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Development and Evaluation of Sustainability Criteria for Land Revitalization

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ABSTRACT

Land revitalization offers the opportunity to reconsider the functional roles that individual land parcels can contribute to sustaining environmental systems. Although the ability of individual parcels to make these systems more resilient and move more toward sustainability may be limited, their influence can be substantial when considered collectively. This report identifies criteria for land revitalization and how these criteria would need to be applied so as to support sustainable environments.

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PREFACE

The mission of U.S. Environmental Protection Agency is to protect human health and the environment. Because changes in land use for meeting human needs present one of the greatest challenges to meeting this mission, it is essential that land uses are explored within concepts of protection and sustainability. Spent land uses and sites that may be contaminated by prior uses, e.g., brownfields, offer the opportunity to consider how land might be revitalized to meet new uses and achieve sustainable environments. EPA regulations[1] and ASTM Standards[2] that address green cleanup practices on sites should be considered with this report.

The information presented in this report supports the U.S. Environmental Protection Agency Office of Research and Development strategic goals 3 (Land Preservation and Restoration) and 4 (Healthy Communities and Ecosystems).

[1] http://clu-in.org/greenremediation/subtab_b5.cfm
[2] http://www.astm.org/DATABASE.CART/WORKITEMS/WK23495.htm

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EXECUTIVE SUMMARY

It is not possible to meet human needs, build societies, and expand economies without consuming natural capital. However, these activities would also not be possible unless natural systems remain sufficiently intact to provide goods and services that sustain them and human life. Developed parcels of land that have outgrown their useful life offer the opportunity to breathe new vitality into society and economy. However, that new vitality would be short lived if the environment is not adequately maintained to sustain it. Because a sustained environment retains much of the integrity of natural systems, conditions that would maintain this integrity can be used as planning criteria. These criteria inform how land is to be used so that the environment still performs and functions as it must to sustain human life. Development of these sustainability criteria for land uses is guided by seven points:

- The definition of sustainability
- What must be sustained
- The immediacy of the need to achieve sustainability
- Limitations of the human-environment relationship
- The need to focus at regional, continental, and global levels to achieve local sustainability
- The limited role that any particular land site can contribute toward sustainability
- Sustainable environmental conditions

This report provides a set of criteria that enables land use decisions that revitalize previously developed sites while keeping intact the natural systems that sustain human life and economic development; and establishes a sound basis for developing science relating to human-environment relationships.

1. INTRODUCTION

GOAL OF THIS REPORT

Because all land uses affect finite natural systems[3] that are essential for human life, human activities should protect and restore natural systems and the effects of land use should be counteracted. Aldo Leopold (1949) made this point in his 'Land Ethic' asking us to change our activities to conform with environmental capacities. Establishing a harmonious human-environment relationship became U.S. policy as part of the National Environmental Policy Act of 1969[4]. Among the earliest attempts to address this objective is illustrated in the work of Ian McHarg (1992) who developed a system of map overlays to represent attributes of nature that should be retained. Land areas that were not required by nature were deemed appropriate locations for development. This relationship between humans and the environment was a primary subject of the Rio Summit (UN 1992); and subject of development principles including: The Precautionary Principle[5]; The Earth Charter (UN 1999); The Bellagio Principles[6]; The Aalborg Commitments[7]; The Ahwahnee Principles[8]; and The Natural Step[9].

Application of these principles has tended toward minimizing the environmental effects of development through evolving programs such as the US Green Building Council's Leadership in Energy and Environmental Design (LEED)[10], Smart Growth Network[11], New Urbanism[12], Green Globes[13], and the Sustainable Sites Initiative[14]. Although these provide a good foundation a sustainable human-environment relationship, prospects for achieving this sustainable relationship at the individual site are limited.

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[3] Finite components of functioning natural systems include the amount of biomass that can be sustained, habitats, biodiversity, land surface and soils, water resources, the physical space habitable by human life, the amount of pollutants that can be attenuated without added technologies, etc.
[4] 42 U.S.C. 4321-4347 Sec.2
[5] http://en.wikipedia.org/wiki/Precautionary_principle
[6] http://www.iisd.org/measure/principles/progress/bellagio.asp
[7] http://www.aalborgplus10.dk/default.aspx?m=2&i=307
[8] http://www.walkablestreets.com/ahwah.htm
[9] http://www.naturalstep.org/
[10] http://www.usgbc.org/
[11] http://www.smartgrowth.org/sgn/default.asp
[12] http://www.cnu.org/
[13] http://www.greenglobes.com/design/homeca.asp
[14] http://www.sustainablesites.org/report/

The problem is that effects of land uses cannot be resolved solely by decisions focusing on the site alone. This is especially true for sites that are subject to remediation where opportunities to consider environments beyond the site are not established. Because the effects of land use radiate outward from and well beyond any project site, but cannot be reversed by any decision made at the project site, additional decisions must be made to address effects of human activities. However, if the effects of proposed land use change on natural systems were addressed at and beyond the site, environmental qualities necessary for human life could be preserved and protected. This report will provide a framework for making decisions that would align new land uses on previously developed sites with environments that would also be sustainable.

A broad literature helps to identify a basis for making land use decisions. Natural capital accounting (Wackernagel, *et al*. 1999) and ecological accounting (Heal 2007) utilize the concept of maintaining natural capital when making decisions, corporate investments, and consumer choices to achieve sustainability and utility to humanity. The use of ecosystem science helps to identify prerequisites for maintaining energy and material flows, their dynamics, and spatial scales of natural systems (Chapin, *et al*. 2002). Natural resource restoration and management (The Bay Institute 1998) provide references to ecosystem attributes and indicators of ecosystem health. Issues related to protection stem from the work of MacArthur and Wilson (1967) who showed biodiversity and characteristics of land were related. Criteria are generally defined for maintaining soil function, i.e., biomass production, filtration, buffering and materials transformation, and habitats to ensure space for housing, industry, infrastructure, mineral extraction, and cultural heritage (Blume, *et al*. 1998). Land use responses based upon biological sciences are illustrated by works of Lyle (1999), Duerksen (1997), Randolph (2003), and The Land and Natural Development Code (Balmori and Benoit 2007).

2. CONTEXT OF SUSTAINABILITY

2.1 SUSTAINABILITY WITHIN EPA'S MISSION

Sustainability has diverse meanings that have been debated and analyzed since the concept was initiated in the Brundtland Commission report. Because of EPA's mission to protect human health and to safeguard the natural environment upon which life depends, sustainability and protection are synonymous. The purpose of these goals is ultimately to provide some long-term assurance that the environment will be able to sustain human life. This assurance will require EPA to anticipate threats to human health and the environment and make certain that options and opportunities for humanity to meet its needs and expectations always exist so that humanity can remain and adapt in place (Benyus 1997). However, the geologic record shows that 99% of the species that ever lived are now extinct proving that there are no assurances. Because we have no control over natural forces that can alter the fate of humanity, the assurance that we seek is that humanity does not become the cause of our demise. Because we must simultaneously use and protect the environment, Gilbert White (2006) suggested a rational approach, "People will not be able to completely avoid any alteration in the natural ecosystem, but they can order their activities so as to avoid serious decrease in environmental quality." The challenge is to identify the essential qualities of functioning natural systems so that these qualities can be integrated into human activities, especially land use decisions.

3. CONNECTION OF LAND REVITALIZATION TO SUSTAINABILITY

3.1 SPATIAL REQUIREMENTS OF SUSTAINABILITY

Land that is to be redeveloped is typically cleansed of pollutants that could pose risks to human health and the environment. However, this alone will not sustain human life or the environment if natural systems remain compromised. Cleansing, reducing risks, and minimizing further environmental impacts may be all that is possible on many urban sites. When land parcels are platted and developed for human uses, they are typically removed from their connection to many of their ecological systems. Their functional roles in supporting natural productivity, biodiversity, soils, water, and air are altered. Although some of these roles can be partially reversed, cleaning and reuse of an individual site will seldom restore its functional roles in ecological systems. This would be sustainable if enough of natural systems remain intact to provide ecosystem services to fulfill demands for them, but the human footprint on the environment exceeds its capacity. Because sustainability is valued and nearly all the natural environment has been affected by human activities, it is essential to find ways to revitalize scarred lands. Eliminating risks will necessitate that a site be clean. However, to breathe vitality into the land will require that it be restored to its functional roles in its ecosystem so that it contributes to environmental functions at local, regional, landscape, continental, and global scales.

3.1.1 Sites

Cleaning and redevelopment of an individual site offers few opportunities to restore a site's functional roles in ecosystems, but sites can integrate with proximate sites to restore systemic vitality. This would work best if all proximate sites were revitalized simultaneously, but this is seldom possible. Because sites are usually remediated and redeveloped incrementally, they must be revitalized within a natural systems framework that will eventually be applied to all proximate sites that affect and support the same natural systems. Although each individual patch or a small cluster of revitalized sites do not contribute much toward sustainability, over time, by including neighboring sites, they can function as a sustainable ecosystem.

3.1.2 Systems

Because individual land users incrementally and cumulatively erode the natural systems that sustain human life, individual land parcels must become instrumental in keeping these systems intact. This is possible if additional neighboring sites are incorporated and if fundamental traits of functioning ecosystems are well defined to guide land use decisions. These criteria of functioning ecosystems can be used as criteria for sustainable land use at all scales.

Communities present an opportunity to reconsider existing and future development at a large enough scale to envision a new and sustainable future[15]. This would require that ecosystems be defined so that changes to individual land uses throughout the community can play vital roles in restoring natural structures, functions, and processes. Land-revitalization can contribute toward sustainability if land use decisions are made within this ecosystems context.

3.2 SHORT AND LONG TERM REQUIREMENTS OF SUSTAINBILITY

3.2.1 Losses are due to land development

Sustainability must be applied daily and focus on long-term impacts. It compels us to measure the impact of current development on future generations. This is possible if we implement a strategy to protect ecosystems in the near future. Figure 1 illustrates that the greatest land use change due to population growth began c.1950 and is expected to continue through 2050. If ecosystems are to continue to provide services to humanity, land use decisions will need to meet human needs and maintain environmental qualities that provide viable ecosystem services. Land use change during the first 60 years of this period was most often developed without consideration to sustaining the natural systems and the services they provide. We must now provide the information that enables decision-makers to be develop the built environment in a manner that sustains the environment.

[15] Primary application of this concept is possible at the community scale as illustrated in the EPA planning of Stella, Missouri in 2006/07.

