns below Glen Canyon Dam



While hydrological conditions have improved somewhat in recent months, the long-term outlook is as yet undetermined.[85] Data reviewed by SCS in the preparation of this report did not factor in these recent temperature developments. As such, SCS made no attempt to address any variables that might be associated with unusual persistent drought conditions, other than specifically stated. On the contrary, SCS made an effort to select data sets that were representative, to the extent possible, of the average condition of the project.

6.5.5. Water Resource Depletion

In addition to direct outflows, net water resource depletion from a reservoir can occur when water: 1) evaporates and transpires into the atmosphere; and/or 2) seeps into sediments and rocks on the lake floor and banks as lake levels rise.

As required under the Colorado River Basin Project Act of 1968, Public Law 90-537, the Water Resources Group of the Bureau of Reclamation has been preparing reports of consumptive water uses and losses for successive 5-year periods since October 1970. These reports include annual evaporative loss estimates for Lake Powell. Evaporative losses are directly linked to lake water elevation, since the higher the elevation, the greater the lake water surface area. The Bureau's methodology for calculating evaporation utilizes "a multiple regression equation relating gross annual evaporation to elevation and latitude" with adjustments as needed to reflect climatic subareas.

Potter and Drake [1989] modeled evaporation at various lake elevations, based on Bureau data. At two-thirds full, the lake's surface is approximately 125,000 acres. At this level, based on the Bureau of Reclamation data, Lake Powell loses a net 500,000 acre-feet/year (af/y) to evaporation. (This net calculation is based on evaporation levels from the lake minus pre-dam evaporative losses from the river.) When full, this net loss increases to about 725,000 af/y (Figure 6.9).[86]

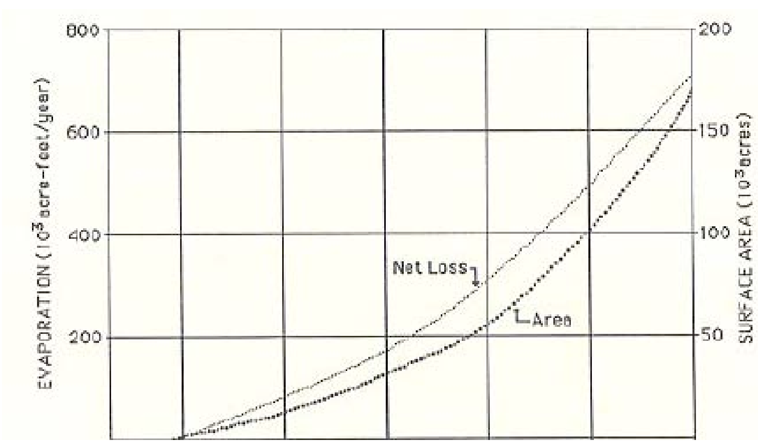


Figure 6.9. Net evaporation losses at different lake surface levels, Lake Powell.

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[85] Tom Ryan, Bureau of Reclamation, July 11, 2005 Update. http://www.usbr.gov/uc/water/crsp/cs/gcd.html.

[86] *Lake Powell: Virgin Flow to Dynamo,* Lauren D. Potter and Charles L. Drake, University of New Mexico Press, Albuquerque, 1989. In terms of pre-dam evaporation, Potter and Drake state: "From an analysis of the topography and the vegetation and with an effective annual precipitation of 5.71 inches in the area, the pre-lake evaporation losses were calculated to be about 227,000 acre-feet per year (af/yr). However, this includes about 60,000 af/yr of evaporation of precipitation that once fell on the hillsides and now falls directly into the lake, considered to be but an augmentation to the reservoir. If this is subtracted, the net pre-lake evaporative loss for comparative purposes would be about 167,000 af/yr." (page 210.)

In terms of remaining observed water losses, the Potter and Drake discounted transpiration as a significant factor, since the increase in terrestrial vegetation around the lake was noted to be relatively minor as the lake surface rose between 1964 and 1980. Instead, they concluded that the highly permeable sediments and rocks along the floor and wall likely have absorbed the remaining water. This bank storage was noted, but not included in water depletion calculations.[87]

In calculating net water evaporation for this study, SCS assumed the lake to be two-thirds full, on average, over its 40-year lifetime, which equates to approximately 21 million acre feet (maf) of water active capacity[88]. This assumption was made to take into account the high storage years of the mid-1980s and the more recent low storage years of the drought period (Table 6.3). (Note that evaporation levels in the drought years of 2004 and 2005 exceed historic evaporation levels of the pre-dam river by only about 20%. In March 2007, reservoir storage was reported to be 11.52 million acre-feet, 47% of capacity.[89])

Table 6.3. Evaporation at Lake Powell
Source: U.S. Bureau of Reclamation

	Evaporation (1,000 af/y)	
1996	582.0	
1997	592.7	
1998	605.3	Nearly full
1999	605.6	
2000	576.9	
5-year Average (1996—2000)	**592.5**	
2001	533.0	Decline in lake level due to drought (2000–2005)
2002	436.5	
2003	352.8	
2004	278.3	
2005	289.0	
5-year Average (2001—2005)	**377.9**	

No water depletion was calculated to take into account the creation of habitat in new high water zones (NHWZ) (see 6.5.6 below) along the river banks, for instance, with respect to the aggressive invasive tamarisk shrubs that are known to deplete water through their deep tap roots and exceptionally high rates of evapotranspiration.[90]

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[87] According to Potter and Drake, “Some of the [water] returns to the lake during low-water seasons. The remainder becomes a part of the ground-water system . . . Since it will not be subject to evaporation and is at depths too great for root systems to penetrate, this water could become a significant water resource.” Pg. 210.
[88] Data provided by Gary Burton from the Colorado River Storage Project Book.
[89] Tom Ryan, USBR Water Resources Group. “Lake Powell - Glen Canyon Dam - Current Status” http://www.usbr.gov/uc/water/crsp/cs/gcd.html, March 2007.
[90] National Park Service, Nature and Science website: http://www.nature.nps.gov/biology/ipm/manual/exweeds1.cfm

No additional water resource depletion was calculated for the combined cycle natural gas assumed to be used as the auxiliary power source during the post-ROD period.

6.5.6. Uncertainty Surrounding Causes of Observed Adverse Impacts

Extensive environmental monitoring in the Glen Canyon and along the Colorado River has called attention to a number of environmental impacts observed in the upstream and downstream regions impacted by the facility. At the same time, the causal relationship between specific stressors and effects remains uncertain.

For instance, in assessing effects on native and non-native fish species, one must consider not only the dam-related impacts — such as changes in water temperatures, changes in daily and seasonal flow fluctuations, and the physical barrier of the dam itself – but also factors such as the stocking of non-native species for recreational purposes (e.g., trout), pest and disease vectors (e.g., Asian tape worm), etc.

In this study, it was not possible to tease out the cause and effect relationship for every parameter. In the case of species-specific effects, too little data existed for most species during pre-dam conditions to fully understand what changes (increases or decreases) may have occurred. Even for those species where population or habitat estimates were available for a large segment of time, the cause of changes was not always clear.

As a result, SCS assumed a one-to-one relationship between physical disturbance and observed changes to the associated ecosystem parameters. No attempt was made to allocate effects amongst numerous causes. If the extent of a species or habitat changed (increased or decreased over time) and at least part of the cause was related to dam construction or operations, SCS assumed that the full change is associated with the dam. This assumption led to conservative calculations that may well overstate the impacts associated with dam operations; however, without an ability to pin down the causes of impacts, this approach provided a more precautionary set of results.

6.5.7. Creation of Habitat

As noted in the 1995 Glen Canyon FEIS, and in the Interior Secretary's 2001 Report to Congress, the construction and operation the Glen Canyon facility has resulted in positive as well as negative impacts on certain habitats and species.

In this study, both the creation and depletion of habitats were considered. For habitats that are endemic to the area, increases or decreases were tabulated and a net value was calculated for habitat disturbance when appropriate. For example, a net value for available river habitat could be calculated, since the river habitat is endemic to the area and might either be increased or decreased over time. For habitats that are not endemic to the area, such as Lake Powell, SCS identified and quantified those habitats and listed them in the habitat discussion below. Newly created habitats were not, however, used in net value calculations or in calculations of environmental ratings. There is no question that newly created habitat, such as Lake Powell, can provide a variety of social and ecological benefits. However, before the benefits can be duly incorporated into the LCSEA calculations, further work is needed to quantify the extent to which these newly created habitats support the endemic species and habitats. Studies that document the similarities and differences between newly created habitat and pre-existing habitat and species would allow SCS to incorporate these habitats into the net value calculations.

6.5.8. Auxiliary Power to Augment Post-ROD Power Generation

The institution of the modified low-fluctuating flow regime has transformed Glen Canyon from a system that provided load following power to a system providing more baseload support for the WECC power grid. Prior to the 1996 Record of Decision (ROD), daily fluctuations were allowed between 3,000 – 30,000 cfs. Starting with interim flow modifications instituted in 1991, and formalized by the 1996 ROD, daily fluctuations dropped to a daily maximum fluctuation of 8,000 cfs. Accordingly, the Glen Canyon power plant is no longer running at its maximum capacity. At this scale of power generation, the total loss in operating capacity is about 500 MW.[91]

The environmental benefits of this modified flow regime are being closely tracked by the GCMRC, Western, and other research institutions and stakeholders. Less well understood are the potential unintended environmental trade-offs associated with the use of make-up power to fulfill the following load function.

6.6. Habitat Disruption and Effects on Species – Gross Impacts Allocation Case

As described in Sections 2 and 3, LCSEA evaluation of impacts includes an accounting of the direct habitat disturbance as well as decreases or increases in species abundance and productivity from land use functions such as buildings, roads, mines, dams and transmission lines, as well as from project operations. As described in Section 6.5.1, the Gross Impacts Allocation Case assigns all impacts of the Glen Canyon facility to hydropower.

6.6.1. Habitat Disruption to Areas Occupied by Facilities

The areas affected directly by the construction of Glen Canyon dam include portions of the Colorado River and Glen Canyon. These areas encompass both terrestrial and aquatic habitats containing a wide variety of species.

The facilities at Glen Canyon include buildings, bypass, the dam, parking lots, the power plant, and the substation. Roads in the area were not included as most serve multiple purposes and were not attributed to facilities alone.

The terrestrial cover types and the aquatic (riverine) areas disturbed by dam facilities are shown in Table 6.4 below. The total habitat disruption due to facilities is 44 acres, while the total riverine habitat disrupted is 13.8 acres.

[91] Correspondence with G. Burton, Western Area Power Administration.

Table 6.4. Areas of Disturbance Associated with Glen Canyon Dam Facilities

Facility	Description	Perimeter	Area
Building	Shadscale-Mixed Grass-Mixed Scrub	570 ft.	0.397 ac
Bypass	Mormon Tea-Mixed Scrub	502 ft.	0.348 ac.
	Shadscale-Mixed Grass-Mixed Scrub	362 ft.	0.188 ac.
	Water	3580 ft.	9.05 ac.
Dam	Mormon Tea-Mixed Scrub	3580 ft.	9.05 ac.
	Water	3580 ft.	7.05 ac.
Parking lot	Shadscale-Mixed Grass-Mixed Scrub	2864 ft.	4.60 ac.
	Water	2864 ft.	4.60 ac.
Power station	Mormon Tea-Mixed Scrub	1537 ft.	2.02 ac.
	Shadscale-Mixed Grass-Mixed Scrub	1537 ft.	2.02 ac.
Sub station	Shadscale-Mixed Grass-Mixed Scrub	3528 ft.	12.5 ac.
	Shadscale-Mixed Grass-Mixed Scrub	1827 ft.	4.25 ac.

6.6.2. Habitat Disruption Due to Glen Canyon Project Operations

Dam operations accounted for the largest subset of physical disturbance associated with the project. The operation of the dam created Lake Powell, which is responsible for inundating a significant run of the Colorado River and associated tributaries upstream of Glen Canyon dam, as well as Glen Canyon itself. In addition, more than 200 miles of the Colorado River downstream of Glen Canyon have been affected by dam operations. Changes in flow dynamics over time have led to a number of habitat alterations. In addition to the dam itself, the installation and maintenance of transmission lines can have a potential impact on associated habitats; as such, SCS worked to identify the types of habitats associated with transmission lines as well as the level of disturbance caused by maintenance of the lines.

Sections 6.6.2.1 and 6.6.2.2 describe the affected areas and the methods SCS used to estimate the associated physical disturbance.

6.6.2.1. Aquatic and Riparian/Wetland Habitats

Pre-dam River Habitat Upstream of Glen Canyon Dam

A number of studies describe the physical area of Glen Canyon.[92] Many studies include discussions of the length of river that was inundated by the flooding of Glen Canyon and its tributaries. However, SCS was unable to find any estimates of the amount of river habitat disturbed upstream of the dam.

[92] *Citations to be inserted, final report.*

To determine the amount of river habitat affected by the creation of Lake Powell behind Glen Canyon Dam, SCS obtained the assistance of GIS specialists from Western Area Power Administration (WAPA).[93] First, USGS maps were located that showed contours of the original course of the Colorado River and tributaries.[94] To calculate the pre-Glen Canyon Dam Colorado River and related tributary channels, the accuracy of the boundaries shown was checked. Three methods were used to ensure the accuracy of the boundary identifications:

- A comparison was made of contour line features between the 1921 Southern California Edison Co. and 1977 USGS 1:24K Topographic Maps. This comparison resulted in a reasonably exact match of historic channel delineation. A digital overlay comparison was not done because the 1921 maps were not geo-referenced and created at a smaller (uncommon) scale.

- The historic river channel was identified both by symbol and title on the 1977 USGS 1:24K Topographic Maps.

- The channel boundary symbol was confirmed from the USGS Bathymetric Features symbol set.

The boundaries were then digitized from the historic river and tributary channels identified on the USGS 1:24000 Topographic maps. Table 6.5 shows the USGS maps used.

The maps were not sufficient to provide a direct measure of riparian habitat along the Colorado River and tributaries upstream of the dam. To estimate riparian habitat that existed above the dam site prior to construction, SCS conferred with GCMRC staff (Barbara Ralston). GCMRC provided estimates of riparian habitat coverage in present-day areas similar to those believed to be in existence prior to the dam. Using these estimates, SCS expanded the estimate by multiplying it by the length of river now inundated by Lake Powell.

[93] WAPA Contract GIS Specialists Eric Weisbender and Bob Almovdar

[94] *Citation to be inserted, final report.*

Table 6.5. USGS Maps Upstream of Glen Canyon Dam

24K QUAD ID	24K QUAD NAME	STATE
o36111g2	Cedar Tree Bench	Arizona
o36111h1	West Canyon Creek	Arizona
o36111h2	Face Canyon	Arizona
o36111h3	Wild Horse Mesa	Arizona
o36111h4	Page	Arizona
o37110a8	Rainbow Bridge	Arizona
o37110b4	Monitor Butte	Utah
o37110b5	No Mans Mesa North	Utah
o37110b6	Deep Canyon North	Utah
o37110b7	Wilson Creek	Utah
o37110b8	Nasja Mesa	Utah
o37110c4	Mikes Mesa	Utah
o37110c5	Nokai Dome	Utah
o37110c6	Alcove Canyon	Utah
o37110c7	The Rincon	Utah
o37110c8	Davis Gulch	Utah
o37110d5	Halls Crossing NE	Utah
o37110d6	Halls Crossing	Utah
o37110d7	The Rincon NE	Utah
o37110d8	Stevens Canyon South	Utah
o37110e5	Knowles Canyon	Utah
o37110e6	Bullfrog	Utah
o37110e7	Hall Mesa	Utah
o37110f4	Good Hope Bay	Utah
o37110f5	Ticaboo Mesa	Utah
o37110g3	Copper Point	Utah
o37110g4	Hite South	Utah
o37110g5	Mount Holmes	Utah
o37110h3	Sewing Machine	Utah
o37110h4	Hite North	Utah
o37111a1	Cathedral Canyon	Utah
o37111a2	Gregory Butte	Utah
o37111a3	Gunsight Butte	Utah
o37111a4	Warm Creek Bay	Utah
o37111a5	Lone Rock	Utah
o37111b1	Navajo Point	Utah
o37111b2	Mazuki Point	Utah
o37111b3	Sit Down Bench	Utah

Table 6.6 shows the measures of river habitat inundated by the construction of Glen Canyon dam and the creation of Lake Powell.

Table 6.6. Pre-dam River Habitat Upstream of Glen Canyon Dam

RIVER NAME	PERIMETER	AREA SQ_METERS	ACRES	SQ_MILES
Colorado River	337 miles	42,663,838.761	10,542.420	16.47260
San Juan River	120 miles	10,357,831.922	2,559.466	3.99918
Escalante River	53.3 miles	1,851,064.124	457.406	0.71470
Dirty Devil River	29.2 miles	632,835.472	156.376	0.24434
TOTAL	539.5 miles	55505570.3	13715.7	21.4

Post-dam Lake Habitat Upstream of Glen Canyon Dam

In addition to estimating the loss of river habitat, a measure of habitat created by the project was required – in this case, the addition of one of the largest lakes in North America, Lake Powell. Numerous publications provided information pertaining to the size of Lake Powell.[95] SCS chose to verify those figures by digitizing current USGS topographic maps and calculating the surface area of Lake Powell. Table 6.7 shows the area calculated for Lake Powell by this process. The size calculated matches well with published figures (156,000 – 165,000 acres). For this study, SCS used 158,127 acres (63,993 hectares), a compromise between SCS's digitized calculations and those cited in the literature.

