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Environmental Security

Sustainable Cities and Military Installations

Edited by
Igor Linkov

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Sustainable Cities and Military Installations

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Series C: Environmental Security

Sustainable Cities and Military Installations

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Preface

Reliable and affordable access to sustainable energy, water, and services is inherent to the economic and mission success of small cities and military installations. Acknowledging this, diverse military and civilian organizations are actively pursuing locally oriented strategies to address energy source sustainability, energy and water resource quality and quantity, the use and reuse of natural resources, and the capability of infrastructure systems to maintain safe, reliable, and resilient communities. For example, the US DOD is developing a comprehensive strategy for energy, water, and waste sustainability at military installations that is expected to include increased conservation and efficiency measures, alternative fuels and energy sources, and organizational/behavioral or programmatic features. A key concern for planners, however, is that climate change and other environmental stressors may radically impact the efficacy of otherwise sustainable strategies for these communities. In the face of uncertain climatic change and future resource availability, small cities and military installations must seek ways to factor future changes and potential stressors into energy, water, and infrastructure strategies to minimize vulnerability and increase overall resiliency.

The idea for this book was conceived at the NATO Advanced Research Workshop (ARW) on "Sustainable Cities and Military Installations" held June 2012 in Hella, Iceland. The workshop was attended by 50 scientists, engineers, and policymakers representing 15 different nations and multiple fields of expertise, reflecting the global and interdisciplinary nature of climate and sustainability research. The workshop focused on identifying ways for military installations and small cities to integrate energy, water, and infrastructure sustainability strategies into city and installation management planning in a way that accounts for climate uncertainties. Discussions centered on the application of current and emerging technologies, methods, and frameworks to sustainable development; energy infrastructure; climate change; environmental impacts; installation security; and military readiness. The workshop had four primary purposes:

- Summarizing the state of science related to small city and military installation sustainability

- Sharing and developing strategies, methods, and frameworks for achieving long-term sustainability in cities and military installations
- Defining how energy, water, and infrastructure technologies and management strategies can be integrated in sustainable management plans
- Identifying specific research needs for improving sustainability and resiliency in the face of climate change and other constraints and stressors

The organization of the book reflects major topics and discussions during the workshop. Sections review accomplishments, challenges, and knowledge gaps in the areas of energy, water, infrastructure, and integration. Each section begins with a workshop group summary which reviews principles, ideas, and initiatives that were discussed during the workshop. The remaining content reflects the diverse backgrounds and viewpoints of those in attendance. Part I is a summary of the challenges facing cities and military installations and provides background on the concepts of sustainability. In addition to reviewing climate-associated impacts such as floods, wildfires, and rising temperatures, which pose extreme security threats to both militaries and metropolitan areas, this section discusses the complexity of decision making in these communities.

Part II discusses the challenges facing water resource managers. This section explores the need for risk management and the roles that value engineering, community engagement, and big data can play in the integration of the water and energy sectors. Currently, the primary issues of concern are water quality and availability and habitat degradation. Key to tackling these issues are the needs to address water resource planning across spatial and temporal scales and objectives. The section also highlights prevalent decision-making processes and the current state of water resources.

Part III summarizes the state of the science in the energy sector and explores the need for an integrated systems approach to planning, energy quality analysis, and long-term, multifaceted energy management solutions. Highlighted in this section are the Army's Net Zero program and the potential impact of micro-grids on the energy landscape. In addition to technical solutions, potential financial, regulatory, and political barriers and solutions are discussed.

Part IV discusses the varied range of vulnerabilities facing infrastructure and systems integration. Because of the interconnectedness of infrastructures and the potential for cascading effects, attention must be paid to identifying, reducing, and responding to potential threats. Multi-criteria mapping is suggested, and, because of the complexity of infrastructure systems, a multi- and transdisciplinary approach is encouraged. Infrastructure modeling, the role of poverty, and European case studies are presented in this section.

Climate change and other stressors are expected to alter the environments in which small cities and military installations operate. To successfully deal with these challenges, current and emerging technologies, methods, and decision and management frameworks, coupled with resiliency and increased efficiency, must be explored in the context of uncertainty. This book addresses these issues and reflects the ongoing efforts of society to examine the challenges and successes of sustainable development in the face of an uncertain future.

Concord, USA
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Igor Linkov

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Part I
Sustainable Cities and Military Installations: Challenges

Chapter 1

Sustainable Urban Systems: A Review of How Sustainability Indicators Inform Decisions

Elisa K. Tatham, Daniel A. Eisenberg, and Igor Linkov

Abstract The Brundtland commission defined sustainable development as: *development that meets the needs of the present without compromising the ability of future generations to meet their own needs* (Butlin (1989) Our common future, by World Commission on Environment and Development. Oxford University Press, London, 1987). Translating this definition into an urban context has led to a focus on the use of indicators and indicator sets to quantify sustainability and guide government and stakeholder decisions. Although sustainability assessment methodologies demonstrate a direct link between indicator use and decisions made, there is limited discussion on how indicators actually help decisions. In this review, we examine 22 applied urban sustainability studies to assess whether indicators foster decisions. The 22 studies were analyzed on six dimensions that play a role in indicator development and use: the indicators themselves, stakeholder involvement, geographic and cultural impact, framing sustainability, definition of urban, and decision-making. Our results show that the connection between indicators and their effect on decision outcomes is not considered in indicator development, and although decision-making is briefly discussed by most of the evaluators it is rarely explored in-depth. In addition, vague definitions of sustainability and urban, geographic and cultural diversity, and a lack of concrete measures of the social qualities of sustainability have hampered the ability of indicators to create holistic decisions. We conclude that indicators themselves do not foster decisions and must be applied within a broader framework that can incorporate social and perceptual

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issues with indicators, such as multi-criteria decision analysis. Otherwise, the lack of clarity found in sustainability assessment prevents substantive decisions to improve environmental, economic, and social qualities of urban systems.

1.1 Introduction

Urban systems (i.e. cities) are interested in reducing their environmental footprint through methods of sustainable development. Defined by the Brundtland commission as *development that meets the needs of the present without compromising the ability of future generations to meet their own needs* [4], sustainable development is a desirable way to improve the sustainability of any urban system. However, urban systems pose challenges when harnessing sustainable development, such as a complex combination of needs and the integration of multiple stakeholder views. The lack of a clear approach is hampered by the inherent ambiguity associated with the Brundtland commission definition. Even in a single city, business, political, social, and environmental interests often reach different conclusions on the best way to meet the needs of current and future generations. Although the ambiguity serves a purpose – no precise definition of sustainable development could incorporate the significant cultural, geographic, and political variations between any two urban systems – efforts to produce sustainable urban systems are still unsuccessful over 25 years after the definition's release.

To assess urban sustainable development, urban sustainability indicators are used. Indicators are quantitative descriptions of the environmental, social, economic, political, and physical qualities of an urban system. Currently, there is no consensus on which indicators accurately address urban sustainability, resulting in a glut of indicators and selection methods [36]. In general, two types of indicators exist for urban sustainability, descriptive and diagnostic [14]. Where descriptive indicators only require direct measurement of an objective, diagnostic indicators try and establish the root causes to unsustainable practices. Diagnostic indicators can provide a more effective tool for solving problems, yet identifying the root-cause of unsustainable social practices is difficult. Descriptive and diagnostic indicators can be further segregated into two categories depending on their application, universal and case-specific. Universal indicators are developed to measure the sustainability of any urban system, where case-specific indicators are created for a single urban system. As the efficacies of descriptive and diagnostic indicators differ, so do opinions on their applications. Some authors argue the development and usage of indicators in a universal context is valuable because it simplifies the promotion of sustainable development world-wide [33, 40]. Others argue that universal indicator applications cannot capture the diverse economic, social, and environmental issues that correspond to urban sustainability [31].This discord attests to the confusion of measuring sustainability.

Since measuring the sustainability of an urban system is too difficult for any single indicator, different indicators are combined into sets. The most common

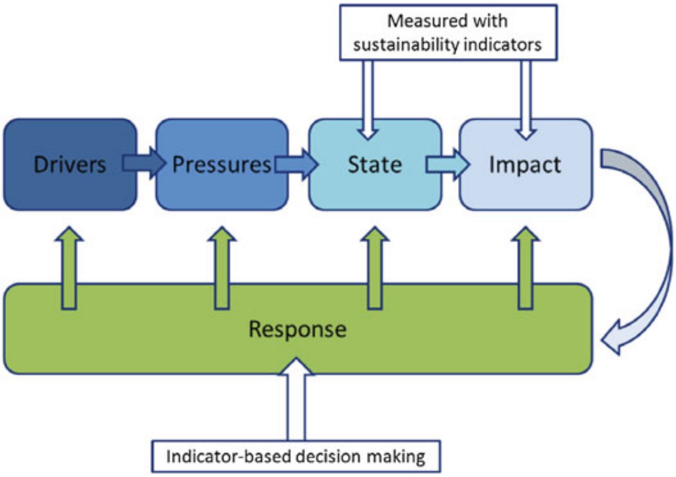

Fig. 1.1 Driver State Pressure Impact Response (*DSPIR*) model depicting the feed-back loop between changes in the state and impact of a system measured as sustainability indicators and the responsive decisions informed by those indicators

method used to organize indicator sets is to employ the concept of triple bottom line (TBL). TBL is defined as the three pillars of sustainability: the environment, society, and economy. To treat sustainability as the TBL is to consider each pillar equally, where a sustainable urban system must not compromise the quality of one pillar for another, e.g., economic decisions must not cause significant deleterious effects on the environment. Although TBL is used in the majority of urban sustainability applications, the TBL definition of sustainability is not specific enough to guide the creation of sensible indicator sets. Indicator sets found in literature which use TBL for organization are often created with ad-hoc approaches to represent each sustainability pillar, resulting in dissimilar sets. As a result, urban system sustainability cannot be compared directly across studies. Furthermore, the social pillar of an urban system is often poorly represented within indicator sets in comparison to economic and environmental [3].

In urban systems, governments and decision makers utilize sustainability assessments to employ indicator sets for decisions. We explore the importance of indicators for decisions through one of the most prominent assessment methodologies, driver-state-pressure-impact-response (DSPIR) (Fig. 1.1). In the DSPIR framework, the connections between the drivers, state, pressures, impacts, and responses of sustainability in an urban system are represented via arrows. There is a flow of information amongst the driver, pressure, state, and impact nodes that eventually leads to a response (decision). In DSPIR, impacts are defined and measured by indicators, and are the only inputs for response. The reliance on indicators implies that sustainability evaluation plays a key, if not the only, role in how sustainable development decisions are made.

In this chapter, we discuss the use of indicators to guide sustainable development decisions. The current glut of indicators, difficulties in their development, and debate over their use suggests that applications of the DSPIR and similar sustainability assessment methodologies may not be effective. Amongst the myriad of issues surrounding the indicators themselves, there is minimal discussion on whether these indicators foster sustainable development decisions. We address urban sustainability indicators and decisions through an illustrative literature review of sustainability assessments of cities from different world regions. The purpose of this review is to answer three questions:

1. Do urban sustainability indicators foster decisions?
2. Are there missing dimensions of urban sustainability that indicators are not addressing?
3. What tools offer a solution to help indicators foster future decisions?

Question 1 is the primary purpose to conduct this review. Since DSPIR is an iterative process, reflecting on how indicators are being used in real-world applications can improve sustainable development decisions and indicators together. Question 2 is devised to determine if and why some indicator sets foster decisions more readily than others. The failure of TBL to generate holistic indicator sets suggests that current applications must be analyzed for possible "missing dimensions" of urban sustainability. Question 3 attempts to extract answers from successful sustainability assessments. Where no solution was clear, we searched in other fields, namely operations engineering, to find suitable methods.

1.2 Literature Review

1.2.1 Methods

Although decisions to include studies in this review were made subjectively, we used specific and consistent selection criteria. Because our focus is on the relationship between sustainability indicators and decisions, particular emphasis was put on applied works that mentioned policy response or decisions. In addition, we sought representation of urban systems that have geographic, cultural, and regional diversity. Peer-reviewed sustainability assessments were accessed through the ISI web of knowledge [37] using the following search terms: indicator*, sustain*, urban or city (882 records); indicator* or metric*, sustain*, urban or city, and decision* (216 records). From these records, 22 applied research articles met our selection criteria.

All 22 articles chosen for this work assessed the sustainability of entire urban systems. The majority of peer-reviewed work collected using our established search terms assessed only part of an urban system (e.g. buildings, or transportation infrastructure). We did not include works of this nature to focus on the sustainability of the entire urban system. This enabled us to make a more focused review on indicators and decision-making with respect to an entire city.

The articles were assessed using six dimensions which were chosen from literature reviews on urban sustainability. These dimensions were: Indicators, stakeholder involvement, geographical location, definition of sustainability, definition of urban, and decision-making. In addition to the six dimensions, missing dimensions emerged during the course of the review and are addressed in the discussion section.

1.2.1.1 Indicators

Indicator and indicator sets were compared on several criteria, including: number of indicators, types of indicators used, and their universal or case-specific application. The dimensions of stakeholder involvement, definition of sustainability, and definition of urban also played an important role in these comparisons.

1.2.1.2 Stakeholder Involvement

The extent of stakeholder involvement in the development and use of indicators was compared in this review. Participation and consensus building are found to be primary components of successful sustainable development initiatives [14]. However in a 2001 survey of 350 U.S. cities, Edward Jepson [19] found that the impediment to action for sustainability was potentially the result of "low public interest, inappropriateness, and lack of knowledge." Comparing the ways stakeholders were involved between studies may correlate to the success of indicators fostering decisions.

1.2.1.3 Geographic and Cultural Impact

We compared how geographic location and culture influenced indicators and decisions in sustainability assessments. The role of geography and culture in sustainability is discussed in recent literature, but questions still arise about their role in global sustainability [3] Regional differences are apparent in sustainability measurements, but the public's perception of what makes a city livable and functional play a large factor in whether a city is sustainable and this is not accounted for in most assessments. For example, what someone in Shanghai considers sustainable can be dramatically different from a person in San Francisco – cultural viewpoints can skew opinions such that environmental quality may only play a small role in overall sustainability.

1.2.1.4 Framing Sustainability

How the term sustainability was used in the articles was noted in order to see the overlap or ambiguity in how research is framing the basic idea of sustainability. Indicator selection is driven by how sustainability is defined. Because there is no universally accepted definition of sustainability, the concept of sustainability varies from city to city and results in diverse goals and indicators [16]. In other words, the questions and goals of an assessment influence their conclusions.