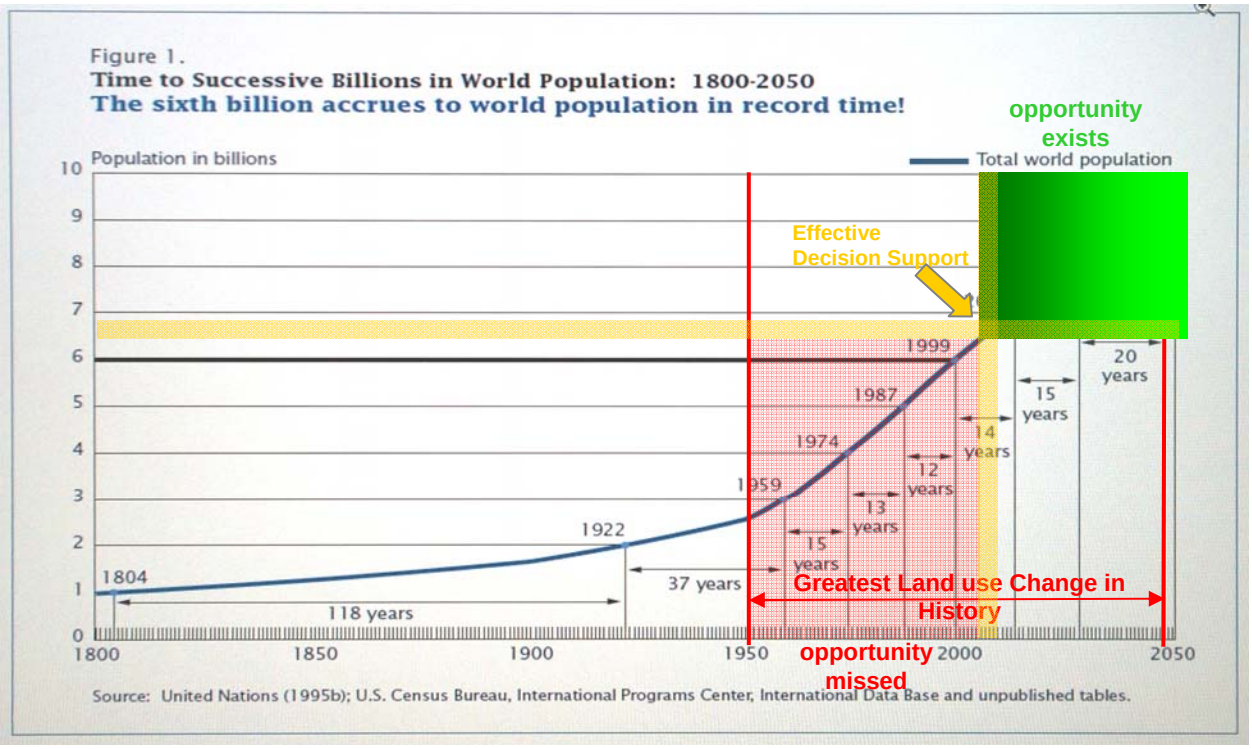


Figure 3 - 1 –Timeframe to Make Land Use Decisions to Protect Natural Systems.

If development to meet this predicted population increase of 100 million (USCensus 2002) follows traditional patterns of urban sprawl (Lang 2006) and agriculture doubles (Tilman, *et al*. 2002) from year 2000 levels, the capacity of large portions of ecoregions to provide ecosystem services to people could be severely diminished and potentially unrecoverable. An overlay of future mega-cities on Robert Bailey's (1995) map of ecoregions (see figure 3-2) reveals that five ecoregions of the United States will be predominantly covered by urban development by 2050[16]. Comparing Bailey's ecoregions with U.S. Department of Agriculture's (2007) map of percentage of land used for crops (see figure 3-3) reveals four additional ecoregions are significantly altered by land uses[17]. Because land use change causes environmental losses and is more intense in these nine ecoregions, ecosystem services are likely to be lost unless anthropogenic land uses can be planned so as to keep natural systems intact and

[16] Ecoregion 221- Eastern Broadleaf Forest (Oceanic) Province; Ecoregion 242 – Cascade Mixed Forest—Coniferous Forest—Alpin Meadow Province; Ecoregion 255 - Prairie Parkland (Subtropical) Province; Ecoregion 261 – California Coastal Chaparral Forest Shrub Province; and Ecoregion 411 – Everglades Province.
[17] Ecoregion 222 – Eastern Broadleaf Forest (Continental) Province; Ecoregion 332 – Great Plaines Steppe Province; Ecoregion 251 – Prairie Parkland (Temperate) Province; and Ecoregion 262 – California Dry Steppe Province.

functioning. For example in Texas (ecoregion 255 of figure 3-2), the water level of the Edwards Aquifer[18] has dropped significantly, and if this resource fails to meet use requirements, it will have a devastating impact on the U.S. economy and agriculture. As decades pass and natural systems are degraded, preservation of natural systems will take on increased urgency, but the capacity to address them may be largely gone because natural systems will be less intact and resilient. Therefore, a strategy to align land uses with intact natural systems is necessary.

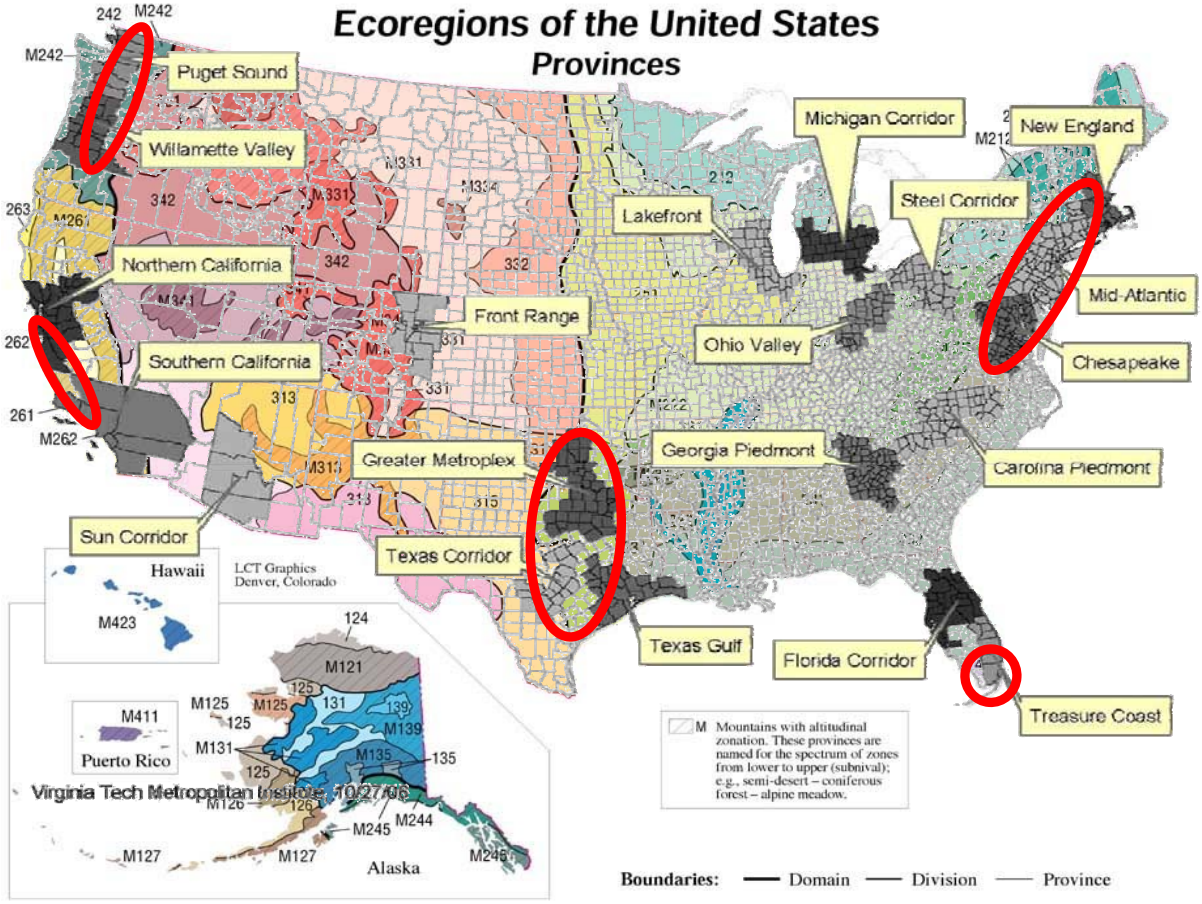


Figure 3 - 2 – Impact of Future Mega-cities on Ecoregions

[18] http://www.edwardsaquifer.net/

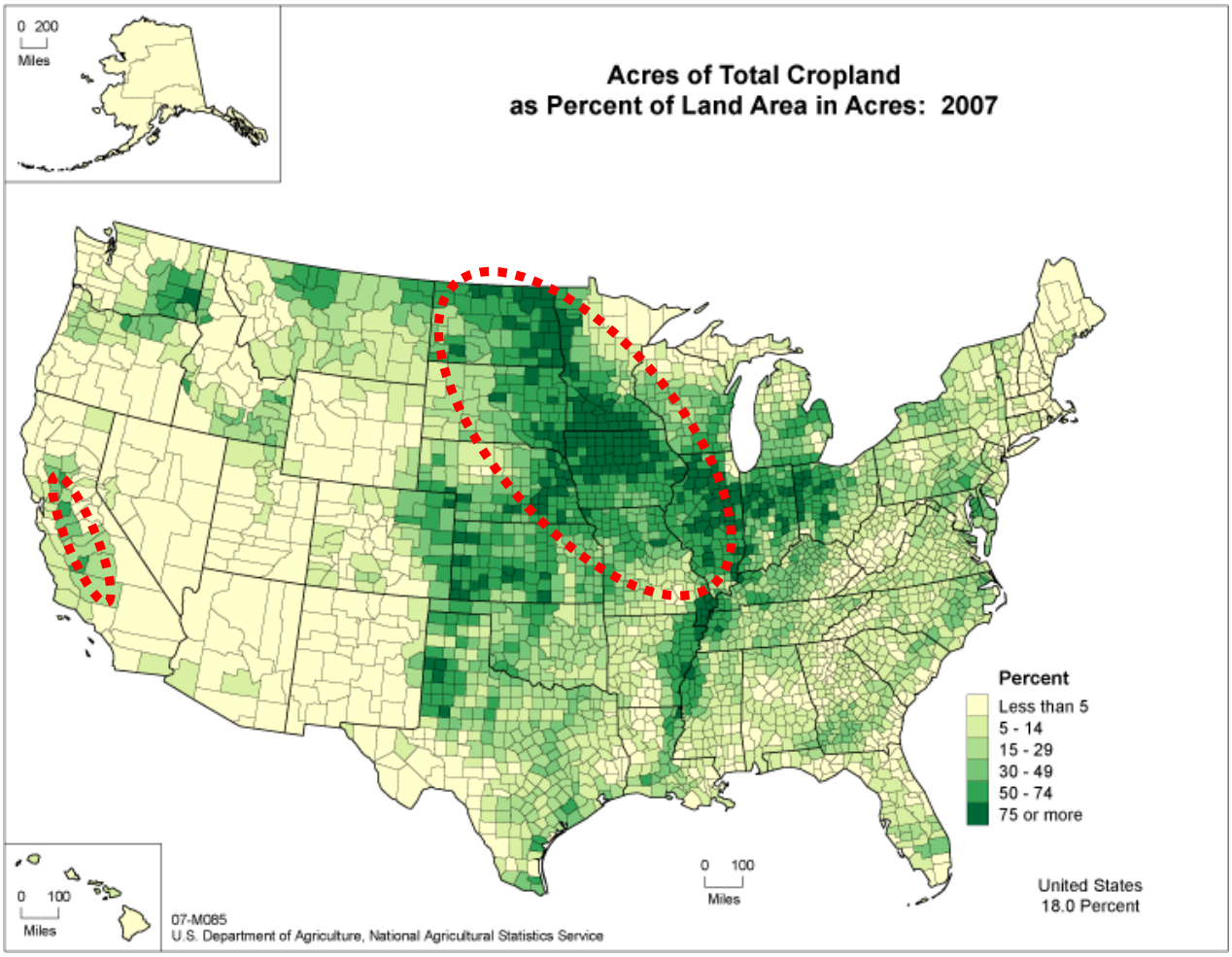
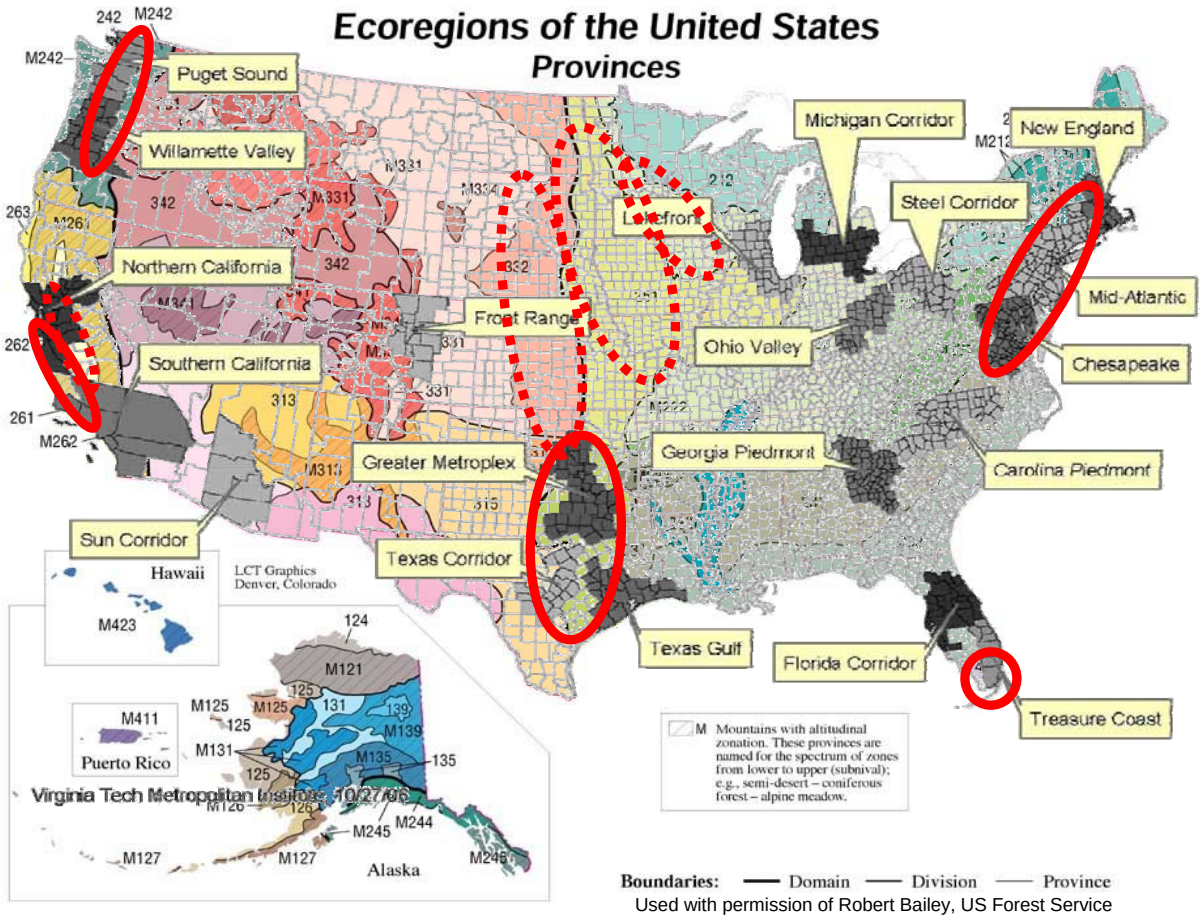