Table 6.7 Post-dam Lake Habitat Upstream of Glen Canyon Dam, based on Digitized Data

Size of Lake Habitat	
Perimeter	1432.8 miles
Area in Square Meters	639,920,128
Acres	158,127
Square Miles	247

Pre-Dam and Post-Dam River Habitat Downstream of Glen Canyon Dam

The disturbance associated with the Colorado River downstream of Glen Canyon dam is the subject of ongoing intensive studies. Not surprisingly, the literature on the ecological impacts of Glen Canyon Dam is substantial and complex. Numerous reports, publications and Internet websites describe the types and amounts of impacts to river habitat, riparian habitat, and even to some associated terrestrial habitats. These resources provide descriptions of the native species in place before the dam, and their associated habitats, as well as descriptions of the changes that have occurred to the species complexes and their habitats after the operation of the dam for several decades.

[95] *Citations to be inserted, final report.*

The literature leaves no doubt that there have been significant changes to in-river species as well as species that depend on riparian and terrestrial habitats adjacent to the Colorado River. The Environmental Impact Statements that have been published provide good summaries of the relevant information.

As described in earlier sections, the LCSEA methodology requires that both aquatic and terrestrial habitat changes be calculated. In the case of the downstream portion of the river, it is clear that river habitat is still available; however, there is no single compilation of the amount of river habitat that may have been lost or added as a result of the operations of the dam. SCS also found no specific quantitative estimates of the loss of in-river habitat or riparian habitat downstream of Glen Canyon dam.

To determine the most efficient way to compile a quantitative measure of in-river habitat changes over the 200+ miles of affected river downstream, SCS met with staff members of Argonne National Laboratory. In discussions about the available data and literature on Glen Canyon dam, it was decided that the most practical way forward was to use existing sets of data that had already been gathered and compiled into databases as part of previous projects — i.e., STARS, the Grand Canyon Ecosystem Model (GCM), the Colorado River Flow Stage & Sediment Model (CRFSS). SCS contracted Ecometric Research Inc., the company that helped develop the Grand Canyon Ecosystem Model, to assist in identifying ways to estimate in-river habitat and riparian habitat from pre- and post-dam conditions.

For in-river habitat, a decision was made to use the wetted width of the river by river-mile by month for a given set of years representing pre-dam and post-dam conditions. Wetted width for this project is defined as the area that is inundated 100% of the time assuming specific flows. To estimate changes in wetted width over time, several parameters first had to be defined:

- Appropriate periods of time for calculating pre-dam and post-dam estimates
- Length of the river effected by Glen Canyon Dam

Time series were identified for both pre-dam (1956) and post-dam (1992) conditions by using discharge rates over various periods of time in the following way:

1. The historical record of monthly volumes released from Glen Canyon Dam or past the Lee's Ferry gauge was ranked to determine the median annual volume between 1948 and 2004 (8.72 maf).

2. The proportion of volume in each month for each year was computed and average proportions for each month for the pre-dam (1948-1960) and post-dam (1975-2004) periods calculated. Years between 1960 and 1975 were omitted from the analysis because of the potential effect of dam construction and reservoir filling on monthly volume patterns.

3. Each year during the pre-dam and post-dam periods was ranked according to its similarity in relative seasonal volume patterns to the average condition for the appropriate period. Ranking was conducted by minimizing the sum of squared differences between the average monthly proportions and the year-specific proportions.

1956 was used to represent the pre-dam condition because its annual volume (8.51 maf) was very close to the median value (8.72 maf), and the seasonal pattern in volume distribution was the fourth closest out of the thirteen years used to represent pre-dam conditions. 1992 was used to represent the post-dam conditions because of its similar annual volume (8.03 maf) to the median and because it ranked first in terms of the seasonal volume distribution out of the 30 years used to represent the post-dam period.

Temperature data by river mile were compared pre-and post-dam to determine the length of river necessary to input into the estimates. Temperature, reflecting differences in hydrology, was the most consistent measure available over long periods of time that could be modeled to determine if differences based on hydrology could be seen. Monthly averages for each reach for these two years were computed. No data were available for 1956, so data for the pre-dam period were used to represent a monthly pattern for the entire river. Water temperature data in 1992 were only available for the Glen Canyon and Furnace Flats reaches. Temperatures for other reaches were predicted by the Grand Canyon Ecosystem Model (GCM).

Table 6.8 shows observed and predicted temperature data. The data show that observed temperatures are different from both predictions along the entire length of the river from Glen Canyon almost to Lake Mead.

Table 6.8. Temperature Comparisons by River Reach from Glen Canyon to Lake Mead.

Predicted (GCM) and observed average water temperatures (degrees Celsius) by month and reach

	Reach	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Predicted													
1956		3	3	6	14	19	23	27	25	23	14	9	4
1992	Average	7.0	6.3	7.1	10.4	12.3	13.4	14.2	13.8	13.7	11.3	9.4	8.0
	GCD-Paria	8.3	7.6	7.7	8.6	9.3	9.9	10.3	10.2	10.4	10.0	9.5	9.5
	Permian Gorge	8.1	7.4	7.6	8.9	9.8	10.3	10.8	10.7	10.9	10.2	9.5	9.3
	Supai Gorge	8.0	7.3	7.5	9.1	10.1	10.7	11.2	11.1	11.2	10.3	9.5	9.1
	Redwall Gorge	7.7	7.1	7.5	9.3	10.6	11.3	11.8	11.6	11.8	10.6	9.5	8.9
	Marble Canyon	7.3	6.7	7.3	9.9	11.5	12.5	13.0	12.7	12.8	11.0	9.4	8.4
	Furnace Flats	7.0	6.3	7.1	10.5	12.3	13.3	14.2	14.0	13.7	11.3	9.4	8.0
	Upper Granite	6.7	6.0	7.0	10.9	13.1	14.3	15.2	14.9	14.6	11.6	9.3	7.6
	The Isles	6.6	5.9	7.0	11.0	13.2	14.5	15.4	15.0	14.7	11.7	9.3	7.5
	Mid. Granite	6.5	5.8	6.9	11.1	13.5	14.9	15.9	15.4	15.1	11.8	9.3	7.4
	Muav Gorge	6.3	5.7	6.9	11.3	13.8	15.2	16.3	15.7	15.4	11.9	9.3	7.2
	Lower Canyon	5.7	5.2	6.7	11.9	14.9	16.7	18.0	17.2	16.8	12.4	9.2	6.6
	Lower Granite	5.5	5.0	6.6	12.0	15.3	17.2	18.6	17.7	17.2	12.6	9.2	6.4
Observed													
1992	GCD-Paria	9.1	8.1	7.7	7.7	7.8	8.3	8.3	8.4	9.1	9.3	9.6	10.0
	Furnace Flats	8.5	8.1	8.5	9.4	10.4	11.0	10.7	10.6	10.6	10.5	9.3	9.1

The pre-dam temperature data shows strong seasonal variation with very low water temperatures during winter months (3-6° C), rapid increases in temperature during the spring, and maximum water temperatures during the summer of 23-27° C. In the post-dam period, water temperature variation has been greatly reduced. Observations in 1992 showed a temperature range of 7.7-10.0° C flowing through Glen Canyon Dam with maximum temperatures occurring in November and December (a temporal inversion in monthly thermograph). Temperatures are warmer downstream and show maximum values during summer months due to longitudinal warming. Post-dam maximum temperatures are well below maxima reached during the pre-dam period, and lower than required by native fish.

Table 6.9 shows the comparisons of discharge rates over time used to determine the best fit of discharges to pre-dam and post-dam periods of time. There was a fairly large discrepancy between predicted and observed water temperatures in 1992 at the Furnace Flats reach. GCM model parameters were tuned to match observed water temperatures observed since 2000. Reduced volumes from Glen Canyon Dam since 2000 have led to water temperatures at Furnace Flats during the summer of 13-15° C. Observed data from 1992 may be reflective of the overall temperature pattern in the post-dam period, but not of temperatures in the last five years (see Section 6.5.3). The predicted data for 1992 may provide a more representative picture of seasonal and longitudinal trends in water temperature for the 2000+ post-dam period.

Wetted width estimates were then calculated for the length of the river and time series determined in the steps outlined above. Minimum wetted width is a performance measure intended to capture the amount of aquatic riverine habitat under prescribed times (pre- and post-dam). Daily minimum flows for each month in 1956 and 1992 were determined from 15-minute discharge records at the Lee's Ferry gauge. Daily minimum discharge was used as input to the STARS-derived wetted width-discharge relationship for over 700 cross-sections between Glen Canyon Dam and Diamond Creek on the Colorado River in Grand Canyon to compute minimum daily wetted widths. These minimum widths were then averaged by reach and month (Table 6.10).

Trends in wetted width follow known effects of Glen Canyon Dam and other dams. Operation of Glen Canyon Dam has reduced discharge during the spring and increased baseflows during fall, winter, and summer. As a result, wetted widths in the pre-dam period tended to be higher than in the post-dam from April through June, and visa-versa during other months. The minimum productive area represented by minimum wetted width is considerably higher in the post-dam period in September, October, and December, and moderately lower in May and June. The change in wetted width between pre- and post-dam periods varied by reach, with narrower reaches showing less change in width for a given change in discharge.

Table 6.9 Comparison of Discharge Rates Over Time

	Diff between Avg. and annual pattern		Proportion of Annual Volume by Month											
			1	2	3	4	5	6	7	8	9	10	11	12
6	0.007299463	1948	0.03	0.04	0.05	0.13	0.27	0.26	0.08	0.04	0.02	0.03	0.03	0.03
2	0.003427639	1949	0.02	0.02	0.05	0.09	0.21	0.30	0.14	0.04	0.02	0.04	0.03	0.03
1	**0.001730115**	**1950**	0.03	0.04	0.06	0.11	0.18	0.28	0.13	0.04	0.03	0.03	0.03	0.04
5	0.005841878	1951	0.03	0.04	0.04	0.05	0.17	0.29	0.14	0.08	0.04	0.04	0.04	0.03
8	0.009460041	1952	0.03	0.02	0.02	0.13	0.28	0.29	0.09	0.05	0.03	0.02	0.02	0.02
10	0.015032961	1953	0.05	0.04	0.05	0.06	0.12	0.34	0.11	0.08	0.03	0.04	0.05	0.04
13	0.024934509	1954	0.05	0.06	0.06	0.09	0.21	0.13	0.11	0.05	0.06	0.08	0.06	0.05
3	0.004446934	1955	0.04	0.03	0.08	0.09	0.23	0.23	0.08	0.07	0.03	0.03	0.04	0.05
4	**0.005451961**	**1956**	0.04	0.03	0.06	0.10	0.25	0.30	0.06	0.04	0.02	0.02	0.03	0.03
12	0.023063739	1957	0.02	0.02	0.03	0.04	0.14	0.30	0.21	0.08	0.04	0.04	0.05	0.03
11	0.015160221	1958	0.03	0.04	0.05	0.12	0.31	0.28	0.05	0.02	0.02	0.02	0.03	0.03
7	0.007845981	1959	0.04	0.04	0.05	0.06	0.15	0.26	0.11	0.06	0.03	0.07	0.07	0.05
9	0.011383937	1960	0.03	0.04	0.09	0.18	0.18	0.26	0.07	0.02	0.02	0.04	0.04	0.03
	0.018299363	1961	0.04	0.05	0.05	0.08	0.16	0.22	0.05	0.05	0.10	0.10	0.07	0.05
	0.013070978	1962	0.02	0.06	0.04	0.17	0.25	0.20	0.12	0.03	0.02	0.04	0.03	0.02
	0.127805958	1963	0.12	0.27	0.13	0.04	0.04	0.10	0.06	0.04	0.04	0.04	0.04	0.05
	0.055255142	1964	0.02	0.07	0.12	0.24	0.09	0.02	0.02	0.05	0.05	0.08	0.11	0.12
	0.03471661	1965	0.05	0.04	0.05	0.11	0.20	0.20	0.06	0.08	0.06	0.06	0.05	0.05
	0.004953	1966	0.07	0.07	0.09	0.11	0.12	0.10	0.09	0.08	0.08	0.07	0.07	0.06
	0.005770689	1967	0.08	0.07	0.09	0.12	0.12	0.10	0.08	0.08	0.07	0.05	0.06	0.08
	0.006079987	1968	0.07	0.05	0.09	0.12	0.11	0.10	0.09	0.08	0.07	0.07	0.07	0.07
	0.002797901	1969	0.06	0.05	0.08	0.10	0.09	0.10	0.10	0.10	0.08	0.07	0.08	0.09
	0.00498732	1970	0.09	0.05	0.06	0.12	0.11	0.10	0.09	0.09	0.08	0.06	0.05	0.08
	0.005040596	1971	0.05	0.04	0.07	0.11	0.10	0.11	0.11	0.10	0.08	0.06	0.08	0.09
	0.003343625	1972	0.09	0.05	0.04	0.09	0.10	0.10	0.10	0.11	0.10	0.07	0.07	0.11
	0.023211435	1973	0.13	0.08	0.12	0.18	0.07	0.09	0.07	0.06	0.05	0.06	0.05	0.04
	0.005083364	1974	0.10	0.04	0.04	0.06	0.09	0.10	0.14	0.13	0.09	0.07	0.08	0.06
23	0.004041309	1975	0.09	0.06	0.06	0.05	0.10	0.11	0.14	0.11	0.11	0.07	0.05	0.06
19	0.003385025	1976	0.08	0.08	0.07	0.07	0.11	0.08	0.08	0.08	0.09	0.08	0.10	0.09
29	0.014674817	1977	0.14	0.06	0.06	0.02	0.03	0.06	0.12	0.16	0.13	0.05	0.05	0.11
17	0.002655914	1978	0.10	0.07	0.06	0.05	0.07	0.08	0.08	0.12	0.11	0.08	0.07	0.10
25	0.006039015	1979	0.13	0.09	0.03	0.05	0.07	0.08	0.11	0.13	0.08	0.07	0.10	0.08
24	0.005972978	1980	0.05	0.06	0.05	0.07	0.07	0.14	0.14	0.11	0.08	0.07	0.08	0.07
15	0.002375363	1981	0.09	0.08	0.06	0.06	0.07	0.07	0.11	0.12	0.09	0.08	0.08	0.11
21	0.003863377	1982	0.10	0.08	0.06	0.07	0.07	0.07	0.09	0.10	0.07	0.09	0.11	0.11
30	0.018382751	1983	0.05	0.04	0.03	0.05	0.06	0.18	0.18	0.10	0.08	0.08	0.08	0.08
20	0.003387765	1984	0.07	0.07	0.07	0.08	0.12	0.12	0.10	0.08	0.07	0.07	0.07	0.07
26	0.007078223	1985	0.10	0.09	0.07	0.07	0.12	0.14	0.10	0.09	0.08	0.04	0.04	0.04
27	0.007679387	1986	0.06	0.06	0.08	0.09	0.14	0.11	0.07	0.08	0.09	0.06	0.07	0.08
22	0.003895256	1987	0.14	0.10	0.07	0.07	0.07	0.09	0.10	0.11	0.08	0.04	0.06	0.07
13	0.002033814	1988	0.11	0.10	0.09	0.07	0.07	0.07	0.09	0.10	0.09	0.07	0.08	0.08
3	0.000567258	1989	0.09	0.08	0.07	0.07	0.07	0.09	0.10	0.11	0.10	0.07	0.07	0.08
5	0.000833211	1990	0.09	0.08	0.08	0.07	0.08	0.10	0.10	0.12	0.09	0.06	0.06	0.07
2	0.000474942	1991	0.08	0.07	0.07	0.06	0.09	0.10	0.11	0.11	0.10	0.07	0.07	0.08
1	**0.000297008**	**1992**	0.10	0.08	0.07	0.07	0.07	0.08	0.11	0.11	0.09	0.07	0.07	0.08
6	0.000864408	1993	0.10	0.08	0.07	0.07	0.07	0.07	0.10	0.11	0.08	0.06	0.07	0.10
4	0.000738146	1994	0.10	0.09	0.08	0.08	0.08	0.08	0.11	0.11	0.08	0.06	0.06	0.09
14	0.002182477	1995	0.08	0.07	0.06	0.06	0.06	0.10	0.11	0.11	0.11	0.09	0.08	0.09
18	0.003004874	1996	0.09	0.07	0.10	0.10	0.10	0.09	0.09	0.08	0.08	0.06	0.06	0.08
16	0.002608427	1997	0.07	0.08	0.10	0.08	0.08	0.10	0.09	0.08	0.08	0.08	0.08	0.08
7	0.000945604	1998	0.10	0.09	0.09	0.06	0.07	0.09	0.10	0.10	0.08	0.07	0.07	0.07
9	0.001471495	1999	0.08	0.07	0.07	0.06	0.09	0.08	0.09	0.10	0.10	0.09	0.09	0.09
28	0.009970665	2000	0.09	0.07	0.08	0.11	0.13	0.06	0.06	0.06	0.08	0.07	0.09	0.10
12	0.002001572	2001	0.11	0.08	0.08	0.07	0.08	0.07	0.10	0.10	0.06	0.08	0.08	0.10
8	0.001191757	2002	0.10	0.08	0.08	0.08	0.08	0.10	0.12	0.11	0.06	0.06	0.06	0.08
11	0.001926709	2003	0.10	0.09	0.10	0.07	0.08	0.10	0.11	0.11	0.06	0.06	0.06	0.07
10	0.001856698	2004	0.09	0.09	0.10	0.08	0.07	0.09	0.11	0.11	0.06	0.06	0.08	0.07