1.2.1.5 Defining Urban

Studies included in this review were compared based on population size, location and geography of the cities they assessed. Defining what makes a city habitable, livable and sustainable drives indicator development as much as the definition of sustainability. Within the United States the definition of a city varies from state to state [32]. Similarly, European cities are labeled differently depending on location. While urban areas and cities are often used interchangeably, an urban area is defined by governments as a having a significant population density and built-up growth [39]. Thus, a populated "city" and a densely populated urban area may be characterized as the same entity, making comparisons between some indicators and decisions inappropriate.

1.2.1.6 Decision-Making

The purpose of this review is to assess how indicators foster decisions. We broke this analysis into two parts. We first noted which sustainability assessment methodology (if any) was used in each study to connect indicator sets and decisions together. Second, we analyzed the text of each study to compare how decision-making is discussed with respect to indicator use.

1.3 Results

Table 1.1 summarizes the 22 studies included in this review. Even with the vast diversity between studies, there are common elements between indicator sets and sustainability assessment methods. Many indicator sets include similar indicators if they were from the same region. For example, disposable income per household, life expectancy, population size were common indicators used in Chinese sustainability studies, and instead, quality of life indicators such as resident satisfaction and community participation were used in European and American studies [45]. In many cases, specific indicators had the same measurement goal (i.e. air quality),

Table 1.1 Summary of studies included in this review

Study # and reference	Area of study	Population size	World region	Amount of indicators	Indicator type	Indicator application
[1] Gonzalez-Mejia et al. [11]	City of Cincinnati, suburbs and metropolitan statistical area	2.1 million	North America	60	Descriptive	Case specific
[2] Huang et al. (1997)	Taipei, Taiwan	2.7 million (at time of study)	Asia	80	Diagnostic	Case specific
[3] Lee and Huang [23]	Taipei, Taiwan	2.6 million	Asia	51	Diagnostic	Case specific
[4] Fan and Qi [8]	31 Chinese Cities	1.4–32 million	Asia	5	Diagnostic	Universal
[5] Yuan et al. [45]	Chongming County, Shanghai	0.7 million	Asia	17	Diagnostic	Case specific
[6] Moussiopoulos et al. [29]	Thessaloniki, Greece (GSA)	1 million	Europe	88	Diagnostic	Case specific
[7] Huang et al. [17]	Taiwan	23 million	Asia	22	Diagnostic	Case specific
[8] Jarrar and Al-Zoabi [18]	Jerusalem	801,000	Middle East	6	Diagnostic	Case specific
[9] Li et al. [24]	Jining city	7.9 million	Asia	52	Diagnostic	Case specific
[10] Scipioni et al. [33]	Padua, Italy	210,000	Europe	70	Diagnostic	Case specific
[11] Duran-Encalada and Paucar-Caceres [6]	Puerto Aura, Mexico	Unavailable	North America	34	Diagnostic	Case specific
[12] Van Assche et al. [40]	13 Flemish Cities	~60,000–600,000	Europe	200	Diagnostic	Case specific
[13] Posner and Costanza [29]	Baltimore	5.8 million	North America	25	Descriptive	Universal
[14] Kohsaka [22]	Nagoya, Japan	2.2 million	Asia	Does not report indicators used	Unavailable	Unavailable
[15] Yu et al. [43]	Yantai, China	6.5 million	Asia	36	Descriptive	Case specific
[16] Chunmiao and Jincheng [5]	Harbin city, China	9.47 million	Asia	37	Diagnostic	Case specific
[17] Budd et al. [3]	49 US urban areas	150,000–2.1 million	North America	5	Diagnostic	Universal
[18] Yu and Wen [44]	46 Chinese cities	500,000–23 million	Asia	10	Descriptive	Case specific
[19] Wen et al. [42]	6 Chinese cities	1–10 million	Asia	1	Descriptive	Universal
[20] Van Dijk and Mingshun [41]	4 Chinese cities	340,000–2.6 million	Asia	22	Descriptive	Universal
[21] Abusada and Thawaba [1]	Ramallah Governorate, Palestine	279,730	Middle East	20	Diagnostic	Case specific
[22] Gagliardi et al. [10]	Naples, Italy	~3 million	Europe	18	Diagnostic	Universal

(continued)

Table 1.1 (continued)

Study #	What stakeholders were involved?	Who chose the indicators used?	How does the study frame sustainability?	Definition of urban	Decision-making addressed?
[1]	None	Authors	TBL	None	No
[2]	NGOs and public	Authors	TBL	Heterotrophic system	No
[3]	Experts and government	Authors	TBL with institutional, political	None	No
[4]	None	Authors	TBL	None	No
[5]	Government and academic	Authors	TBL	None	No
[6]	Public	Authors	TBL	Defined by TBL	No
[7]	Experts	Stakeholders	TBL with physical	Defined by TBL	No
[8]	Experts	Authors	TBL	Defined by TBL	Address decision-making without stakeholder engagement
[9]	None	Authors	TBL with cultural	Complex ecosystem	No
[10]	Public	Stakeholders	TBL	None	No
[11]	Project Manager and Gov’t	Stakeholders	TBL with institutional	None	No
[12]	Government	Stakeholders	TBL with institutional, physical, activities	None	Address decision-making but framework use not discussed
[13]	None	Authors	TBL	None	No
[14]	Undefined	Stakeholders	TBL with political	None	Address decision-making without inclusion of indicators
[15]	None	Authors	TBL	None	No
[16]	None	Authors	Economy, society, population, resources	Artificial/complex ecosystem	No
[17]	None	Authors	TBL with political	None	No
[18]	None	Authors	TBL	Combination of three complex systems	No
[19]	None	Authors	TBL with political	Combination of five complex systems	No
[20]	Experts	Authors	Urban Status, coordination, and potential	None	No
[21]	Experts and public	Stakeholders	Government, physical, socioeconomic, infrastructure availability, environment	None	No
[22]	None	Authors	Economy, environment, energy and urban plan	None	No

TBL triple bottom line

but approached it differently. For example, Fan and Qi [8] used quantitative sustainability data such as air quality, traffic noise, etc. while Wen Yuan et al. [45] incorporated indicators such the level of environmental quality enhancement.

1.3.1 Indicators

The number, type, and application of indicators varied widely throughout the studies (Table 1.1). The largest set of indicators was 200 [40] where some studies used as few as five indicators [8]. Indicators developed with stakeholder input were specific to the region being studied [23, 43].

While some researchers cite the importance for universal indicators, only six studies used universal indicator sets. Scipioni et al. [33] reviewed the use of ISO 14031 in Padua, Italy, which is a universal framework for measuring sustainability. They found that implementing context indicators in a top down approach allowed locals to view their city in time and within the context of global sustainability. Posner and Costanza [31] combined 25 separate indicators into the Genuine Progress Indicator (GPI), to measure the sustainability trends in Baltimore, Maryland. GPI is an alternative approach to GDP which incorporates environmental factors into economic analysis. The authors found that the GPI is easily reproducible and comparable across levels such as cities, counties and states, though the author's state that there is no mutually agreed upon way to use GPI. van Dijk and Mingshun [41] use the Urban Sustainability Index (USI) to measure the urban status, coordination, and potential of four Chinese cities. USI emphasizes sustainable use of natural resources as well as minimizing impacts of pollutants. The studies that utilized universal frameworks provided a global perspective for cities to benchmark their progress.

A global perspective was implemented in the 15 case-specific studies which did not employ universal indicator sets. This was accomplished by reference to studies which used universal indicator sets or UN/OECD reviews when developing their respective sets [6].In addition, the authors employed various frameworks to guide their studies in order to integrate their research into a global context. However, it was acknowledged that issues arose in combining global perspectives and local policy action.

1.3.2 Stakeholder Involvement

The majority of studies suggest that indicators are being derived using stakeholder involvement from multiple sources, including: experts, government, NGOs, or citizens. Specific works discussed how to foster decisions using indicators through stakeholder involvement. Stakeholders should be involved as early in the indicator development process, otherwise, it is difficult to assess the decision-making

Fig. 1.2 Locations of case studies. The *larger dots* represent case studies which examined more than one urban area in a region. If more than one study was completed in a single urban area one dot is used

possibilities. Moussiopoulos et al. [29] suggest a "fruitful public dialogue" on indicators after stakeholders reach a consensus among themselves. For environmental management projects, decision makers often use four generalized types of project inputs: the results of modeling and monitoring studies, risk assessment, cost-benefit analysis, and stakeholder preferences [21]. Incorporating stakeholder preferences poses the most considerable challenge, as it enables the influence of biases and misunderstanding. Van Assche et al. [40] suggest that using a participatory approach fosters the use of community indicators and generates interesting side effects such as networking within and between city authorities. Van Dijk and Mirgshun [41] point to three elements for successful participation in urban sustainability management, which are: availability of information, stakeholder consensus and public supervision of projects to ensure the fulfillment of goals.

1.3.3 Geographic and Cultural Impact

The 22 case studies are geographically and culturally diverse. Twelve of the studies were located in Asia, six in Europe, and the remaining four were in North America (Fig. 1.2). The urban areas ranged in size from large, dense capital cities [27], to small urban areas [11]. Explanations of what constitutes an urban area vary greatly between studies on two sides of the world. For instance, in the United States, rural areas near urban developments are not included within the "system". In contrast, in China, local rural areas are often included in "urban" studies [17]. Variations also existed in terms of region, climate, population size/density, and political climate. For example, Moussiopoulos et al. [29] assessed Thessoloniki, Greece which has a population of one million, while Abusada and Thawaba [1] assessed the Ramallah governorate in Palestine which only has a population of 200,000. No studies were found to include cities in the southern hemisphere.

1.3.4 Defining Sustainability

Though the TBL and the Brundtland definition were commonly cited, there is ambiguity in how sustainability is defined between papers. Lee and Huang [23] discuss that although the Brundtland definition is widely recognized as the foundation of sustainable development goals, it is too broad and ambiguous because it strives to find a perfect balance which is difficult to attain. In 10 studies, the authors describe sustainable development in terms of TBL, as a balance between environmental, social, and economic pillars. In six studies, the authors describe sustainable development as the same three pillars plus one. The additional pillar varied from institutional [23] to physical [17] aspects of urban systems. Additional pillars also suffered from vague definitions, such that ad hoc approaches were still employed to determine final indicator sets and studies which use the same additional pillar use different indicators.

1.3.5 Defining Urban

Only eight studies gave a definition of what the author's deemed to be a city or urban system. Three of the studies define an urban system as an expansion of TBL (Moussiopoulos et al. [29], Huang et al. [16]; Jarrar and Al-Zoabi [18]). Although this creates consistency within the study, TBL as a vague concept fails to frame an urban system in a consistent manner. Five studies created a unique definition of urban system. Four of these five used the term "complex system" to suggest that an urban system is a combination of both man-made and natural components [5, 24, 42, 44]. Although these four studies use similar terminology, each suggests different system components define an urban system. Overall, the limited, vague, and conflicting definitions of an urban system within studies indicates.

1.3.6 Decision-Making

Instead of using only indicators for assessing sustainability, every study integrated the indicators with methodologies to provide a visualization of context, linkages, and trade-offs. For example, Driver-Pressure-State-Impact-Response, or similar methods, was used in six studies (Fan and Qi [8], Duran-Encalada and Paucar-Caceres [6], Kohsaka [22], Huang et al. [16], Huang et al. [17], Scipioni et al. [33]). Many authors combined DSPIR with other methodologies to provide a more robust sustainability assessment, such as Scipioni et al. [33] which combined DPSR (without impacts) and ISO standard assessment methods.

No study included in this review, or found using our search terms, discussed the substantive policy or decision outcomes by using assessments or indicators. Those that discussed decision-making or policy did so by exploring the importance of trade-offs in stakeholder involvement and policy integration [3, 17, 22, 23, 29, 33, 41]. Certain studies focused on solely benchmarking a city's sustainability, while others focused on the indicator development process in order to open communication among stakeholders and policy-makers. Yu and Wen [44] explained that benchmarking is important for less sustainable cities, while Van Assche et al. [40] believe that sustainability assessments should be used as decision aides rather than benchmarks. Multiple studies discussed the importance of visualization for decision-making and stakeholder involvement and this was illustrated in different forms. Some studies used visuals such as smiley faces or −/+ to show the state of the indicators [24, 29, 31]. Huang et al. [17] took a less simplified approach and created a sensitivity model in order to enable consensus around possible policy change. Communication, simplicity of indicators, and inclusion of stakeholders were common themes throughout the studies. Authors discussed inter-disciplinary communication, further integration of decision-making and comparisons between the global and local level as important topics for future research [3, 22, 45].

1.4 Discussion

1.4.1 Do Urban Sustainability Indicators Foster Decisions?

There were successful examples of indicators fostering sustainability engagement within our review. In general, two types of indicators are used for urban systems: descriptive and diagnostic [14]. In Thessoloniki Greece, Moussiopoulos et al. [29] developed a system of indicators that were understandable for stakeholders in order to create an effective management assessment. By building a consensus among stakeholders from the beginning, the indicators better reflected the true opinions of the local community and as a result are expected to better inform the local decision-making body. The studies that did not act as benchmarking tools, but rather as sources for communication and knowledge sharing, were more effective in incorporating decision possibilities in their outcomes. Scipioni et al. [33] successfully created a set of indicators by encouraging participants to "comment, share or modify political choices" after building consensus around TBL critical issues. Decision-making is limited to available local knowledge, yet indicators will be ineffective if they do not fit in with the local policy debate. In order to influence policy and decision-making, indicators must be able to integrate with policy directions as they did in van Assche et al.'s [40] study of Flemish cities.

Based on the reviewed case studies, we found that sustainability indicators alone were ineffective at promoting decisions. The studies that employed general metrics offered only cursory evaluations or city-to-city comparisons. In the case study of Baltimore, the use of GPI was effective as a benchmarking tool but there was no indication of which indicators were important to the local population, or what changes would be the most effective in treating un-sustainability [31]. Indicator systems developed for a specific urban system had more practical application, yet either ignored key sustainability features or had impractical goals. Fan and Qi [8] used only the following indicators: GDP per capita, air quality, traffic noise, rural/urban income ratio, and urbanization level. Similar to the issues with generalized frameworks, these metrics give little indication of social goals or concerns making it difficult for policy or decision makers to translate into actions. Considering stakeholder opinions was suggested for policy implementation, but it was not always effective. Yuan et al. [45] incorporated public participation from the beginning of their study of Chongming County in Shanghai, and through their consultations discovered that each sector of the community interpreted sustainable development differently. This resulted in regional variations in stakeholder opinions.

1.4.2 Are There Missing Dimensions of Urban Sustainability that Indicators are Not Addressing?

A key component to decisions that is not addressed by indicators is conceptual differences between people and regions. The way that people perceive complex terms such as sustainability and urban systems has a direct effect on the success of the assessments studied in this work. Additionally, the segregation of an urban system into environmental, social, economic, and institutional sections is difficult to realize since each of these sections themselves are systems of systems. No matter how well the indicators represent an urban system, there is bound to be a loss of information that makes decisions harder to manage.