Figure 3 - 3 – Impact of Agriculture on Ecoregions



Used with permission of Robert Bailey, US Forest Service

Figure 3 - 4 – Impact of Agriculture and Urban Development on Ecoregions

3.2.2 Temporal context of sustainability

Sustainability should be based upon the science of human-environment relationships and developing criteria to guide decision-making. Because this science is incomplete, adaptive management provides some direction (Gunderson and Holling 1996; Hurni 2000; Hollander, *et al*. 2007). Adaptive management can be used to make initial land use decisions because it offers the ability to shift the focus: from outputs to inputs and processes; from industrial production to mimicking natural processes and productivity; from consideration of single output to placing importance on all species and natural services; from avoiding product shortage to avoiding biodiversity loss and soil degradation; from viewing part of the environment as a production system to viewing ecosystems and their services; and from economic efficiencies to cost effectiveness (Chapin, *et al*. 2002). These principles can represent the sought-after environmental

qualities that should be ordering human activities to avoid their serious degradation[19], but they need to be defined to enable land remediation. Therefore, these criteria are developed in the following sections. These criteria can be used in adaptive management, especially for remediating lands surrounded by healthier land uses. The alternative to adaptive management is to manage human land uses so that our activities do not interfere with ecosystem structures, functions, and processes and makes them more robust. Because sustainability is a product of maintaining a conditional relationship between human objectives and environmental qualities, the criteria of these environmental qualities can guide land use decisions so that natural systems and the ecosystem services they provide remain intact.

[19] Refer to quote by Gilbert White in Section 2.1.

4. CRITERIA THAT LINK LAND REVITALIZATION TO SUSTAINABILITY

4.1. THEORY OF SUSTAINABILITY CRITERIA

All development erodes the ability of this planet to meet human needs. As agriculture and urban areas convert natural landscapes to human-made landscapes, native productivity is reduced, habitats and their ability to support native biodiversity are compromised, and hard surfaces block water infiltration and increase runoff and erosion, etc. As development continues, ecosystem services decline as the human need for them increases. Therefore, it will be necessary to manage the environment and/or manage human activities with regard to the environment as explained in this report. If land is to be used without compromising the provisioning, regulating, and supporting capabilities of natural systems, it is essential to have in place a structure that enables decision-makers to examine the larger environmental contexts that these decisions affect.

If it can be presumed that natural systems would manage themselves in the absence of humanity, then it can be hypothesized that they would also manage themselves with human presence as long as natural structures[20], processes[21], and functions[22] remain intact. This makes land uses conditional upon keeping natural systems intact[23] or returning them to fully functional states. If these characteristics of intact natural systems can be identified, they can be used as planning criteria to explore alternative land uses with regard to desired environmental qualities and environmental performance.

4.2. DEVELOPMENT OF CRITERIA

If the assumption is correct that natural systems would manage themselves if natural structures, functions, and processes remain intact, criteria for making land use decisions should incorporate environmental attributes that protect or enhance these qualities. This is supported by research that largely relates to natural productivity, biodiversity[24] and habitat size (Franklin 1993), soil health (Doran and Zeiss 2000; Herrick 2000), water quantity and quality (Baron and Poff 2004), and energy requirements (Hoehler 2004).

[20] Species geographical range, spatial dispersion, age distribution, and carrying capacity
[21] Evolution, migrations, speciation, succession, replacement, competition, and life-cycles
[22] Photosynthesis, energy flows, evapotranspiration, atmosphere-organism cycles
[23] Intact natural systems consist of interacting components described in the above footnotes.
[24] Biological diversity or biodiversity is the variation of life forms within a given ecosystem. Because the goal of sustainable land use in this report is self-managing ecosystems, biodiversity typically refers to native life forms within a given ecosystem.

The vocabulary that defines the attributes of a desirable natural environment is evolving. The Swedish Ministry of the Environment identified 16 goals within the context of sustainable ecosystem services (Deutsch, *et al*. 2003). Six of these directly relate to ecosystem performance or prerequisites of their continued functionality: sustainable lakes and watercourses; flourishing wetlands; a balanced marine environment and a healthy coastline and archipelago; living forests; and a rich agricultural landscape. The general terms that describe these prerequisites, e.g., clean, high quality, sustainable, flourishing, balanced, rich, majestic, good, and safe require accurate definition to be useful, but they begin to catalogue this important conditional relationship between humanity and the natural environment. Conservation International, in its attempt to define wilderness areas, developed requirements that describe areas that maintain biodiversity and ensure intact natural systems retain the capacity to provide ecosystem benefits to people (Mittermeier, *et al*. 2002). Such areas should be a distinct biogeographic unit (or composite) within a biome type, contain at least 70% native vegetation, a human density about 5 or fewer inhabitants per square kilometer, and more than 1500 endemic vascular plant species.

Coordination or alignment of the built environment with natural systems requires the use of numerous sets of principles that align human activities relative to nature[25] and social, economic and ecological integrity. These principles define sustainable responses rather than define the environmental conditions that must be in place for these systems to remain intact. Principle 5c of The Earth Charter (UN 1999), i.e., "Promote the recovery of endangered species and ecosystems", is a response rather than a condition. Similarly, The Natural Step principles used by John Cairns Jr. (1997) generated 10 goals of sustainability with 21 conditions and sub-conditions. Because these conditions relate more to sustainability goals rather than natural systems, they are too general for making land use decisions that would meet human needs and keep natural systems intact. Planning decisions require specific statements that either describe the limitations on land use or how the system is to perform, e.g., 'habitats must exist that will sustain minimum viable populations of native species'. Land use criteria such as this provide planners the ability to evaluate whether any proposed decision is acceptable. Because we want

[25] The Brundtland/UNCED Principles of Sustainable Development, the 12 Principles of Green Engineering by the Green Chemistry Institute, The Earth Charter, IUCN, UNEP, and WWF Caring for the Earth, The Natural Step Environmental Institute, the Bellagio Principles, the Hannover Principles, the Aalborg Commitments, the Ahwahnee Principles, and numerous others.

ecosystem services to remain intact, we can identify criteria that will assure their performance and criteria that define parameters within which their performance is possible.

Development of these criteria, outlined in the Appendix, is based upon why ecosystems must be sustainable, their functions, and the conditions that must exist for them to fulfill these roles. Assuming ecosystem integrity exists when/where productivity, biodiversity, soils, and water exist in near-natural conditions (Forman 1995), then a list of criteria can be derived for these four near-natural conditions. They can also be defined by what is known about ecosystem structure. Ecosystem integrity requires complete biotic communities, abiotic physical and chemical factors of environments, interactions between biotic-biotic and biotic-abiotic components, and energy flows and cycling of nutrients and chemicals. Additionally, the Millennium Ecosystem Assessment (2005) identified four groups of services that human life requires: a) ecosystem provisioning services; b) ecosystem regulating services; c) ecosystem cultural services; and d) ecosystem supporting services. Because these services must continue to meet human needs, each of these services becomes an objective. Examination of each objective within the context of the goals of sustainability and the main assumption for achieving those goals reveals a set of prerequisites for meeting these objectives.

1. The reason that humans are interested in sustainability is that we want some assurance that this planet will be able to sustain human life indefinitely. We remain and adapt here or we perish (listed in column 1).
2. Because the environment is composed of complex and dynamic systems that we did not create, but within which humanity evolved, this assurance is best provided if nature is managed[26] to maintain natural structures, functions, and processes. This assumption is a prior condition to the sustainability goal listed above (listed in column 2).
3. Assurances that human life will be sustained is dependent upon ecosystem services as identified in the Millennium Ecosystems Assessment (MEA 2005) (provisioning, regulating, supporting, and cultural services), and intact social and economic systems (listed in column 3).
4. The ecosystems services and social and economic systems listed above are co-dependent and each is conditional upon the other five being intact. Therefore, adjacent to each service and system is listed the other five ecosystem services (listed in column 4). The

[26] This management could be achieved by Adaptive Management or natural systems managing themselves.

continued functioning of each of these is dependent upon a subset of conditions. For example an ecosystem provisioning service is the product of food stocks remaining secure, which in-turn is the product of secure crops, livestock, capture fisheries, aquaculture, and wild food products (these, too, are listed in column 4).