Table 6.10. Wetted Width Pre- and Post-Dam

Average daily minimum wetted width (in feet) by month and reach in 1956 (pre-dam) and 1992 (post-dam)

	Reach	D/S-RM	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1956	GCD-Paria	0	450	407	462	501	552	559	468	431	246	266	428	351
	Permian Gorge	10	294	266	297	308	322	318	299	281	162	175	280	230
	Supai Gorge	22	192	174	197	211	230	225	199	184	105	114	183	150
	Redwall Gorge	39	202	183	207	221	243	239	208	193	111	119	192	157
	Marble Canyon	60	319	289	324	340	373	371	326	305	175	189	304	249
	Furnace Flats	76	345	311	352	374	392	392	356	330	188	204	328	268
	Upper Granite	117	178	161	181	191	201	201	182	170	97	105	169	138
	The Isles	124	192	174	196	207	219	218	198	184	105	114	183	150
	Mid. Granite	139	203	184	207	219	232	231	209	194	111	120	193	158
	Muav Gorge	159	157	141	161	174	188	187	163	150	86	92	149	122
	Lower Canyon	213	271	244	277	293	310	309	279	259	148	160	257	210
	Lower Granite	239	220	200	223	230	236	236	224	211	121	131	210	172
1992	GCD-Paria	0	473	463	455	459	459	465	477	475	468	454	457	464
	Permian Gorge	10	301	298	295	297	297	299	302	301	299	295	296	298
	Supai Gorge	22	201	197	194	196	196	198	202	202	199	194	195	198
	Redwall Gorge	39	211	207	204	206	206	208	212	211	209	204	205	208
	Marble Canyon	60	329	325	321	323	323	326	330	329	327	321	322	325
	Furnace Flats	76	362	356	349	353	353	357	364	362	359	349	351	356
	Upper Granite	117	185	182	179	181	181	183	186	185	184	179	180	182
	The Isles	124	200	198	194	196	196	198	201	201	199	194	195	198
	Mid. Granite	139	212	209	206	207	207	209	213	212	210	205	206	209
	Muav Gorge	159	166	162	159	161	161	163	167	166	164	159	160	163
	Lower Canyon	213	284	279	274	277	277	281	285	284	282	274	276	280
	Lower Granite	239	225	223	221	222	222	224	226	225	224	221	222	223
Difference between Pre and Post														
1956-1992	GCD-Paria	0	-23	-56	7	42	93	93	-9	-44	-222	-188	-29	-113
	Permian Gorge	10	-7	-31	2	12	26	20	-3	-20	-138	-121	-16	-68
	Supai Gorge	22	-9	-24	2	15	34	26	-4	-18	-94	-80	-12	-48
	Redwall Gorge	39	-9	-25	2	15	37	31	-4	-18	-99	-84	-13	-50
	Marble Canyon	60	-10	-36	3	17	50	46	-4	-24	-152	-132	-18	-76
	Furnace Flats	76	-17	-44	3	22	39	34	-7	-33	-170	-145	-24	-88
	Upper Granite	117	-7	-21	1	10	20	18	-3	-15	-86	-74	-11	-44
	The Isles	124	-8	-24	1	11	23	20	-4	-17	-94	-80	-13	-48
	Mid. Granite	139	-9	-25	2	12	25	22	-4	-18	-99	-85	-13	-51
	Muav Gorge	159	-9	-21	2	13	27	24	-4	-16	-79	-66	-11	-41
	Lower Canyon	213	-13	-35	2	16	33	28	-6	-26	-134	-114	-19	-70
	Lower Granite	239	-5	-23	1	8	14	13	-2	-15	-103	-90	-11	-51

Pre-Dam and Post-Dam Riparian/Wetland Habitat Associated with Glen Canyon Dam

The impoundment of water in Lake Powell resulting from the construction of Glen Canyon dam eliminated upstream riparian/wetlands habitats along the Colorado River and its tributaries, the San Juan, Escalante and Dirty Devil rivers.

In terms of downstream disruption of riparian habitat, the situation is more complex. Prior to dam construction, the high flow rate was around 125,000 cfs, leaving a very small band of riparian habitat well above the canyon floor. This band is referred to as the old high water zone (OHWZ). Upon building of the dam, the flow was regulated such that the high flow rates dropped to around 33,000 cfs. As a result, the new high water zones (NHWZ) along the canyon walls directly downstream of the dam in Glen Canyon, and further downstream in the Grand Canyon National Park, are significantly lower than the OHWZ. While vegetative communities in the OHWZs are generally in decline, most likely due to dewatering and lack of nutrient replenishment, some of the OHWZ plants are long-lived, and this zone therefore still forms a distinct band of vegetation in the Grand Canyon.

During the pre-ROD period, the riparian zone expanded due to less scour, more sediment stabilization, and longer exposure of the wetted surface area. All of these factors allowed vegetative cover to expand. In the post-ROD period, flow rates have been further reduced to a high flow of around 15,000 cfs, with an average flow between 10,000 – 11,000 cfs in recent years, augmented by four experimental flood flows in 1996, 1997, 2000 and 2004. This flow regime allowed for further expansion of the riparian areas.

SCS is unaware of any prior research conducted on the total riparian area change along the entire stretch of the Colorado River affected by the Glen Canyon Dam (both upstream and downstream). A recent study by GCMRC (Ralston, B., 2006) involving mapping of riparian vegetation downstream of the Glen Canyon Dam made it possible for GCMRC to provide SCS with estimates of riparian vegetation at a few specific points along the river. These estimates were then combined with distance along the river, and used to produce estimates for this study of total riparian zone vegetation along the Colorado River downstream of Glen Canyon Dam.

The estimate of riparian vegetation existing prior to dam construction is about 33,191 hectares (82,000 acres). Since construction of the dam, a NHWZ of about 104,000 hectares (257,000 acres) of riparian vegetation was estimated for the pre-ROD period. The NHWZ is estimated to have expanded to about 280 thousand hectares (close to 700 thousand acres) since flows were further modified to comply with the ROD.

6.6.2.2. Terrestrial Habitats

Terrestrial habitat disruption can be accounted for by the loss of terrestrial habitat upstream of the Glen Canyon Dam due to the filling of Lake Powell. Little to no significant terrestrial habitat has been removed or disrupted downstream of Glen Canyon Dam, with the exception of riparian habitat which is handled as a separate topic and indicator in this study (see 6.6.2.1).

Current calculations confirmed by GIS experts at Western show that a total of 144,411 acres (58,442 hectares) of terrestrial habitat was flooded. This figure was derived by taking the coverage of Lake Powell (158,127 acres) and subtracting the area covered by the river channels flooded above Glen Canyon dam. In addition, the footprints of the facilities (buildings, bypass, dam, parking lot, power station, and substation) were checked, estimated (58 acres), and added to the total.

SCS also reviewed the degree to which terrestrial habitats may have been affected by construction and maintenance of transmission lines linking the Glen Canyon Dam to the interconnected grid. To estimate actual physical disruption associated with transmission lines, it was first necessary to identify those lines that were built to specifically connect Glen Canyon dam operations to the existing electricity grid. The lines identified are shown in Table 6.11.

In addition, it was necessary to identify the land cover types in the Right of Ways (ROWs) associated with each line. ROWs are those designated areas in and around the transmission lines that are required to be kept clear of any objects that could cause damage to, or the loss of operation of, transmission lines. Table 6.11 shows each land cover type as well as the amount of each type of land cover associated with each transmission line.

The last issue to be examined was whether any of the land cover areas associated with ROWs are regularly or periodically cleared of vegetation to ensure that there are no objects that could cause loss of operation of the transmission lines. For these areas, SCS considered the clearing of vegetative cover as a cause of physical disruption, as it does cause loss of biological diversity in the areas of the lines, as well as disrupt the potential continuity of ecosystems where the lines occur.

The total vegetative land cover within transmission line ROWs is 9,232 acres, which excludes areas covered by water or industrial buildings. According to the unit in Western that manages the ROWs, none of the ROWs for Western are required to have vegetation cleared at regular intervals. However, those land cover areas that contain Ponderosa Pine are the most likely to require at least periodic maintenance (some sort of clearing or pruning). SCS considered the areas with Ponderosa Pine the only areas worth considering as containing physically disrupted ecology. This reduced the 9,232 acres to only 535 acres of disrupted vegetative cover.

Table 6.11. Land Cover in Transmission Right of Ways Associated with Glen Canyon Dam

Vegetation Cover for Glen Canyon to Flagstaff Transmission Lines				
LINE NAME	**ROW WIDTH FEET**	**LINE LENGTH MILES**		
230-GLEN CANYON - NAVAJO	125	7.462		
VEGETATION DESCRIPTION	**AREA SQ_METERS**	**PERIMETER**	**ACRES**	**SQ_MILES**
GB Mormon Tea-Mixed Scrub	538181.0120	14667.2470	132.987	0.20779
GB Shadscale-Mixed Grass-Mixed Scrub	335721.9970	9692.9590	82.958	0.12962
Water	6858.0140	332.4000	1.695	0.00265
Industrial	32087.2140	964.0830	7.9290	0.01239
LINE NAME	**ROW WIDTH FEET**	**LINE LENGTH MILES**		
345-GLEN CANYON-FLAGSTAFF #1	150	37.906		
VEGETATION DESCRIPTION	**AREA SQ_METERS**	**PERIMETER**	**ACRES**	**SQ_MILES**
GB Blackbrush-Mixed Scrub	1214736.1635	424592.5120	300.166	0.46901
GB Mixed Grass-Mixed Scrub	3882012.0248	6753901.2915	487.816	1.49885
GB Mixed Grass-Mormon Tea	355817.0875	92000.6616	458.580	0.71654
GB Mixed Grass-Sagebrush	143218.8458	66871.7220	35.390	0.05530
GB Mixed Scrub	134390.4098	155360.9004	33.208	0.05189
GB Mormon Tea-Mixed Scrub	1601292.5002	3854329.7977	395.686	0.61826
GB Shadscale-Mixed Grass-Mixed Scrub	7273286.3291	3854329.7977	1797.261	2.80823
Pinyon-Juniper (Mixed)	1332300.5790	769676.8742	329.217	0.51440
Pinyon-Juniper-Mixed Grass-Scrub	604613.5819	127435.6303	149.402	0.23345
PJ/Sagebrush/Mixed Grass-Scrub	686049.2344	142714.7847	169.526	0.26489
Ponderosa Pine	731944.2197	64620.3757	180.867	0.28261
Ponderosa Pine-Gambel Oak-Juniper/Pinyon-Juniper Complex	334526.1776	125933.4586	82.663	0.12916
Water	13196.4051	17820.2434	3.261	0.00510
LINE NAME	**ROW WIDTH FEET**	**LINE LENGTH MILES**		
345-GLEN CANYON-FLAGSTAFF #2	150	37.841		
VEGETATION DESCRIPTION	**AREA SQ_METERS**	**PERIMETER**	**ACRES**	**SQ_MILES**
GB Blackbrush-Mixed Scrub	888865.2241	439892.7102	219.643	0.34319
GB Mixed Grass-Mixed Scrub	3806071.0730	7024596.2235	940.497	1.46954
GB Mixed Grass-Mormon Tea	278778.5428	92000.6616	68.887	0.10764
GB Mixed Grass-Sagebrush	157368.1520	66871.7220	38.886	0.06076
GB Mixed Scrub	156694.6478	155360.9004	38.720	0.06050
GB Mormon Tea-Mixed Scrub	1864110.8984	1331780.6883	460.630	0.71974
GB Shadscale-Mixed Grass-Mixed Scrub	7263452.3008	3854329.7977	1794.831	2.80444
Pinyon-Juniper (Mixed)	1367270.4488	769676.8742	337.858	0.52791
Pinyon-Juniper-Mixed Grass-Scrub	581396.3041	127435.6303	143.666	0.22447
Pinyon-Juniper-Mixed Shrub	146287.8124	167993.1648	36.148	0.05648
PJ/Sagebrush/Mixed Grass-Scrub	650190.6815	142714.7847	160.665	0.25104
Ponderosa Pine	715358.4178	64620.3757	176.768	0.27621
Ponderosa Pine-Gambel Oak-Juniper/Pinyon-Juniper Complex	383605.4816	125933.4586	94.791	0.14811
Water	16459.4342	17820.2434	4.067	0.00636
LINE NAME	**ROW WIDTH FEET**	**LINE LENGTH MILES**		
69-GLEN CANYON-POWELL	75	0.711		
VEGETATION DESCRIPTION	**AREA SQ_METERS**	**PERIMETER**	**ACRES**	**SQ_MILES**
GB Mormon Tea-Mixed Scrub	29681.4671	265799.5622	7.334	0.01146
GB Shadscale-Mixed Grass-Mixed Scrub	128599.1067	1792858.4322	31.777	0.04965
Water	16459.4343	17820.2434	4.067	0.00636
LINE NAME	**ROW WIDTH FEET**	**LINE LENGTH MILES**		
69-GLEN CANYON-SLAVENS-POWELL	75	0.797		
VEGETATION DESCRIPTION	**AREA SQ_METERS**	**PERIMETER**	**ACRES**	**SQ_MILES**
GB Mormon Tea-Mixed Scrub	21633.3971	265799.5622	5.346	0.00835
GB Shadscale-Mixed Grass-Mixed Scrub	160953.3845	1792858.4322	39.772	0.06214
Water	11424.8780	17820.2434	2.823	0.00441

6.6.2.3. Overall Habitat Disruption

Table 6.12 summarizes the calculations of habitat disruptions described in previous sections.

Table 6.12. Overall Habitat Disruption

	Area Disrupted	
Terrestrial Habitat	Acres	Hectares
Inundated by Lake Powell	144,411	58,441
ROWs	535	217
Facilities	58	23
TOTAL	145,004	58,681
Riparian/Wetland Habitat		
Upstream /Downstream River	82,000	33,184
ROWs	16	6
TOTAL	82,016	33,191
Lake Habitat*		
Above Glen Canyon Dam	0	
Below Glen Canyon Dam	0	
	Eq. River Miles	
Riverine Habitat		
Above Glen Canyon Dam	307	
Below Glen Canyon Dam	225	
TOTAL	532	

** As there was no lake prior to construction of the dam, there was zero disruption to lake habitat attributable to the dam project.*

6.6.3. Glen Canyon –Effects on Key Species

This section discusses several species that have been affected by the construction and operation of the Glen Canyon dam. Considerable data have been compiled by GCRMC and others regarding the status of species endemic to the Colorado River and its surrounding environs, as well as introduced, both above and below Glen Canyon dam. Table 6.13 provides a summary of these species.

Table 6.13. Species Overview

Native Fish Species	Introduced Fish Species	Endangered Species	Locally Extinct Species
Bluehead sucker	Black crappie	American peregrine falcon	Bonytail chub
Bonytail chub	Bluegill	Bald eagle	Colorado squawfish
Colorado squawfish	Channel catfish	Belted kingfisher	Razorback sucker
Humpback chub			Roundtail chub
Razorback sucker	Largemouth bass	California brown pelican	Southwestern river otter
Roundtail chub	Smallmouth bass	California clapper rail	Yuma clapper rail
Speckled dace	Striped bass	Desert pupfish	
	Walleye	Hualapai Mexican vole	
	Fathead minnow	Humpback chub	
	Green sunfish	Kanab ambersnail	
	Red shiner	Light-footed clapper rail	
	Western mosquitofish	Moapa dace	
	Flathead catfish	Mojave tui chub	
	Blue tilapia	Osprey	
	Yellow bullhead		
	Common carp	Sonoran pronghorn	
	Rainbow trout	Southwestern willow flycatcher	
	Threadfin shad	Vaquita	
	Golden shiner	Virgin river chub	
	Brown trout	Woundfin	
	Goldfish		
	Plains killifish		
	Black bullhead		
	Sailfin molly		
	Brook trout		
	Rio Grande cichlid		
	Arctic grayling		
	Cutthroat trout		
	Northern pike		
	Redside shiner		
	Redear sunfish		
	Mozambique tilapia		
	Redbelly tilapia		
	Rock bass		
	Guppy		
	Yellow bass		
	White crappie		
	Shortfin molly		
	Rio Grande sucker		
	White bass		
	Bigmouth buffalo		
	Smallmouth buffalo		
	Brown bullhead		
	Convict cichlid		
	Grass carp		
	Black buffalo		
	Warmouth		
	Spotted bass		
	Yellow perch		

For the purposes of this LCIA study, within the allocated budget, an indicator species was selected to represent the impacts of the dam construction and ROD. This is consistent with the requirements of the Draft National Standard (SCS-002) (Appendix 6), which requires that the loss of key species be estimated by examining the data for all key species and selecting the species that has the greatest added mortality from project operations. Considerations in the selection of the indicator species were:

- **Native to the region.** A species native to the region was selected in order to provide a reflection of changes attributable to the Glen Canyon dam since its construction.
- **Fish species.** A fish species was selected in order to capture changes occurring over the largest potential area of altered habitat, which in this case was river habitat.
- **Endangered.** A listed endangered species was selected consistent with the requirements of the SCS-002 standard.