The general perception of urban sustainability assessment and management interfere with decision making. In particular, the translation from indicators into decisions fails due to an inability to compensate for fundamental differences in how sustainability and urban systems are defined by individuals. Although there is a near universal acceptance of TBL as an effective basis for sustainability assessment, the definition is too vague to foster practical application [30]. Beyond the pillars of TBL, there is also the component of time that is never addressed by the indicators or assessment methods. TBL represents a spectrum of viewpoints on sustainability with respect to time, ranging from highly reliable urban systems that do not change to those that are designed for constant replacement and re-engineering. Even though a strong environment, society, and economy are the goal of every assessment, it is almost impossible to assume that any two evaluators or decision makers will have an identical perspective. These inherent differences are why a single urban sustainability assessment method has not been accepted universally [34]. In fact, just the term "sustainability assessment" is difficult to define in a universal context [30]. Yuan et al. [45] explain that because the stakeholders involved in the assessment process define sustainable development differently, differences are reflected in the indicators. This implies that the indicator frameworks have the potential to be either ineffective at conveying useful information, or worse, presenting bias that might lead to undesirable decisions.

Cultural and geographic information also played a key role in shaping how evaluators and decision makers perceived sustainability and urban systems. The dramatic differences between where a city was located and how "urban" was locally defined directly affected the outcome of sustainability assessments. For instance, in assessments of Chinese cities, Li et al. [24] explained that urban areas include traditionally classified rural areas because they fall under the administrative reach of a nearby city. There are three tiers of cities in China as determined by the Chinese Urban Planning Act, so an area with a population as small as 60,000 is still deemed a city. Within this research only one study referenced this Act and included which tier the assessed city was categorized under [8]. The end result of this could be substantially different results city to city, making cross comparison inconsequential.

Where economic and environmental goals might be easily reduced into an indicator, the measurement of the social facets of sustainability is much more difficult. The DSPIR framework used by the studies in this review follow a "reductionist" paradigm that fails to compensate for the complexity of social networks and interactions [14]. Previous studies correlate urban sustainability planning and policies to a region's social and political culture [3]. Within the context of this work, characteristics of a thriving social network such as the creative class [9] and political structure were widely ignored. In the studies that relied heavily on stakeholder involvement, the focus was predominately on the measurable qualities of sustainability and there was little to no discussion on what makes an urban area a desirable place to live. Van Assche et al. [40] discusses quality of life in the article, but the indicators used are typical of the social factor of TBL, e.g. unemployment rate and education. There is a general lack of discussion about what constitutes a thriving urban area, and instead an emphasis on creating indicators for the sake of measurement.

1.4.3 What Tools Offer a Solution to Help Indicators Foster Future Decisions?

In this work, indicators alone were not effective at informing decisions. In general, substantive decisions result from understanding the problem, obtaining stakeholder opinions and engagement, and generating alternatives [12]. The inclusion of stakeholder opinions and generating alteratives creates confusion when using indicators by themselves. Instead, a framework that can combine decision needs with indicators is recommended to improve decisions and allow faster reassessment and changes to urban sustainability plans [26, 28]. Huang et al. [17], created a sensitivity model to visually display the interrelationships among indicators chosen by expert participants. They found that when the experts were able to visualize the interrelationships, it was easier to arrive at a consensus for specific policy recommendations. While sensitivity modeling is an effective way to approach sustainable decision-making, it is a complex process. Brunner and Starkl [2] reviewed decision aid methodology with a focus on multi-criteria decision support, which provides a less technical approach that would be better applied to policy experts. Despite the inability of indicators to promote urban sustainability decisions, decision frameworks can assist in their application. In particular, multi-criteria decision analysis (MCDA) offers specific benefits that can improve urban sustainability decisions, by exposing the linkages between indicators and weighing stakeholder opinions [25].

The Economic Development Administration describes MCDA as an aid for decisions, education, planning and communication of information [38]. For example, MCDA can be used to optimize project impact (design tool), to winnow or compare projects (decision tool) and to describe project impact (communication tool). MCDA has been used in various applications such as adaptive and environmental management [15, 20, 26]. In our review two studies used the analytic hierarchy process (AHP) MCDA method to benchmark sustainability [5, 43]. Although both studies used weighting systems in order to benchmark sustainable development, stakeholder values were not studied or used for weighting criteria. As a result, data transparency is lost, and sustainability assessment was still ineffective at promoting decisions. If indicators are going to foster substantive decisions, applications of MCDA must be more transparent to stakeholders and decision-makers involved. The utility of MCDA in the urban sustainability context is its ability to overcome perceptual, cultural, and social issues that hamper indicator applications. Future indicators and indicator sets must not only consider stakeholder involvement in indicator development, they must also consider decision-maker needs and perceptions at an early stage. Only then can the results from a sustainability assessment elicit a substantive response to unsustainable practices.

Furthermore, the use of MCDA in an assessment framework such as DSPIR offers the possibility to generate more valuable sustainability indicators via iteration. It is difficult to create an initial sustainability assessment that includes a precise definition of sustainability and urban, stakeholder involvement, and geographic and cultural implications on local needs. Initial assessments are bound to overlook key elements of the urban system sustainability simply because it was impossible to recognize their importance pre-assessment. Once indicators are developed and the urban system is assessed, combining this information with decision-maker viewpoints will reveal new assessment needs and help refine current indicators to offer more accurate measurement. The primary purpose of the iterative DSPIR processes in Fig. 1.1 is to measure progress and refine responses with previous indicators. With MCDA, this process can include the addition of new indicators, changes to previous indicators, and even improve sustainability and urban definitions and local understanding of geographic and cultural factors.

1.5 Conclusion

Developing sustainable urban systems requires the use of indicators, but it is still unclear how they foster decisions. The 22 studies herein utilized diverse indicators and indicator sets, had varying amounts of stakeholder involvement, and were from different geographic and cultural regions. Definitions of sustainability and urban remain vague amongst studies, resulting in ineffective assessments. Although case-specific applications were more successful at incorporating stakeholders into the assessment process, there was still limited discussion on the use of indicators for decisions. Therefore, even after the inclusion of stakeholder and expert information, few assessments offered actual decision support. The reasons enumerated above demonstrate that the attention used in the creation of indicator sets must also be applied to the decisions they are supposed to support, or substantive decisions are not possible.

We found that the use of indicators tends to ignore major conceptual issues surrounding sustainability assessment. Missing dimensions from current indicators and indicator sets include: vague applications of TBL, constant redefinition of the word urban, ignoring how different people have different viewpoints on sustainability, and reducing complex social qualities of urban systems into a single value. Ignoring each of these issues can lead to biased, ineffectual, or even harmful decisions. None of the studies included in this review could manage these issues due to a narrow focus on indicators.

A possible solution to the issues preventing urban sustainability decisions is the use of MCDA. MCDA can weigh indicators alongside various opinion and conceptual differences. Although two studies included in this review utilized MCDA, they failed to include stakeholder needs, ruining the possible transparency of the studies. Having a transparent connection of indicators to stakeholder and decision maker needs can provide a more legitimate means to foster decisions and improve the environment, society, and economy simultaneously. In addition, MCDA can help create more precise and effective indicators through iteration. It is difficult to successfully include all important urban sustainability dimensions into an initial assessment. With MCDA, assessment iterations not only improve responses, but refine the indicators as well.

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Chapter 2
Military Installations and Cities in the Twenty-First Century: Towards Sustainable Military Installations and Adaptable Cities

B.A. Harmon, W.D. Goran, and R.S. Harmon

Abstract Military installations and cities in the twenty-first century share many of the same dynamics and face many of the same challenges – i.e. the same environmental, climatic, and anthropogenic pressures. The military response to these challenges is, however, constrained by hierarchy and the culture of command and control. In a city, informal adaptations, experiments and solutions can arise to pressing urban issues that were unanticipated or unanswered by the formal city. By contrast, decisions and solutions in military installations have traditionally come down the chain of command. In an ever more complex world in which the future is ambiguous and change is a certainty, top-down decision making and the predictive sciences, alone, will not be enough to ensure a sustainable future. Cities and military installations will need to be adaptable and resilient to survive the complex, ever-changing, and uncertain threats of the future.

2.1 Introduction

Cities, especially megacities, are panarchies of urban adaptive cycles. In these environments, the urban landscape is in constant flux, with new dwellers moving into existing urban spaces, others pushing out the boundary of the urban footprint, and innovators filling gaps and finding opportunities to provide specialized urban

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services – whether as real estate developers, mobile street vendors, or trash collectors. Governments can provide some services and infrastructure to stretch across these expanding urban boundaries, but at best they are catching up with the rapid pace of urban change, and most assets and property in these urban environments are owned, held, or occupied by private entities.

2.2 Twenty-First Century Military Installations

2.2.1 Up the Chain and Across the Fence Line: U.S. Military Bases and Their Neighbors

Urbanized military bases have many similarities to cities, but they are held and managed as public resources. A military installation includes housing, retail, office, recreational and industrial spaces, just like other urban areas. However, on a military installation a commander is responsible for all the assets and operations – the land, personnel, facilities, and services – within the installation boundary, i.e. the "base fence line." Installation commanders and their staff respond to hierarchical decision making within authorities established by federal legislation and overseen by a chain of stovepipe bureaucracies created by US Department of Defense [1] policies and procedures.

Military bases can have very significant populations with large payrolls. Thus, the presence and vitality of these installations can dramatically impact local communities, but the communities are, at most, only peripherally engaged in the key decisions about the base. For example, maintenance and repair (M&R) needs at any one base are compared to those of other bases across the nation, and unmet needs are stacked up at the end of the year and added to the "backlog of maintenance and repair" that accumulates from 1 year to the next [2]. Certainly, not every M&R need can be addressed, no matter how flush the DoD budget, but the processes to define and defend needs are ordered, predictable, and utilize accepted current technological approaches, the needs of rapidly growing cities, particularly the megacities of the present day, are frequently met through chaotic innovation initiated by private citizens and local citizen groups and have the potential to go well beyond the changes made by various tiers of government.

Military installations have a focused purpose, a mission – they are not just workplaces and homes. Bases do, however, have their own dynamic rhythms of change. For example, as forces build for deployment, base populations rapidly grow during periods of "in-processing" and training, and then shrink when units deploy to operational theatres. When populations are high, troops under training may be housed in temporary facilities. In the interim, between deployments, troop numbers may rapidly decrease and facilities may be given to other users, deconstructed, or mothballed.

In cities, there is a tension between the pulse of change generated by numerous local residents and the government entitles established to address the corporate needs of the urban and adjacent rural populations. To a greater or lesser extent, governments are responding or adapting to private actions. On military bases, there is a tension between vertical organizational processes and structures and the horizontal or local context for planning and operations at the installation level. Tightly controlled processes, such as planning and funding, tend to draw the bases in a vertical direction towards headquarters and oversight organizations, such as the U.S. Congress. To a greater or lesser extent, the soldiers, civilians and soldiers' families on the base are responding and adapting to the institution where they work and live.

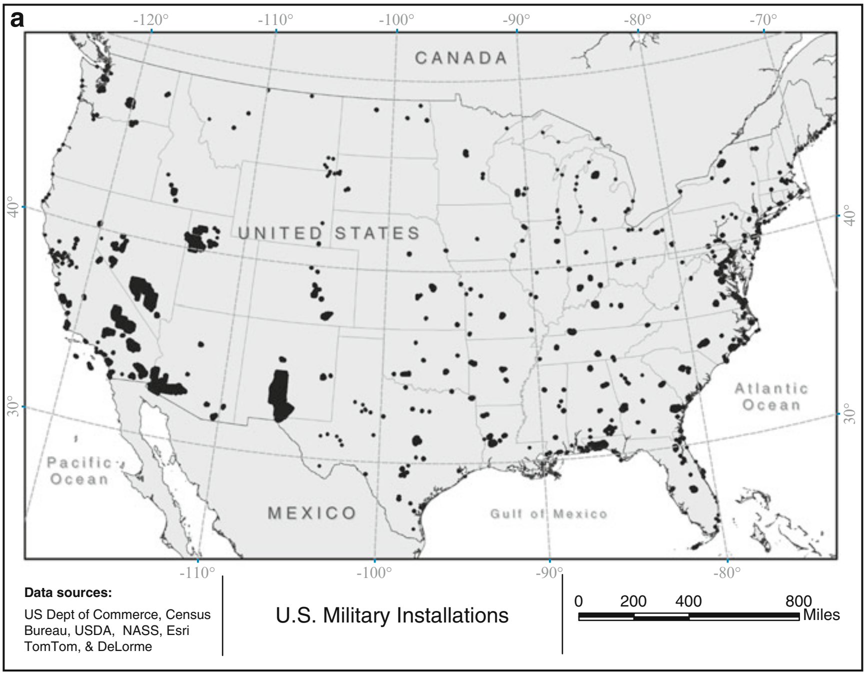
Bottom up initiatives, such as sustainability and strategic planning at the base level, or joint base-community land use planning, tend to tug in a horizontal direction – enhancing interactions between different sub-organizations across a base and with surrounding communities and stakeholders.

Balancing these tensions forces base master planning to follow common "unified facilities criteria" guidance for all DoD bases, which calls for base decision making, especially with regards to facilities and infrastructure, to be responsive to local context. But the processes that govern actions, and provide resources, are vertical in nature – and the staff executing these processes are accountable up their chains-of-command, sometimes resulting in sub-optimal solutions at the base level. For example, buildings all too often are planned and sited one at a time, despite their impacts on transportation options, ecological habitat, land use suitability, storm water runoff or even worker effectiveness, due to budget and time pressures at higher levels of the chain-of-command.

