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Linked Visualizations in Sustainability Modeling: An Approach Using Participatory GIS for Decision Support

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Why Community and Regional Sustainability Matters

The World Commission on Development and Environment in 1987 published in *Our Common Future* that sustainable development is defined as the ability of humanity *"to ensure that it [development] meets the needs of the present without compromising the ability of future generations to meet their own needs"*. Because water is such a fundamental resource and one of the first to be degraded during development, a Task Force of Civil Engineers explain in *Sustainability Criteria for Water Resource Systems* that "*Sustainability is an integrating process. It encompasses technology, ecology, and the social and political infrastructure of society. It is probably not a state that may ever be reached completely. But is it one for which we should continually strive. And while it may never be possible with certainty to identify what is sustainable and what is not, it is possible to develop some measures that permit one to compare the performances of alternative systems with respect to sustainability."*[1] In 1999, the National Research Council published in *Our Common Journey: A Transition Toward Sustainability* that *"While many definitions about sustainable development have appeared, each sharing a common concern for the fate of the earth, proponents of sustainable development differ in their emphases on (1) what is to be sustained, (2) what is to be developed, (3) the types of links that should hold between the entities to be sustained and the entities to be developed, and (4) the extent of the future envisioned."*[2]

Drawing those views into focus, we suggest a perspective about "community and regional sustainability", making use of Farrell and Hart's (1998) description about competing social, economic, and environmental objectives for communities that may or may not be considered together with carrying capacities, and Rees' (1998) description about the importance of generational equity in sustainable community development. Bringing those concerns together, community and regional sustainability relates to growth management - a necessary link if community and regional sustainability is to make progress within current institutional contexts, as many communities plan under growth management laws for guiding decisions to improve quality of life (see figure next page).

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[1] Task Committee on Sustainability Criteria, Water Resources Planning and Management Division, American Society of Civil Engineers and Working Group UNESCO/IHP IV Project M-4.3 1998, *Sustainability Criteria for Water Resource Systems* p. 36.

[2] National Research Council 1999. *Our Common Journey: A Transition Toward Sustainability* National Academy Press, Washington, D. C. p. 23

Growth Management and Sustainability

Competing objectives, carrying capacity, and intra/inter-generational equity, combine to form a progression of weak to strong community and regional sustainability. Growth management concerns are about competing objectives and intra/inter-generational equity (weak and semi-strong sustainability), but growth management seldom addresses social, economic and environmental concerns simultaneously. The natural, physical, and social sciences continue to assess carrying capacity related to various social, economic and environmental concerns, the basis of "integrated assessment science" and considered the core of "sustainability science" (Kates et. al. 2001). Sustainability assessment cuts across jurisdictional boundaries, e.g., in watershed sustainability studies. Watersheds do not align themselves nicely with political governance – as the problems of sustainability do not either.

Social, Economic, and Environmental Objectives and Constraints	**Generational Equity** Intra-generational perspective	**Generational Equity** Intra- and Inter-generational equity perspectives
Competing objectives considered	***Weak sustainability*** as a concern about competing objectives from an intra-generational perspective commonly considered a growth management perspective	***Semi-strong sustainability*** as a concern about competing objectives and from an intra- and inter-generational perspectives sometimes considered a growth management perspective
Competing objectives and carrying capacity constraints considered	***Semi-strong sustainability*** as a concern about competing objectives and carrying capacity constraints from an intra-generational perspective	***Strong sustainability*** as a concern about competing objectives and carrying capacity constraints from intra- and inter-generational perspectives

A framework for characterizing community and regional sustainability in terms of three levels - weak, semi-strong, and strong. Weak and semi-strong sustainability can be considered "growth management" in some circumstances.

Across the U.S., business plans (with capital improvement programs) of City government departments do not link to comprehensive plans (or any of the neighborhood plans which are part of that Comprehensive Plan). That is, plans and programs may or may not be consistent – we really do not know; but, probabilities being what they are, the plans and programs are likely only somewhat consistent. That implies that society progresses without adequate understanding of the progress.

CIP Projects Should Link to Comprehensive Plans
CIP Projects Contribute to Community Sustainability

Growth management comprehensive plans vision a 20-year perspective, e.g., “Seattle’s Comprehensive Plan: Toward a Sustainable Seattle” (1994-2014) consisting of nine “elements”: Land Use, Transportation, Housing, Capital Facilities, Utilities, Economic Development, Neighborhood Planning, Human Development, Cultural Resources[3]. City Departments create business plans to guide their capital improvement program (CIP) project activities. Business plans are not necessarily consistent with the Comprehensive Plans because information system designs do not link them. The missing link makes it rather difficult to track performance in capital improvement programs as to whether projects contribute toward sustainability. For example, Seattle Public Utilities' CIP projects and planning efforts help meet goals of “dependable service, public health and environmental stewardship”. Tracking CIP projects can help assess progress toward community sustainability. Whether there is progress at community and/or regional scales is unknown, and a potential research topic as identified by the National Research Council (1999) Report entitled *Our Common Journey*. In fact, there have been many such research questions posed by members of that National Research Council group (Kates et. al. 2001).

Core Questions of Science and Technology for Sustainability
http://sustsci.harvard.edu/questions.htm

1. How can the dynamic interactions between nature and society – including lags and inertia – be better incorporated in emerging models and conceptualizations that integrate the Earth system, human development, and sustainability?

2. How are long-term trends in environment and development, including consumption and population, reshaping nature-society interactions in ways relevant to sustainability?