In the case of Glen Canyon dam, several species have been affected by the construction and operation of the dam. However, little quantitative data is available on these species. The species for which the most data have been collected, and the best estimates of population change over time exist, is the humpback chub.

The humpback chub (*Gila cypha*) is a member of the minnow family. According to the U.S. Fish and Wildlife Service, the humpback chub is believed to have evolved 3-5 million years ago, and lives primarily in canyons with swift currents and white water. "Historically, it inhabited canyons of the Colorado River and four of its tributaries: the Green, Yampa, White and Little Colorado rivers, with the largest known populations in the Little Colorado."[96]

The humpback chub was formally listed as an endangered species by the U.S. Fish and Wildlife Service in the 1960s, and given full protection under the Endangered Species Act of 1973. Since its initial listing, U.S. recovery strategies have included boosting and protecting river flows in the spring, monitoring fish population numbers and managing stocking of non-native predatory fish. GCMRC oversees monitoring and research of the Grand Canyon population of humpback chub under the auspices of the Glen Canyon Dam Adaptive Management Program (GCDAMP). Recovery efforts are also being monitored by the Upper Colorado River Endangered Fish Recovery Program, a public/private partnership.

Estimates of the humpback chub population since the construction of the dam until 1989 are highly uncertain, given the lack of monitoring data. The population of humpback chub at the time that formal monitoring efforts commenced in 1989 was estimated to be around 10,000 using constant mortality, and 13,500 with variable mortality. Since that time, monitoring data indicate that the population of humpback chub steadily declined to

[96] U.S. Fish and Wildlife website: http://www.fws.gov/coloradoriverrecovery/Crhbc.htm

4-5,000 in 2000, then stabilized, showing a slight increase by 2005 (Figure 6.10). According to GCMRC:

> "The death of 15% to 20% of adult fish each year and a low rate of juvenile fish surviving into adulthood contributed to the decline. Adult mortality rates and the failure of juvenile fish to reach adulthood have both been attributed to changes in Little Colorado River and Colorado River hydrology, the weakening of young fish by the nonnative Asian tapeworm (*Bothriocephalus acheilognathi*), and competition with and predation by nonnative fish species." [97]

With respect to the recent stabilization in humpback chub population, GCMRC reported:

> "The exact causes of the stabilization of the adult population and increased numbers of young humpback chub cannot be specified at this time. However, humpback chub in Grand Canyon are thought to have benefited from several changes, including the experimental removal of nonnative fish, experimental water releases, and drought-induced warming."

It is not clear whether an end of the drought would reverse the current stabilized trend, given river conditions and continued adaptive management measures.

6.7. Habitat Disruption and Effects on Species – Hydropower Function Case

As described in Section 6.5.1, the Hydropower Function Case assigns the impacts of only the construction and operation of the power plant to hydropower. It is the difference between the project as it currently operates and the project as if it were not operated for power generation.

6.7.1. Riparian/Wetland Habitat Disruption

This indicator represents habitat losses on the low side of the riparian zone. Power operations cause somewhat higher water surface elevations than would be caused by releases for water delivery alone. The 1995 Glen Canyon Dam Operation EIS estimated that current power operations would reduce riparian/wetland habitat by 16.5 percent, or 66 hectares.

However this would be a short-term loss. Any habitat lost along the low side of the riparian zone because of the somewhat elevated water surface would be replaced along the high side by vegetation supported by the somewhat raised water table.

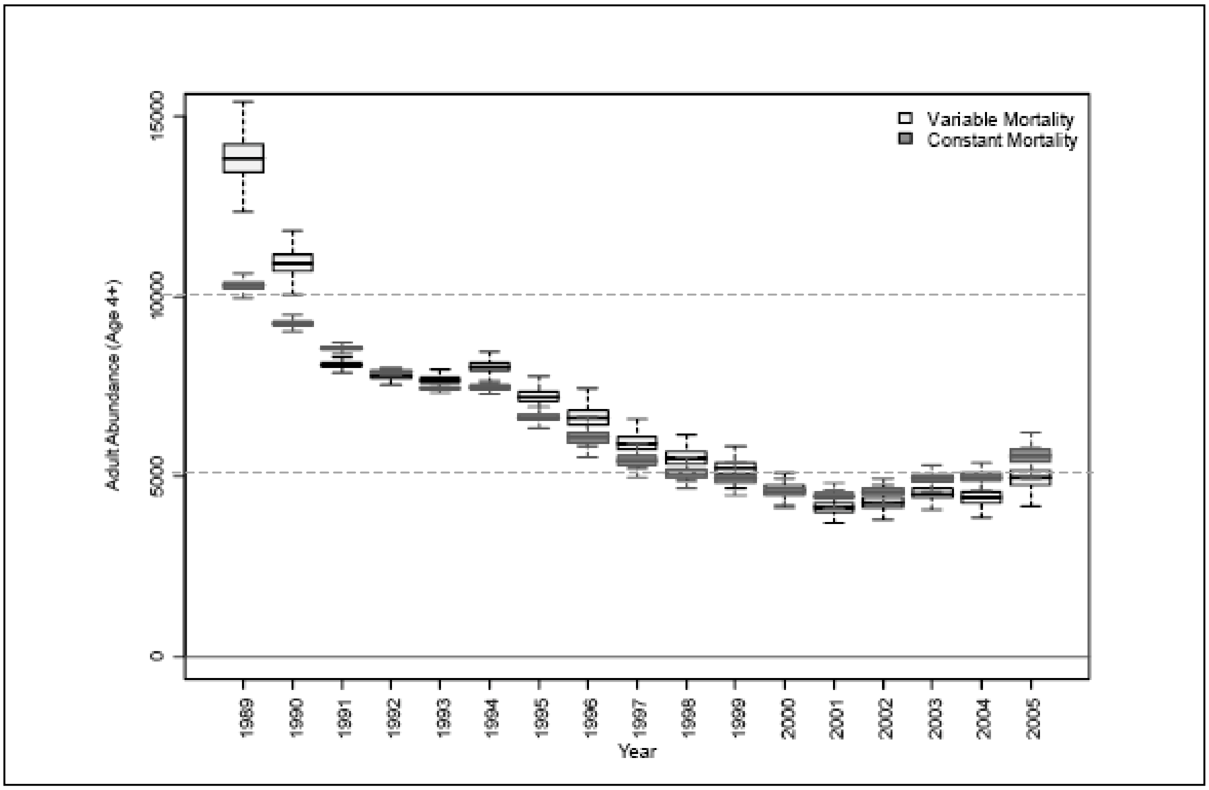
6.7.2. Loss of Key Species: Humpback Chub

The loss of key species, i.e. humpback chub, because of power operations could not be calculated due to scientific uncertainty. With available data it is impossible to distinguish the effect of power operations from other environmental factors. The humpback chub population

[97] U.S. Department of Interior, USGS Fact Sheet 2006-3109 Final. "Grand Canyon Humpback Chub Population Stabilizing." July 2006. Available at www.gcmrc.gov/files/pdf/fs_2006_3109.pdf.

has been affected by parasites, competition with and predation by other species, and lower, warmer flows. In addition some perceived population changes may be attributable to methodological artifacts.

Figure 6.10. Age Structured Mark Recapture Models of Grand Canyon HBC Population
Source: USGS[98]



6.8. Summary LCI Results

The life-cycle inventory results for the Glen Canyon dam and hydropower generation system are shown in Table 6.14.

98 *Ibid*.

Table 6.14. Main Life-Cycle Inventory Results for the Glen Canyon Hydropower Generation System compared to the WECC Power Pool Baseline. (Normalized to a production of 1,000 GWh.)

		Glen Canyon Hydropower Generation System	WECC Power Pool Baseline
Inventory	**Unit**		
Outputs			
Emissions, air			
Arsenic	kg		16
Benzene	kg		6
Cadmium	kg		1
CFC-114	kg		34
CH4	kg	2	906,170
CO2 (annual emissions)	kg	69,200	478,383,000
CO2, (construction emissions)	kg	3,270	
PM10, TSP, dust	kg	5	197,030
HC, VOC	kg	320	29,910
HCl	kg		26,959
HF	kg		683
Mercury	kg		7
Manganese	kg		14
NOx	kg	1,005	956,413
Lead	kg		10
Rad. act. Rn-222	GBq		2,910
Rad. act. noble gases	GBq		250
SO2	kg	45	731,940
Emissions, water			--
Energy			
electric power	MWh		1,000,000
Hazardous waste			
Resources			
Coal	kg	3,726	200,080,000
Lignite	kg		
Crude oil	kg	21,460	3,631,900
Natural gas	kg	31	48,502,000
Uranium in ore	kg U	0.003	3,048

6.9. LCSEA Results

From the LCI data, the LCSEA indicator results have been calculated, using the appropriate stressor and environmental characterization factors, as discussed in Sections 2 and 3. In Table 6.15, LCSEA indicators are summarized for the Glen Canyon Hydropower Generation System and the WECC regional power pool.

Table 6.15. Life-Cycle Impact Indicator Results for the Glen Canyon Hydropower Generation System, and the WECC Power Pool Baseline. Data are normalized to a production of 1,000 GWh.

Key Indicator	***Unit***	Baseline: WECC Power Pool	Gross Impacts Allocation Case	Hydropower Function Case
Non-Renewable Energy Resource Depletion	Eq. GJ of oil	5,207,000	1,011	1,011
Water Resource Depletion	Acre-feet	*NC*	151,000	--
Terrestrial Habitat Disruption	Eq. Ha disturbed	1,882	18,000	--
Aquatic (Lake) Habitat Disruption	Eq. Ha disturbed	**--**	--	--
Aquatic (Lake) Habitat Created	Eq. Ha disturbed	**NC**	20,000	--
Aquatic (River) Habitat Disruption	Eq. river miles	***35****	160	--
Riparian/Wetland Habitat Disruption	Eq. Ha disturbed	***3,175****	9,997	66
New Riparian/Wetland Habitat Created	Eq. Ha disturbed	*NA*	285,300	--
Loss of Key Species: Humpback Chub	% loss of key species	*NA*	50% loss	*NC*
Accumulated GHG Radiative Force Loading	Eq. t CO_2	500,000	71	71
Acidification Loading (Oceanic)	Eq. t CO_2	165,000	23	23
Acidification Loading (Regional)	Eq. t SO_2	6.5	--	--
Ground Level Ozone Loading	t O_3	8.9	--	--
Particulate Matter Loading	Eq. t PM_{10}	12.2	--	--
Pulmonary Toxic Chemical Loading	Eq. kg benzene	5.2	--	--
Systemic Toxic Chemical Loading	Eq. kg TCDD	*NC*	--	--
Neurotoxic Chemical Loading	Eq. kg of mercury	5.7	--	--
Ecotoxic Chemical Loading	Eq. kg of arsenic	*NC*	--	--
Radioactive Hazardous Wastes	Eq. GBq Pu 239	*NC*	--	--

(--) denotes a result of negligible or zero; (*) represents a calculated value for a highly environmentally efficient hydro facility in the WECC, and therefore is an extreme worst case for WECC mix; NA is not available, NC is not calculated.
Habitat creation indicators shown in green. Results above 10,000 have been rounded to the nearest 1,000.

For the Gross Impacts Allocation Case, as reflected in the green rows, new lake habitat and new riparian habitats have been created as a result of the dam construction, and are accordingly included in the impact profile. However, these indicator results were not integrated with the aquatic (lake) habitat depletion or riparian/wetland habitat depletion indicators. Integration into a net habitat change (depletion / creation) is only possible when the habitats created and the habitats depleted are of comparable composition.

- The aquatic (lake) habitat depletion indicator refers only to the depletion of existing lake habitat. As there was no lake habitat prior to construction of the dam, this indicator result is zero.

- The riparian/wetland habitat depletion indicator refers to loss of riparian/wetland habitat that existed at the time of dam construction. Significant losses in existing riparian/wetland habitats also occurred as a result of altered river flows after construction of the dam and particularly after institution of the ROD. The new habitat that has emerged at the NWHZ has undergone significant alteration in composition, in part as a result of the intrusion of non-native species.

Tables 6.16 to 6.18 present in more detail the calculations used to determine the non-renewable energy resource depletion, accumulated GHG radiative force loading and oceanic acidification loading indicator results.

Table 6.16. Non-Renewable Energy Resource Depletion Results for the Glen Canyon Hydropower Generation System. Data are normalized to a production of 1,000 GWh.

Non-renewable Energy Resource Depletion	Inventory Resource	Energy Resource Consumed (t)	Stressor Characterization Factor (SCF) (GJ/t)	Equivalent Energy Resource Consumed (GJ)	Resource Depletion Factor (RDF_{25}): Rate of dep. / Rate of oil depl.	Equivalent Resource Depletion (GJ oil eq.)
Electric Power System: Glen Canyon	Crude oil	21	45.6	979	1.0	979
	Natural gas	0.03	53.4	2	0.94	2
	Coal	4	28.0	104	0.28	30
	Uranium in ore	3.4E-06	900,000	3	0.54	2
				1,088		**1,011**

Table 6.17. Accumulated GHG Radiative Force Loading Results for the Glen Canyon Hydropower Generation System. Data are normalized to a production of 1,000 GWh.

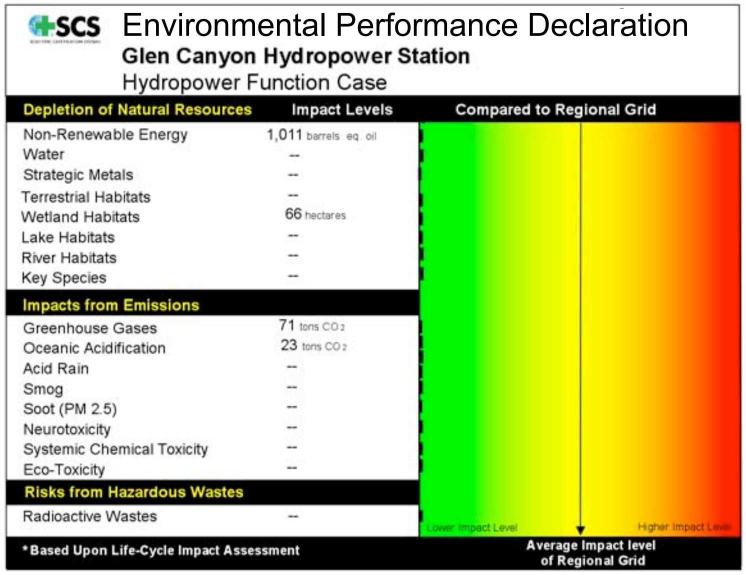
Accumulated GHG Radiative Force Loading	Inventory Emission	Life-Cycle Inventory Result (t/a)	Global Warming Potential (t CO_2 eq./t)	Gross Emission Loading (t CO_2 eq.)	Environment Characterization Factor (ECF)	Net Emission Loading (t CO_2 eq.)
Electric Power System: Glen Canyon	Fossil CO_2 (construction)	3.3	1.0	3	0.46	2
	Fossil CO_2 (operation)	69	1.0	69	1.00	69
				72		**71**

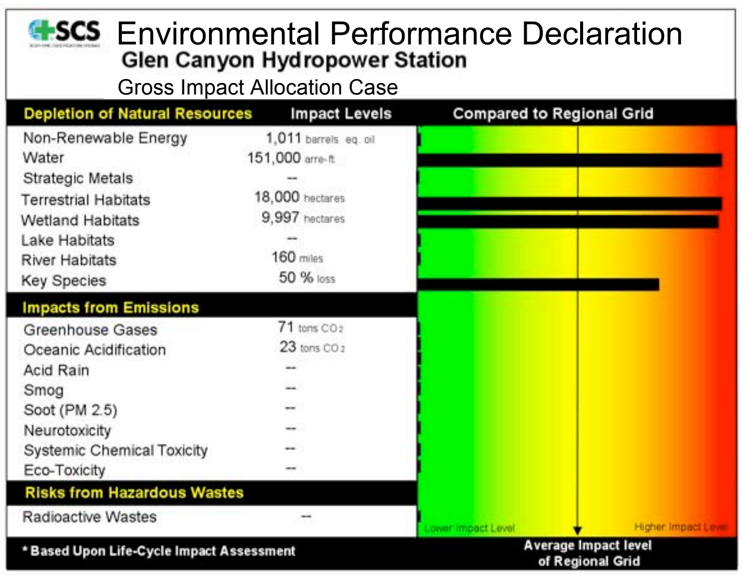
Table 6.18. Acidification Loading (Oceanic) Results for the Glen Canyon Hydropower Generation System. Data are normalized to a production of 1,000 GWh.