5. Column 5 aside each of the sub-set conditions listed above are the preconditions that must be met to achieve these sub-set conditions. For example, crops are secure (column 4) and require that soil regeneration and renewal are greater than or equal to soil erosion and depletion.
6. However, soil regeneration/renewal also depends upon soil parent material to provide new materials and minerals. Therefore, preconditions of achieving items listed in column 5 are listed in column 6.
7. Each column to the right identifies preconditions to conditions listed in columns to the left. These culminate in a list of criteria that can apply to land use (column 7). Often more than one criterion will apply to an individual condition listed in columns at the left.

The above procedure identified an extensive list of criteria that apply to maintaining natural systems so they continue to provide ecosystem services. Their use within the context of land-remediation is to provide a structure for making sustainable land use decisions that integrate environmental qualities and effectively manages human activities with regard to them. An example of this search for criteria is illustrated in table 4-1 and more fully in the Appendix. Because the ‘Sustainability Goal’ and the ‘Assumption’ that natural systems must remain intact and able to manage themselves or be managed to mimic natural structures, functions, and processes remains constant throughout, columns 1 and 2 that these topics occupy are omitted from this example, but shown in the Appendix.

Table 4- 1 -- Example of search for criteria

Column 3	Column 4	Column 5	Column 6	Column 7
Requirement to sustain human life	**Conditions of column 3**	**Condition of column 4**	**Condition of column 5**	**Criteria**
Ecosystem provisioning services are intact (MEA).	Ecosystem regulating services, ecosystem supporting services, ecosystem cultural services (MEA), social systems, and economic systems remain intact			
Condition of requirement listed in column 3				
	Food stocks remain secure.	"The integrity of interactions between species is critical… (Hassan, *et al*. 2005)"	Habitats exist that will sustain minimum viable and effective populations of native species. Connectivity between habitats exist.	Criteria are determined from evaluating each of the sub-objectives of this sub-objective. – see below
	Sub-condition to above condition			
	Crops are secure	Soil regeneration and renewal ⟨ erosion + depletion + contamination	Soil parent material provides new material and minerals Soil organisms (fungi, bacteria) exist to decompose organic and inorganic matter. Plant crops are not vulnerable to widespread infestations and diseases.	- Soil is renewed by deposition of weathered soil and rock. - Adequate moisture exists to make nutrients soluble. - Soil chemistry and pH sustains native soil microorganisms and plants. - Growing trees and plants bring nutrients from deep soils to form cellulose at the surface where it decomposes. - Organic natural wastes are abundant. - Genetic diversity exists (Andersen 2006). - Native and non-native species are isolated from each other.
	Livestock is secure.	Range vegetation provides adequate feed. Rangeland has adequate vegetative cover. Genetic diversity is maintained. Adequate water is available.	Livestock is not vulnerable to widespread infestation and disease.	All of above criteria + - Livestock genetic diversity exists.

Table 4-2 – Criteria for Sustainable Natural Systems

System Component	No	Prerequisite of Intact Natural System	Site	Regional
Productivity	1	Productive biomass of any land area is at near-natural levels.		X
	2	Native plants predominate the ecosystem		X
	3	Growing trees and plants bring nutrients from deep soils to form cellulose at the surface where they decompose.		X
	4	Native coastal mangroves, wetlands, seagrass beds, and coral reefs are intact.		X
	5	Water chemistry of sea-water is sufficient to maintain photosynthesizing plankton.		X
Biodiversity	6	Genetic diversity exists.		X
	7	Native and non-native species are isolated from each other.	X	X
	8	Fragments of truly native environments remain intact.	X	X
	9	Natural disturbance regimes exist or are simulated when they can not exist.		X
	10	Distribution of redundant species is maintained across multiple time and space scales.		X
	11	Habitats exist in configurations, sizes, and quality that meet physiological and behavioral needs of native populations and communities.		X
	12	Habitats are refreshed/renewed with clean water.		X
	13	Native spawning/birthing/hatching sites continue to exist in useful condition.		X
	14	Connectivity between spawning/birthing/hatching sites and maturation areas and return is open and accessible (including migration).		X
	15	Individual species and communities are widely dispersed beyond the range of any disturbance regime.		X
	16	Connectivity between habitats is redundant and grain is appropriate for native species.		X
	17	Unique environments remain intact.	X	X
Soils	18	Soil minerals are renewed.		X
	19	Adequate moisture exists to make nutrients soluble.		X
	20	Soil chemistry and ph sustains native soil bacteria, microorganisms, and plants.	X	X
	21	Organic natural wastes are abundant.		X
Water	22	Ground water recharge ⟨ withdrawals.		X
	23	Surface water recharge ⟨ all combined water uses.		X
	24	Wetlands exist to purify waters.	X	X
	25	Avenues for groundwater recharge are clean.	X	X
	26	Air and water must be clean enough for autotrophs to live.	X	X
	27	Water quantity and speed of surface flows meet historic cycles, durations, and intensities.	X	X
	28	Soil compaction/impermeability and soil cover do not increase runoff above near-natural levels.	X	X
	29	Trees/plants break the force of falling rain and loosen soil to allow absorption and slow runoff.	X	X
Air/Atmosph	30	Sufficient forests exist to generate Hydroxyl radicals to process pollutant levels in the atmosphere.		X
	31	New deciduous forests and crops exist in higher latitudes and old forests exist to consume CO_2.		X
Energy	32	Forests exist in sufficient contiguous sizes to translate and moderate energy influx.		X

Criteria often apply to multiple objectives and sub-objectives as shown in column 7 of the Appendix. This creates duplicates that were eliminated by re-arrangement of criteria into system components, i.e., natural productivity, biodiversity, soils, water, air/atmosphere and climate, energy, social systems, and economic systems. Criterion 44 (Resource use is linked with investment in resource renewal.), for example, is applicable to meeting nearly all objectives at both regional and site scales. Tables 4-2, 4-3, and 4-4 illustrate this re-arrangement to simplify their application to land uses in the planning process. This enables land use decisions that assure the protection of ecosystem services. It graphically illustrates which criteria must be addressed at the site and/or regional scales to maintain ecosystem services. Boxes marked “X” identify the scales at which criteria are applied.

Table 4-3 —Criteria for Sustainable Social Systems

System Component	No	Prerequisite of Intact Social System	Site	Regional
Social	33	A history and progression of how people faced problems is evident and transparent.		X
	34	Places that provoke spiritual feelings remain intact.		X
	35	Plant and animal taxonomy is documented.		X
	36	People are able to freely interact and share ideas, labor, and resources.		X
	37	Individuals have a voice in matters that affect them.	X	X
	38	Risks to human life/health are known.	X	X
	39	Human life is isolated from stochastic events.	X	X
	40	Institutions exist to serve collective society.		X
	41	Health risks are monitored and potential risks are made public.	X	X

Table 4-4 – Criteria for Sustainable Economic Systems

System Component	No	Prerequisite of Intact Economic System	Site	Regional
Economic	42	Materials are efficiently used and reused as much as possible.		X
	43	Waste is attenuated by environmental processes.		X
	44	**Resource use is linked with investment in resource renewal.**	X	X
	45	Qualitative community resources are improved.	X	X
	46	Net economic effects > costs incurred to natural systems.	X	X
	47	Net economic effects > costs incurred to social systems.	X	X
	48	Consumption of natural resources is counted as a cost.	X	X
	49	All costs are calculated before being incurred.	X	X
	50	Financial resources are sufficient to maintain community infrastructures, institutions, and services.		X

The criteria of natural (Table 4-2), social (Table 4-3) and economic (Table 4-4) systems are interrelated. Although the focus of this compilation is on criteria of intact natural systems, social and economic systems are addressed because if they do not remain intact, natural systems will be compromised.

4.3. A THEORY OF CRITERIA APPLICATION

The planning process enables us to meet human objectives within a set of conditions, and concepts of sustainability and protection define these relationships. Typically, these conditions are defined in non-environmental terms: budgets constrain how much money or time can be used to meet objectives, building codes constrain how the building is designed to be structurally sound and safe for occupants, and structural requirements place limits on strength and properties of materials. Because sustainability is also a conditional relationship between human needs and ecosystem services that largely fulfill those needs, these conditions define the environmental constraints within which land use is possible without compromising the natural systems that sustain human life. The use of these conditions as planning criteria provides a structured methodology for meeting human land use objectives while retaining the environmental conditions that also meet needs of future generations.

4.3.1. Criteria Application: Example 1 – Provisioning Services

Ecosystem provisioning services supply food, fiber, materials, genetic resources, and biochemicals and medicines. Because essential providers of these services are plants and animals, it is essential that these survive. However, survival of species depends upon their having the natural resources that they have evolved to utilize and require. If human land uses require these same resources, either native species or humanity will suffer. The appendix and table 4.1 illustrate how these criteria based upon these relationships were derived. This example explains how they are applied to land use decisions.

Nature controls whether a species will survive, but people can control whether the opportunities for species survival exist. The challenge to those who plan land uses and make land use decisions is to assure that land uses do not compromise the resources that are required to sustain native species. Decision-makers can respond to criteria that relate to these species in several ways; and land uses can take several forms:

i. The built environment should be planned to occupy land that does not affect stream flows or quality.
ii. Dams and the need for dams that block migrating fish can be eliminated.
    a. Landscapes and agriculture can consist of plants that do not need stored water from streams/rivers to irrigate.
    b. Fish ladders can be created to enable fish migrations.
iii. The built environment can be created so that surface runoff volume, velocity, intensity, and duration are no greater than without development.
iv. The built environment can assure that water quality is maintained in all stream flows.
    a. Landscape barriers between development and streams can be created so that all runoff is filtered before it enters streams and water quality is maintained.
    b. Waste water can be processed before entering streams.
    c. Activities that block fish migrations by increasing stream temperatures can be avoided.
v. The built environment can be created using environmentally friendly materials and processes that do not pollute waters.
vi. Timber production, road construction, and building construction can avoid creating sediments in streams.

vii. Agriculture can avoid excessive use of nitrates that leach into streams and create hypoxia zones at sea.

4.3.2. Criteria Application: Example 2 – Regulating Services

Ecosystem regulating services maintain air, atmosphere, soil, and water qualities. They also control pests and diseases, assure pollination, and moderate natural hazards. We do not have the ability to provide these services sufficient to meet human needs and nature gives them freely. This example illustrates one of these services, air quality.

Condition or sub-objective: Air quality regulation occurs.

1st level Condition: Atmospheric CO_2, methane, nitrous oxide, and other green-house gases remain balanced.

2nd level Condition: Natural quantities of hydroxyl radicals exist in the atmosphere to convert pollutants into less harmful chemicals (Hassan, *et al*. 2005).

3rd level Condition: Sufficient forests exist to generate hydroxyl radicals to process pollutants in the atmosphere.