2.2.2 Up the Chain- Managing Within a Federal Departmental Structure

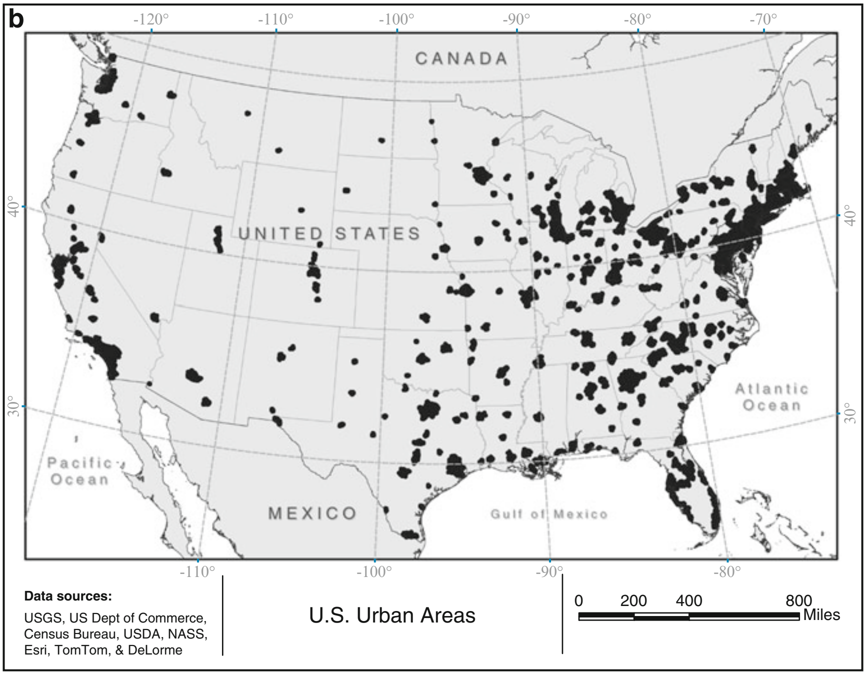
Military installations submit their operational budget requests, in accordance with agency policies, procedures and tools, upward through organizational and regional hierarchies. Local input will help shape these requests, such as local condition assessments of facilities to prioritize facility maintenance requests, but the total amount of funding allocated for maintenance will be determined for the whole agency in Congressional authorizations, and, subsequently for an individual base by dividing up the authorized and appropriated resources across multiple bases within a regional or organizational command. Local requestors must give a full justification to their headquarters of how requested resources are to be used, and then, if funds are provided, to fully account for the outcomes of these expenditures.

Currently, some activities on military bases are "privatized" such as many of the infrastructure services (water, energy, and telecommunications) obtained from local providers. More recently residential housing has also been privatized [3]. But these privatized assets fit within the context of the base master plan. Individual residents are not deciding when or where to build housing or locate a store. They may not even be paying their own utility bills.



U.S. Military Installations

Data sources:
US Dept of Commerce, Census Bureau, USDA, NASS, Esri TomTom, & DeLorme



U.S. Urban Areas

Data sources:
USGS, US Dept of Commerce, Census Bureau, USDA, NASS, Esri, TomTom, & DeLorme

Bases are usually managed by a commander who operates something like a city manager, but who rotates with greater frequency, usually after a 2–3 year assignment. Stability is provided more by civilian civil servants, who provide expertise in planning, finance, facility and land management – all within the system of government policies and guidelines. Both uniformed military and civilian residents of bases are "tenants" of the garrison, occupying space and using resources on a temporary basis, no matter how long their stay.

Bases grow or shrink largely because of external factors. They do not grow based upon local enterprise, but rather on decisions made higher up in the military chain-of-command about the stationing of units, insufficient or excess facility and land needs, and the realignment and closure of bases related to changing mission needs. Military bases are relatively insensitive to economic cycles and to local economic dynamics. Bases also have a population that is highly mobile and may not be well connected to the local region or have roots within it. Soldiers and their families tend to build allegiances to the other families in their military unit rather than with their neighbors "outside the fence." Base families are also very globally connected, with "roots" in a series of communities where they have previously been stationed.

2.2.3 The Location of U.S. Bases

U.S. military installations are scattered across the United Sates and the rest of the world, but there is a greater concentration of bases in the desert southwest, the southeastern region of the U.S., and along the mid-Atlantic coast than elsewhere (Fig. 2.1a). These bases range from relatively small facilities, such as a cluster of buildings for a local National Guard unit, to the large bases whose populations are equivalent to that of a medium-sized city, some with over 100,000 residents and workers. Many of the military bases have significant holdings of lands which may provide a buffer around sensitive or noisy mission assets, such as airfield runways or ammunition depots, or may be critical for live-fire training exercises, firing ranges, weapon testing, and other land intensive military activities. Balbach et al. [4] examined the changing historical reasons for base locations, finding that they were initially located where they could provide protection for harbors, navigable rivers, wagon trails, and railways. Then in the twentieth century, as deployments were

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Fig. 2.1 (**a**) The geographic distribution of military installations across the conterminous United States, illustrating the generally higher density of military installations along the U.S. east coast, in the mid-Atlantic states, in the south-central states, and in the desert southwest. (**b**) The geographic distribution of urban centers across the conterminous United States, illustrating the uneven distribution of U.S. cites, their clustering in the eastern half of the country and along U.S. coastlines, and the highly urbanized urban corridor of the east coast of the U.S. between Washington D.C. and Boston typically overseas, the ability to rapidly and effectively “project” force became an increasingly important location criteria – so access to airfields, rail lines, interstate highways and ports grew in importance. These considerations are illustrated by the comparison with the location of U.S. cities (Fig. 2.1b). U.S. cities are concentrated in the eastern half of the country. The clustering of urban centers within 100 km of a coastline and the very highly urbanized region along the Washington D.C.-Boston corridor is clearly illustrated in the figure. The tendency for co-location of cities and military installations in the southeastern and Midwestern US in part reflects the fact that urban development occurred around military installations once the installations were established. Today there it is common to find a shared urban-military installation infrastructure in such areas.

In more recent decades, few new bases have been established and many have been closed or transitioned to other uses. A few bases have expanded their boundaries, such as Fort Carson in Colorado, which added a large training area – Pinon Canyon – in the 1980s, and Fort Irwin, California, which expanded land holdings in the Mojave Desert during the 1990s. But these expansions are exceptions, made to accommodate the large land requirements for “force-on-force” training with tanks and other large land vehicles. Many more bases have been closed or realigned in the multiple rounds of base realignment and closure – BRAC (see e.g. [5]) authorized by the U.S. Congress. Closures and expansion reflect changing mission priorities, but also reflect local public opinions about the military presence, which is viewed in some locations as the cornerstone of the economy, while decried in other locations for occupying valuable real estate that could be put to better and more intensive use if converted to private ownership.

The protection of communication, data collection, and command and control networks has become a determining factor in the recent siting of military installations. Thus military installations may be located at critical “nodes” on data, telecommunications, power, and shipping networks. While the geographic location is still important, the landscape of location is transforming from simple latitude and longitude on the earth’s surface to include virtual, mobile, and extraterrestrial space. These changes in location considerations may, in the short term, have little impact on military bases, but over many years could dramatically alter the use of and need for traditional bases.

2.2.4 Across the Fence Line

Bases exist within a regional context – they share roads, watersheds, ecosystems, air sheds, school districts, waste disposal and many other resources and processes with their surrounding communities. These shared assets are often well coordinated and planned, but the dynamic nature of conditions on both sides of the fence requires frequent interactions.

As bases represent major employers and spenders in a local area, they receive the attention and respect of local governments and local citizens. Bases often raise the standard of living in their surrounding communities in terms of income levels, education levels, and other factors – but that depends on the nature of the base and of the surrounding communities. Work forces frequently change due to deployments from a home base, resulting in wide swings in the number and type of personnel on site.

Bases have several priority concerns with regard to their neighboring communities. First, do the communities provide the necessary services needed to support their missions and the soldiers and civilians that pursue these missions? Second, are communities planning or allowing any actions that could potentially compromise their base's mission activities, such as residential development "up to the fence line" or new road access through or around a base? Third, how might base activities, such as environmental contamination, smoke from controlled or wild fires, or noise disturbances impact the local communities?

Congress and the military departments have put in place numerous programs and mechanisms to address these concerns. One of the oldest of these is the DoD Office of Economic Adjustment (OEA) which was established in 1961 "to assist communities impacted by Department of Defense (DoD) program changes" [6]. OEA has helped communities in all 50 states and major United States territories develop comprehensive strategies to adjust to defense industry cutbacks, base closures, force structure realignments, base expansion, and incompatibilities between military operations and local development. OEA operates programs to assist communities when bases expand, are reduced in size or mission, or are closed. There is also a compatible use program designed to help military facilities and communities work together:

> OEA's Compatible Use Program promotes cooperative planning efforts among military installations, ranges, and military training corridors and surrounding communities. Technical and financial assistance is provided to State and local governments to plan and implement a Joint Use Study (JLUS), a strategic plan with specific implementation actions to ensure civilian growth and development are compatible with vital training, testing, and other military operations. [6]

Noise is one the key issues addressed in collaborative planning exercises between bases and communities. Besides the JLUS and other compatible use programs, the services have developed several programs that deal specifically with military noise issues. The U.S. Army Public Health Command runs the Operational Noise Program and the Air Force Center for Engineering and the Environment operates the Air Installation Compatible Use Zones program to address issues with noise from military aircraft. Efforts to address these noise issues often result in programs to manage complaints. The military has invested significant effort into understanding how noise travels under different conditions. In many cases, noise-generating activities are limited to certain hours or conditions so as to minimize disturbance to neighbors.

Another important coordinate relates to natural resources management on and around the military bases. The Sikes Acts (16 USC 670a-670o, 74 Stat. 1052), which was first approved by Congress in 1960,

> ... provides for cooperation by the Department of the Interior and Department of Defense, together with State agencies, in planning, development and maintenance of fish and wildlife resources on military reservations throughout the United States."

Subsequent revisions of the Sikes Act have added the requirement for all Defense bases to develop, every 5 years, integrated natural resources management plans (INRMP), and to engage local stakeholders to review and help shape these plans. Then, in 2004, the Defense Authorization Act included a provision to allow military bases to join with other stakeholders to purchase easements on lands in proximity to bases. The purpose of this authority was to help protect mission activities that are sometimes threatened by conversion of lands near bases to more intense and less compatible uses. The Army entitled their program relating to this authority the Army compatible use buffers (ACUB – US [7]) and the ACUB website offers this definition for encroachment: "as urban development surrounding military installations that affects the ability of the military to train realistically." The website also states that "more than 40 % of installations report encroachment issues" [7].

Another important horizontal initiative is the installation sustainable planning initiative. Starting at Fort Bragg, North Carolina in 2003, Army bases and some bases in other services have engaged stakeholders across the base and around the neighborhood to set 25-year goals for sustainability. This type of long-term planning at the base enterprise scale, if endorsed by the base commander, can quickly gain momentum and a groundswell of participants. Bases have set goals to reduce energy consumption, improve transportation options, decrease waste, and reduce base sprawl with multi-story facilities and mixed-use districts (Army Installations Sustainable Planning Guide).

However, there will be many different base commanders over the design life of these 25-year plans, and momentum can be difficult to sustain between leaders. In addition, military funding and processes result in stove-piped decisions, which require accountability back up the organizational chain, but do not necessary account for the system-wide implications of decisions across the base or across the fence line.

When a decision is made about a new facility or facility complex, it is reviewed up a vertical chain-of-command all the way to the U.S. Congress, which authorizes funding for one facility at a time. Master planning guidelines and regulations also call for the review to be conducted across the base to ensure that each facility fits into an overall plan, but this is often a secondary consideration since time and budgetary constraints are often the key drivers rather than the operational implications of how a facility will impact the campus. A new Master Planning Unified Facility Code (UFC), published in 2012, seeks to enhance and improve across the base and across the fence line planning elements on all Defense bases. Furthermore, there are new efforts to strengthen base enterprise planning by conserving energy and water, reducing waste, and enhancing livability.

In the past few years, some new regional organizations have been created to enhance regional coordination between states, communities and military installations. One of these is the Southeast Regional Partnership for Planning and Sustainability (SERPPAS), which defines itself as "a unique six-state partnership comprised of state and federal agencies that promotes collaboration in making resource-use decisions supporting conservation of natural resources, working lands, and national defense." SERPPAS has been actively working with complex regional issues, such as bringing multiple agencies and organizations into discussions about the preservation of regional habitat for endangered species. Bases often provide critical regional habitat for threatened and endangered species, but cannot alone provide sufficient habitat for viable populations of these species, so regional approaches are critical for species preservation and for halting habitat loss and degradation on bases [8]. Other DoD and federal organizations focused on regional issues now also exist around the country.

2.2.5 Emerging Issues and Paths Forward

Two key issues will help shape future military bases. First, the Defense Department is seeking to shape a more adaptive and resilient military force. If successful, this approach will also reshape the role of military bases. Several important questions arise in this context. Are adaptive units best-housed and trained in enclaves separated from populations? Do adaptive soldiers and units still need the same type and number of fixed firing ranges and training events? Can live training adapt at the pace of change that has been experienced in our adversaries' tactics, or will we shift more and more to sophisticated simulations to reduce the cost and time of our adaptive processes? Some types of military training and operations are already shifting from land intensive to electrical grid and internet intensive, from live to virtual, from force-on-force training with heavy vehicles to training pilots stationed thousands of miles from the fight to operate drones in distant theatres.

Second, many military installations are located in environments where changing conditions – urbanization, climatic patterns, economic conditions, regulatory constraints, infrastructure resources, public opinion and regional threats to stability will make these bases more or less capable of supporting future mission needs.

Recently the DoD military services and their respective installations have been anticipating future conditions and how these conditions will impact future base missions. Services and regional organizations are considering various "scenarios" for dynamic change that involve not only mission changes but also changes in climate, urbanization, water resource shortages, and other factors that impact both the bases and their surrounding communities. Furthermore, training planners are examining the degree to which a key feature of readiness is adapting to unanticipated threats. So, what base features are most critical to support a more adaptive military?

In the past couple of decades, there have been numerous efforts to forecast "alternative futures" scenarios for military installations. The first was conducted by Prof. Carl Steinitz from the Harvard School of Design for Marine Corps Base Pendleton in California [9]. A subsequent effort was conducted by Army Training and Doctrine Command through the U.S. Army Construction Engineering Research Laboratory (CERL) for Fort Huachuca in Arizona [10]. More recently, CERL conducted a study for the fall-line sand hill bases (from Fort Benning, Georgia to Fort Bragg) as part of a strategic sustainability assessment project, similar to alternative futures [11]. To date, these studies have had limited impact into base operations, but will likely find paths for insertion into base plans such as strategic and master plans, integrated natural resource management plans, and critical infrastructure planning.

2.2.6 Incorporating Changing Conditions into Plans

Military planners need to understand how conditions in the region, across the nation and around the globe are changing, and how these changes might impact troops, bases and military missions. The DoD is beginning to mainstream change and vulnerability assessments into agency planning processes. As an example, the new master planning Defense Unified Criteria document for 2012 includes guidance to incorporate changing environmental conditions into plans. This is specified in a section of the new guidelines:

> Where changing external conditions impact planning decisions, master planners will seek to understand, monitor and adapt to these changes. Such conditions include, but are not limited to, changes in land use and population density in the vicinity of installations; changes in climatic conditions such as temperature, rainfall patterns, storm frequency and intensity and water levels; and changes in infrastructure assets and configurations beyond and linking to the installation. These and other changes will impact existing facilities and infrastructure, and also will impact new facilities and infrastructure through their design life (Master Planning Unified Facilities Criteria).