3. What determines the vulnerability or resilience of the nature-society system in particular kinds of places and for particular types of ecosystems and human livelihoods?

4. Can scientifically meaningful “limits” or “boundaries” be defined that would provide effective warning of conditions beyond which the nature-society systems incur a significantly increased risk of serious degradation?

5. What systems of incentive structures – including markets, rules, norms and scientific information – can most effectively improve social capacity to guide interactions between nature and society toward more sustainable trajectories?

6. How can today’s operational systems for monitoring and reporting on environmental and social conditions be integrated or extended to provide more useful guidance for efforts to navigate a transition toward sustainability?

7. How can today’s relatively independent activities of research planning, monitoring, assessment, and decision support be better integrated into systems for adaptive management and societal learning?

[3] accessed March 6, 2002, http://www.ci.seattle.wa.us/planning/CompPlan/CP0-AdoptionHistory.htm

City of Seattle - Sustainability Management System Model (draft)

a year to year total quality management perspective
incorporating sustainability modeling

Sustainability Policy based on Comprehensive Plan Values

Assess/Revise

- Baseline assessment of sustainability
- Determination of significant aspects
- **Create *value-objective-indicator trees appropriate for Comprehensive Plan***

Business Unit Plans for Community Capital Improvement Programs

Check

- Ongoing monitoring and evaluation using sustainability indicators expressed in appropriate information structures
- Multimedia Triple bottom line report

Plan

- Links between comp plan and business plans articulated as input to ***sustainability modeling process***
- Sustainability Action Agenda
- Cross-department plans

Do

- Departmental activities
- OSE work program makes use of ***sustainability modeling process examines sustainability progress on community capital improvement programs***
- Cross-departmental work, encouraging cooperation across business unit work programs

Research Questions about Participatory GIS Use in Sustainability Science Research

(Kates et. al. 2001 "Sustainability Science", Science, April, p. 642)

To address the broad-based research questions 6 and 7 (Kates et. al. 2001), we can pose a number of more specific research questions grouped in terms of a) information needs, b) information tool outcomes, c) participatory processes, and d) sustainability information outcomes. This grouping is based in part on research about collaborative decision support (Jankowski and Nyerges 2001).

1. Information Needs

a) What are the different levels of information needs, as organized by a conceptual framework, underpinning a comprehensive information architecture for urban sustainability management? Is this much the same or different than the Managing for Sustainability (MFS) framework? Are performance indicators and sustainability indicators at different levels of information? If so, how are they related to each other in the eyes of OSE staff?
b) What are the "components of a MFS-SMS conceptual framework" that link values in the Comp Plan to objectives in the department plans? How are components the same and different between a focus on local government sustainability activity and a community sustainability activity?

2. Information Tool Outcomes

a) How does a geospatial information architecture enhance and/or limit a City's urban sustainability management framework? What is the character of an information system architecture to support urban sustainability modeling in terms of indicator design, management, analysis, display, and reporting?
b) How critical are capabilities in geospatial information software in supporting the implementation of that architecture? What added information, (overall perspective) does a geospatial information approach provide?

3. Participatory Processes

a) How do organizational sustainability management processes at the City department level and overall city level influence the character of urban sustainability modeling? How does a total quality management perspective influence both the sustainability management process and the urban sustainability modeling process in terms of the conceptual framework for sustainability indicators that are needed by participants to conduct their activities?
b) How do the phases of tool use for urban sustainability management differ among a conventional tool environment, a face-to-face meeting arrangement with laptops, and a conference-call meeting arrangement?

4. Sustainability Information Outcomes

a) What are the different levels of information outcomes supported by the indicator information structures for urban sustainability management? Is/Was this much the same or different than the information provided by the use of conventional tools? In what way are/were performance information and sustainability information different, and how did this matter to OSE staff in the context of sustainability management?
b) What indicators needed by a city government sustainability perspective, also satisfy/satisfied needs for a community sustainability perspective? Which ones do/did not?
c) In what way does sustainability indicator information make a difference in the interpretation of how City Departments are influencing work undertaken by the city in regards to citizen quality of life improvement?
d) What are the gaps in our knowledge about the link between urban sustainability science and urban sustainability management? How might future developments of geospatial information tools support the closing of that gap?

SustainabilityModeling with Linked Information Structures

Linked information structures promote "deep knowledge"
about sustainability exploration, assessment, and evaluation

Comprehensive Plan and CIP Information from Assess/Revise Phase

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Value-directed indicator design, database development and mapping
Value-objective-indicators (VOI) trees are a basis for database design, development, and indicator mapping of CIP projects for Departments and City-wide

↓

Sustainability scenario exploration
Scenarios formed through situational indicator development using digraphs – a first step in simulation modeling. Scenario-based reference needed for interpretation of sustainability concerns

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Change and impact assessment
Compute before and after CIP project displays
Implement map displays using change/impact models linked to scenario VOI trees

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Sustainability decision evaluation
Develop sensitivity analysis displays to foster interpretation and evaluation of a balanced score card for Department and City-wide as appropriate to information need