Acidification Loading (Oceanic)	Inventory Emission	Life-Cycle Inventory Result (t/a)	Global Warming Potential (t CO_2 /t)	Gross Emission Loading (t CO_2)	Environment Characterization Factor (ECF)	Net Emission Loading (t CO_2)
Electric Power System: Glen Canyon						
	Fossil CO_2 (construction)	3.3	1.0	3.3	0.33	1.1
	Fossil CO_2 (operation)	69	1.0	69	0.33	22.8
				72		**23.9**

Figure 6.11 provides a graphic representation of the impact profile of the Gross Impacts Allocation Case. This graphic representation is limited in that it does not include a representation of created lake or riparian habitats, as discussed further in Section 6.9.

Figure 6.11. Environmental Impact Profile of Glen Canyon Hydropower Generation System, Gross Impacts Allocation Case, relative to the WECC baseline, per 1,000 GWh





6.10. Discussion of Results

All results for the Glen Canyon hydropower generation system are shown in comparison to the WECC regional power pool (Table 6.19).

Table 6.19. Percent Deviation of the Glen Canyon Dam Category Indicator Results Compared to WECC Baseline, per 1,000 GWh

			Gross Impacts Allocation Case		Hydropower Function Case	
Indicator	Units	WECC Regional Power Pool Baseline	Impact Profile	% change in impact levels relative to baseline	Impact Profile	% change in impact levels relative to baseline
Energy Resource Depletion	Eq. GJ oil	5,207,000	1,011	+99%	--	+99%
Water Resources Depleted	Acre-feet	*NC*	150,000	-99%	--	+99%
Terrestrial Habitat Disruption	Eq. ha depleted	1,882	18,000	-99%	--	+99%
Aquatic (Lake) Habitat Disruption	Eq. ha depleted	--	--	+99%	--	+99%
Aquatic (Lake) Habitat Creation	Eq. ha created	*NC*	(20,000)	* Not included	--	* Not included
Aquatic (River) Habitat Disruption	Eq. river miles	35*	160	-99%	--	+99%
Riparian/Wetland Habitat Disruption	Eq. ha depleted	143*	9,997	-99%	66	+99%
Riparian/Wetland Habitat Creation	Eq. ha created	*NC*	(95,000)	* Not included	--	* Not included
Loss of Key Species: Humpback Chub	% loss	*NA*	50% loss	0%	*NC*	+99%
Accumulated GHG Radiative Force Loading	Eq. t CO_2	500,000	71	+99%	--	+99%
Acidification (Oceanic)	Eq. t CO_2	165,000	23	+99%	--	+99%
Acidification (Regional)	Eq. t SO_2	6.5	--	+99%	--	+99%
Ecotoxic Chemical Loading (Soil/Water)	Eq. kg of arsenic	*NC*	--	+99%	--	+99%
Ground Level Ozone Loading	t O_3	8.9	--	+99%	--	+99%
Particulate Loading	Eq. t PM-10	12.2	--	+99%	--	+99%
Pulmonary Toxic Chemical Loading	Eq. kg benzene	5.2	--	+99%	--	+99%
Systemic Toxic Chemical Loading	Eq. kg TCDD	*NC*	--	+99%	--	+99%
Neurotoxic Chemical Loading	Eq. kg of mercury	5.7	--	+99%	--	+99%
Radioactive Hazardous Wastes	Eq. GBq. Pu 239	*NC*	--	+99%	--	+99%

(--) denotes a result of negligible or zero; (*) represents a calculated value for a highly environmentally efficient hydro facility in the WECC, and therefore is an extreme worst case for WECC mix; NA is not available, NC is not calculated.
Results above 10,000 have been rounded to the nearest 1,000.
** Habitat creation indicator results were not included in the calculation of the Environmental Performance Index. Further discussion regarding the altered composition of new riparian habitat and the new lake habitat is recommended to determine whether such indicators should be included.*

Indexing the percent to which each impacts was reduced or higher than the WECC provides a detailed mapping of the impact profile on the Glen Canyon Hydropower Station. The Environmental Performance Index (EPI) reflects the relative change in impact levels that occurred as a result of: 1) dam construction, and 2) the ROD. As shown in the table, the individual indicator ratios that are used to calculate the Glen Canyon indexing tends to fall into extremes, reflecting the physical scale of the Glen Canyon system and the inherent non-polluting nature of hydropower generation. A short discussion follows.

6.10.1. Non-Renewable Energy Resource Depletion

Because the Glen Canyon Hydropower System utilizes a renewable resource, only a negligible amount of non-renewable energy resources associated with operations and power transmission are depleted per 1000 GWh generation. The rating for this indicator is +99% relative to the WECC baseline. As discussed in Section 4, the impact profile of the WECC baseline itself is significantly influenced by the degree to which it is constituted by hydropower (28%) as compared to most other North American baselines.

6.10.2. Water Resource Depletion

In the Gross Impacts Allocation Case, the loss of water resources due to enhanced evaporation makes Lake Powell second only to Lake Mead (Hoover Dam) in terms of water depletion rates for power systems within the WECC. In the Hydropower Function Case, there is no water depletion impact.

6.10.3. Terrestrial Habitat Disruption

In the Hydropower Function Case, there is minimal terrestrial habitat impact. Some impact is associated with transmission line ROW creation and operation.

In the Gross Impacts Allocation Case, terrestrial habitat disruption can be accounted for by the loss of terrestrial habitat upstream of the Glen Canyon Dam due to the filling of Lake Powell. Little to no significant terrestrial habitat has been removed or disrupted downstream of Glen Canyon Dam, with the exception of riparian habitat which is handled as a separate topic and indicator in this study.

Given the sheer size of Lake Powell, terrestrial habitat disruption per 1,000 GWh is clearly among the largest in the WECC thus far. Although SCS has not had the data required to calculate the average terrestrial habitat disruption for all hydro projects in the WECC, the following factors support the assigned -99% index value: 1) the fact that hydropower only makes 28% of the power generated in the WECC, and 2) the fact that most of the remaining power comes from sources involving far less terrestrial habitat disruption.

6.10.4. Riverine Habitat Disruption

In the Gross Impacts Allocation Case, the loss of 307 miles of river (186 miles of the Colorado river, 72 miles of the San Juan River, 32 miles of the Escalante River, and 17 miles of the Dirty Devil River) above Glen Canyon Dam (as measured by GIS specialists at WAPA), plus the disruption of 225 miles of river downstream of Glen Canyon Dam as a result of modified flow regulation, represents a total of 532 miles of Colorado River and tributaries disrupted by the building and operation of Glen Canyon Dam. Only a couple of other western hydropower installations (e.g., Hoover Dam, Grand Coulee, Shasta Dam and Yellowtail Dam) impact river miles on a similar scale, while the majority of power generation in the WECC baseline (72%) impacts little to no river miles.

6.10.5. Riparian/Wetland Habitat Disruption

In the Gross Impacts Allocation Case, the decline of the old high water zone (OHWZ) riparian habitat below the dam, combined with the inundation of riparian habitat above the dam, is estimated at 33,191 hectares. Even though there has been a simultaneous increase in the riparian habitat in the new high water zone (NHWZ), this new habitat was not included in calculations of the EPI. Sufficient work has not yet been conducted to know the full extent of change over time in terms of the diversity and abundance of the species making up the riparian zone. It is known that many of the indigenous species from pre-dam times also occur in the present day riparian zones. However, it is also well documented that some non-native species, including one highly invasive species, the tamarisk, began to occupy the riparian zone after the building of the dam and has since increased significantly in both absolute and percent cover over time.

In order to calculate a net increase between the old and new riparian zones, it would be necessary to determine that the composition of the biological community between time intervals (comparing pre-dam baseline conditions to post-dam conditions) is of equal biological integrity and ecology to allow a net increase to be estimated. If the increase is due to a significant shift in the biological community that comprises the riparian zone (i.e., a significant shift away from the non-disrupted state before the dam), then a net increase would not apply as the pre-dam biology/ecology would not be expanding. Instead the expansion would be due to a highly modified biological community, and potentially to species that would cause other shifts in the ecology of the area.

GCMRC is currently conducting studies to help determine the type or extent of change over time. At this time, SCS's estimate, based on worst-case assumptions, is that there has been a 70-90% shift in species coverage away from the original composition since the building of the dam in at least some of the NHWZ riparian areas. Thus, given the length of the affected river corridor downstream of the dam, as well as the inundated riparian zones above the dam, SCS has assumed in indicator ratio of -99. Should ongoing studies show that the riparian biota is closer to the original state than qualitatively estimated in this report, the EPI could be improved.

The Hydropower Function Case shows a loss of 66 hectares of riparian/wetland habitat due to a slightly elevated high water zone. However, this loss could be offset in the long term by new habitat supported along the upland edge of the riparian strip by a slightly elevated water table.

6.10.6. Key Species Losses

As described in Section 6.2.3, humpback chub was selected as the indicator species for this impact category. The highest abundance estimated since data has been collected (1989) was nearly 10,000 fish. According to the most recent scientific studies reported by GCMRC, the humpback chub has now stabilized at around 5,000 fish. It is not yet known whether the chub will continue to increase in abundance, or resume its decline, given river conditions and continued adaptive management measures.

Accordingly, in the Gross Impacts Allocation Case, population losses are estimated at 50 percent. In the Hydropower Function Case, there is no evidence that population declines have been caused by power operations.

6.10.7. Accumulated GHG Radiative Forcing and Oceanic Acidification Loadings

The WECC has the lowest greenhouse gas loading per 1,000 GWh of any NERC region in the US solely because of the large percentage of hydropower constituting the overall power mix (28%). The large storage hydropower units, such as Glen Canyon, are the major pillars of the hydropower complex supplying the WECC. Without Glen Canyon, an additional 2.4 million metric tons per 1,000 GWh would be emitted by the WECC, assuming that make-up power was derived from the same mix of WECC power sources in the same proportions.[99]

In both the Gross Impacts Allocation and Hydropower Function Cases, the only significant source of greenhouse gas loading came from the residual greenhouse gases still in the atmosphere from the concrete used in the construction of the dam. This result highlights just how much concrete was required. However, this loading is very minor in comparison to the greenhouse gas loading associated with the WECC baseline.

6.10.8. Regional Air Emission and Human Health Emission Impact Categories

Acidification (terrestrial/inland water) Loading, Ground Level Ozone Loading, Particulate Loading, Systemic Toxic Chemical Loading, Pulmonary Toxic Chemical Loading, Neurotoxic Chemical Loading

As a comprehensive assessment approach, LCIA requires that all issues of human health and environment linked to the power production system be included in its scope. Many studies tend to emphasize areas of significant impacts while ignoring those areas of negligible impacts. This study confirms that Glen Canyon does not contribute to human-health or regional environmental impacts. All regional impact indicators had negligible loadings.

6.10.9. Eco-toxic Chemical Loading and Radioactive Wastes

There were no impacts related to Glen Canyon operations.

[99] If hydropower were to be decommissioned throughout the WECC, the overall greenhouse gas loading for the WECC would jump by 43%, from 497,000 to 715,000 eq. tons CO_2 /1000 GWh, assuming that this power was made up consistent with the current WECC power mix.

6.11. Next Steps

6.11.1. Impact Allocation According to Economic Benefits

Hydropower projects are unique among power generation systems in their service of multiple functions. In the Gross Impacts Allocation Case, all impacts associated with the Glen Canyon project were allocated to hydropower generation. This worst-case allocation ignores the other key functions served by the dam, including land reclamation, flood control, water storage and recreation. Even under this worst-case allocation, this study confirms the fact that (and quantifies the extent to which) Glen Canyon contributes positively to the WECC baseline per 1000 GWh production in terms of energy resource depletion, greenhouse gas loadings, oceanic acidification, regional air impact loadings, and hazardous waste.

It is a matter for others to consider as to whether the remaining impacts should be reallocated among the various functions served by the Glen Canyon project. However, as a next step, SCS would suggest that the impacts of Glen Canyon be recalculated given a range of allocation approaches. For example, where no other scientifically-based allocation methods are available, LCIA allows the environmental impacts to be allocated proportionally to a project's economic benefits.

6.11.2. Determining Credits for Created Riparian and Aquatic (Lake) Habitat

As discussed in this Section, it was not possible with the available data and project budget to adequately evaluate the quality of lake and riparian habitats created. As such, although these habitats were identified and quantified, they were not included in EPI calculations. Once a quality factor is assigned to these habitats (i.e., an environmental characterization factor), it will be possible to incorporate them into the calculation. This could significantly improve the Glen Canyon EPI, as any amount of created habitat will add to the overall rating.

6.11.3. System Assessment

As noted earlier, the degree to which the operations of the Glen Canyon Hydropower Station fit within the larger Colorado River system of hydropower plants was not addressed in the current study. For instance, the contribution of hydropower to the CRSP from Aspinall and Flaming Gorge dams was not taken into consideration, despite their role in supporting the load following function. Nor did this study take into consideration the degree to which Glen Canyon water storage decisions are influenced by the needs of Hoover Dam.

SCS would recommend that an extended analysis of the Colorado River hydropower system, be considered.

Supplemental Report

Life Cycle Impact Assessment Methodology Applied To Thermal Generation Technologies Compared to the WECC Baseline: A Conceptual Demonstration

Prepared for the Western Area Power Administration,
the United States Bureau of Reclamation,
Tri-State Generation and Transmission Association, Inc.
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Life Cycle Impact Assessment Methodology Applied to Thermal Generation Technologies Compared to the WECC Baseline: A Conceptual Demonstration

Description of Supplemental Report

The LCIA method, applied to renewable electrical generation technologies, as shown in this report, is a useful tool for understanding the environmental impact of different electrical renewable generating technologies. The case studies used here are a large hydroelectric power plant on a major river in the Western United States and a wind generator in the same U.S. region. In order to understand the context in which these technologies exist, their environmental impacts were compared to the existing WECC baseline.

The LCIA method holds promise for thermal generating technologies as well. As part of its commission from Western, SCS gathered data from two thermal electric power plants: Colstrip, a coal-fired power plant in western Montana; and a generic natural gas-fired power plant in the western United States.

Because only public data were available, detailed LCIA assessments could not be made. The goals of this task are: (1) to demonstrate how an LCIA method might be used in the case of a thermal generator; and (2) to identify problems that might arise in a complete LCIA analysis of power plants similar to those chosen for this demonstration project.

SCS has labeled this as a supplemental report. It differs significantly from the LCIA assessment done for Glen Canyon Dam and the Stateline Wind project in that it lacks data from specific categories of the life cycles of these electrical generators. For example, we had no data on the coal supply contract for the Colstrip facility. Therefore in order to carry out a more detailed analysis we used some generic information about the environmental effects of coal mining generally. This data gathering helped us to understand more specifically what data would be needed – in addition to those that are publicly available – to complete an LCIA assessment of a coal-fired power plant.

What follows is a detailed description of an LCIA method applied to two thermal power plants using data that are readily available. Again, as with the renewable technologies assessed in our earlier report, the environmental impacts of these two generators are compared to the detailed WECC baseline in order to make the results comparable to the earlier report on the two renewable technologies.

Significant insights have been gained in studying an LCIA method approach to examining the environmental footprint of these two thermal technologies. With these new insights, a complete and cogent LCIA analysis and Life Cycle Impact Declaration could be completed if a complete data set were used.

Section 7.
COLSTRIP COAL POWER GENERATION SYSTEM

7.1. Project Description and Background

7.1.1. Project Description

Under this project, SCS evaluated the utility of the LCIA methodology to determine the ecological footprint of the Colstrip electric power generation system. The resulting impact profile was then compared to WECC baseline impact profile.

7.1.2. Project Background

The importance of coal as an electricity fuel source is undisputed. Its abundance, domestic accessibility, relatively low cost, and dispatch reliability make it the cornerstone of any future energy scenario for the US economy. At the same time, concerns about the environmental and human health impacts of coal combustion persist.

Past LCIA studies of coal power have demonstrated that the actual levels of impacts can vary quite widely, depending upon such factors as: 1) the assay of coal inputs; 2) the method of mining; 3) the type of energy generation at the power plant; 4) the type of pollution control technologies employed; and 5) the location of the mine and power plant relative to areas of high population density or areas susceptible to exceedance of environmental thresholds.[100] Given the skepticism with which many policymakers and stakeholders regard coal power, an important objective of this project was to demonstrate the comprehensive reach of the LCSEA technique in establishing an accurate impact profile of coal power generation systems in light of these variables.