These criteria call for planners to understand not only how conditions are changing during the design phase of a project, but also how conditions are projected to change during the design life of a project.

In recent years, there has been considerable concern about “sustainable” supplies of water for military bases. The Army has conducted several studies to examine the water supply through 2030, including the Army Installation Water Sustainability Assessment, An Evaluation of Vulnerability to Water Supply by Jenicek et al. [12]. Many Defense bases exist in watersheds that have vulnerable supplies, and these bases will likely need to develop strategies with their neighbors who share these watersheds to provide for their long-term water resource needs. Several bases have already taken creative steps with their neighbors, such as the new desalination plant that was built on land in Fort Bliss, Texas with both federal and state support to provide a more secure water supply for the rapidly growing forces at the fort and for the City of El Paso (US [13]).

While there are many agents working on these challenges throughout the DoD, there are still many barriers to overcome. The U.S. military is a huge organization with many traditions, subcultures, stakeholders, and oversight entities that consciously or unconsciously resist change. A recent study by the Institute for Defense Analysis explored the requirements for adaptability as a meta-skill for both uniformed soldiers and DoD civilians and suggested that “an effective adaptability training strategy would involve training interventions at every level of an individual’s career and for every size and type of organization—small through large and joint, interagency, and multi-national” [14].

The Capstone Concept for Joint Operations states that: "the future operating environment will be characterized by uncertainty, complexity, rapid change, and persistent conflict" [15]. Citing this concept, Burns and Freeman write that:

> . . . adaptability is a key competency to deal with uncertainty - complexity and rapid change, but while leaders often speak of adaptability, there has not been widespread buy-in to the idea that adaptability needs to be developed in an intentional manner. In fact, developing adaptability is hindered both by particular aspects of organizational culture and by specific barriers that span the vast spectrum from human nature to governmental legislation.

Striving for a more adaptive military, including a more adaptive approach to military basing at home and abroad, will enhance the resilience of our military to sustain capability within a wider range of circumstances despite the increasing pace of environmental, technical and social change. This calls for a new understanding of the military mission and the military culture and the government institutions that govern and shape this culture. Clearly, the DoD as an organization, from top to bottom, needs to expect rapid changes, prepare leaders to quickly access and adapt to new threats and challenges, and be prepared for these adjustments to impact every facet of the military – including where, how, when and why assets and people are based.

2.3 Twenty-First Century Cities

In twenty-first century megacities, like Mumbai or Rio de Janeiro, the seeming chaos of informal settlements coexists side-by-side with the order of modular high-rises; mazes of corrugated metal, brick, and plastic fill the voids in a forest of concrete, glass, and steel (Fig. 2.2). Some of these informal settlements have been evicted and redeveloped, subsumed by the order of the formal city. Some have survived and thrived, developing their own urban infrastructure [16, 17, 18], and a few have even invaded the formal, ordered city where it has failed, infilling abandoned, unfinished towers [19, 20]. Such cities are dynamic; change is constant.

Cities and their urban regions are constantly and irreversibly changing, being destroyed and rebuilt, in a continual process of creative destruction and renewal driven by its history, by the memory encoded in its structure and culture. In the sense that it can never return to a previous state, a city today is not the same as it was in any time past. At all scales, the fabric and flows of the city are in constant flux – energy fluxes change, economies emerge and collapse, buildings are razed and new ones built, and inhabitants come and go [21]. The city and its region change irreversibly along novel trajectories driven by their historical legacies and present dynamics; they evolve to adapt to new challenges as civilization and the natural world change inexorably. The city is continually evolving.

Cities and the ecosystems that support them are dynamic. The city is a plexus of processes and forms interacting across myriad spatiotemporal scales. Networks of energy, food, water, waste, information, and commerce flow through cities and shape them. Diverse patterns and processes coexist and interact in an ever-shifting,

Fig. 2.2 Informal development along a utility corridor besides high-rise residential development in Mumbai. With land and housing in high demand, informal development fills available interstitial spaces in the city such as utility corridors, stream corridors, roadsides, and green space

unstable mosaic [22]. Each of these process-form interactions is constantly changing in an adaptive cycle of rapid growth, conservation, release, and reorganization [23, 24]. Cities, inseparable from their geographic context, are subject to the vagaries of climate change and the risks of natural disasters and disturbance regimes. The panarchic city – the dynamic set of urban adaptive cycles – evolves, irreversibly and uniquely, as it adapts to new demands, disturbances, and crises. Eventually, given a long-enough timescale, hierarchical disturbances will disequilibrate any adaptive cycle. Local instabilities in a nested adaptive cycle can underlie citywide stability, temporarily answering unmet needs like low-cost housing [16, 25].

New challenges for cities and their urban regions arise in a non-equilibrium paradigm. If a city is no longer considered to be a system perpetuated in a state of dynamic equilibrium, but rather a panarchy of urban adaptive cycles in an urban region, any of which may descend into disequilibrium, then the city is stochastic, unstable, and unpredictable. Any attempt to centrally plan a city would be undermined by the uncertainty of an ambiguous future [26].

Cities in the twenty-first century face unprecedented challenges, both old and emerging, caused or exacerbated, respectively, by the unprecedented scale of humanity's footprint. With a global population of approximately seven billion, humanity's ecological footprint has exceeded Earth's biocapacity by 6.2 billion global hectares, a biocapacity deficit of more than 50 % [27]. By overshooting our planet's sustainable carrying capacity, humanity is severely stressing global biodiversity and ecosystems, consuming unsustainably, and driving global climate change [27, 28]. Humanity's disproportionate impact on the atmosphere is evidenced by anthropogenic global climate change, its effect manifest on the biosphere by biodiversity loss and the hydrosphere by ocean acidification [27, 29]. Furthermore, humanity is transforming the Earth's surficial landscape, reshaping geomorphic systems through linked processes such as urbanization, land degradation and accelerated erosion regimes, and hydrological controls like dams and channelization [30]. Cities, now must adapt not only to complex urban dynamics like excessive population density and the spontaneous growth of informal settlements, but also to natural disturbances, disasters, and global climate change. As the climate changes, deserts will encroach on urban regions, changing sea levels will threaten coastal and riverside cities, and failing ecological resilience will threaten the provision of ecosystem services ([28, 31]). Natural disturbances like floods and wildfires, natural disasters like hurricanes and tsunamis, anthropogenic disturbances like air and water pollution, and anthropogenic disasters like nuclear reactor meltdowns already threaten cities. Climate change will exacerbate these threats [28]. Furthermore, urban dynamics are growing ever more complex. For example, rapid growth and a lack of planning in megacities throughout the developing world have caused the proliferation of informal settlements [16, 17].

2.3.1 Urban Geodesign

A promising new design and planning paradigm – geographic design or *geodesign* – is emerging that seeks to unite design with geographic science. It promises to revolutionize sustainable design by combining creative, innovative problem solving with scientific analysis. In this integrated and ideally fluid process, a designer could draw a sketch on a napkin, digitize the sketch, analyze it with geospatial simulations, and then learn from the feedback. However, given the unpredictability of the non-equilibrium dynamics, this vision of geographic design, driven by the sciences of prediction, will not be enough to ensure a sustainable future in the long-term. In a stochastic, unstable, and unpredictable world, sustainable design should be inspired by the science of resilience rather than prediction. Given the challenges that cities face in the twenty-first century, they should be designed and managed for resilience, i.e. for the capacity to adapt to disturbance and change.

Engagement, feedback, prioritization, optimization, adaption, and evolution are geographic design strategies that can build resilience despite the stochasticity, instability, unpredictability, and uncertainty inherent in a non-equilibrium paradigm. These strategies have been theorized, developed, and tested throughout many, diverse disciplines ranging from conservation biology to landscape architecture.

2.3.2 Geodesign Theory

2.3.2.1 Geographic Design

Defined broadly, *geodesign* is “changing geography by design” [32], but it has also been more narrowly defined as “a design and planning method which tightly couples the creation of design proposals with impact simulations informed by geographic contexts” [33]. An example of this narrower view of geodesign is the popular vision of a rapid, seamless process in which “a napkin sketch is evaluated and analyzed with geospatial modeling” [34]. This might be an intuitive process in which an architect scribbles a sketch on the back of a napkin, scans the sketch directly into a geographic information system (GIS), runs geospatial models and simulations, and then learns from the feedback. As new iterations, drawn on trace or digitally drafted, are added to the GIS and modeled, the design evolves, flexibly, but geographically informed. In such a process, design generation and scientific analysis could be tightly integrated through progressive cycles of conception, evaluation, and feedback.

Bridging the barriers between design and geographic science in such a manner, however, will not be enough to ensure the long-term sustainability of the built environment. Stochasticity, instability, and unpredictability will undermine design efforts that rely primarily on suitability mapping and forecasting. Given the unpredictability of non-equilibrium dynamics [35] and that uncertainty, over a sufficiently long timescale, will confound prediction with chaos [36], a reliance on the sciences of prediction will not lead to truly sustainable design, management, or policy [37]. Thus, over the long term, sustainability will require responsive, rather than static designs, i.e. designs that learn and evolve as their context, along with dynamics of the system in which they exist, changes. By accepting risk and learning from it [37], by accepting and working with disturbance and other dynamics, designers and scientists can create resilience and adaptability [23, 38]. Geographic design should be first and foremost a learning process, in which both knowledge and designs are continually created, critiqued, and adapted.

2.3.2.2 Resilience Theory

Change is inevitable; thus, over a sufficiently long time scale, any urban region will have a tendency to transition toward a state of disequilibrium in response to cultural, political, and economic forces, and both climate and the Earth’s surficial landscape will change in response to both natural forcings and anthropogenic impacts. Every city will change, each following a unique trajectory that will be determined by the legacy of its own history and its local circumstances. As anthropogenic landscapes, urban regions are subject to nested adaptive cycles of climatic, ecological, geomorphic, and socio-cultural processes across multiple spatiotemporal scales [24, 39, 40]. Driven at different spatiotemporal scales by plate tectonics, geomorphological evolution, and climate instability – natural factors such as hydrogeomorphic evolutionary pathways, hierarchical disturbance regimes, disturbance legacies, multiple post-disturbance pathways, space-time contingencies, spatiotemporal variability, and system hysteresis will force an urban region toward disequilibrium and thus towards a new, alternative state or adaptive cycle [24, 35, 41–43]. Anthropogenic impacts, such as hydrological modification and land use change, typically operating on relatively larger and faster spatiotemporal scales, can also drive regions to disequilibrium, often creating novel socio-ecological systems [39, 44, 45].

The nonlinear dynamics inherent in a non-equilibrium paradigm introduce a high degree of uncertainty, enhance spatial heterogeneity, and enrich diversity. System-wide patterns emerge out of this diversity of parts and processes, giving rise to recursive states regulated by feedback dynamics [46]. Multiple socio-cultural, geomorphic, and ecological process-form interactions occur within an urban region at different spatiotemporal scales [40]; each is a system, a recursive state. And each follows an adaptive cycle, a lifecycle of rapid growth, conservation, release, and reorganization. A *panarchy* is such a set of nested adaptive cycles [23, 24, 39]. The fate of a panarchy rests in its adaptive capacity, its dual capacity to resist change and recover from change. Stability is the potential to recover from disturbance and resilience is the potential to weather disturbance and remain in a stability domain [24].

Change is both inevitable and necessary in a non-equilibrium paradigm. Since resilient urban regions can better adapt to change, building resilience is a sound strategy for an unpredictable future. Given the challenges arising from non-equilibrium dynamics – stochasticity, unpredictability, and instability [35] – and the resulting uncertainty, predictive science alone should not guide design or adaption. Resilience is key to a sustainable future.

2.3.3 Strategies for Non-equilibrium Paradigm

Given the challenges posed by non-equilibrium dynamics, strategies like engagement, feedback, prioritization, optimization, adaption, and evolution will be required to design and build urban resilience. *Engagement* can build resilience by creating commitment, fostering learning, and mitigating uncertainty. It is a prerequisite for the sustained success of the other strategies. Without nurturing bottom-up, self-organizing processes, planners and managers will have fewer, more constrained opportunities to learn from feedback, will not build support for priorities, optimization, or adaptive management, and will not be able to catalyze evolution. *Feedback* provides the knowledge of change required for learning and thus adaptation. With *prioritization* and *optimization*, scarce resources can be conserved and used efficiently. *Adaption* provides the flexibility to accommodate change within a system or to find a new stability domain; it is the key to resilience. Finally, through *evolution*, change can be learned from, fitness improved, and resilience enhanced. Ultimately case-specific syntheses of these strategies will be needed to meet the challenges of a non-equilibrium paradigm.

Since engagement is a prerequisite for sustainable design, the case studies in this article illustrate examples of engagement. After a brief overview of each geodesign strategy, a case study about engaging with an informal, urban community is explored. In the following section, the sustainability of military installations is discussed and a case study about engaging with military decision makers is presented.

2.3.3.1 Engagement

Enabling and encouraging engagement can reduce uncertainty, encourage commitment and investment, foster learning, and lead to the co-production of knowledge and the co-design of plans and policies. Wider engagement can reduce the uncertainty that arises from delusion and deception in management by necessitating communication, increasing transparency and thus improving accountability, and opening access to information [47]. Engagement can also lead to greater stakeholder investment in a project, thus facilitating consensus based decision-making and creating opportunities for education, feedback, and learning through participatory modeling, participatory design, and citizen science. The co-production of knowledge [48] and design solutions [26, 49] tightly integrates science and design and is an important step towards realizing the goals of geographic design. By encouraging collaboration, disciplinary boundaries can be bridged, thus permitting the cross-dissemination of ideas and the synthesis of once disparate knowledge. Strategies for engagement include consensus building [50], various "open" movements like *open science* [51], the co-production of knowledge [48], participatory design [26, 49], and spatial decision support [52, 53].

2.3.3.2 Feedback

Change is inevitable in cities and the unexpected a certainty. Planners and managers can adapt to the dynamism and instability of urban regions through active learning [54]. Adaptive management is a process of actively learning from feedback to better manage change. It is a continual cycle of monitoring, learning, and response [23, 55]. With feedback, scientists and managers can learn from change and novelty. Such learning is the foundation for adapting to change and building resilience [23]. Methods for acquiring feedback about the natural and built environment range from traditional surveys and censuses to innovative remote sensing and "crowd sensing" technologies that can be applied to buildings that sense and respond, like the digital water pavilion in Zaragoza, Spain [56]. With the pervasiveness of digital information and communication technology (ICT) – especially in the built environment – there are growing opportunities for harnessing the networked public and built infrastructure as real-time monitors of the urban environment. Quantitative geospatial data can be collected from mobile phones and Bluetooth devices, GPS, geotagged user generated content, and both mobile and static sensors placed in the urban environment [57, 58]. Crowd-sensing has been used, for example, to map in real-time the dynamics of museum visitors in the Louvre [58], air pollution in London [59], and traffic in Rome [60]. Participatory crowd-sensing could create a feedback loop between the city and the citizen, allowing individuals to contribute information and learn about their environment [61].