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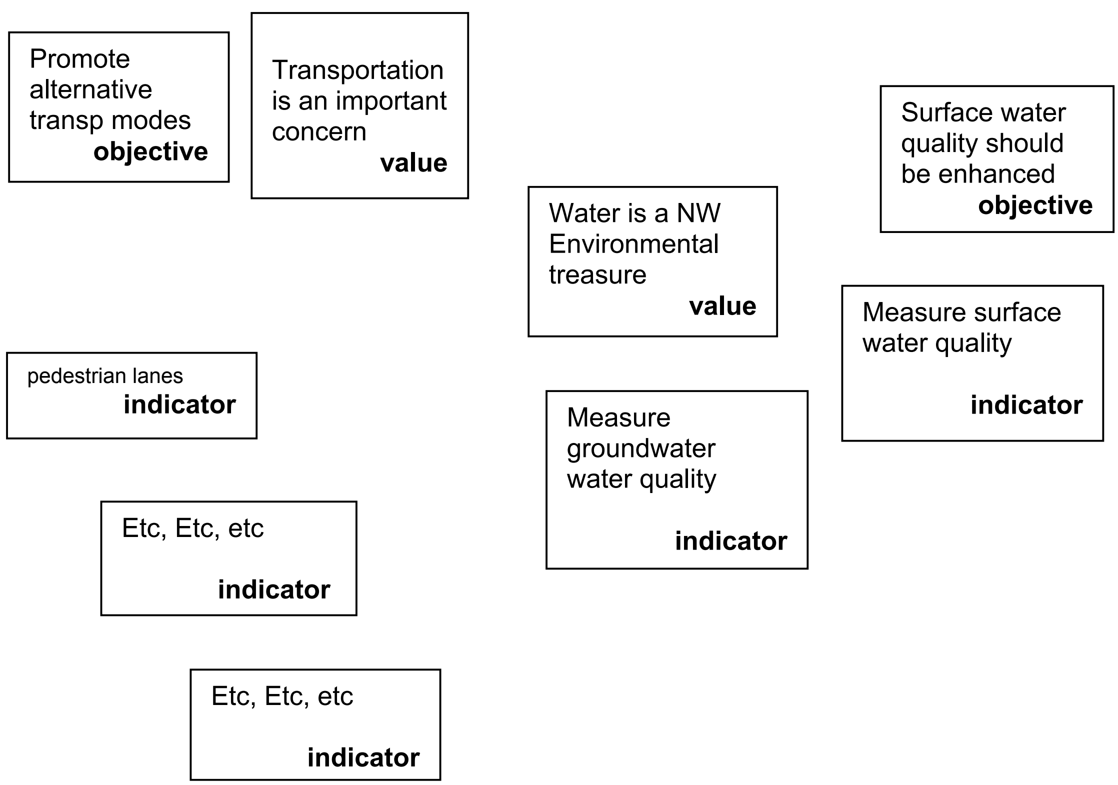
Contribution to Sustainability Action

Affinity Diagramming for Brain-writing in a Group
as a first step in
Value-directed indicator design and database development

Affinity diagramming starts as cards representing any issues/ideas/concerns related to the topic at hand (Brassard 1989). These issues/ideas/concerns could be values, objectives, and indicators created through group work activity about sustainable community develop. A Web-based, Participatory GIS is the expected platform to support this kind of group activity.

Indicators represent "publicly understandable data" as the measurements of "objectives and values". Indicators are not necessarily of the information content of "sustainability indicators", unless a reference frame is provided for time and space. If such indicators are publicly understandable, and measured across time and space, and represented at different levels of spatial aggregation, then they are candidates for "sustainability indicators".

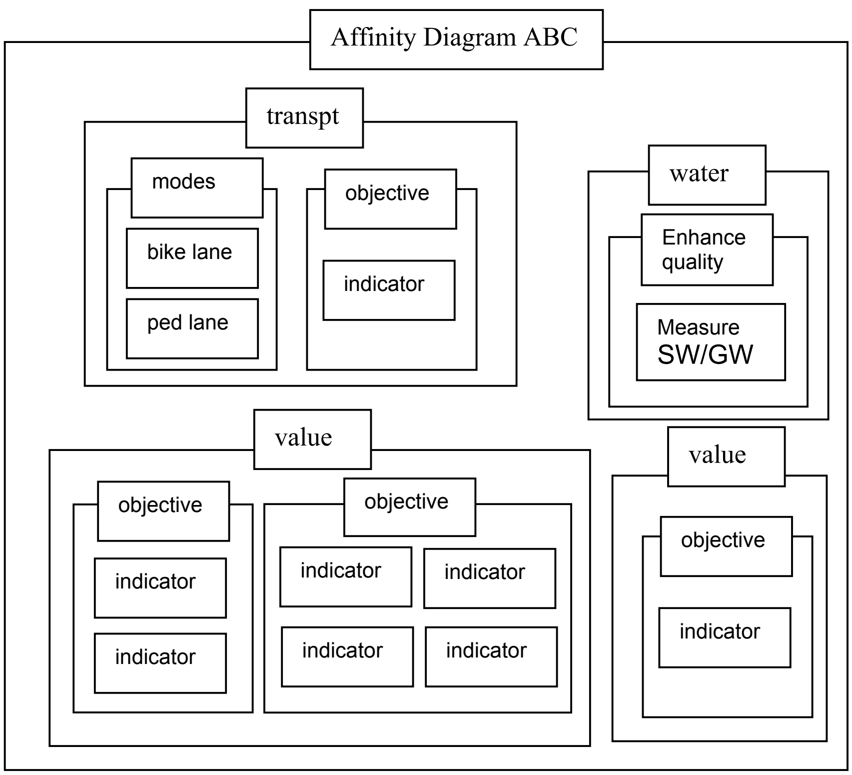
Stage 1 – the brain-writing stage – cards shown on a large screen display if only one computer; shown on individual screens THEN on large screen display if multiple computers