Although strictly speaking, the Colstrip power plant is situated on the MAPP side of the borderline between the WECC and MAPP regional power pools in the state of Montana, the decision was made to compare the Colstrip power generation to the WECC baseline impact profile for consistency with the other projects included in this supplemental report.

[100] Scientific Certification Systems, Inc. *Life-Cycle Stressor Effects Assessment of the PJM Regional Power Pool and Selected Exelon Assets Within the PJM.* December 2001. Scientific Certification Systems, Inc. *An Environmental Assessment of Selected Canadian Electric Power Generation Systems Using a Site-Dependent Life-Cycle Impact Assessment Approach.* February 2005.

7.2 Colstrip Power Generation System Description

7.2.1. Colstrip Station Power Plant

The Colstrip power plant is located in the town of Colstrip in southeastern Montana, east of the state's most populous city, Billings (Figure 7.1).[101] The four coal-fired generating units that comprise the plant have a combined generation capacity of 2,094 MW. At this size, Colstrip is the second largest coal-fired project west of the Mississippi. The two older units — Units 1 and 2 — each with a capacity of about 307 MW, began providing power commercially in 1975 and 1976. The more recently built units — Units 3 (1984) and 4 (1986) — each have more than twice the capacity of the older units, about 750 MW per unit.

Figure 7.1. Colstrip Power Plant

The plant is co-owned by PPL Montana LLC, a subsidiary of PPL Generation LLC, Portland General Electric Company, Puget Sound Energy, Inc., PacifiCorp, AVISTA Corporation and NorthWestern Energy LLC. PPL is the largest of the owners, with a 50% stake in Units 1 and 2, and a 30% stake in Unit 3, for a combined generating capacity of 529 MW.

The plant's utilization of low-sulfur coal and state-of-the-art scrubbers enables it to keep sulfur dioxide emissions below the levels mandated under Phases One and Two of the Clean Air Act. The efficiency of the flue gas desulfurization (FGD) equipment installed at Units 1 and 2 is 76%. At the newer Units 3 and 4, the FGD efficiency is 94.5%. Flue gas particle removal efficiency is 99% at Units 1 and 2, 98.8 % Unit 3 and 4. The plant also meets US EPA standards for nitrogen oxide emissions.

A schematic of the model used for LCA calculations of the Colstrip plant is shown in Figure 7.2. The entire system modeled for the assessment includes the power plant itself, and the following main upstream processes: coal mining and transport, limestone production and transport, primary oil refining and fuel distribution, natural gas production, processing and distribution. These unit processes, shown in the following simplified schematic, were derived from the KCL-ECO LCI model.

[101] http://www.pplweb.com/ppl+generation/coal+plants/colstrip.htm

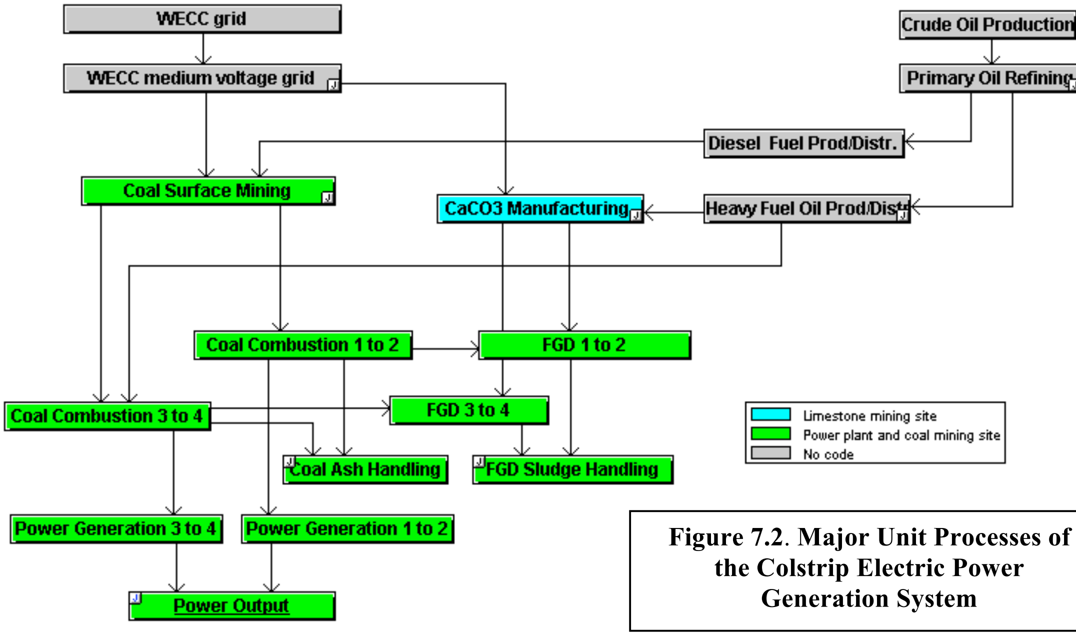

Figure 7.2. Major Unit Processes of the Colstrip Electric Power Generation System

7.2.2. Coal Assay, Mining and Transport

The Rosebud Mine is operated by Western Energy Company, a surface coal mining subsidiary of Westmoreland Mining LLC (part of Westmoreland Coal Company).[102] According to the company website, "Colstrip is one of the region's most cost-efficient and cleanest power plants."

The 25,000-acre Rosebud surface mine complex is located near the town of Colstrip and the Northern Cheyenne Indian Reservation. It produces approximately ten million tons per year from three active pits.[103] In 2004, the mine produced 12.7 million tons. Coal reserves and deposits are estimated at 502 million tons.

Until 1958, the coal mined from this location was used to power Northern Pacific Railroad locomotives. After locomotives were switched to diesel fuel, coal mining at the site was suspended. After a ten-year hiatus, coal mining was resumed in 1968, this time to supply coal for electric power generation. Almost all of the coal mined at Rosebud is sold to the Colstrip Station, built adjacent to the mine, under long-term contracts. The power plant was specifically designed to burn Rosebud coal, which has a heat content of 8,529 BTU/lb and a sulfur content of 0.74%.

Rosebud coal is delivered to the Colstrip Station primarily via conveyor belts, and also partly by truck and rail.

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[102] www.westmoreland.com/coal.asp?topic=westmoreland_mining#rosebud
[103] All tons referenced in this section are short tons.

The company lists total disturbed acreage as 15,255 acres, plus an additional 6,969 reclaimed acres. According to the company, "Reclamation activities consist of filling the voids created during coal removal, replacing sub-soils and top-soils and then re-establishing the vegetative cover. At the conclusion of reclamation activities, the area disturbed by mining will look similar to what it did before mining begun."[104] An example of reclamation activities is described on the Montana State University Ecosystem Restoration website for the Eagle Rock site located at the Rosebud mine.[105]

7.2.3. Transmission

A 500-kV transmission system transfers Colstrip power to markets within and to the west of state of Montana.[106] The length of transmission lines from Colstrip to the nearest tie-in had not yet been determined at the time of this writing.

7.3. Baseline Case: The WECC Regional Power Pool

The averaged impact profile for power generated in the WECC power pool, per 1,000 GWh, serves as the baseline impact profile for comparison. A detailed description is provided in Section 6 of this report.

7.4. Data Sources

7.4.1. Colstrip Station

The data for LCI modeling of the Colstrip Station unit processes were derived from Colstrip documentation for plant year 2000 contained in the EGRID 2002 database, as well as from data submitted in EIA forms. The information covered boilers, flue gas desulfuring and generators.

7.4.2. Rosebud Mine

Data related to coal mining at the Rosebud mine was obtained from the Westmoreland Coal Company website and the RDI CoalDat coal transaction database (2001).[107]

7.4.3. Additional Emissions Data for Coal Plant Operations from SCS LCSEA Database

Data from recent LCSEA studies served as a valuable benchmark for the current study. For instance, during a study recently completed for the Canadian Electricity Association, SCS

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[104] www.westmoreland.com/coal.asp?topic=coal_overview#chart
[105] ecorestoration.montana.edu/mineland/histories/coal/eagle_rock/default.htm.
[106] http://www.northwesternenergy.com. Northwestern Energy is a co-owner of the transmission lines from Colstrip, and leases 30% of the power generated by Unit 4 of the Colstrip Station. The Northwestern Energy's electric transmission system services more than two-thirds of Montana, with voltage levels ranging from 50,000 to 500,000 volts. Its transmission system has interconnections to five major transmission systems located in the WECC area, as well as one interconnection to a system that connected with the MAPP region.
[107] http://www.westmoreland.com/coal.asp?topic=westmoreland_mining#rosebud; RDI, CoalDat Database, 2001.

was given an opportunity to review detailed privately held documents related to an Alberta-based coal power generation system. Review of these documents enabled SCS to confirm many assumptions that otherwise would have had greater uncertainty. One example were the detailed data provided regarding the routes of exposure for heavy metal releases, which confirmed that dispersion into the receiving environment was limited and that potential uptake into either the food chain or water systems was not significant. Given the similar population density of Alberta to the Montana area, similar fate and exposure routes were extrapolated to the Colstrip case. Such information was vital for modeling three of the four chronic hazardous chemical loading impact categories.

In addition, the SCS database contains: 1) numerous coal plant descriptions and estimates of actual emissions obtained from Title V Applications; 2) stack monitoring data compiled by Environment Canada confirming the mass of release for chemicals such as barium, chromium, copper, nickel, lead, manganese, polycyclic aromatic, and arsenic compounds, and acids such as hydrochloric, sulfuric and hydrogen fluoride; 3) Air Information Management System (AIMS) data on actual emissions of SOx, NOx, CO, VOCs, PM-10 and fugitive dust; 4) data from the Fossil Information Report Management System (FIRMS); and 5) data from various NPDES, water consumption, and hazardous waste reports.

7.4.4. Ancillary Upstream Unit Processes

SCS evaluated the potential contribution of impacts from upstream unit processes — lime production and transport; primary oil refining and fuel distribution; and natural gas production, processing and distribution — and determined that site-dependent issues would not influence the overall Colstrip system calculations when normalized to the functional unit, 1,000 GWh. As such, SCS modeled these unit processes based upon its extensive coal database, including data from European and North American operators, and in addition, utilized surrogate data obtained from the KCL-ECO LCI model. Sensitivity analysis was used to justify the use of these data. This analysis consisted of tripling the LCI values to determine whether this change would affect the final indicator results. Where any such changes were negligible, the data were accepted.

7.4.5. Dispersion Modeling of Emissions

Dispersion modeling data directly related to the various emissions from the Colstrip Station were not found during the course of this research and therefore were not available for use in this study. SCS relied on concentric dispersion modeling approach described in Sections 3 and 4, based on European published data.[108]

7.4.6. Physical Disturbance

No data were made available to SCS pertaining to the types or degree of habitat disrupted or key species disturbance in connection with power generation activities. Nor could total acres of habitat disrupted be normalized to the total coal output from the mine due to lack of production data relative to the acres disturbed. While initial estimates could be ventured,

[108] Bachmann, T. and Krewitt, W., 2001.

such estimates would carry significant uncertainty, and would require verification. Specifically, the following data would be required:

- Based on prior research, including a study of 29 coal plants in the PJM regional power pool, and Swiss LCA data, SCS would estimate the physical footprint of the power plant to be between 100-120 acres (40-49 hectares).[109] Information on the types of habitat and species disturbed by the siting of this plant would be required to determine indicator values.

- As noted earlier, total disturbed acreage at the Rosebud mine is reported to be 15,255 acres. Applying the method described in Section 4, SCS would anticipate that the actual habitat disruption from the mine would be less than this amount. The factors that would be taken into consideration would be: 1) the amount of land undergoing reclamation; 2) the amount of land being actively mined; 3) previous uses of the land, prior to current mining activities to support electricity generation; and 4) the types of habitat and species disturbed.

- Assuming 500 kV steel tower-supported transmission lines, the standard US regulated right-of-way is 160 feet. The following data is needed before SCS can determine the habitat disruption associated with these transmission lines: 1) distance from Colstrip Station to nearest tie-in line; 2) current and previous land use with the ROW zone; 3) number (and type) of towers; 4) habitat types for the land occupied by the transmission lines; and 5) maintenance schedules to clear back vegetation. For example, data collected for the Glen Canyon Project (Section 8) show that despite long transmission lines, these lines have resulted in little habitat disruption, since the naturally low growing vegetation has not been altered, and no vegetation maintenance is required.

7.5. Key Assumptions and Considerations

Classification and characterization assumptions and considerations pertinent to the Colstrip project and the other projects included in the current study have been discussed in Sections 3 and 4 of this report. The following discussion focuses on issues that relate exclusively to the Colstrip electric power generation system and that require further elaboration.

7.5.1. Issues Related to Impact Categories with Human Health Endpoints

7.5.1.1. Potential Hazardous Chemicals of Concern

Toxic Release Inventory (TRI) data were available for the Colstrip plant from the US EPA database. However, for this modeling exercise, these data were not applicable. Whereas TRI data are generated for regulatory purposes based on generic EPA emissions factors, the LCSEA Model requires site-specific emission data in order to accurately assess impact indicators.

[109] Scientific Certification Systems, Inc. Life-Cycle Stressor Effects Assessment of the PJM Regional Power Pool and Selected Exelon Assets Within the PJM. December 2001. Also, Frischknecht, R. et Al. 1996.

SCS relied on NREL data and data related to comparable combustion technology as the basis of the indicator calculation.[110] One exception was the mercury emission factor, which was taken as reported for Colstrip in EGRID2002 (0.024 mg/kWh).

For comparison, two sets of data for some relevant chemicals are shown in Table 7.1.

Table 7.1. Stack emission factors for coal combustion according to Colstrip TRI data as listed in EPA database, and data published in NREL Coal LCA 1999.

Chemical compound emitted	Colstrip: TRI data mg/kWh	NREL Coal LCA: TRI data (mg/kWh)
Arsenic Compounds	0.0110	0.0495
Cadmium Compounds	--	0.0041
Lead Compounds	0.0197	0.0300
Manganese Compounds	0.1689	0.0430
Mercury Compounds	0.0241	0.0366

7.5.1.2. Characterization of Wastes

Mining and plant operational wastes are potentially hazardous due to their high metal content (particularly slags, sludges, slurries and ashes). Dewatering practices from mining can involve re-injection of groundwater and, therefore, can result in contamination. In order to characterize the waste streams from a coal power generation system, both groundwater and surface water monitoring data are needed to ensure wastes are fully contained for the duration of their potential to leach into the receiving environment. Based on results from earlier studies performed by SCS, it was assumed for the current project that the projected waste stream management practices of the Colstrip system are resulting in no measurable impact on groundwater quality.

7.5.2. Physical Disturbance

As described in Section 7.4.6, additional data collection and analysis are required before these indicators can be calculated.

7.5.3. Transmission

As discussed in Section 4, a 2% loss of delivered power due to line losses in transmission was assumed, based on the statistical average for the transmission distances involved.

[110] NREL 1999. Spath P.L., Mann M. K., Kerr D. R.: "Life Cycle Assessment of Coal-fired Power Production." NREL/TP-570-25119.

7.6. LCI Results

The functional unit for the study is 1,000 GWh. All data pertaining to net annual generated electricity are normalized to 1,000 GWh to faciliate the analysis and to provide a common basis for comparison to the WECC baseline impact profile. LCI results are summarized in Table 7.2.

Table 7.2. Life-Cycle Inventory Results for the Colstrip Power Generation System and the WECC Power Pool Baseline, per 1,000 GWh

		Colstrip Power Gen. System	WECC Power Pool Baseline
Inventory	Unit		
Outputs			
Emissions, air			
Arsenic	kg	47	16
Benzene	kg	12	6
Cadmium	kg	4	1
CFC-114	kg	--	34
CH4	kg	156,770	906,170
CO2, fossil	kg	1,041,720,000	478,383,000
TSP coarse	kg	618,820	197,030
PM-10 (power plant)	kg	188,020	NA
VOC, HC	kg	3,580	29,910
HCl	kg	23,850	26,959
HF	kg	930	683
Mercury	kg	23	7
Manganese	kg	41	14
NOx	kg	2,119,600	956,413
Lead	kg	28	10
Rad. act. Rn-222	GBq	34	2,910
Rad. act. noble gases	GBq	2	250
SO2	kg	814,220	731,940
Emissions, water		--	--
Wastes		NA	NA
Energy			
electric power	MWh	1,000,000	1,000,000
Inputs			
Resources			
Coal	kg	666,749,000	200,080,000
Crude oil	kg	4,987,500	3,631,900
Natural gas	kg	459,080	48,502,000
Uranium in ore[111]	kg U	29	3,048
Limestone/dolomite	kg	15,906,000	3,183,900

-- denotes negligible or zero result; NA denotes data not available or not provided

[111] The uranium ore value in the Colstrip column reflects the fact that the grid electricity used by lime production and coal mining contains nuclear electricity.