Sensors embedded in urban environments can be used not only to learn about, but also to influence various complex and dynamic aspects of the city, improving economic, social, and environmental sustainability. By coupling digital sensing and real-time data processing in a feedback loop, urban dynamics can be analyzed as they unfold to better inform decision-making. Digital sensors can monitor and capture information as conditions change, thereby providing immediate information to the city managers, infrastructure operators, and the public. The LIVE Singapore! project, for example, provides real-time analysis and visualization of urban processes ranging from traffic disruptions to the dynamics of urban heat islands to the public, industry, and government [62]. Real-time knowledge about urban dynamics can enhance decision-making about the use of urban resources, the provision of services, operation of the urban transportation network, personal mobility, and social interaction [57]. Properly deployed and utilized, such technology could become a cornerstone to urban sustainability and resiliency.

2.3.3.3 Prioritization

By identifying what should be valued most, limited space and resources can be used more effectively. Systematic, effective, and efficient planning requires that priorities be set, and that values be evaluated and ranked. Prioritization is implicit in all design. If decisions are to be made, priorities must be set whether implicitly or explicitly.

If prioritization is to be ethical and problem solving agile and creative, then generative conversations – discourses that occur when two different, distinct bodies of knowledge intersect – should be at the root of prioritization. A generative conversation is the process of collaboratively generating new knowledge to resolve the incompatibility between conflicting bodies of knowledge [63]. Therefore, potential stakeholders should be engaged and given a voice. If there are currently incompatible views, new knowledge and creative resolutions should be sought. Thus, as a creative, discursive process hoping to solve problems for which there are not yet answers, design – and geographic design in particular – should seek to recognize and bridge conceptual barriers, engage in generative discourse, co-produce knowledge, and thus promote an ever-shifting, multiplicity of justice.

Decision makers can use multi-criteria decision analysis (MCDA) – the rigorous and structured analysis of values and decision options by transparent, mathematical methods – to help find solutions to complex problems with multiple stakeholders. In MCDA, the criteria that the decision will be based upon are evaluated for performance and weighted according to the decision makers' or stakeholders' preferences. By comparing the weighted criteria scores for alternative decision options, these options can be ranked. This process can guide decision makers towards rational, scientifically informed, and defensible choices [64].

2.3.3.4 Optimization

After priorities have been defined, the most efficient allocation and structuring of resources, space, and time can be determined for the given priorities. For example, multi-criteria map overlay analysis can be used to map and identify the most suitable sites for development or conservation [65, 66]. Least cost-path analysis can be used to find the optimal route for a new transportation link. Network analysis using combinatorial optimization can be used to plan the best routes for journeys and deliveries or to identify the ideal location for a store [67].

2.3.3.5 Adaption

Learning is the key to dealing with ambiguous threats or successfully undertaking experimental transformations. Organizations can adapt to the unknown through learning. In a city, learning should be distributed and collaborative; city management, firms, designers and design collectives, and individuals should seek to learn, collaboratively, through each project and intervention. Organizing to learn is an experimental approach that calls for collaboration to promote creative problem solving, rapidly iteration to promote innovation, and knowledge-sharing to efficiently generate solutions [68, 69].

Adaptive management can enhance an urban region's innate capacity to absorb disturbances, bolstering its resilience. According to Salafsky and Margoluis [55] "[a]daptive management – an iterative process of monitoring, learning from feedback, and tailoring management actions to suit changing conditions – reduces uncertainty, mitigates risk, and optimizes decision-making." Management becomes research. Knowledge can be advanced, uncertainty and risk reduced, and the practice of management improved through this continual process of critically questioning and systematically testing assumptions [55].

2.3.3.6 Evolution

Evolution is a strategy for learning through change. It is a continual quest for greater 'fitness-for-purpose.' Biological evolution has inspired advances in diverse fields ranging from artificial intelligence and evolutionary computation to architecture and design [26, 70]. John Frazer, inspired by evolution in nature, demonstrated that architectural designs could evolve through iterative improvement to generative rules – combinatorial rules for generating form. In evolutionary architecture "architectural concepts are expressed as generative rules so that their evolution may be accelerated and tested" [70]. Evolutionary architecture is an iterative process in which architectural prototypes are evaluated based on their performance in simulations, the generative rules are adjusted, and a new, fitter generation of forms is computed. While evolutionary architecture seeks to develop better architectural forms through an accelerated computational process [70], peer-to-peer (P2P) urbanism is an analogous, social process for developing better urban and architectural forms by empowering individuals and thus enabling and accelerating the emergence of a contemporary vernacular [26]. Both share the philosophy aptly expressed by Gordon Pask that, "the role of the architect… is not so much to design a building or city as to catalyze them" [70].

2.3.4 Strategies for Engagement

In contrast to expert decision-making – the traditional modus operandi of architecture and design – consensus decision-making [71] encourages transparency, engagement, accountability, information sharing, and the co-production of knowledge. In consensus decision-making, diverse groups of experts, decision-makers, and stakeholders are brought together to collaboratively explore alternative decisions, propose tradeoffs, and work towards consensus through quorum responses. Consensus decision-making – in comparison to individual decision-making – improves group cohesion, decision accuracy, and decision-making speed ([50, 72]). By engaging with concerned parties, uncertainty can be addressed by creating opportunities for communication, information sharing, and the exploration of collective knowledge and needs.

By engaging a local community in the co-production of knowledge about flood risk, scientists redistributed knowledge and expertise within their extended research collective. By combining scientific knowledge with local experience and histories to create a new flood risk simulation, the collective generated new, contextual, place-specific knowledge that reflected the local reality of place more accurately than standard flood models [48]. Political deadlock between scientists and the local community was mediated through the creation of a shared intellectual space. Collaborative science can be a consensus building process. As such it is a more democratic science and can lead to more just policy and planning. Whereas engagement through local participation is motivated by rationalism, by the perceived need to educate a local public and thus build support, collaborative engagement in the co-production of knowledge instead harnesses controversy in a critical and democratic process, potentially leading to consensus [48]. Thus, co-production not only leads to a place-specific science [48] that recognizes the uniqueness, the exigencies of time and place [43], but also effectively engages and builds trust and commitment within local communities.

Collaboration is championed over expertise in P2P urbanism [26] and the closely related open-source architecture movement [73]. P2P urbanism argues that the site-specificity, accumulated knowledge, and iterative processes of vernacular design and technology bring local, contextual knowledge and experience to the design and evolution of cities that central planning cannot. Drawing on vernacular processes, peer-to-peer urbanism seeks to develop urban fabric at a human scale by enabling individuals. P2P urbanism calls for individual justice and self-determinism, participatory co-design and potentially co-construction, the co-production and sharing of open source knowledge, and the accumulation of collective urban knowledge [26]. Through the accumulation of this shared knowledge, technology, and practice the built environment can evolve and adapt in response to the ever-changing challenges it faces.

Drawing on the biophilia hypothesis [74], Salingaros [75] argues that there are fundamental, geometric patterns that are biophilic, that have a crucial, life-sustaining emotional effect. These geometric patterns and characteristics – present in nature and in some vernacular urban fabric – include size distributions scaled according to the inverse power law [76], fractal scaling, mathematical symmetries, and structural invariants [75]. This research highlights the importance of maintaining a human-scale in the built environment. The presence of such geometries in vernacular architecture and urbanism suggests the importance of self-organization, of bottom-up processes. P2P urbanism and open source architecture both aim to enable self-organization by harnessing new technologies – such as ICT – to facilitate engagement and feedback. Open source architecture seeks to update vernacular design with cutting-edge technology, calling for crowd-funding, creative commons licensing and blueprints, universal and open standards, open source software, mass customization, and feedback from embedded sensors [73].

By integrating GIS with collaborative, participatory design processes, geographic knowledge and spatial designs can be co-produced. In the Spatial Delphi method, a geodesign methodology that integrates GIS and participatory design, stakeholders collaborate and work towards a geographically informed consensus. Effective, democratic solutions to complex geospatial issues can be reached by engaging communities, experts, and decision-makers in collaborative mapping and planning processes powered by GIS. This approach is based on the premise that group decision-making is more effective than individual decision-making [49]. The Spatial Delphi method has been used in experiments to more fully realize the goal of geodesign – the seamless integration of design and geographic science. In a research project in Costa Rica, analog sketches drawn by community members with digitizing pens on graphics tablets were imported into GIS-based alternative futures scenarios for discussion and subsequent geospatial analysis. Technological and disciplinary barriers to collaboration were bridged by providing community members with an intuitive interface with GIS [49]. Alternative futures analysis is a theoretical framework and conceptual workflow for spatial decision support and geodesign. By analyzing and evaluating geographic issues and then forecasting alternative futures, decision-makers can compare future scenarios to prioritize design decisions. An iterative cycle of representation, process, evaluation, change,

Fig. 2.3 A researcher using the Tangible Geospatial Modeling System [79] to explore the process-form interactions of dune morphology and storms on the Outer Banks of North Carolina

impact, and decision models is used to describe the geography in question, learn how it operates, evaluate its effectiveness, consider potential interventions, predict changes, and prioritize interventions [52].

There is a disjunction between the analog and the digital, the physical and the virtual. Tangible user interfaces (TUIs) make human-machine interaction more intuitive, making use of our great physical dexterity and kinesthetic intelligence [77]. Tangible user interfaces like the Urban Planning Workbench [77], Illuminated Clay [78], and the Tangible Geospatial Modeling System (TanGeoMS) allow users to interact with digital models by manipulating linked physical models [79]. In TanGIeoMS, a malleable terrain model, such as one constructed from plasticine clay, is coupled with a digital elevation model (DEM) in a GIS through a continuous feedback cycle of 3-D scanning and projection (Fig. 2.3). As users manipulate and modify the clay terrain model with their hands, their changes to the terrain are scanned into the GIS, geospatial simulations are run, and the results are projected back onto the clay model. Through this cycle of haptic interaction, digitization, simulation, and projection, users can intuitively experiment, test hypotheses or designs, and learn from simulations [79].

TanGeoMS is not only a system for understanding and interacting with three-dimensional space and time; it is also a system for collaborating in three-dimensional space and time [80]. Because multiple users can collaborate and shape landforms simultaneously, TanGeoMS can facilitate participatory landscape design. As users manipulate landforms, vegetation, buildings, infrastructure, or model parameters (such as infiltration rates) they will be informed by dynamic simulations about important design considerations such as slope, water flow, erosion, or solar radiation and shade. By learning together users can collaboratively develop a better, more effective design [79].

TanGeoMS has been used study the process-form interactions of barrier island dunes (Fig. 2.4) and to test landscape design strategies [79, 81, 82]. When combined with light detection and ranging (LIDAR) time series data, the system allows

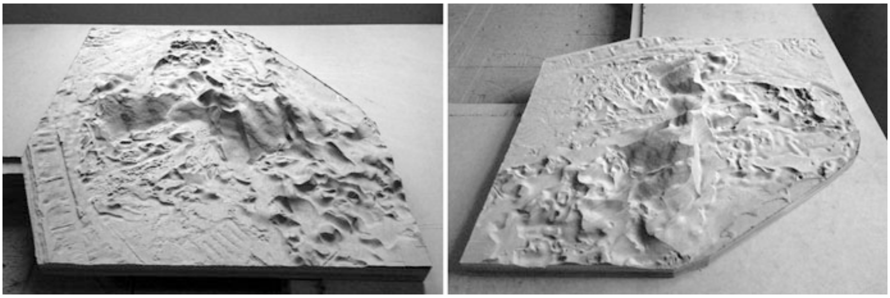

Fig. 2.4 A model of the Jockey's Ridge dune system on the Outer Banks of North Carolina representing the stable core of the dune that has remained unchanged from 1974–2009. This model was used with TanGeoMS to study dune morphology

users to understand and interact with terrain as an evolving and dynamic three-dimensional layer. Past terrain change can be derived from airborne LIDAR time series using raster analysis or a space-time voxel model in GIS, future changes can then be simulated in GIS, and scenarios tested using TanGeoMS [79, 80, 82].

2.4 Case Studies

2.4.1 A Case Study in Urban Engagement: Forage Tracking

Catadores, informal recyclers, roam the streets of São Paulo, on foot or by truck, searching for recyclable waste. In a project called Forage Tracking, researchers from MIT and the University of São Paulo have been working with a cooperative of Catadores to learn how they collect recyclables, to optimize their collection, and to help them realize new business partnerships [83]. Little was known about the dynamics of the Catadores and, due to this lack knowledge, some local businesses were loath to reply on informal recycling. In collaboration with the COOPAMARE recycling collective, the researchers are developing a system for tracking and facilitating networks of informal recycling using location based communication technologies. Initially, the Catadores will be tracked using GPS, building knowledge about poorly understood informal processes and their spatial dynamics. Eventually this knowledge will used to better coordinate collection, optimize routes, and build trust. Using a mobile internet-based participatory platform, clients would be able to book pickups and Catadores could plan optimized pickup routes, openly and transparently. By co-producing and sharing knowledge about the logistics of informal recycling, the collective would become more transparent and may build trust with potential partners such as local businesses. Through crowd-sensing, the researchers are able to tap into the tacit knowledge of the Catadores and learn about an informal urban dynamic [83]. Furthermore, through this collaborative research, the Catadores are engaging in citizen science and co-producing knowledge.

2.4.2 A Case Study in Engagement: Tangible Geospatial Modeling Scenarios for Fort Bragg

Land degradation threatens the long-term sustainability of military installations and training grounds. Urbanization at military installations and vehicular and aircraft maneuvers at training grounds cause major ecological and geomorphological disturbances such as landscape fragmentation, noise pollution and edge effects, soil compaction, and accelerated erosion regimes. Erosion is a continuing challenge at Fort Bragg, a major US military installation with approximately 57,000 personnel [84] in the Sandhills region of North Carolina. The Sandhills is a sensitive landscape of relict dunes, composed of Cretaceous marine sands and clays left by the once advancing coastline [85]. Heavy vehicular traffic and rotor wash from helicopters have accelerated erosion and triggered the formation of gullies at Falcon Airstrip, a training ground in Fort Bragg. If military land managers are to understand, restore, and ideally avoid such land degradation, then planning and management must be driven by geographic science and should be systemic yet flexible. Since every landscape is unique [43], bespoke and thus creative solutions are required; therefore, science and design should be coupled in an intuitive geodesign workflow. In a proof-of-concept study, the Tangible Geospatial Modeling System – TanGeoMS – was used to intuitively test alternative design interventions in a series of restoration scenarios for Falcon Airstrip [81]. Ideally, using TanGeoMS as a spatial decision support system, military land managers and stakeholders could collaborate, engaging in consensus decision making guided by geographic science and modeling. Military land managers and decision makers could engage and interact, hands-on, with a diverse range of military actors, scientists, and civilian stakeholders.