Organizing Content into an Affinity Information Structure
a basis for value-directed database development and mapping

Affinity diagramming moves on to a clustering of issues/ideas/concerns cards representing values, objectives, and indicators about sustainable community development

Stage 2 – Organizing the brain-writing stage – clustering by value, objective, indicators – is a facilitated process, e.g., Technology of Participation.
You can "see" the hierarchy in this information structure

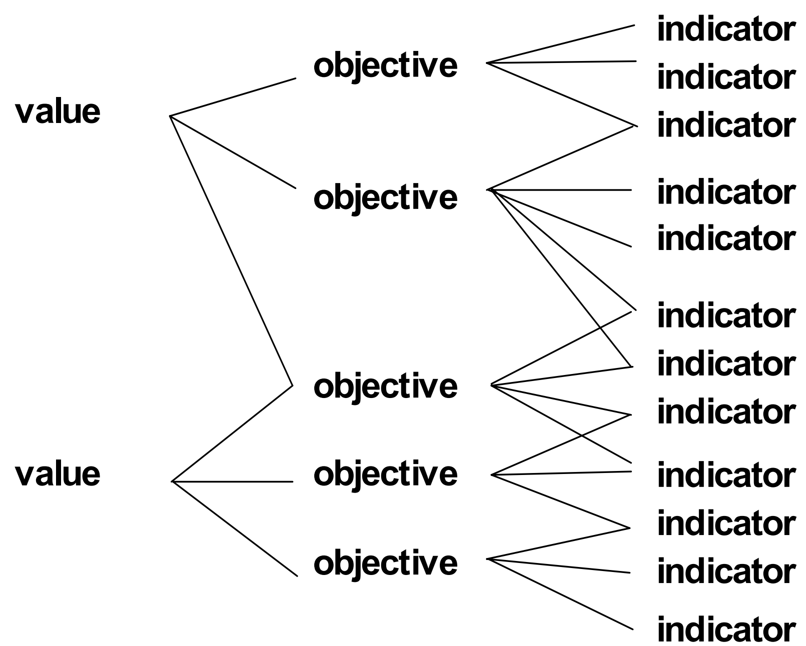


Values-Objectives-Indicators (VOI) Tree Information Structure

same content as in an Affinity Diagram ABC (previous figure)
but, **VOI tree** provides a different information structure

You can see the hierarchy as well (figure below), but you can also see multiple inheritance of concepts to uncover redundancy. Value trees (and when implemented in a specific setting – value structures), have been used to organize public values and objectives related to impacts of environmental projects (Edwards and von Winterfeldt 1987, Kenney, vonWinterfeldt, Eppel 1990).

VOI tree information structure will show what two or more objectives might share an indicator (measurement of objective, hence the values).



More values

More objectives

More indicators

Non project specific (broadly applicable)

Groupings of indicators are project specific

Another way of organizing the brain-writing of the group

again, similar content, but different structure Potentially a test of "tables versus graphics"

Values, Objectives, Indicators (VOI) Structure
based on Benchmark Program from the King County, WA

Value	**Objective**	**Indicator**
Economic Development	Promote family wage jobs	1. Real wages per worker
	Increase income and reduce poverty	2. Personal and median household income: King County compared to United States
		3. Percent of population below the poverty level
	Increase business formation, expansion and retention	4. New businesses created
		5. New jobs created by employment sector
	Create jobs that add to King County's economic base	6. Employment in industries that export from the region
	Increase educational skill levels	7. Educational background of adult population
		8. High school graduation rate
Environment	Protect and Enhance Natural Ecosystems	9. Land cover changes in urban and rural areas over time
	Improve Air Quality	10. Air quality
		11. Energy Consumption
		12. Vehicle Miles Traveled per year
	Protect water quality and quantity	13. Surface water and groundwater quality
		14. Water consumption
		15. Change in groundwater levels
	Protect wetlands	16. Change in wetland acreage and functions
	Protect the diversity of plants and wildlife	17. Continuity of terrestrial and aquatic habitat networks
	Increase salmon stock	18. Change in number of salmon
	Decrease noise levels	19. Rate of increase in noise from vehicles, planes and yard equipment
	Decrease waste disposal and increase recycling	20. Pounds of waste disposed and recycled per capita
Affordable Housing	Provide sufficient affordable housing for all King County residents	21. Supply and demand for affordable housing
		22. Percent of income paid for housing
		23. Homelessness
		24. Apartment vacancy rate
	Promote affordable home ownership opportunities	25. Home purchase affordability gap for buyers with (a) median renter household income and (b) median household income
		26. Home ownership rate
		27. Trend of housing costs vs. income
	Promote equitable	28. Public dollars spent for low income housing