This third level condition can be used to affect land use change during the planning process. The challenge to planners is to create the built environment that keeps these forests intact or reduces the amount of forests that are needed to compensate for the effects of the built environment. Planning responses that change land uses can take several forms.

i. The built environment can be planned to occupy land where forests do not grow.
ii. Land within such forests can be used in a manner that keeps forest intact.
iii. Agricultural lands can be reconfigured to restore units of forest.
iv. Land no longer used by people can be reclaimed as forests.
v. The built environment can be planned so that sufficient acreage of forest land remains intact.
    a. Transport vehicles can be designed to use non-polluting fuels.
    b. Communities can be designed to be walkable so that fewer polluting vehicles are needed.
    c. Mass transit can be implemented to reduce the number of polluting vehicles.
    d. Buildings can be designed to use renewable energy.
    e. Food can be produced locally so that fewer vehicle miles are needed for transport.

4.3.3. Criteria Application: Example 3 – Regulating Service

This second example of regulating services addresses climate change.

Condition or sub-objective: Climate is naturally regulated and unaffected by people.

1st level Condition: Greenhouse gases do not accumulate in the atmosphere beyond their ability to return to normal background levels.

2nd level Condition: Rooted plants pump water from soil and release it into air as water vapor (Prugh, *et al*. 1999).

3rd level Condition: Native plants predominate across the landscape[27].

4th level Condition: Minimum viable habitats exist beyond the range of stochastic events

4th level Condition: Obligatory dependent species exist.

The use of these conditions as planning criteria prescribes and measures the impact of alternative land use decisions related to climate. Planning responses to these criteria can be to:

i. Use native plants to landscape the built environment.
ii. Configure the built environment in the voids between contiguous viable habitats.
iii. Develop more compact built environments to protect native landscapes.
iv. Eliminate the use of fuels that pose risks to native plants in the form of acid rain.

4.3.4 Criteria Application: Example 4 – Cultural Services

Ecosystems are valuable to human culture because they create cultural diversity provide knowledge systems, inspire us, provide a sense of place and recreation, and are integral to spiritual, religious, and education values. This example examines cultural diversity.

Condition or sub-objective: Cultural diversity.

1st level Condition: A cultural memory exists from which to learn how to live so that the resource base is sustained.

2nd level Condition: A history and progression of how people faced past problems is evident and easily interpreted.

Planning responses to this second level condition or criterion can be:

[27] Because native plants are well-adapted to local environments, they provide some assurance that the level 3 prerequisite can be met.

i. Land uses conform to local climate, geology, habitat requirements of native species, plant and animal community ecology, natural disturbance regimes, etc.
ii. Buildings are shaped by local climate and materials availability, and the physical form of the built environment reflects the combination of local influences that reflect uniqueness of place.

4.3.5. Criteria Application: Example 5 – Supporting Services

Ecosystem supporting services are ecological processes that maintain the integrity and functionality of the environment.

Condition or sub-objective: Geochemical cycling, storage, mineral-gaseous cycles, and water and air quality is maintained.

1st level Prerequisites: Raw materials are extracted from the ground without increasing concentration or byproducts in the ecosphere (Rosenblum 1999a), and manufactured or disposed materials do not become concentrated in the ecosphere (Rosenblum 1999b).

2nd level Prerequisites to both of the above:

Materials are efficiently used and reused.

Wastes are released into the environment-at-large in amounts that can be transformed or attenuated by extant environmental processes.

Environmental impacts are systematically counteracted to the extent possible.

Planning responses to this criterion can be:

i. Minimizing disturbances to land during development of the built environment
ii. Use of renewable resources rather than mined resources
iii. Developing the built environment on already disturbed land while minimizing disturbance of natural areas
iv. Use of recycled materials rather than new materials
v. Reclaiming damaged lands
vi. Employing trees and plants (phytoremediation) to extract geological and produced chemicals from soils

vii. Planing the built environment so that less material is needed and less embodied energy is required to produce materials

4.4. THEORETICAL EVALUATION OF CRITERIA USE

An evaluation of the use of the criteria developed above is based upon three outcomes.

1. Is EPA's mission to protect and safeguard human health and the environment closer to being realized?
2. Is the vitality of these sites increased?
3. Is the environment more sustained and able to sustain human life and activities?

The first measures of the criteria developed above are whether the intent of the National Environmental Policy Act of 1969 and the Environmental Protection Agency's central objectives are realized: (a) Has a productive and enjoyable harmony between humanity and environment been achieved? A harmonious relationship requires that the needs of one party to the relationship are reflected in the actions of the other party. Because Nature is a non-negotiating party to this relationship, only humanity can adjust its actions to conform to the needs of nature. The criteria in this report establish the conditions of this relationship and enable people to integrate these into land use decisions. (b) Are efforts promoted that will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of people? The only way to prevent damage and provide protection is to anticipate and evaluate possible outcomes of activities before actions are implemented. Because the criteria in this report are applied in the planning process, these criteria allows for prior evaluation . The health and welfare of people are interwoven with the health of the economy and the environment. Conditions of all three of these were used to develop the criteria in this report. Their use as planning criteria enables prior consideration and integration into human land use activities. (c) Has the understanding of the ecological systems and natural resources important to the Nation been enriched? Criteria developed in this report are based on relationships between society, the economy, and the environment within a dual context, that humanity both affects ecosystem services and is the beneficiary of them. Application of these criteria within the planning process is pivotal to understanding how Nature and Nation are interconnected.

Secondly, these criteria should measure whether sites to which they have been applied have more value. If valuable, these criteria should enhance a site's contribution toward more robust economic, social, and environmental systems. Applied to land that is subject to cleanup and

reuse, these criteria provide human, economic, and environmental contexts for infusing new life into lands where life has waned. Because opportunities for application of these criteria are fewer on sites that are already developed and contained within the urban fabric, sites to be revitalized require renewal of the site within larger spatial and temporal contexts.

Land use decisions are predominantly issued within the context of a bounded parcel of land. These are addressed by programs such as LEED[28], Green Globes[29], Sustainable Sites Initiative[30], New Urbanism[31], and Smart Growth[32]. They provide decision support tools that minimize the environmental impacts of land use decisions. These tools are essential to enable environmentally responsible site development. However, minimizing environmental impacts are not enough to sustain the environment. Effects of those land uses will radiate from the site into the broader local, regional, landscape, continental, and global environments where site owners and users have no authority. This presents those involved in land remediation with three issues to resolve if land remediation is to be instrumental in environmental sustainability. First, land is typically revitalized one site at a time so that there are seldom any decisions that can be made off site or at a regional scale. Although individual sites are included in regional environments, the regional context of land use decisions is not subject to change. Second, because the land is already impacted by the proximate built environment, the option to resolve environmental impacts before development is not available. Third, land remediation does not determine whether progress toward sustainability[33] occurs; sustainability is the product of how land is used *after* remediation. These land remediation issues can be resolved as follows:

1. Cleaning a site to remove or isolate its risks to human life and the environment is the starting point. Because procedures for site remediation exist, they are not addressed here.

[28] Leadership in Energy and Environmental Design is a green building program by the US Green Building Council. http://www.usgbc.org/

[29] Green Globes is a green building program by the Canadian equivalent of the LEED program (see above). http://www.greenglobes.com/design/homeca.asp

[30] Sustainable Sites Initiative is a program by the American Society of Landscape Architects, the Lady Bird Johnson Wildflower Center, and the US Botanic Garden to measuring how a site can protect, restore and regenerate ecosystem services. http://www.sustainablesites.org/report/

[31] The Congress of New Urbanism is establishing new standards for green design at the neighborhood http://www.cnu.org/

[32] The Smart Growth Network us a partnership between the US EPA and several non-profit and government organizations to encourage development that serves the economy, community and the environment. http://www.smartgrowth.org/about/default.asp

[33] One Cleanup Program (OCP) is an EPA initiative promoting cross-program coordination in EPA's Land Revitalization Office to ensure that cleaned sites remain clean. http://www.epa.gov/swerosps/bf/tools/lts_fs_10_2006.pdf

2. The site's functional roles in natural systems must be restored. After remediation, land revitalization sites must be addressed individually within a natural systems framework. Because nature's response to how we use land is the ultimate measure of our land use decisions, this natural systems context is essential.
3. New land uses on the site must retain the site's restored natural system structures, functions, and processes. The criteria for re-establishing a natural systems framework will enable these land use decisions to be made. Because new development will also impact the broader environment, a community-wide program that enables land users to participate in counteracting the broader effects of land uses on individual sites must be enacted.

Third, as the title of this report suggests, an important measure of these criteria is whether the restored environment is more sustained and better able to sustain human life and activities. Development of these criteria is based upon protecting and perpetuating the ecosystem services that sustain human life. If human activities are also planned to keep natural systems intact, then the environment should also be more sustained.

4.4.1. Evaluation of Sustainability Criteria

Questions concerning these criteria may relate to the feasibility of their use and whether this list is accurate, complete, and sufficient to enable land use decisions that also keep natural, social, and economic systems intact. Because these criteria will be used before they are verified by science, it is likely that these criteria are incomplete. Their application should reveal that some criteria developed here are not useful, need refinement, or new criteria will be required.

4.4.2. Feasibility of Using Planning Criteria

Applications of criteria that relate to intact natural systems are feasible because they merely add another layer of conditions to a planning process that already exists and to which all participants are familiar.

A first question about the feasibility of using criteria relates more to whether sufficient information exists to enable good decisions. Many of the gaps in our knowledge of ecosystems (Heinz 2002) could inhibit the ability of planners to adequately meet some of these criteria. These gaps are important but do not paralyze one's ability to make land use decisions. These criteria define environmental qualities that we want to maintain; therefore, all potential land uses

can be evaluated before they are made. These criteria instruct how to make decisions and measure them.

A second question regarding feasibility relates to economic considerations. Because of the costs of delaying a project, adding a review to address natural systems will undoubtedly cost more than not doing so. However, low impact development procedures, e.g., how to handle storm water (PBS 2008), can be less expensive than more traditional engineered solutions. Concerns over costs often evaluate short and immediate costs and neglect long-term costs. If these environmental costs are considered, the importance of using criteria to plan land uses that eliminate environmental impacts becomes readily apparent.

A third question of feasibility relates to whether anyone can be required to meet these preconditions. Washington State recently required that new home developments reduce the flow of polluted storm water to local water systems (PBS 2008). This may eventually be tested in the courts; however, numerous precedents exist that impose legal requirements on land uses. Zoning codes have been formalized since 1916, and the U.S. Supreme Court upheld zoning in 1926 in *Euclid v. Ambler Realty Company*. This case challenged that zoning constituted a taking of property rights.

A similar challenge could be made against any regulation that required the imposition of these criteria in making land use decisions. However, these criteria do not infringe on property rights. They merely state that an individual can use owned property as current laws allow as-long-as such use meets certain criteria. The fact that meeting these criteria would also align such land uses with the rights of downstream property owners and all of society who also have rights and would be affected by such land uses should strengthen the legal case for using these criteria.

4.4.3. Sufficiency of criteria

As land use development to meet human needs continues without considering natural systems, these systems will be compromised. If humans are to avoid serious decrease in environmental quality, they must consider the impacts their actions will have on the environment. The value of these criteria is that they provide a means to consider functioning natural systems in the decision-making process well in advance of impacting land.

If every planning team were to ask how to meet human needs within these preconditions of natural systems, meeting these criteria within the planning process will enable us to meet both objectives. Compiling the results of implemented plans will form a catalogue of responses that

will be applicable to many land uses and different environmental conditions. Even if this set of criteria is insufficient, it enables consideration of natural systems during current land use decisions. Attempts to use these criteria constitute experiments that will generate data to improve them and to test the hypothesis presented earlier in this report. These experiments will help to develop a firm scientific basis for creating a sustainable human-environment relationship.