In a series of seven scenarios, scientists using TanGeoMS manipulated a malleable, physical terrain model of Falcon Airstrip with their hands, intuitively testing potential interventions such as check dams, infill, riprap, and drainage ditches [81]. Guided by near real-time feedback from GIS analyses, the scientists could test the efficacy of their interventions with hydrological and erosion models. A clay model of the airstrip was coupled with a digital elevation model of the airstrip, interpolated from LIDAR data. As changes – such as the filling of a 200-m long, 33-m wide, and 4-m deep gully – were made to the clay model, the changes were scanned into the GIS, analyses run, and the results projected back onto the physical terrain model, to guide and inform the scientists [81]. By hand shaping landforms they could explore, collaboratively, how morphological changes affect runoff and erosion, unhindered by the conceptual barriers of digital manipulation and visualization.

2.5 Conclusions

In a non-equilibrium paradigm, sustainability means resilience; a resilient city or military installation is sustainable. The continued resilience of urban centers and military installations will require engaging stakeholders, learning from feedback, setting priorities, optimizing limited resources, adapting to uncertain and ambiguous challenges, and learning through continual evolution. Through a synthesis of these strategies, urbanized areas may become more resilient despite the unpredictability of the future. For now a myriad of cultural and institutional barriers – in government and the military – resist adaptability and change. Attitudes towards change and hierarchical decision-making should be reexamined. Decision-makers should seek to collaborate with stakeholders to co-produce knowledge and develop innovative solutions. With crowd-sensing and crowd-sourced science, individuals can learn not only about their own dynamics, but also about the dynamics of their city, base, or environment. By engaging the public, opportunities for more just, consensus decision-making may emerge.

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Chapter 3
Assessing Adaptive Capacity of Cities and Regions: Concerns Over Methodology and Usability

S. Juhola

Abstract Cities are key locations within which responses to climate change need to be taken. The vulnerability of cities depends on combined factors of exposure to climate impacts, sensitivity of the system and adaptive capacity of the city that can be mobilised for action. According to the Intergovernmental Panel on Climate Change, adaptive capacity is defined as the ability or potential of a system to respond successfully to climate variability and change, and includes adjustments in both behaviour and in resources and technologies. Determinants of adaptive capacity are considered to include issues such as political institutions, economic resources, technological potential, infrastructure and equity.

Many studies have attempted to assess adaptive capacity of systems, and drawing on earlier work, this chapter presents results from a study that mapped adaptive capacity on the regional and city level. The results show widely differing capacities within cities and regions in Europe that can potentially have an impact on adaptation policy. Urging caution in terms of using the results to steer policy, this chapter concludes by discussing the shortcomings of adaptive capacity assessments in terms of methodological challenges.

3.1 Introduction

Cities are the key locations within which responses to climate change need to be taken. This is because most of the world's population now live in cities and approximately three quarters of all large cities are located on the coastline [1], making them vulnerable to climate change induced sea level rise, for example.

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The vulnerability of cities depends on the combined factors of exposure to climate impacts, sensitivity of the system and adaptive capacity that can be mobilised for action [11].

Adaptation, alongside mitigation, is a societal response to climate change that involves adjustments in the ways societies are organised in order to reduce vulnerability to slow on-set climate changes, as well as to rapid, extreme events. Thus adaptation refers to the processes, practices, and structures to moderate or offset potential damages or to take advantage of opportunities associated with the changing climate [2].

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) defines adaptation as ‘adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities’ [11]. Adaptation, as a societal process, can take place through different ways, either as an anticipatory or as a reactive response to already experienced climatic changes. It can also take place through actions that are considered to be planned adaptation, i.e. measures that are undertaken by different governmental actors specifically to deal with a climate impact. In contrast, autonomous measures are taken by private actor without any steering from the public sector [3]. Autonomous adaptation has been termed as private and planned adaptation as public adaptation in the Third Assessment Report of the [2].

Adaptive capacity is a concept that is closely linked to adaptation. The IPCC defines as the ability or potential of a system to respond successfully to climate variability and change, and includes adjustments in both behaviour and in resources and technologies [11]. Hence, adaptive capacity is a crucial component of understanding a system’s vulnerability as the vulnerability is based not only on the exposure of the system to climatic changes that matters but also on the ability of the system to adapt to changes, whether experienced or projected. Adaptive capacity consists of different kinds of determinants that underlie adaptive capacity. These determinants include, for example, political institutions, economic resources, technological potential, infrastructure and equity.

Many studies have attempted to assess adaptive capacity of systems, and drawing on earlier work [22], this chapter presents the results from a study that mapped adaptive capacity on the regional and city level. The results show widely differing capacities within cities, and regions and this can potentially have an impact on adaptation policy making. As a note of caution, this chapter concludes by discussing the shortcomings of adaptive capacity assessments in terms of methodological challenges, as well as their use in policy making.

3.2 Background: Cities and Climate Change

It has now been widely accepted that due to the inertia of the earth’s climate system, there is a need to adapt, despite the efforts to reduce the amount of greenhouse gases emitted [4]. Cities play a key role in adapting to climate since they are concentrations of people, wealth and other resources [5]. Adaptive capacity is a relevant concept here since it is used to explore what enables adaptation processes to take place and what kinds of resources can support adaptation to take place and what hinders it. Hence there is a need to understand what constitutes adaptive capacity in order to better understand how cities can respond the climate challenge.

Although there are many common issues that urban areas and cities face in terms of climate change, they all have particular traits, including location, structure and density that make their residents and assets vulnerable to climate change [6]. These challenges are also depended on the projected climate change for that particular area, depending on whether they are coastal or mountainous cities, for example.

On the whole, the impacts of climate change are likely to be faced in all sectors within the city. Storm events can have an impact on the transport sector [7], and through extremes in temperature and an increase in the frequency of hot days can impact the underground rail system [8]. Climate change is also going to impact urban energy demand and infrastructure maintenance, irrespective of efforts taken by cities already. The impact on the potential produce renewable energy is likely to be regionally specific, as the trend can be either positive or negative [9].

It is crucial to focus on cities since they are also interconnected to the regions around them, playing an important economic role in a wider geographical region of their own. This of course has an impact on the adaptive capacity that cities have and their ability to adapt to the changes. Hence, the purpose of this chapter is to review the literature and present a case study example of where adaptive capacity has been assessed in European cities and regions.

3.3 Assessing Adaptive Capacity

Adaptive capacity determines to extent to which a society is able to adapt to climate change, irrespective of whether adaptation is autonomous or planned. In the literature, the existence of adaptive capacity is shown to be a prerequisite for the design and implementation of adaptation measures that reduce the effects of adverse impacts from climate change [10]. Adaptive capacity, also, enables the society to take advantages of any favourable conditions created by climate change.

Although it is acknowledged that adaptive capacity is a dynamic concept, it is possible to identify a set of determinants that affect a region's ability to adapt [2], see Table 3.1. Economic resources are important because societies with more resources are able to fund more adaptation measures. Technological resources enable societies to design and develop different kinds of adaptation solutions and the lack of these resources inhibiting them from doing so. Third, skilled and informed personnel can increase the adaptive capacity of a society whilst an uneducated population is likely to affect adaptive capacity negatively. A well-functioning infrastructure enables a society to consider a greater variety of adaptation options. Fifth, accountable and functioning political institutions are also likely to lead to more satisfactory and acceptable adaptation options than those with little public regard. Finally,

Table 3.1 Determinants of adaptive capacity (Adapted from [2])

Economic resources	Economic assets, capital resources, financial means and wealth
Technology	Technological resources enable adaptation options
Information and skills	Skilled, informed and trained personnel enhances adaptive capacity and access to information is likely to lead to timely and appropriate adaptation
Infrastructure	Greater variety of infrastructure enhances adaptive capacity
Institutions	Existing and well-functioning institutions enable adaptation and help to reduce the impacts of climate-related risks
Equity	Equitable distribution of resources contributes to adaptive capacity

availability and access to resources in a societally equitable manner is likely to lead to more efficient adaptation. As can already be seen, these determinants are not independent of each other, nor are they mutually exclusive. Rather they should be interpreted as a combination of determinants that are interconnected with each other.

The Fourth Assessment of the IPCC distinguishes between two aspects, a generic one and a specific one [11]. Generic capacity is considered to be the general ability and capacity of a system to respond to climate change, drawing on its economic, political and social resources. Alternatively, specific capacity refers to a particular climate impact, such as a drought or a flood, for which capacity is necessary to deal with either in an anticipatory or a reactive manner [2].

A particularly interesting case study is that of the A-Team which, as part of a larger ecosystem vulnerability assessment analysed adaptive capacity further by producing indicators for European regions [12]. The authors divide adaptive capacity into three components, awareness, ability and action and they can further be linked with the IPCC determinants identified in Table 3.1. Awareness includes the determinant of knowledge and awareness. Second, ability consists of technological capacity and infrastructure, and finally, action consists of determinants that are related to carrying out the adaption measures, i.e. political institutions and economic resources [12].

In the literature, much effort has been placed on understanding what the characteristics of a system are that affect its ability or propensity to act. There have been a number of studies that have focused on the national level [13–16], or on the local level [17] and across all levels of governance [18].

Adaptive capacity is also context specific, in that it has a distinct temporal and spatial flavour. A system's capacity is determined by a locally determined set of resources and conditions that constrain or facilitate the ability of the system to successfully adapt to the changes in climate [13, 19]. Furthermore, it can vary from country to country and region to region, as well as within social groups and individuals. Also, this capacity changes over time, as mentioned above [19]. Adaptive capacity, across different scales, varies in value and these scales are not independent or separate from each other [19]. For example, a capacity of a country influences the capacity of a city to act, and vice versa.

The adaptive capacity of a city changes over time, corresponding with the society's economic, institutional, social and political conditions. Adaptive capacities have been shown to vary according to the scale of governance in question [18]. In this study of four different European countries, it is argued that different capacities are important at the national level whilst other capacities are considered to be crucial on lower levels of governance.

Interestingly, the lower the level of governance, the more intertwined and dependent on each other the capacities become [18]. An example the authors highlight, is a case where climate information and networks were considered to be beneficial and enabling adaptation but the lack of human capital hindered the use of those. Moreover, the lack of human capital to access different kinds of networks meant that local authorities were able to further build their other capacities of financial and social capital that would have enabled to build their human capital.

Studies have also focused on the sub-national level, for example addressing the governance system [20] or at the municipal level flood plain management in the United States [17]. In the latter study the author conducts a quantitative test of the relationship between adaptive capacity and the socio-economic status of a municipality. The findings indicated that the socio-economic characteristics of a municipality are associated with the ability of the municipality leaders to bring about action on climate change.

Assessing adaptive capacity can be considered a conceptual and a methodological challenge, given the discussion above. There are but a few comprehensive assessments and it is acknowledged that 'the literature lacks consensus on the usefulness of indicators of generic adaptive capacity and the robustness of the results' ([11], p. 728). For example, a review of five vulnerability studies demonstrates that there is little consistency across the findings when countries are ranked in terms of the vulnerability [21]. Another study further supports these findings by demonstrating that an exhaustive ranking of countries based on their adaptive capacity is dependent on the objectives of their adaptation policies [14]. In other words, a nation's ability to adapt is altered when their aspirations of adaptation are changed, leading to a different outcome in ranking.

Despite these challenges, determinants can be identified that are linked to national levels of overall development, such as political stability, economic wellbeing and social and human capital [11]. In addition, proxy indicators have been used to bring issues such as human and civic resources, and environmental capacity into the assessment. The following section presents a study where this has been done.

3.4 Assessing Adaptive Capacity: A Case Study

The objective of the ESPON Climate project was to develop a combined adaptive capacity index for the regions within Europe, based on a selection of available indicators that measure the generic adaptive capacity of each region [22]. Although in this case the focus was on the regional level, this study also assesses the adaptive

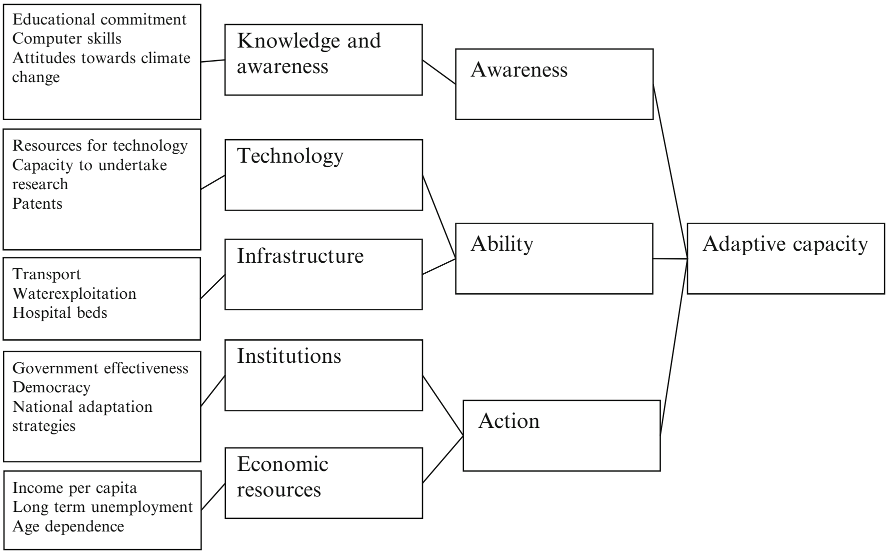


Fig. 3.1 Determinants and indicators of adaptive capacity (Adapted from [12])

capacity of cities because most cities are their administrative unit, making this example relevant when discussing cities. Based on a literature review, the definition of adaptive capacity used by the IPCC was adopted and a region is considered to consist of a NUTS3 region. Furthermore, as in the study by Schröter et al. adaptive capacity was considered to consist of three parts: awareness, ability and action, which are further comprised of determinants of adaptive capacity as defined by the IPCC and others, see Fig. 3.1.

Hence, knowledge and awareness enable a society to identify vulnerabilities and adaptation measures in relation climate change. Ability, in terms of technology and infrastructure enable adaptation measures, whilst institutions and economic resources enable societies to act on adaptation. In this study, equity, one of the IPCC determinants has been left out of the analysis, but issues related to it are explored in other determinants, i.e. unemployment and status of women in democracy. Furthermore, the focus was on generic determinants that can be assessed across a wider geographical scale, and it was assumed that there are determinants, such as education and income that enable adaptation irrespective of a particular location.