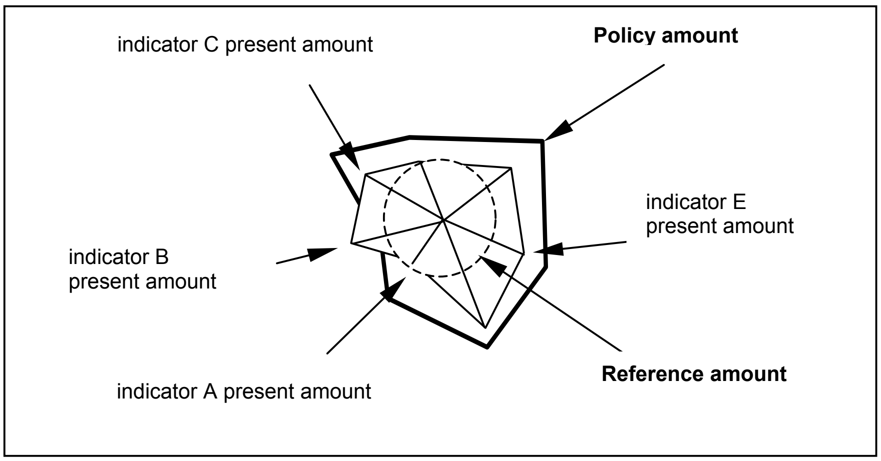
Value	Objective	Indicator
	distribution of affordable low-income housing throughout King County	
		29. Housing units affordable to low income residents
Land use	Encourage a greater share of growth in urban areas and urban centers; limit growth in rural/resource areas	30. New housing units in urban areas and rural/resource areas, and in urban centers
		31. Employment in urban areas, rural/resource areas, urban centers and manufacturing/industrial centers
	Make efficient use of urban land	32. New housing units built through redevelopment
		33. Ration of land consumption to population growth
		34. Ratio of achieved density to allowed density of residential development
		35. Ratio of land capacity to 20 year household and job targets
		36. Land with 6 years of infrastructure capacity
	Encourage livable, diverse communities	37. Acres of urban park and open space
	Balance job and household growth	38. Ratio of jobs to housing in Central Puget Sound Counties, and King County sub-regions
	Maintain quality and quantity of natural resource lands	39. Acres in forest land and farm land
		40. Number and average size of farms
Transportation	Transportation and land use linkage	41. Percent of residents who commute one-way within 30 minutes
	Availability of modes other than single occupant vehicle	42. Metro transit ridership
	Mode split	43. Percent of residents who walk or use transit, bicycles or carpools as alternatives to the single occupant vehicle
	Reduce commercial traffic congestion	44. Ability of goods and services to move efficiently and cost effectively through the region
	Protect and improve transportation infrastructure	45. Number of lane miles of city, county, state roads and bridges in need of repair and preservation

The indicator "leaves" of this tree represent the fundamental data categories in a database design for sustainability modeling. Such a database design could be expressed using a language such as the Unified Modeling Language (Rumbaugh, Jacobson and Booch 1999), but the two "information structures" would require integration.

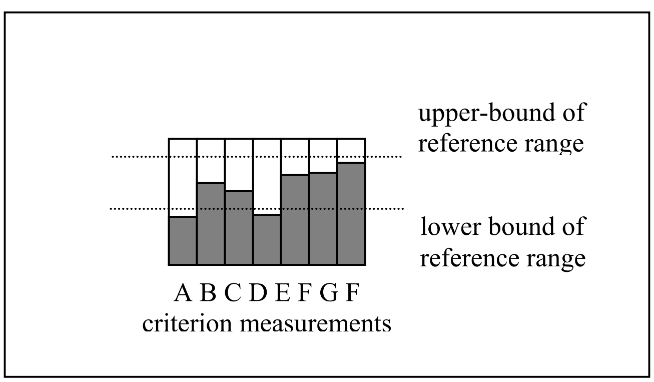
Mapping Multiple Indicators and Making Sense of the Displays

Indicators represent "publicly understandable data". If such measurements are publicly understandable, and measured across time and space, and represented at different levels of spatial aggregation, then they are candidates for "sustainability indicators" (Nyerges 2001).

Sustainability Index (collection of indicators) as an **AMOEBA**.
An AMOEBA map symbol for a CIP project (having multiple indicators)
depicts a set of baseline reference levels and policy threshold levels for indicator set