7.7. Habitat and Species Disruption

As described in Section 7.4.6, habitat disruption and species mortality data collection and analysis are required before these indicators can be calculated.

7.8. LCSEA Results

The impact indicator results are calculated for the entire system, based on the classification and characterization steps described in Sections 3 and 4, and incorporating the special study assumptions and considerations described above. These impact indicator results together comprise the impact profile of the Colstrip electric power generation system, as summarized in Table 7.3. Below, the spreadsheets in Tables 7.4 to 7.8 show examples of LCSEA indicator calculations by impact category.

Table 7.3. Colstrip Impact Profile — Impact Indicator Results per 1,000 GWh Production Compared to the WECC Regional Baseline

Key Indicator	Unit	Colstrip Impact Profile	WECC Baseline
Energy Resources Depleted	Eq. GJ of oil	4,042,000	5,207,000
Water Resources Depleted	Acre-feet	--	NC
Terrestrial Habitat Disruption	Eq. ha. disturbed	NC	1,882[112]
Aquatic (Lake) Habitat Disruption	Eq. ha. disturbed	NC	*Not broken out*
Aquatic (River) Habitat Disruption	Eq. river miles	NC	*Not broken out*
Riparian/Wetland Habitat Disruption	Eq. ha. disturbed	NC	*Not broken out*
Loss of Key Species	% loss key species	NC	NA[113]
Greenhouse Gases	Eq. t CO_2	1,045,000	500,000
Acidification Loading (Oceanic)	t CO_2	NC	165,000
Acidification Loading (Terrestrial / Inland Waterways)	Eq. t SO_2	111	6.5
Ground Level Ozone Loading	t O_3	4.9	8.9
Particulate Matter Loading	Eq. t PM_{10}	4.1	12.2
Neurotoxic Chemical Loading (ingestion)	Eq. kg Hg	1.3	6
Pulmonary Chemical Loading (inhalation)	Eq. kg Benzene	4	5.2
Systemic Chemical Loading	Eq. kg TCDD	NC	NC
Eco-Toxic Chemical Loading	Eq. kg As	NC	NC
Radioactive Waste Loading	Eq. GBq Pu-239	--	NC

(--) *denotes negligible or zero* ***result. NA is not available, NC is not calculated.***
Results above 10,000 are rounded to the nearest 1,000.

[112] As noted in Section 2, the ASTM draft standard E06.71.10 has identified four habitat disruption indicators. At the time the current study was initiated, however, habitat disruption calculations were collapsed under a single indicator. The WECC indicator result was calculated at that time.
[113] Not applicable. The baseline for key species is based on pre-system species populations in the same region. See Section 3.

Table 7.4. Project #2: LCSEA Energy Resource Depletion Results for the Colstrip Power Generation System, per 1,000 GWh

Energy Resource Depletion	Inventory Resource	Energy Resource Consumed (t)	Stressor Characterization Factor (SCF) (GJ/t)	Equivalent Energy Resource Consumed (GJ)	Resource Depletion Factor (RDF_{25}): Rate of dep / Rate of oil dep	Equivalent Resource Depletion (GJ oil eq.)
	Uranium in ore	0.029	900,000	25,983	0.510	13,251
Power Gen. System: Colstrip	Crude oil	4,988	45.6	227,431	1.000	227,431
	Natural gas	459	53.4	24,515	0.940	23,044
	Coal	666,749	20.2	13,494,666	0.280	3,778,507
				13,772,595		**4,042,233**

Table 7.5. Project #2: LCSEA Greenhouse Gas Loading Results for the Colstrip Power Generation System, per 1,000 GWh

Greenhouse Gases Loading	Inventory Emission	Life-Cycle Inventory Result (t/a)	Global Warming Potential (t CO_2 eq./t)	Gross Emission Loading (t CO_2 eq.)	Environment Characterization Factor (ECF)	Net Emission Loading (t CO_2 eq.)
Power Gen. System: Colstrip	Fossil CO2	1,041,720	1.0	1,041,720	1.000	1,041,720
	CH4	157	23.0	3,606	1.000	3,606
	CFC-11	0.004	21,800.0	84	1.000	84
				1,045,410		**1,045,410**

Table 7.6. Project #2: LCSEA Acidification Loading Results for the Colstrip Power Generation System, per 1,000 GWh

Acidification Loading	Inventory Emission	Life-Cycle Inventory Result (t)	Stressor Characterization Factor (t SO_2 eq./t)	Gross Emission Loading (t SO_2 eq.)	Environment Characterization Factor (ECF)	Net Emission Loading (t SO_2 eq.)
Power Gen. System: Colstrip	SO2	814	1.000	814	0.070	57
	NOx	2,120	0.700	1,484	0.035	52
	HCl	24	0.880	21	0.070	1
	HF	1	1.680	2	0.070	0
				2,321		**111**

Table 7.7. Project #2: LCSEA Ground Level Ozone Loading Results for the Colstrip Power Generation System, per 1,000 GWh

Ground Level Ozone Loading	Inventory Emission	Life-Cycle Inventory Result (t)	Stressor Characterization Factor (SCF) (t O3/t)	Gross Emission Loading (t O3)	Environment Characterization Factor (ECF)	Net Emission Loading (t O3)
Power Gen. System: Colstrip	NOx	1,060	1.000	1,060	0.005	5
	CH4	78	0.010	1	0.005	0
	VOC, HC	2	0.550	1	0.005	0
				1,062		**5**

Table 7.8. Project #2: LCSEA Particulate Matter Loading Results for the Colstrip Power Generation System, per 1,000 GWh

Particulate Matter Loading	Inventory Emission	Life-Cycle Inventory Result (t)	Stressor Characterization Factor (SCF) (t PM_{10} eq./t)	Gross Emission Loading (t PM_{10} eq.)	Environment Characterization Factor (ECF) Factor	Net Emission Loading (t PM_{10} eq.)
Power Gen. System: Colstrip	PM-10	807	1.00	807	0.001	1
	SO2	814	1.50	1,221	0.001	1
	NOx	2,120	1.00	2,120	0.001	2
				4,148		**4**

7.9. Summary of Results and Discussion

The Colstrip impact profile reflects a combination of factors, including the combustion of coal with low contaminant levels, the location of the plant and mine relative to areas of population density and areas of susceptibility to exceedance of environmental thresholds, the use of advanced combustion technology and high-end pollution control technologies, and the sparse population density of Montana. The results are summarized by indicator in Table 7.9.

Table 7.9. Comparing Net Indicator Results between the Colstrip Power Generation System and the WECC per 1000 GWh

Indicator	Net Indicator Results		Environmental Significance Between Net Indicator Results
	Colstrip Power System	WECC Baseline	
Energy Resource Depletion	4,042,000 GJ	5,207,000 GJ	The 22% advantage associated with Colstrip as compared to the WECC corresponds to the fact that the WECC includes a high percentage (26%) of natural gas, which has a high RDF. The ratio between net and gross energy depletion for the WECC is 0.53, but for Colstrip is only 0.29.
Terrestrial Habitat Disruption[114]	NC	1,880 Ha	This indicator could not be calculated by based on information obtained to date.
Greenhouse Gas Loadings	1,045,000 Eq. t CO_2	500,000 Eq. t CO_2	This result was expected, since hydropower, a significant contributor to the WECC baseline, does not emit greenhouse gases, and since the greenhouse gas emissions from nuclear power are limited to those associated with fuel enrichment.
Acidification Loading	111 Eq. t SO_2	6.5 Eq. t SO_2	This result was expected, again given the significant contribution of nuclear power and hydropower to the WECC baseline. It should be noted that only about 5% of the gross emissions of acidifying gases emitted by Colstrip result in deposition in areas of exceedance.
Ground Level Ozone Loadings	4.9 t O_3	8.9 t O_3	The Colstrip system had a lower ground level ozone loading than the WECC baseline, based on the plant's location, and more specifically, the sparse population density of the Montana region and the low average background concentrations for the Montana region when compared to the overall WECC
Particulate Loadings	4.1 Eq. t PM_{10}	12.2 Eq. t PM_{10}	The Colstrip system's advantage relative to the WECC baseline reflects differences in population densities and the potential for exposure. It demonstrates a benefit of locating coal plants in rural areas.
Neurotoxic Chemical Loading	1.3 Eq. kg Hg.	6 Eq. kg Hg.	Same comment as Particulates, above.
Systemic Chemical loading (heavy metals)	NC	NC	This indicator could not be calculated within the scope of this study.

-- denotes a zero or negligible result; NC denotes that an indicator result was not calculated.

[114] Aquatic and riparian/wetland habitat disruption were not broken out in the baseline case.

7.10. Preliminary Environmental Performance Analysis of Colstrip

The environmental performance of the Colstrip power generation system relative to the regional WECC power pool impact profile is presented in Table 7.10.

Table 7.10. Preliminary Environmental Performance Analysis of the Colstrip Power Generation System Relative to the WECC Power Pool

Indicator	Unit	Colstrip Impact Profile	WECC Regional Power Pool
Energy Resources Depleted	Eq. GJ of oil	4,042,000	5,207,000
Water Resources Depleted	Acre-feet	--	NC
Terrestrial Habitat Disruption*	Eq. ha disturbed	NC	1,880
Aquatic Habitat Disruption	Eq. ha disturbed	NC	*Not broken out*
Riparian/Wetland Habitat Disruption	Eq. ha disturbed	NC	*Not broken out*
Key Species	% loss	NC	NA
Greenhouse Gases	Eq. t CO_2	1,045,000	500,000
Acidification Loading	Eq. t SO_2	111	6.5
Ground Level Ozone Loading	t O_3	4.9	8.9
Particulate Matter Loading	Eq. t PM_{10}	4.1	12.2
Neurotoxic Chem. Loading (ingestion)	Eq. t Hg.	1.3	5.7
Pulmonary Chemical Ldg. (inhalation)	Eq. t benzene	4	5.2
Systemic Chemical Loading	Eq. kg TCDD	NC	NC
Eco-Toxic Chemical Loading	Eq. kg As	NC	NC
Radioactive Wastes	Eq. GBq Pu-239	--	NC

(--) denotes negligible or zero result. NA is not available, NC is not calculated.
Results above 10,000 are rounded to the nearest 1,000.

The results presented in table 8.10 shed light on the significance of the technologies currently in use, and establishing a benchmark for evaluating potential upgrades and power generation options. Most power generation systems are no more or less efficient in their overall environmental performance than average power generation in their regional pools.

The Colstrip system is, on balance, more environmentally efficient than average power generated by the WECC power pool. As shown in Table 7.13, the calculated results for many impact indicators were lower than might be expected, reflecting the rural location of the facility and the efficiency of the combustion technology employed. If the Colstrip system does not cause significant disruptions to aquatic or riparian/wetland habitats, its performance for these indicators will be high as well.

Section 8.
NATURAL GAS POWER GENERATION SYSTEM

8.1. Project Description and Background

8.1.1. Project Description

Under this project, SCS evaluated the utility of the LCIA methodology to determine the ecological footprint of two natural gas-fired power generation systems. The resulting impact profile was then compared to the WECC baseline impact profile.

8.1.2. Project Background

Two separate examples of “base load” natural gas power production were selected to demonstrate the environmental impacts at different levels of efficiency.

- **Scenario 1:** Natural gas is often the fuel for conventional singe cycle steam turbine (NGSC) applications. NGSC processes tend to be used for quickly varying loads and for partial loads corresponding to a capacity factor around 10% to 40%, as natural gas prices have reached rather high levels. For very short peak load periods single cycle gas turbines (GT) are deployed, but such GT plants are not included in this assessment.

- **Scenario 2:** The higher fuel efficiency attainable with combined cycle natural gas (NGCC) plants has led to an increasing number of such installations, often by adding waste heat recovery boilers and a steam cycle to existing GT power plants. NGCC plants are better suited as base load plants than NGSC plants because they have better fuel economy. NGCC plants are also fast load followers

8.2. Power Generation System Description

8.2.1. Unit Processes

The NGSC and NGCC natural gas power generation systems include the power plants, upstream processes such as natural gas production, processing and distribution, and power transmission. A schematic of the natural gas systems modeled in this Project is shown in Figure 8.1. A flow diagram of a combined cycle plant is shown in Figure 8.2.

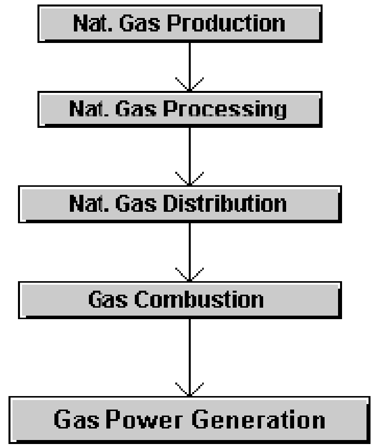

Figure 8.1. Major Unit Processes of the Natural Gas Power Generation System

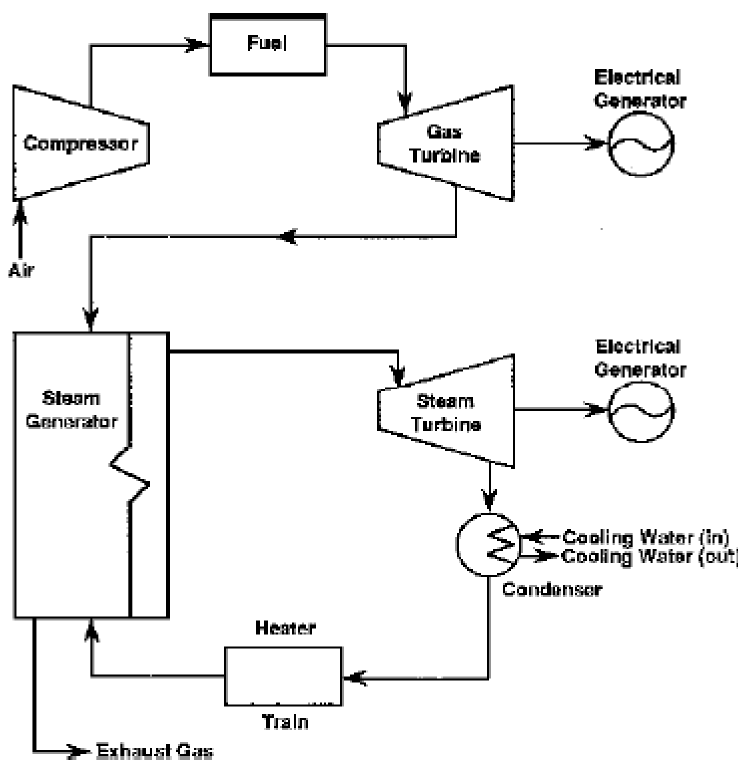

Figure 8.2. Flow diagram of NGCC plant.

8.2.2. Plant Location

The natural gas plants modeled were assumed to be located near the Pacific coast, in the vicinity of Portland, Oregon. The location was chosen to be near that of the Stateline windfarm, the subject of Project #5.

8.2.3. Differences between NGSC and NGCC Systems

The most relevant characteristic of NGSC plant efficiency is the heat rate, expressed as gigajoules (GJ) of fuel input per MWh produced. In the EGRID02 database, the utility natural gas power plant heat rates for NGSC plants vary from around 12,000 to 14,000 Btu/kWh (12.6 – 14.8 GJ/MWh). In the NGSC scenario modeled in this Project, a value of 13.1 GJ/MWh (12,417 Btu/kWh) was used. Other important characteristics are listed in the LCI Table 8.1.

The main difference between the NGSC and NGCC systems is the heat rate, which according to EGRID02 and SCS database information is 8,000 - 9,000 Btu/kWh (8.4 - 9.5 GJ/MWh). In the NGCC system modeled in this Project, a heat rate value of 9.23 GJ/MWh (8,749 Btu/kWh) was used.

8.3. Baseline Case

The averaged impact profile for power generated in the WECC power pool, per 1,000 GWh, serves as the baseline impact profile for comparison. As described in Section 6 of this report, the WECC power pool system consists primarily of base load units (coal, nuclear, hydroelectric and natural gas), reserve units that handle seasonal/daily load demand (produced mainly by coal plants and combined cycle natural gas plants), and peak loading units (mostly natural gas).

8.4. Data Sources

The modeling conducted in this Project is based on data gathered and analyzed by SCS in previous LCSEA studies and other published LCA studies, as well as government and industry reports related to natural gas power production.

8.5. Key Assumptions

This section summarizes assumptions specific to this project only. Other assumptions and considerations related to the application of the LCSEA model are described in Sections 3 and 4.

8.5.1. Assumptions Related to Power Plant Modeling

Environmental impacts from construction material manufacturing and processing were regarded as having low relevance in this model. No other such assumptions were necessary in this assessment other than those described in the general LCSEA framework as presented in Sections 3 and 4.