5. CONCLUSIONS

Land uses often become outmoded leaving under-utilized and sometimes polluted sites that have little value and impose costs to these communities. Communities must pay for urban infrastructures that bypass these sites without obtaining revenue from them and must add infrastructures to newly developed lands. These costs could be eliminated and revenues generated if outmoded sites were revitalized with new uses. The question is how these sites can be renewed so that they will be sustained by environmental, social, and economy systems, that will be able to sustain human life. The interrelationships among these three systems make each conditional upon the others. Because meeting conditional human objectives is achieved in the planning process, these relationships can be accommodated if the essential attributes of these intact systems can be identified. This report identified the criteria for making land use decisions, but their application to sites subject to land remediation requires that these criteria be applied within the spatial and temporal contexts of land remediation on proximate sites. Remediation and redevelopment of any individual site may contribute to a local economy and society, but little to sustaining the ecosystem within which it is contained. This will require that natural structures, functions, and processes that usually reside on or in the land be renewed and reconnected to the ecosystem. This is possible if land use decisions made on each site are made within an ecosystems context, so that decisions made on all sites over time will be made using the same ecosystem references or criteria. This report developed the criteria for making sustainable land use decisions and established the natural systems contexts that give order to land use decisions on sites subject to land-revitalization.

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APPENDIX

Essential Attributes of Natural Systems

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Sustainability Goal	Condition of meeting the objective	Requirement to sustain human life	Condition of column 3	Condition of column 4	Condition of column 5	Criteria
Assurance that Earth will be able to sustain human life --------or-------- Future options or opportunities will exist. --------or-------- Human life will be able to remain and adapt in place (Benyus 1997).	Natural systems remain intact and able to manage themselves.	Ecosystem Provisioning services are intact (Sarukhan and Whyte 2005).	Ecosystem Regulating services remain intact (see column 3). ----------and---------- Ecosystem Supporting services remain intact (see column 3). ----------and---------- Social systems remain intact (see column 3). ----------and---------- Economic systems remain intact (see column 3).	Natural processes exist: Energy flux, dissipation, climate modulation. Hydrological flux, hydrological cycle, water quality. Biological productivity, plant pollination. Biogeochemical cycling, storage, mineral-gaseous cycles, water-air quality. Decomposition, weathering, soil development-stability, soil quality. Biological diversity. Absorbing, buffering, diluting, detoxifying pollutants-zenobiotics.		
		Condition of requirement listed in column 3				
		"	Food stocks remain secure	"The integrity of interactions between species is critical for the long-term preservation of human food production on land and in the sea (Hassan, *et al*. 2005)."	Habitats exist that will sustain minimum viable and effective populations of native species and connectivity between habitats exist.	See criteria below
			Sub-condition to above condition			
		"	Crops are secure.	Soil regeneration and renewal ⟨ erosion + depletion.	Soil parent material provides new material and minerals.	1. Deposition of weathered soil and rock occurs on site.
		"	"	"	"	2. Growing trees and plants bring nutrients from deep soils to cellulose where it decomposes on site.
		"	"	"	Soil organisms (fungi and bacteria) exist to decompose organic and inorganic matter.	3. Soil chemistry and pH sustains native soil bacteria, microorganisms, and plants.
		"	"	"	Plant crops are not vulnerable to widespread infestations and diseases.	4. Plant genetic diversity exists (Andersen 2006).
		"	Livestock is secure.	Range vegetation provides adequate feed. Rangeland has healthy vegetative cover. Genetic diversity is maintained. Adequate water is available for livestock.	Livestock is not vulnerable to widespread infestations and diseases.	See notes above 5. Livestock genetic diversity exists.
		"	Capture fisheries are secure.	Viable populations of native fishes exist.	Native communities are sufficiently intact to fend off non-native invasive species, or invasive species are artificially controlled.	6. Fish habitats exist in sizes, and configurations that are able to sustain fish populations.
		"	"	"	Fishes have the ability to repopulate after their population has been decimated by capture or stochastic events.	7. Habitat connectivity and interaction exists
		"	"	"	Fish capture ≤ population renewal and replenishment.	
		"	"	"	Viable populations of native anadromous fishes have access to spawning beds.	8. Rivers and stream are negotiable to migrating fishes in upstream and downstream directions.
		"	"	"	Pelagic habitats sustain minimum viable populations of native fishes.	9. Native spawning beds continue to exist in useful condition.
		"	"	"	Pelagic resources are sufficient to sustain reproducing fish populations + predations + harvests.	10. Water chemistry of sea-water is sufficient to maintain photosynthesizing plankton.
		"	"	"	"	11. Viable pelagic fish populations must exist in habitats beyond the range of stochastic or man-made event that would risk loss of any population.
		"	"	"	Freshwater habitats exist	12. Supply of clean water is available to renew freshwater habitats.

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Sustainability Goal	Condition of meeting the objective	Requirement to sustain human life	Condition of column 3	Condition of column 4	Condition of column 5	Criteria
Assurance that Earth will be able to sustain human life --------or-------- Future options or opportunities will exist. --------or-------- Human life will be able to remain and adapt in place (Benyus 1997).	Natural systems remain intact and able to manage themselves.	"	"	"	Fish nurseries exist in nutrient rich coastal areas.	13. Native coastal mangroves, wetlands, sea grass beds, and coral reefs remain intact or are restored.
		"	Aquaculture is secure.	Aquaculture relieves pressures on wild fishes.	Genetic diversity is conserved and integrity of aquatic communities are maintained (Gaard 1998).	14. Aquaculture and native fishes are isolated from each other.
		"	Wild food products are secure.	Nature's diversity is more sustained (Holling 2000).	Minimum viable populations (MVP) of native species exist.	15. Habitats exist that will maintain MVP beyond the range of stochastic events.
		"	"	"	Minimum genetically effective populations of native species exist.	16. Habitat connectivity meets native species requirements and is redundant.
		"	"	Diverse forms of native life thrive in viable communities	Environmental dependencies are met, and obligate and symbiotic relationships are fulfilled.	17. Native habitats exist in forms that sustain minimum dynamic populations of native species in native communities.
		"	"	"	"	18. Resources exist to support migratory species.
		"	"	"	"	19. Unique environments are protected.
		"	"	"	"	20. Natural disturbance regimes exist or are simulated where they can not exist.
		"	"	"	"	21. Nursery and spawning areas remain undisturbed.
		"	"	"	"	22. Migration routes remain open between maturation areas and birth/spawning areas, and between summer and winter feeding areas.
		"	"	"	"	23. Distribution of redundant species is maintained across multiple time and space scales (Alberti 2005 from Nystrom and Folke 2001).
		"	"	"	"	24. Connectivity between habitats is redundant and grain is appropriate for native species.
		"	"	"	The environment exists in forms to which behaviors of different species have adapted.	25. Environment meets behavioral requirements for native species, e.g., night light over oceans is greater than land so as to attract young turtles to the ocean upon hatching. (species specific)
		"	"	"	The environment exists in forms that meet physiological needs of native species.	26. The environment meets physiological needs of native species, e.g., soil moisture content is sufficient to sustain native plants (species specific).
		"	"	"	Soil renewal/generation 〈 depletion / loss.	See 1, 2, and 3.
		"	"	"	Native seed stock and genetic material exists.	See 15-26.
			Sub-conditions to above condition			
		"	Water replenishes living cells with nutrients, regulates and renews bodily fluids and temperature, and removes wastes.	Water quantity is sufficient to hydrate living cells.	Water use (direct + indirect + amount needed to sustain other essential life) ≤ water replenishment (natural hydrological cycles + technology + recycling)	27. Projected water demand is calculated prior to use and use is limited to availability.
		"	"	Damaging forces of water are limited to background levels except for catastrophic events.		28. Trees/plants break the force of falling rain and loosen soil to allow absorption and slow runoff (Prugh, *et al*. 1999)
		"	"	Water quality poses no risk to life.	All surface and ground water is free of contaminates	29. Avenues for groundwater recharge are clean
		"	"	Earth forming sculpting capacity is maintained.		30. Water quantity and speed of surface flows meet historic cycles, durations, and intensities.
		"	Fiber	Soils are fertile.	See above	See above
		"	Timber	Soils are fertile.	See above	See above

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Sustainability Goal	Condition of meeting the objective	Requirement to sustain human life	Condition of column 3	Condition of column 4	Condition of column 5	Criteria
		"	Cotton, hemp, silk	Soils are fertile.	See above	See above
		"	Wood fuel	Soils are fertile.	See above	See above
		"	"	The cumulative environmental impact of obtaining food, fiber, and energy ≤ the capacity of the environment to renew these resources.		See 46-48,
Assurance that Earth will be able to sustain human life --------or-------- Future options or opportunities will exist. --------or-------- Human life will be able to remain and adapt in place (Benyus 1997).	Natural systems remain intact and able to manage themselves.	"	Genetic resources	Native biodiversity is intact	Species composition is maintained.	31. Habitats are capable of supporting minimum dynamic populations of native species.
		"	"	"	Native plant communities exist in viable dynamic populations.	32. Habitats exist in sizes and distributions that can sustain native populations beyond the range of disturbance regimes.
		"	"	"	Species have the ability to repopulate after decimated by stochastic events.	See 15-26.
		"	"	"	Environments that native species are adapted to remain intact.	See 20.
		"	Biochemicals, natural medicines, and pharmaceuticals	See food and wild genes above.	See food and wild genes above.	See 1, 3, 6-13, 15-32.
		Ecosystem Regulating services are intact (Sarukhan and Whyte 2005).	Ecosystem provisioning services are intact (see column 3). ----------and---------- Ecosystem supporting services remain intact (see column 3). ----------and---------- Social systems remain intact (see column 3). ----------and---------- Economic systems remain intact (see column 3).	Energy is exchanged in trophic regimes. 1st level – Primary producers or native green plants 2nd level – Primary consumers or herbivores (animals and insects) 3rd level – secondary consumers or carnivores 4th level – tertiary consumers or carnivores that feed on other carnivores 5th level – decomposers or organisms such as fungi and bacteria that break down dead or dying matter in to nutrients.	Native plant and animal species exist in native communities.	See 1, 3, 6-13, 15-32.
		"		Energy gradients are neutralized.	Energy is translated and moderated (Mollison 2001).	33. Forests exist in sufficient contiguous sizes to translate and moderate the amount of energy that is incoming.
		Conditions of requirement listed in column 3				
		"	Air quality regulation	Atmospheric CO_2, methane, nitrous oxide, and other GHG remain balanced.	Natural quantities of Hydroxyl radicals exist in the atmosphere to convert pollutants into less harmful chemicals (Hassan, *et al*. 2005)	34. Sufficient forests exist to generate Hydroxyl radicals to meet pollutant levels in the atmosphere.
		"	"	The process of soil respiration oxidizes carbohydrates	Denitrifying bacteria frees nitrogen from wastes and returns it to the atmosphere.	See 3.
		"	Atmospheric gas regulation	Plant growth results in a net withdrawal of CO_2 from the atmosphere and sequesters C in plant tissues.and releases O_2 to the atmosphere (Prugh, *et al*. 1999).	Natural productivity is at near-natural condition.	35. Productive biomass of any land-area meets historic levels.
		"	"	Photolysis uses high UV radiation to break down water and nitrite into component atoms H and N and allows them to escape into space leaving O_2 in the atmosphere.	Oceans sustain photosynthesis.	See 38.
		"	"	Bacteria keep nitrogen, sulfur, and phosphorus in circulation (Prugh, *et al*. 1999).		See 3.