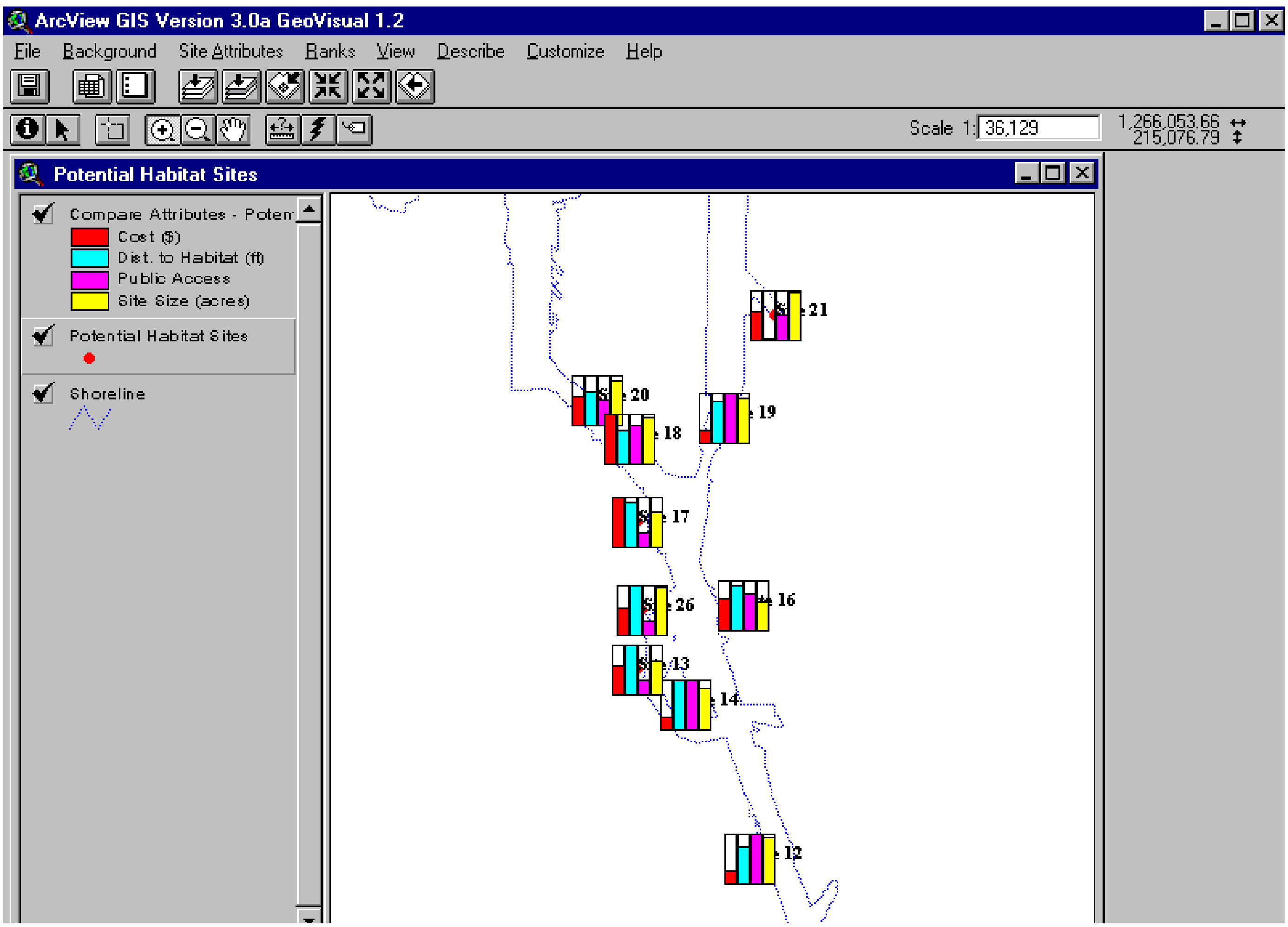
Sustainability Index (collection of indicators) as a set of **Histobars**.
A Histobar map symbol for a CIP project depicts lower and upper bounds
for baseline reference or threshold information



Empirical studies are needed to compare the interpretation of these types of symbolization in a group setting.

Histobar Displays of Project Sites

GeoChoicePerspectives software for collaborative spatial decision support makes use of "histobar" displays (See below). It is possible to set the histobar interpretation such that high bars (lots of colorful graphic) indicate more preferred habitat development sites. Sometimes low data values in a database, e.g., for cost of redevelopment, should be shown as high (more preferred) bar displays. For other attributes like site size, a mid-range of data values, e.g., between 3-5 acres, is more preferred for (re)development of a habitat area that either smaller or larger data values – thus, a user should be able to establish that type of visual interpretation.



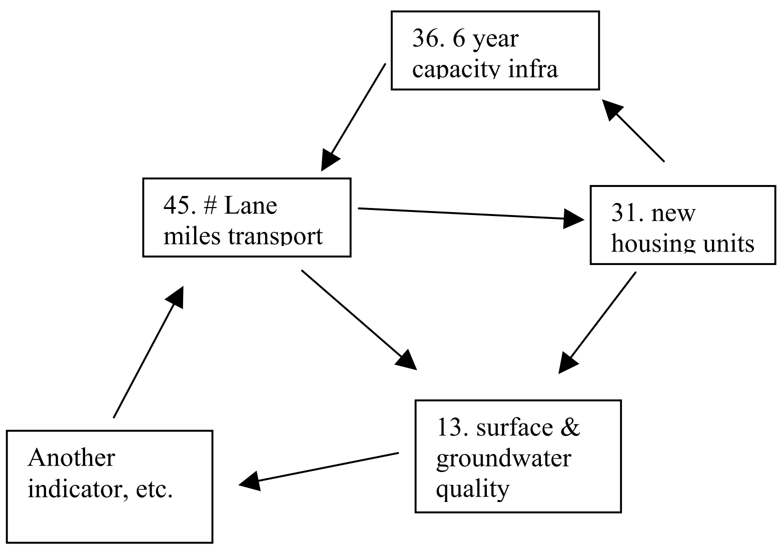
A histobar display of habitat attribute data in GeoChoicePerspectives

Basis of plate 1 in Jankowski, P. and T. Nyerges. 2001 *Geographic Information Systems for Group Decision Making*, Taylor & Francis, p. 114.

Sustainability Scenario Exploration with Pairs of Indicators Depict Causal Tendencies

Digraph diagram depicting relationships between/among King County indicators (indicator # shown) from previous table