8.5.2. Habitat Disruption Assumptions

For this project, SCS assumed that habitat disruption results calculated for the natural gas systems in a prior study (200 acres, or 81 hectares, per 1000 GWh) would serve as a suitable surrogate value for the NGSC system modeled in this project.[115] This habitat was assumed to be general terrestrial habitat, containing no critical habitats. The area of disturbed habitat was assumed to be somewhat smaller (148 acres, or 60 hectares) for the NGCC system, given that the size of the gas turbine, waste heat boiler, and steam turbine is estimated to be relatively constant per consumed fuel unit (see Table 8.3 below).

8.6. Summary LCI Results

The life-cycle inventory results for the two natural gas example systems are shown in Table 8.1.

Table 8.1. Main Life-Cycle Inventory Results for the NGSC and NGCC Systems compared to the WECC Power Pool Baseline, based on KCL-ECO LCI Modeling. (Normalized to a production of 1,000 GWh.)

		NGSC Power System	NGCC Power System	WECC Power Pool Baseline
Inventory	**Unit**			
Outputs				
Emissions, air				
Arsenic	kg	--	--	16
Benzene	kg	--	--	6
Cadmium	kg	--	--	1
CFC-114	kg	--	--	34
CH4	kg	3,432,890	2,602,430	906,170
CO2, fossil	kg	655,192,000	509,251,000	478,383,000
PM10, TSP, dust	kg	60,916	46,228	197,030
HC, VOC	kg	--	--	29,910
HCl	kg	--	--	26,959
HF	kg	--	--	683
Mercury	kg	--	--	7
Manganese	kg	--	--	14
NOx	kg	1,288,326	977,420	956,413
Lead	kg	--	--	10
Rad. act. Rn-222	GBq	--	--	2,910
Rad. act. noble gases	GBq	--	--	250
SO2	kg	59,783	45,360	731,940
Emissions, water		--	--	--
Energy				
electric power	MWh	1,000,000	1,000,000	1,000,000
Inputs				
Resources				
Coal	kg	--	--	200,080,000
Lignite	kg	--	--	
Crude oil	kg	--	--	3,631,900
Natural gas	kg	234,766,000	178,158,000	48,502,000
Uranium in ore	kg U	--	--	3,048
Hazardous waste				

(--) denotes result of negligible or zero

[115] Private study conducted by SCS for a European government entity, 1997.

8.7. LCSEA Results

From the LCI data, the LCSEA indicator results have been calculated, using the appropriate stressor and environmental characterization factors, as discussed in Sections 3 and 4. In Table 8.2, LCSEA indicators are summarized for: 1) the natural gas single cycle (NGSC) power plant, 2) the natural gas single cycle (NGCC) power plant, and 3) the WECC regional power pool. Tables 8.3 to 8.7 present in more detail the key impact indicator calculations.

Table 8.2. Life-Cycle Impact Indicator Results for the NGSC and NGCC systems, and the WECC Power Pool Baseline, based on KCL-ECO LCI Modeling. Data are normalized to a production of 1,000 GWh.[116]

		NGSC Impact Profile	NGCC Impact Profile	Baseline: WECC Power Pool
Key Indicator	***Unit***			
Energy Resources Depleted	Eq. GJ of oil	11,784,000	8,943,000	5,207,000
Water Resources Depleted	Acre-feet	--	--	NC
Terrestrial Habitat Disruption	Eq. Ha disturbed	81	60	1,880
Aquatic Habitat Disruption	Eq. Ha disturbed	NC	NC	*See above*
Riparian/Wetland Habitat Disruption	Eq. Ha disturbed	NC	NC	*Not broken out*
Key Species	% loss of key species	NC	NC	NA
Greenhouse Gas Loading	Eq. t CO_2	734,000	569,000	500,000
Acidification Loading	Eq. t SO_2	30.6	23.3	6.5
Ground Level Ozone Loading	t O_3	16.5	12.5	8.9
Particulates	Eq. t PM_{10}	6.4	4.8	12.2
Neurotoxic Chem. Loading	Eq. t Hg.	--	--	0.0057
Pulmonary (non-carc) Chem. Loading	Eq. t HF	--	--	0.5423
Pulmonary (Carc.) Chem. Loading	Eq. t benzene	--	--	0.0041
Systemic Chem. Loading	Eq. t TCDD	--	--	NC
Radioactive Waste loading	Eq. TBq Pu-239	--	--	NC
Coal Ash Waste Loading		--	--	NC

(--) denotes a result of negligible or zero; NC indicates that the result was not calculated
Results above 10,000 are rounded to the nearest 1,000.

[116] It should be noted that the indicators have been slightly modified to conform to the ISO 14044 and Draft ANSI SCS-002 Standards since this set of calculations was completed. Specifically, a new oceanic acidification indicator has been added, the pulmonary loading indicators have been collapsed back to one indicator, and the coal ash waste loading is now addressed under the Ecotoxic Chemical Loading (Soil/Water) indicator, as shown in Sections 2 and 6. However, these changes will not have a material effect on the impact profile of the modeled natural gas systems relative to the baseline. Modifications will be made to this Section before the report is released for peer review.

Table 8.3. Project #4: LCSEA Energy Resource Depletion Results for NGSC and NGCC Natural Gas Power Generation Systems, Per 1,000 GWh Production

Energy Resource Depletion	Inventory Resource	Energy Resource Consumed (t)	Stressor Characterization Factor (SCF) (GJ/t)	Equivalent Energy Resource Consumed (GJ)	Resource Depletion Factor (RDF_{25}): Rate of dep / Rate of oil dep	Equivalent Resource Depletion (GJ oil eq.)
Electric Power System: Natural Gas Single Cycle	Uranium in ore	0.000000	900,000.0	0	0.510	0
	Crude oil	0	45.6	0	1.000	0
	Natural gas	234,766	53.4	12,536,504	0.940	11,784,314
	Coal	0	15.5	0	0.280	0
	Lignite	0	9.5	0	0.280	0
				12,536,504		**11,784,314**
Electric Power System: Natural Gas Combined Cycle	Uranium in ore	0.000000	900,000.0	0	0.510	0
	Crude oil	0	45.6	0	1.000	0
	Natural gas	178,158	53.4	9,513,637	0.940	8,942,819
	Coal	0	15.5	0	0.280	0
	Lignite	0	9.5	0	0.280	0
				9,513,637		**8,942,819**

Table 8.4. Project #4: LCSEA Greenhouse Gas Loading Results for NGSC and NGCC Natural Gas Power Generation Systems, Per 1,000 GWh Production

Greenhouse Gases Loading	Inventory Emission	Life-Cycle Inventory Result (t/a)	Global Warming Potential (t CO_2 eq./t)	Gross Emission Loading (t CO_2 eq.)	Environment Characterization Factor (ECF)	Net Emission Loading (t CO_2 eq.)
Electric Power System: Natural Gas Single Cycle	Fossil CO2	655,192	1.0	655,192	1.00	655,192
	CH4	3,433	23.0	78,956	1.00	78,956
				734,148		**734,148**
Electric Power System: Natural Gas Combined Cycle	Fossil CO2	509,251	1.0	509,251	1.00	509,251
	CH4	2,602	23.0	59,856	1.00	59,856
				569,107		**569,107**

Table 8.5. Project #4: LCSEA Acidification Loading Results for NGSC and NGCC Natural Gas Power Generation Systems, Per 1,000 GWh Production

Acidification Loading	Inventory Emission	Life-Cycle Inventory Result (t)	Stressor Characterization Factor ($t\ SO_2$ eq./t)	Gross Emission Loading ($t\ SO_2$ eq.)	Environment Characterization Factor (ECF)	Net Emission Loading ($t\ SO_2$ eq.)
Electric Power System: Natural Gas Single Cycle	SO2	60	1.000	60	0.060	3.59
	NOx	1,288	0.700	902	0.030	27.05
				962		**30.64**
Electric Power System: Natural Gas Combined Cycle	SO2	45	1.000	45	0.060	2.72
	NOx	977	0.700	684	0.030	20.53
				730		**23.25**

Table 8.6. Project #4: LCSEA Ground Level Ozone Loading Results for NGSC and NGCC Natural Gas Power Generation Systems, Per 1,000 GWh Production

Ground Level Ozone Loading	Inventory Emission	Life-Cycle Inventory Result (t)	Stressor Characterization Factor (SCF) ($t\ O_3$/t)	Gross Emission Loading ($t\ O_3$)	Environment Characterization Factor (ECF)	Net Emission Loading ($t\ O_3$)
Electric Power System: Natural Gas Single Cycle	NOx	644	1.000	644	0.025	16.10
	CH4	1,716	0.010	17	0.025	0.43
	VOC, HC	0	0.420	0	0.025	0.00
				661		**16.53**
Electric Power System: Natural Gas Combined Cycle	NOx	489	1.000	489	0.025	11.04
	CH4	1,301	0.010	13	0.025	0.33
	VOC, HC	0	0.420	0	0.025	0.00
				502		**12.54**

Table 8.7. Project #4: LCSEA Particulate Loading Results for NGSC and NGCC Natural Gas Power Generation Systems, Per 1,000 GWh Production

Particulate Matter Loading	Inventory Emission	Life-Cycle Inventory Result (t)	Stressor Characterization Factor (SCF) (t PM_{10} eq/t)	Gross Emission Loading (t PM_{10} eq)	Environment Characterization Factor (ECF)	Net Emission Loading (t PM_{10} eq)
Electric Power System: Natural Gas Single Cycle	TSP	60.9	1.00	60.9	0.008	0.5
	SO2	59.8	1.50	89.7	0.008	0.7
	NOx	644.2	1.00	644.2	0.008	5.2
				794.8		**6.4**
Electric Power System: Natural Gas Combined Cycle	TSP	46.2	1.00	46.2	0.008	0.4
	SO2	45.4	1.50	68.0	0.008	0.5
	NOx	488.7	1.00	488.7	0.008	3.9
				603.0		**4.8**

8.8. Discussion of Results

In comparison to the WECC baseline, both natural gas power production systems are burdened by high energy resource depletion, which is explained by the high RDF for natural gas. The acidification and ground level ozone indicators results for the natural gas systems were relatively high as compared to the WECC baseline, due to: 1) the level of NOx emissions associated with these systems; and 2) the location selected for modeling these units. Not only is population density higher in the Portland area than the WECC average, but acidification ECFs are higher as well, because of soil acidification exceedances in the Pacific Northwest area, as shown in Figure 4.2, Section 4.

On the other hand, habitat disruption associated with natural gas systems was quite low compared to the WECC baseline impact profile, and chronic hazardous chemical loadings were negligible, whereas these indicators are active within the WECC given its mix of power generation sources. (See Environmental Impact Profile for NGCC system, Figure 8.3.)

When comparing the two natural gas technology scenarios, the driving factor was the lower resource depletion (24%) associated with the NGCC system. This fuel efficiency led to measurable reductions in most other indicators, since emissions from natural gas combustion, production and transmission per produced electrical energy unit all were reduced in the same proportion.

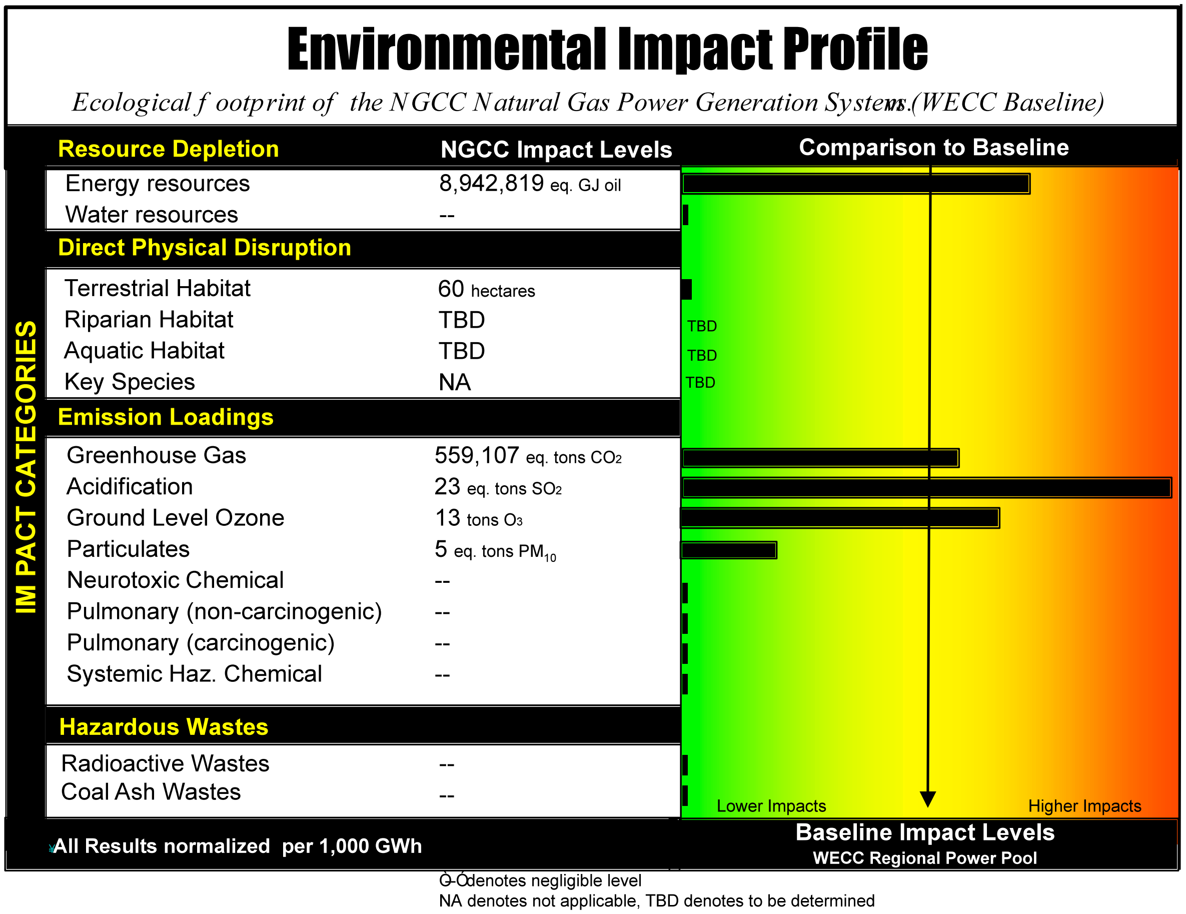

Figure 8.3. Environmental Impact Profile of NGCC System Compared to WECC Baseline

8.9. Environmental Performance Comparison between NGSC and NGCC

The environmental performance of the NGSC and NGCC natural gas systems in comparison to the WECC regional power pool are shown in Table 8.8.

As can be seen from the table, the NGCC's 24% reduction in fuel consumption as compared to the NGSC improves its overall efficiency somewhat. The NGCC showed the following gains in performance over the NGSC scenario:

- greenhouse gas loading — 20% gain in efficiency;
- ground level ozone — 17% gain in efficiency;
- energy resource depletion – 14% gain in efficiency ;
- particulates loading —13% gain in efficiency ; and
- in acidification loading — 7% gain in efficiency.

Table 8.8. Environmental Performance Index of the Natural Gas Single Cycle Power Plant compared to the WECC baseline.[117]

Indicator	Unit	NGSC Impact Profile	NGCC Impact Profile	WECC Regional Power Pool
Energy Resources Depleted	Eq. GJ of oil	11,784,314	8,942,819	5,207,177
Water Resources Depleted	Acre-feet	--	--	NC
Terrestrial Habitat Disruption	Eq. ha disturbed	80	80	1,880
Aquatic Habitat Disruption	Eq. ha disturbed	NC	--	*Not broken out*
Riparian/Wetland Habitat Disruption	Eq. ha disturbed	NC	--	*Not broken out*
Key Species	% loss	NC	NC	NA
Greenhouse Gases	Eq. t CO_2	734,148	569,107	499,970
Stratospheric Ozone Depletion	Eq. t CFC-11	--	--	0.027
Acidification Loading	Eq. t SO_2	30.64	23.25	6.5
Ground Level Ozone Loading	t O_3	16.53	12.54	8.9
Particulates Loading	Eq. t PM_{10}	6.4	4.8	12.2
Neurotoxic Chem. Loading	Eq. t Hg.	--	--	0.0057
Pulmonary (non-carc) Chem. Loading	Eq. t HF	--	--	0.5423
Pulmonary (Carc.) Chem. Loading	Eq. t benzene	--	--	0.0041
Systemic Chem. Loading	Eq. t TCDD	--	--	NC
Radioactive Wastes	Eq. TBq Pu-239	--	--	NC
Coal Ash Waste	Eq. t Hg.	--	--	NC

NA is not available, NC is not calculated.
Results above 10,000 are rounded to the nearest 1,000.

[117] As noted under Section 9.7, the indicators have been slightly modified to conform to the ASTM Draft Standard E06.71.10 since this set of calculations was completed, as described in Sections 2 and 6. However, these modifications will not have a material effect on the EPI of the modeled natural gas systems relative to the baseline. Modifications will be made to this Section before the report is released for peer review.