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Sustainability Goal	Condition of meeting the objective	Requirement to sustain human life	Condition of column 3	Condition of column 4	Condition of column 5	Criteria
		"	"	Ecosystems modulate the gaseous composition of the atmosphere (Prugh, *et al*. 1999).	Ecosystem structures, functions, and processes remain intact.	See 1-36.
		"	Climate regulation (global)	Evapotranspiration and energy flux remains at historic patterns.	Rooted plants pump water from soil and release it into air as water vapor (Prugh, *et al*. 1999).	36. Native plants predominate
		"	Climate regulation (regional and local)	Climate is naturally regulated and unaffected by human influences.	Greenhouse gases do not accumulate in the atmosphere beyond its ability to return to threshold levels.	See 36.
		"	Carbon cycle is maintained.	Carbon cycle is maintained in the atmosphere.	Photosynthesizing plants convert CO_2 into carbohydrates and release O_2.	37. New deciduous forests and crops exist in higher latitudes. Old forests exist to consume CO_2.
Assurance that Earth will be able to sustain human life --------or-------- Future options or opportunities will exist. --------or-------- Human life will be able to remain and adapt in place (Benyus 1997).	Natural systems remain intact and able to manage themselves.	"	"	Carbon is maintained in the biosphere.	Autotrophs produce organic compounds using CO_2 from air or water.	38. Air and water must be clean enough for autotrophs to live.
		"	"	"	Photosynthesizing forests on land and phytoplankton in oceans produce O_2.	See 37.
		"	"	"	Long term carbon storage and release is through natural processes and unaffected by human acts.	See 35-37.
		"	"	Carbon is maintained in the ocean	No human influences on carbon exchange between ocean and atmosphere.	38. Ocean chemistry and pH sustains native planktonic communities.
		"	Nitrogen cycle is maintained.	Nitrogen compounds (proteins and nucleic acids) are available to all living things. Nitrogen is incorporated into compounds, e.g., nitrate ions, ammonia, and urea.	Lightning breaks nitrogen molecules enabling their atoms to combine with O_2 to form nitrogen oxides. Rain dissolves nitrogen oxides forming nitrates and carries them to earth.	39. Plant and animal wastes are abundant. See 1-4, 27-30, 35, 36
		"	"	"	Bacteria and archaea form symbiotic relationships with plants to form ammonia to be incorporated into protein and organic nitrogen compounds.	See above
		"	"	"	Microorganisms break down molecules in excretions and dead organisms into ammonia.	See above
		"	"	"	Plants take up ammonia through their roots and convert it into nitrates.	See above
		"	"	"	Autotrophic nitrifying bacteria (Nitrosomonas oxidize NH3 to nitrites (NO_2) and Nitrobachter oxidize nitrites into nitrates (NO_3) making nitrogen available to plant roots.	See above
		"	"	"	Archaeal microbes convert ammonia to nitrites.	See above
		"	"	"	Legumes fix atmospheric nitrogen and convert organic nitrogen to nitrites and nitrates and release them to soil when they shed their leaves.	See above
		"	"	"	Denitrification reduces nitrates to nitrogen gas replenishing the atmosphere.	See above
		"	"	"	Bacteria living deep in anaerobic soil and sediments use nitrates as an alternative to O_2 in respiration. (see Air Quality Respiration Col 4)	See 2, 3, 36,
		"	Water cycle is maintained.	Hydrologic system is intact.	Solar energy vaporizes surface water.	Unrelated to human activities
		"	"	"	Plants transpire	See 36.

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Sustainability Goal	Condition of meeting the objective	Requirement to sustain human life	Condition of column 3	Condition of column 4	Condition of column 5	Criteria
		"	"	"	Solar energy combined with variations of altitude and latitude creates uneven heating of surfaces driving air circulation, carrying and distributing water vapor.	Unrelated to human activities
		"	"	"	Warmer moist air condenses in cooler dryer air to form precipitation.	Unrelated to human activities
		"	"	"	Precipitation replenishes surface and ground water.	See 27-30, 35, 36, Distribution of precipitation is influenced as it would be with native vegetation. Storage of precipitation is the same as it would be with native vegetation.
		"	Water regulation	Timing and magnitude of runoff, flooding, and aquifer recharge are near historic patterns.	Trees/plants break the force of falling rain and loosen soil to allow absorption and slow runoff (Prugh, *et al*. 1999)	See 27-30.
		"	Erosion regulation	Erosion and its deposits assist land sculpting and land formation.	Patterns of erosion follow historic patterns. .	See 1-4, 28.
		"	"	Earth resists erosive forces and holds depositions.	Plant roots anchor soils (Prugh, *et al*. 1999).	See 1-4.
Assurance that Earth will be able to sustain human life --------or-------- Future options or opportunities will exist. --------or-------- Human life will be able to remain and adapt in place (Benyus 1997).	Natural systems remain intact and able to manage themselves.	"	Water purification and waste treatment	Wetlands exist to purify waters.	Hydric soils and plants process water.	See 27, 29, 30.
		"	"	Waters flow to enable water aeration.	Turbulence exists in flowing water.	See 28-30.
		"	"	The amount of contaminant < capacity of water attenuation.		See 29.
		"	Disease regulation	Diseases rarely overwhelm populations.	Natural structures and systems are robust to develop natural resistances.	
		"	"	The human body is resilient against diseases, infections, and pathogens.	Microorganisms of the human body remain intact.	
		"	Pest regulation	Infestations restart the process of succession without decimating ecosystem provisioning services.	Full complement of natural enemies exists to resist and recover from infestations.	Nearly all apply.
		"	"	Stocks exist to recover from infestations.	Full complement of genetic resources exists for succession.	See 15-26, 31, 32.
		"	Pollination	Redundant means of plant pollination exist.	Native plants offer resources that pollinators require.	See 36.
		"	"	Pollinators survive.	Air, water, other insects, and pathogens pose no threats to pollinator vitality.	Nearly all apply.
		"	Natural hazard regulation	Climate and energy gradients < historic patterns ----------or---------- Climate hazards to land areas are within stochastic regimes.	Soil carbon is at natural background levels.	See 36. Native forests remain sufficiently intact so as to store 86% of the planet's above ground carbon and 73% of the plant's soil carbon. (http://en.wikipedia.org/wiki/Carbon_cycle)
		"	"	"	Soils remain receptive to natural precipitation.	40. Soil compaction and soil cover does not increase runoff above background levels.
		"	"	"	Native plants hold moisture	See 36.
		"	"	"	Wetlands, lakes, soils process and store precipitation.	See 27, 29, 30.

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Sustainability Goal	Condition of meeting the objective	Requirement to sustain human life	Condition of column 3	Condition of column 4	Condition of column 5	Criteria
		Ecosystem cultural services are intact (Sarukhan and Whyte 2005).	Ecosystem provisioning services are intact (see column 3). ----------and---------- Ecosystem regulating services are intact (see column 3). ----------and---------- Ecosystem supporting services remain intact (see column 3). ----------and---------- Social systems remain intact (see column 3). ----------and---------- Economic systems remain intact (see column 3).			
		Conditions of requirement listed in column 3				
		"	Cultural diversity	A cultural memory exists from which to learn.		41. A history and progression of how people faced problems is evident and transparent.
		"	Knowledge systems	Fragments of truly native environments remain intact.		43. Fragments of truly native environments remain intact.
		"		Remnant native plants exist in viable numbers in viable native habitats.		See 15-26, 30-32
		"		Plant and animal taxonomy is known.		44. Plant and animal taxonomy is documented.
Assurance that Earth will be able to sustain human life --------or-------- Future options or opportunities will exist. --------or-------- Human life will be able to remain and adapt in place (Benyus 1997).	Natural systems remain intact and able to manage themselves.	"	Educational values	Diversity of experiences is possible.	Natural systems remain intact. Unique physical features of the environment remain intact. All interrelationships remain intact.	See 15-26, 30-32
		"	Inspiration and aesthetic values	Complete fully functioning remnants of every ecosystem remain intact.		See 15-26, 30-32
		"	Sense of place	Unique traits of native ecosystems remain. Unique and typical human cultural responses to local and regional environmental conditions are recognizable.		See 29, 41.
		"	Cultural heritage values	Typical human responses to local and regional environmental conditions are recognizable.		See 41.
		"	Recreation and ecotourism	Natural areas exist. Diverse environments exist. Complete fully functioning remnants of every ecosystem remain intact.		All apply.
		"	Social relations	Problems get resolved quickly and efficiently.		45. People are able to freely interact and share ideas, labor, and resources.

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Sustainability Goal	Condition of meeting the objective	Requirement to sustain human life	Condition of column 3	Condition of column 4	Condition of column 5	Criteria
		Ecosystem supporting services are intact (Sarukhan and Whyte 2005).	Ecosystem provisioning services are intact (see column 3). ----------and---------- Ecosystem regulating services are intact (see column 3) ----------and---------- Social systems remain intact (see column 3). ----------and---------- Economic systems remain intact (see column 3).			
		Conditions of requirement listed in column 3				
		"	Geochemical cycling, storage, mineral-gaseous cycles, and water-air quality is maintained.	Raw materials must be extracted from the ground without their concentration in the ecosphere (Rosenblum 1999a)		46. Materials are efficiently used and reused as much as possible. 47. Waste is attenuated by environmental processes. 48. All environmental impacts are systematically counteracted.
		"	"	Manufactured materials can not become concentrated in the ecosphere (Rosenblum 1999b).		See 46-48.
		"	Soil formation	Native soil parent materials exist. Soil losses do not exceed background levels. Soil parent material is subject to weathering and decomposition	Soil organisms, bacteria, yeast cells, fungi, algae, and protozoa contribute to soil fertility and waste decomposition breaking it into C, H, N, S and P so they can be used again by other plants (Prugh, *et al*. 1999). and processes that spread seeds, nourish soils, etc, continue to exist.	See 1-3, 27-29.
		"	"	The process of weathering breaks down parent material (rocks) into soil particles.	Plants and animals accelerate weathering by contributing CO_2 and organic acids (Prugh, *et al*. 1999).	See 1-3, 15-26, 27-29.
		"	"	"	Decomposing microorganisms release CO_2 and H_2O into soil and leave humus.	See 2, 3.
		"	"	"	Decomposing microorganisms release CO_2 and H_2O into soil and leave humus.	See 2, 3.
		"	"	Soil losses are balanced with soil formation (natural + technological generations and maintenance)	Decomposition, weathering, soil development-stability, soil quality renew soils at rates > erosion + soil depletion.	See 1-3.
		"	"	Nitrogen is fixed at natural background level of about 10 million tones per year	Soil remains clean enough to sustain microorganisms that allow soil bacteria to live in association with roots.	See 1-4, 27-30, 35, 36
		"	"	The amount of reactive nitrogen in terrestrial ecosystems remains at the level that natural N-fixation occurs.	Organisms exist that feed on plants with nitrogen fixing roots, and release it in organic wastes	See 1-4, 27-30, 35, 36
		"	"	Sulfur is fixed at natural background level.	Sufficient microorganisms exist to convert sulfur into sulfide. Sulfur is not exposed to oxygen and water.	See 1-3. 27-29. 46-48