Each arrow with a pair of indicators represents a situational indicator

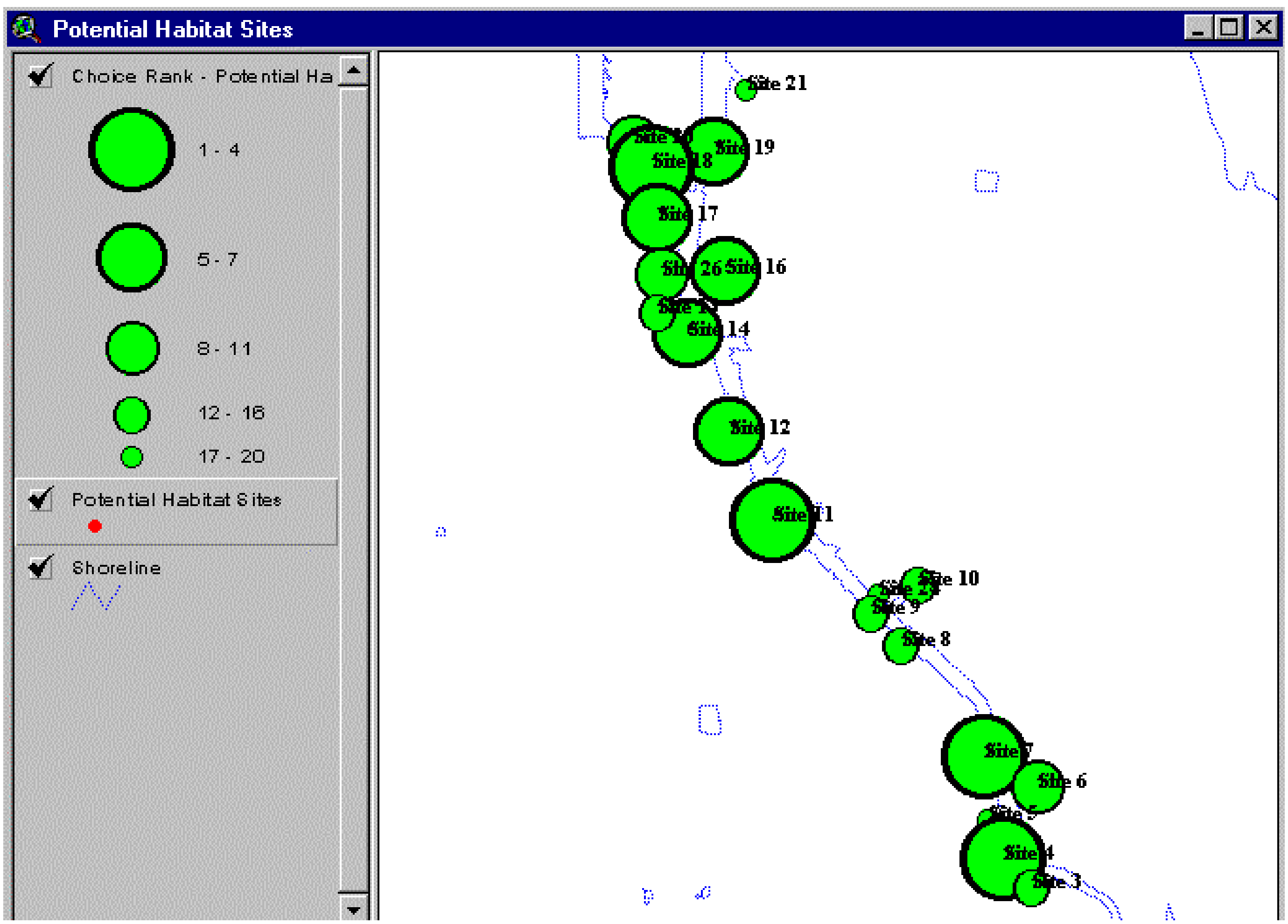


This is the "design" basis of a sustainability simulation model, and the basis for characterizing influences among impact measures.

Impact Assessment Maps Depict Impact Measures for Potential Habitat Redevelopment Project Sites

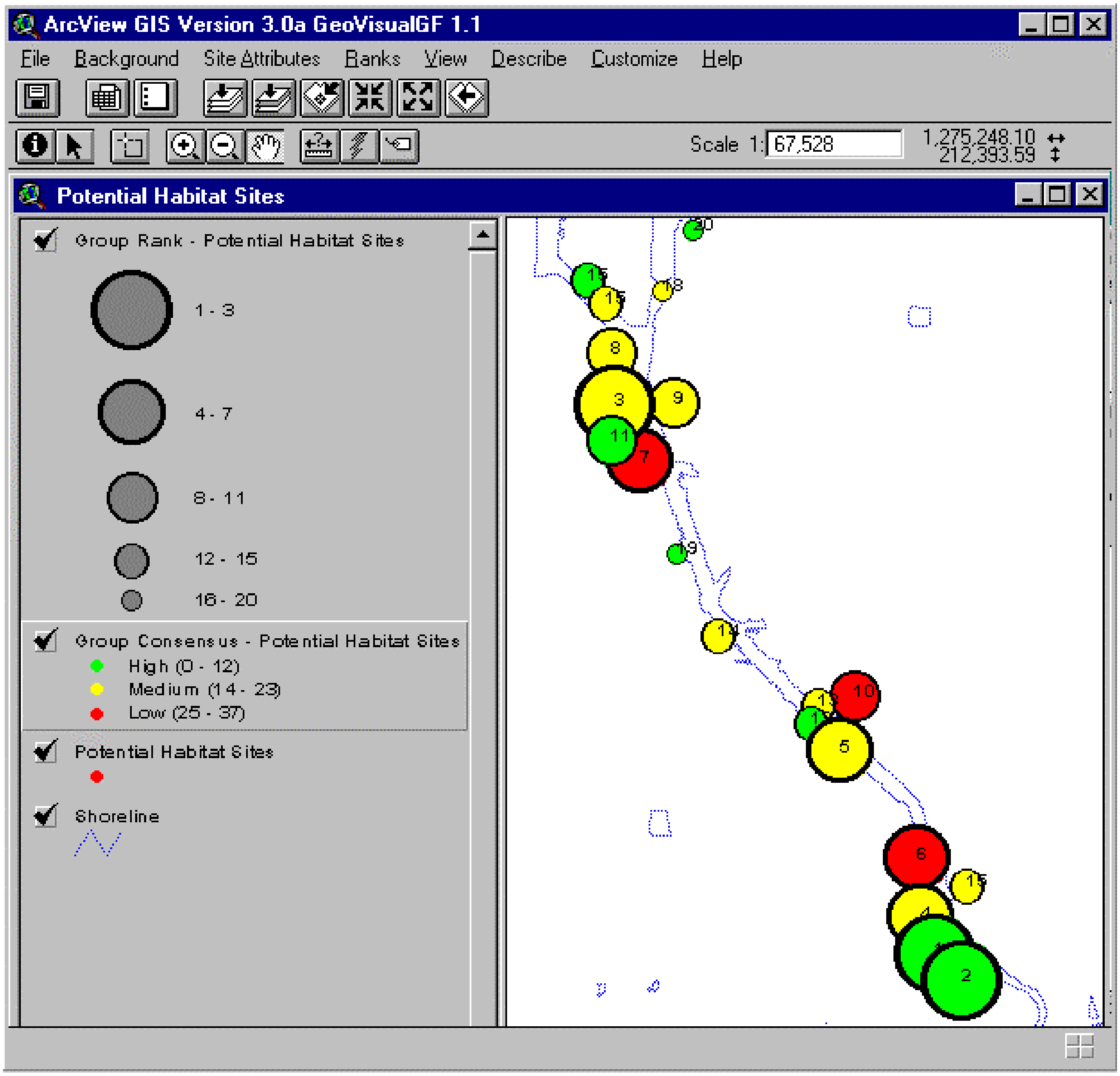
Impact measures are the same as indicators, but the measurements are taken in regards to the internal and external influences of a capital improvement project – for that matter any project such as a habitat redevelopment project. The overall impacts can be combined into a single "priority score" for a rank of project preference.

An impact map resulting from the amount of investment in habitat redevelopment in the Duwamish Waterway of Seattle Washington. Larger circles represent greater impact for potential redevelopment.



Basis of Figure 3 in P. Jankowski and T. Nyerges, 2001. "GeoChoicePerspectives: A Collaborative Spatial Decision Support System", **The Analytic Hierarchy Process in Natural Resource and Environmental Decision Making** (eds.) Daniel L. Schmoldt, Jyrki Kangas, Guillermo Mendoza, and Mauno Pesonen, Kluwer Academic Publishers: Dordrecht, Netherlands, 253-268.

Spatial visualization of a group vote – **Consensus Map**
Habitat site selection for ecosystem redevelopment toward sustainability



Basis of Figure 7 in P. Jankowski and T. Nyerges, 2001. "GeoChoicePerspectives: A Collaborative Spatial Decision Support System", **The Analytic Hierarchy Process in Natural Resource and Environmental Decision Making** (eds.) Daniel L. Schmoldt, Jyrki Kangas, Guillermo Mendoza, and Mauno Pesonen, Kluwer Academic Publishers: Dordrecht, Netherlands, 253-268.

Projects the promote an integration of social, economic, and ecological health are likely to add more to progress toward sustainability. A consensus map showing the ChoicePerspectives™ results of a group vote for habitat improvement priorities for a portion of the Duwamish Waterway in Seattle. The size of each circle reflects the rank of the site option, while the color shows the amount of group consensus regarding the ranked position (green represents relatively high consensus, yellow represents relatively medium consensus, red represents relatively low consensus).

Group Vote – a Table View

A table view of a Group vote about habitat site selection for (re)development – a component of ecosystem (re)sustainability.

ChoicePerspectives 1.2

File Method View Help

Decision Makers	Options	Score	Variance
perspec1	Site 26	100	0
perspec2	Site 4	95	0
perspec3	Site 3	87	5
	Site 10	87	11
	Site 5	82	5
	Site 14	73	5
	Site 9	72	5
	Site 16	65	0
	Site 17	58	5
	Site 8	50	16
	Site 24	48	5
	Site 7	47	21

Method: Ranked Vote View: Group Displaying the result of multiple voting

Basis of Figure 3.3 in Jankowski, P. and T. Nyerges 2001. *Geographic Information Systems for Group Decision Making*, Taylor & Francis, London, p. 81.

A rank order of watershed improvement priorities – based on the aggregated results of group voting. The amount of group consensus regarding an option is measured by the variance. In this example, voters from three perspectives agreed that site 26 was the best candidate for improvement leading to sustainability of the habitat ecosystem in the Duwamish Waterway depicted in the previous map.

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Conclusion

Web-based participatory GIS can support information structuring that connects growth management comprehensive plans to CIP projects in City Department business plans. Connecting Comp plans to business plans using CIP projects can help track progress toward sustainability to improve quality of life. Linking information structures in sustainability modeling provide a basis for constructing "deep knowledge" about community and regional sustainability. Sustainability modeling using linked information structures connects analytic and deliberative aspects of a dialogue for priority setting in a group context to address community and regional sustainability concerns. Such information structures can be implemented in an anytime-anyplace web-based participatory GIS to foster that dialogue. Group participation process is a fundamental concern when linking information structures. Only through monitoring the success of participation models can we establish the beneficial character of participatory GIS and the usefulness of sustainability modeling.

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