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Sustainability Goal	Condition of meeting the objective	Requirement to sustain human life	Condition of column 3	Condition of column 4	Condition of column 5	Criteria
		"	"	Phosphorus (P) residue is restricted to agriculture uptake with no residues released to any aquatic ecosystem so that only natural P cycles exist in the environment.	Aquatic ecosystems contain only natural P cycles.	See 1, 4, 46-48.
		"	Hydrologic flux, hydrologic cycle, and water quality is maintained.	Stream/river flows follow historic patterns	Wetlands, lakes, soils process and store precipitation.	See 27, 29, 30.
		"	Primary production	Primary producers are able to convert sunlight to biomass	Photosynthesizing vegetation breaks down CO_2 and H in water to create sugars and O.	See 35, 36.
		"	"	"	Photosynthesizing phytoplankton in oceans breaks down CO_2 and H in water to create sugars and O_2.	See 10.
		"	"	"	Photosynthesizing cyanobacterium Prochlorococcus in oceans breaks down CO_2 and water to create sugars and O_2.	See 10.
		"	Nutrient cycling	Nutrient loads in streams/rivers and water bodies is unaffected by human activities.		See 29, 30.
		"	Energy flux, dissipation, and climate modulation is maintained.	Solar energy is converted to usable heat, kinetic, and light energy.		See 20, 36.
		"	Climate is not changed by anthropogenic causes.	The amount of incoming solar radiation and infra-red re-radiation is balanced.	Elements extracted from the geosphere remain below toxic levels in the ecosphere (Rosenblum 1999a).	See 46-48
		"	Absorbing, buffering, diluting, detoxifying pollutants-zenobiotics.	Pollutants-zenobiotics do not exceed the ability of natural systems to process them.	Elements produced by society remain below toxic levels in the ecosphere (Rosenblum 1999).	See 46-48
		"	Biological productivity is maintained.	Net primary productivity (NPP) follows natural trajectory.	Natural disturbance and seral recovery regimes remain intact.	See 20, 36.
		"	"	"	Nature's functions and diversity are not impoverished by physical displacement, over-harvesting, or ecosystem manipulation (Rosenblum 1999c).	See 1-40,

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Sustainability Goal	Condition of meeting the objective	Requirement to sustain human life	Condition of column 3	Condition of column 4	Condition of column 5	Criteria
Assurance that Earth will be able to sustain human life --------or-------- Future options or opportunities will exist. --------or-------- Human life will be able to remain and adapt in place (Benyus 1997).	Social systems remain intact -----or-------- Human behavior, organizational structures, and institutional arrangements mediate the relationships between people and nature (Holling 2000)	Social systems assure that all people will have the opportunity to meet needs, that their needs will be provided when faced with nature's capriciousness, and that investments will be made for the benefit of society.	Ecosystem provisioning services are intact (see column 3). ----------and---------- Ecosystem Regulating services remain intact (see column 3). ----------and---------- Ecosystem supporting services remain intact (see column 3). ----------and---------- Economic systems remain intact (see column 3).			
		Conditions of requirement listed in column 3				
		Physiological needs of human life are satisfied (see 'provisioning services' above).	The means of human livelihood is accessible, human opportunities are richer (Holling 2000).	Breathing	The atmosphere contains a mix of gasses that human life requires.	See "Air quality regulation" and "Atmospheric gas regulation" under "Ecosystem regulating services".
		"	"	Drinking	Approximately 5 liters of potable water/person/day is available for consumption.	See "Water replenishes…" under "Ecosystem provisioning services".
		"	"	Eating	Food provides dietary reference intakes and estimated energy requirements per USDA and Institute of Medicine, National Academies	See "Food stocks", "Crops", "Livestock", "Capture fisheries", "Aquaculture", and "Wild plant and animal food products" under "Ecosystem provisioning services".
		"	"	Excreta	Soil organisms, bacteria, yeast cells, fungi, algae, and protozoa contribute to soil fertility and waste decomposition breaking it into C, H, N, S and P so they can be used again by other plants (Prugh, *et al*. 1999).	
		"	"	Sex: The number of births + immigrants 〈 mortality	The population is viable and genetically effective.	
		Safety/Security A predictable and orderly world.	Natural systems that sustain human life remain intact.	Human actions and behaviors become aligned with conditions of intact natural systems.	Social systems are planned to meet human needs within conditions of intact natural systems.	See Natural Systems conditions above.
		"	"	"	Economic systems are planned to meet human needs within conditions of intact natural systems.	See Natural Systems conditions above.
		Personal security	Equity and justice is afforded everyone		Justice prevails. Human rights are institutionalized.	
		"	Institutions exist to serve collective humanity.			See 52.
		"	Community values affect change	Direction of change is a product of human values.	Values are known. A structure exists for making social decisions.	See 52.
		"	"	Individual change is within the context of collective social interests.	Individual decisions relative to society reflect individual values.	49. Individuals have a voice in matters that affect them.

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Sustainability Goal	Condition of meeting the objective	Requirement to sustain human life	Condition of column 3	Condition of column 4	Condition of column 5	Criteria
Assurance that Earth will be able to sustain human life --------or-------- Future options or opportunities will exist. --------or-------- Human life will be able to remain and adapt in place (Benyus 1997).	Social systems remain intact -----or-------- Human behavior, organizational structures, and institutional arrangements mediate the relationships between people and nature (Holling 2000)	Financial security			Labor and a means to exchange labor for goods and services are guaranteed.	
		Health and well-being	Opportunities to live a healthy life are possible. Opportunities to recover lost health are assured. Pursuit of either does not compromise personal or financial security.			50. Risks to human life/health are known.
		"		Human body temperature is maintained @ 98.6 F	Food, fiber, and energy is readily accessible to individual use.	See Natural Systems conditions above.
		"		Pathogens strengthen human natural defenses without overwhelming them.		See Natural Systems conditions above.
		"	Human life is shielded from harmful radiation.	Atmospheric ozone remains intact to absorb UV-B solar radiation.	The atmosphere provides a pool of oxygen from which ozone is formed in the upper atmosphere (Prugh, *et al*. 1999).	See 52.
		"		Exposure limits for all human health risks.	Toxins and heavy metals do not accumulate in human occupied portions of the environment.	See 46-48, 52
		"	Human health needs are met	50 liters of clean water is available per person per day for sanitation, bathing, and cooking (Asian Development Bank)		
		"	"	Medical institutions and laboratories exist to solve and find ways to prevent illnesses and injuries.		See 50, 52.
		"	"	Natural systems retain native diversity that reduces risks of infectious diseases in humans (Hassan, *et al*. 2005).		See Natural Systems conditions above.
		Safety nets against accidents, illnesses, nature's capricousness		.	Surpluses can be generated and saved. Risks can be distributed to society. Human behaviors/acts align with those of nature.	
		"	Stochastic events pose minimal risk to human life.	Human life is not subjected to hazardous effects of known natural disturbances.		51. Human life is isolated from stochastic events.
		"	"	Upland vegetation remains intact (especially forests).	Surface runoff is at historic volumes, velocities, and cutting power.	See 27, 29, 30, 33, 36, 37, 40,
		"	"	Energy gradients are dissipated without harm to human life.		See 33, 36.
		"		Society is shielded from invasions.	Institutions exist to protect society and resolve disputes efficiently, quickly, and equitably.	52. Institutions exist to serve collective society.
		"		Effects of Nature's capriciousness is borne by society.	Knowledge is sought regarding natural systems.	See 52.
		"		"	Institutional responses to Nature's capriciousness is efficient, quick, equitable, and based upon sound knowledge and economic judgment to meet societal interests.	See 52.
		"			Protecting natural systems is a social interest.	See 52.
		"	Risks to human life and health are known.	Right to safe environment is institutionalized	The condition of the environment is monitored and reported.	See 52. 53. Health risks are monitored and potential risks are made public.
		"	"	Population never exceeds carrying capacity of natural systems.	Natural checks exist on all living things.	

Assurance that Earth will be able to sustain human life --------or-------- Future options or opportunities will exist. --------or-------- Human life will be able to remain and adapt in place (Benyus 1997).	Social systems remain intact -----or-------- Human behavior, organizational structures, and institutional arrangements mediate the relationships between people and nature (Holling 2000)	Social needs	Sense of belonging and acceptance.	Friendship	Opportunities to gather with people who share similar ideals/values exist.	
		"	"	Intimacy	Opportunities for person to person interactions exist. Rules of interactions are understood and followed.	
		"	"	Family	Opportunities exist to belong to a group irrespective of race, creed, social status, appearance, or gender.	
		Esteem needs	Respect and be respected with self-esteem.	Someone witnessed that an individual's life existed and had value.	Opportunities exist to use and perfect individual talents. Opportunities exist for others to observe individual talents.	
		Self-actualization	Growth	The drive to transcend the normal and strive for a higher ideal.	The ability to see the imperfect and to seek and obtain the skills to improve.	
		Human culture remains intact	Formal knowledge evolves to meet human needs.			See 52
		"	Traditional knowledge is preserved and known.	Languages of indigenous people are alive.		See 52
		"	"	Traditional medicinal plants are documented and protected.		See 52, 1-4, 6-13, 15-30, 36.
		"	"	Local agricultural traditions and practices are documented and kept alive.		See 42, 44.

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7
Sustainability Goal	Condition of meeting the objective	Requirement to sustain human life	Condition of column 3	Condition of column 4	Condition of column 5	Criteria
Assurance that Earth will be able to sustain human life --------or-------- Future options or opportunities will exist. --------or-------- Human life will be able to remain and adapt in place (Benyus 1997).	A system of production and distribution of goods and services meets human needs and expectations for these goods and services.	The role of any economic system is to efficiently and equitably allocate resources to needs.	Ecosystem provisioning services are intact (see column 3). ----------and---------- Ecosystem Regulating services remain intact (see column 3). ----------and---------- Ecosystem supporting services remain intact (see column 3). ----------and---------- Social systems remain intact (see column 3).			
		Efficiency Conditions				
		Natural capital is available.	Nature's functions and diversity are not impoverished by physical displacement, over-harvesting, or ecosystem manipulation (Rosenblum 1999c).	The laws of thermodynamics govern material and energy use.	Use of a finite system will increase reduce future usability. Because this is not sustainable, the system must be improved as something is taken, renewable resources must be used, and/or substitues must be developed before resource depletion.	See 48. Resource use is linked with investment in resource renewal (Lovins, *et al*. 1999; Daly 2002).
		Human capital is available	Creative individuals exist to address complex problems (R. Florida).	Creative individuals have the ability to share ideas.	Repositories exist to share ideas and knowledge.	See 48
		"	Labor pool exists	Incentives to labor exist: Needs, expectations, and/or growth of laborers are fulfilled.	See "Social Systems remain intact" in section above.	See 48, 50.
		Human-made capital can be invested.	Things that are produced are usable as tools that increase efficiency rather than liabilities that consume capital for their disposal.			See 43-47
		Energy is secure and affordable	Energy sources are diverse.			See 43-48
		Equity Conditions				
		Individuals and society are not burdened with costs that exceed benefits.		Full costs of energy and resources are calculated and evaluated prior to production or extraction.		51. Qualitative community resources are improved (Kinsley 1994; USEPA 1998). 52. Net economic effects > costs incurred to natural systems. 53. Net economic effects > costs incurred to social systems. 54. Consumption of natural resources is counted as a cost (Daly 2002) 55. All costs are calculated before being incurred. 56. Financial resources are sufficient to maintain community infrastructures, institutions, and services.

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