The overall adaptive capacity index in this study was based on relative values of indicators and determinants. The numeric values for the five determinants were constructed by averaging the normalised values of the indicators according to Table 3.2. These values are also normalised. The adaptive capacity index is then calculated as a weighted average of the determinants. The weights of the determinants are drawn from a Delphi survey carried out as part the ESPON Climate project [22]. See Table 3.2 for the specific indicators used.

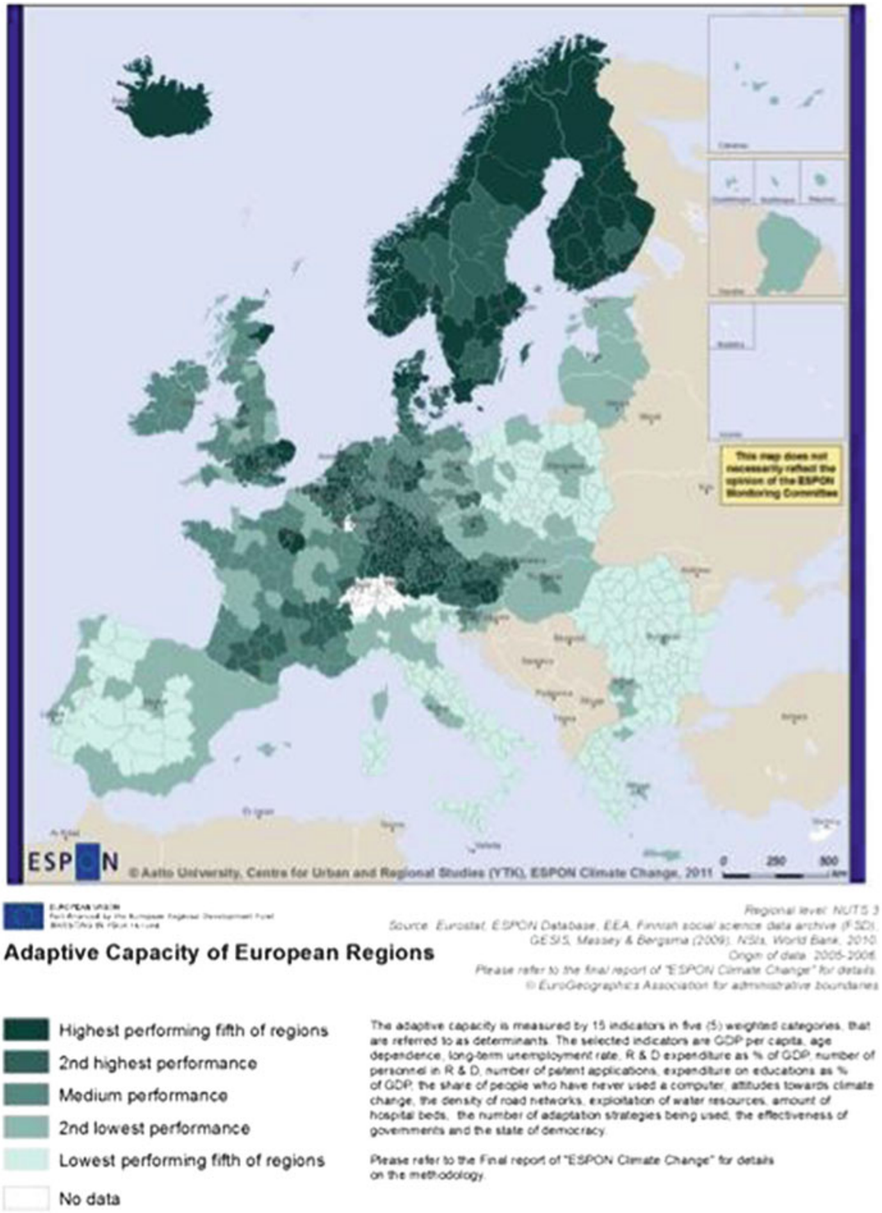
Table 3.2 Indicators for adaptive capacity [22]

Determinant	Proxy	Methodology
Knowledge	Educational commitment	Education expenditure per capita within a region
	Computer skills	Percentage of people who have never used a computer
	Attitudes towards climate change	Eurobarometer questions surveyed in 2008 and 2009
Technology	Resources of technology	Percentage of GDP in R&D investment
	Capacity to undertake research	Number of scientists and engineers in R&D per million labour force
	Patents	Number of patent applications per million inhabitants
Infrastructure	Transport	Kilometres of road per square kilometre
	Water exploitation	Water exploitation index by European Environment Agency
	Hospital beds and doctors	Number of hospital beds per 100,000 inhabitants
Institutions	Government effectiveness	Government effectiveness index that is available from the World Bank Group at NUTS0 level
	Democracy	Gender weighted democratisation index. (Data for this is available from the Finnish Social Science Data Archive)
	National adaptation strategies	Data from IVM used to build an indicator (concerns, recommendations, measures)
Economic resources	Income per capita	GDP per capita (€ PPP) of a NUTS3 region
	Long term unemployment	Percentage of population who are long term unemployed
	Age dependency ratio	Age dependency ratio available from Eurostat at NUTS3 level

The results of the index can be visualised in map form, see Fig. 3.2. The map demonstrates that adaptive capacity, as assessed here varies greatly among regions. On a wider European scale, there are a several trends that can be observed from the map. National level data has been used in some instances, which skews some of the results from the regional and city level.

In terms of the results, it is important to note that there are differences in the capacity between Northern and Western Europe compared to Eastern and Southern Europe. In terms of cities, the capital city regions, overall, appear to have higher capacity than most regions within a particular country. This is hardly surprising, confirming the idea that larger the city, the higher the capacity. This is also true for countries that in general have lower capacity. There are a few exceptions, for example the Baltic countries and Iceland and Norway. These countries have no regional variation in terms of their larger city regions and other more rural regions.

By focusing on specific cities it is further possible to explore the different components of adaptive capacity. In some cities, there is a high level awareness and knowledge of climate change impacts but perhaps a low level of technology



This map does not necessarily reflect the opinion of the ESPON Monitoring Committee

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Regional level: NUTS 3
Source: Eurostat, ESPON Database, EEA, Finnish social science data archive (FSD), GESIS, Massey & Bergsma (2009), NSIs, World Bank, 2010
Origin of data: 2005-2006
Please refer to the final report of "ESPON Climate Change" for details
© EuroGeographics Association for administrative boundaries

The adaptive capacity is measured by 15 indicators in five (5) weighted categories, that are referred to as determinants. The selected indicators are GDP per capita, age dependence, long-term unemployment rate, R & D expenditure as % of GDP, number of personnel in R & D, number of patent applications, expenditure on educations as % of GDP, the share of people who have never used a computer, attitudes towards climate change, the density of road networks, exploitation of water resources, amount of hospital beds, the number of adaptation strategies being used, the effectiveness of governments and the state of democracy.

Please refer to the Final report of "ESPON Climate Change" for details on the methodology.

Fig. 3.2 Adaptive capacity of European regions

or infrastructure capacity to deal with the impacts. In addition, knowledge and awareness can be hampered by low level action capacity, i.e. weak political institutions or lack of economic resources. However, as interesting as the results themselves are, it is also important to keep in mind that there are a number methodological issues related to these kinds of assessments, as well as questions related to the use of these kinds of assessment results in policy-making. These two issues will be discussed next.

3.5 Methodological Concerns

There are a number of issues related to the methodology of these kinds of assessments that can affect the outcome of the assessment itself. These issues are related to the design of the assessment and to the data used in the assessment.

First, there are challenges related to the fundamental question as to whether it is possible to assess or measure a socially constructed concept in the first place. Adaptive capacity is a concept that has been coined in the literature related to climate change vulnerability assessments and does not represent something that can be objectively measured, such as temperature for example. This has been discussed in the literature and Hinkel points out that assessments in these kinds of cases are possible, given that there is a disciplinary consensus in terms of the definition of the object of assessment [23]. In the case study discussed above, and other studies related to the assessment of adaptive capacity, a well-accepted IPCC definition is taken as a starting point.

Second, the choice of determinants is closely related to the definition that is chosen in the analysis. The key question here is who and how the indicators and their proxies are chosen. In the literature, it is acknowledged that in most studies, the selection is based on expert choice, i.e. by the researchers themselves [14]. There are many methods, such as Delphi surveys, but it appears that the choice is always to an extent a subjective exercise. Furthermore, the selection of indicators marks a departure from the original concept as it is being operationalized. This can result in different kinds of framings and interpretations [24–26], making the assessment of adaptive capacity always subject to a certain level of ambiguity.

Third, assessments in the past have been dominated by quantitative approaches, utilising a variety of different kinds of indicators [25]. As with other indicator-based assessments, there are a number of concerns that need to be kept in mind when combining indicators into indices or composite indicators [27–29]. These include, for example, multiple assumptions behind the indicators that assume that a proxy can accurately reflect the object that is being assessed. It is also possible that an important variable is not taken into account when the selection is being made. In addition, most methodologies do not take into account the possible interdependencies between the different variables. Availability of data and projecting to the future is naturally a challenge and can limit a number of proxies from the list of possible indicators, especially when discussing data below the national level [16].

Fourth, projecting into the future in these kinds of assessments is often desirable when entertaining future policy choices. Given that adaptive capacity varies spatially and temporally [19], using other indicators to project future changes is methodologically challenging [24]. Also, distinguishing between the relationships between the different determinants and their relative strength is very difficult [16]. To what extent the relative importance of economic or institutional capacity is higher than the technological one, is not an issue for which research has provided an answer.

Despite these issues, assessments that rely on composite indicators also have certain strengths over qualitative assessments. By combining a number of indicators, it possible to effectively summarise and simplify complex phenomena into more simplistic forms [29, 30]. These can include different types of graphs or maps as is the case in this chapter. Although the findings can be communicated in an easier manner, they nevertheless open up the possibility of misinterpretations and can give misleading policy signals [28]. For this reason, it is urged that care is taken interpreting the results of such visualisations and that the findings should serve as a starting point for further discussion and studies into the matter [27–29].

3.6 Use of Assessments in Policy Making

The use of assessments in policy-making is an interesting prospect. This is particularly interesting, given that the developments in the ICT sector present new possibilities for visualising data and other information. The main questions, however, remain as to how accurate are these assessments and what should they be used for?

It is assumed that on the whole that policy-makers are interested in easily accessible material, either numerical or visual representations of the issue at hand. In these cases, map-based visualisations become appealing because they can be used to identify regions that have a high or a low adaptive capacity [23, 25]. Thus, the maps enable one to identify hotspots and other outliers. But they should not, according to Hinkel be used to raise awareness of climate change, to identify mitigation targets or to monitor adaptation policy [23]. Furthermore, assessments are not designed to be used in decisions related to allocation of funding [31, 32], i.e. the city with the lowest capacity receives the most assistance.

Despite these issues, there are a number of arguments that can be used to justify the contributions that these assessments can make to decision-making. This identification of hotspots is a useful exercise. For example this study highlighted the high capacity that most capital city regions have. At the European level, the focus can be placed on those cities that have not performed quite so well and try to understand the reasons behind this. Furthermore, it is possible to identify other large cities from each country and see how they perform in relation to the capital city region and begin to assess why this could be.

Although adaptive capacity is a theoretical concept, the example provided earlier allows for a simple exploration of how the different components perform in relation to one another. It is possible to consider to what extent the abilities differ from the action or the awareness of the problem. These kinds of findings can serve as a starting point for the policy-makers to begin a discussion that focuses more on the context of that specific city. Of course whilst no direct correlation can be established between the three different components and their interaction, it can open up the space to consider alternative policy solutions.

As well as supporting decision-making, these kinds of research efforts can also help to identify further directions for research and improvements on methodology. For example, the division of adaptive capacity into the three components can perhaps help to move the assessments towards a more dynamic modelling of adaptive capacity. There are possibilities to link the determinants to specific indicators and attach them to specific phases of the adaptation process, for example [33]. Policy windows or focusing events [34, 35] can trigger action during a specific event and help to mobilise capacity when it is needed.

Finally, as mentioned above, adaptive capacity is the underlying ability to engage in adaptation. However, it should also be kept in mind that the bare existence of adaptive capacity, or high levels of it, does not automatically mean that adaptation will take place [36]. Furthermore, high levels of capacity at the national level do not necessarily result in high capacity at the lower levels, i.e. regional or local [37], as also shown in the results of the case study discussed in this chapter. Therefore, it is important to keep in mind that even cities that appear to have high capacity in research results might not pursue adaptation as a policy goal. This is often due to cities not perceiving a specific vulnerability or the need to act proactively to avoid or mitigate climate change impacts. Many times action is taken reactively either during a specific event, i.e. utilising coping capacity, or after the event has taken place and efforts are made to reconstruct.

3.7 Concluding Remarks

This chapter starts from the premise that adaptive capacity is a crucial underlying factor of a city's ability to adapt to climate change. Studies that assess adaptive capacity have emerged and there are a number of unresolved issues related to their methodology. This chapter discusses a number of them, also related to a case study example of a regional level assessment of adaptive capacity. A number of the methodological challenges are highlighted in this chapter are related to general issues that need to be kept in when conducting social research. However, given that vulnerability and adaptive capacity assessments are a topic which is of relevance to policy makers, caution needs to be taken, particularly in relation to visualising the results of the assessments.

In terms of the usability of the results, although city level studies of adaptive capacity are very context specific and therefore make the extrapolation of findings somewhat difficult, these studies have the potential to offer decision-makers an insight into the different kinds of capacities that a city possesses. Some have argued that adaptive capacity needs to be assessed at the regional or city level since the decisions related to adaptation measures are generally made and implemented at that level [20]. This naturally reinforces this link between adaptation and vulnerability assessments and policy-making on adaptation. City level assessments are important since they can be designed to highlight specific aspects of the city that more information is required, as these can pinpoint the importance of social networks and the ability to engage in decision-making [38].

This chapter agrees with most of the critique and caution that is levelled at these kinds of quantitative assessments in the literature. Adaptive capacity should be explored in conjunction with the exposure and the sensitivity of the system, not purely on its own. This way they are a part of a wider effort of understanding vulnerability, be it at a national or at the level of an individual city. A city in many ways offers a good case study as the boundaries of the assessed system can be somewhat clearly defined in terms of geographical scale, as is urged in the literature [39]. These kinds of methodologies need to be further developed in the coming years as this issue is becoming increasingly important in the context of continuing urbanisation and the onset of climate change.

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Chapter 4
Survey: Resource Footprints and Environmental Security at DoD Installations

R. Pincus

Abstract Environmental issues are increasingly at the forefront of planning for US military installations, for a variety of reasons. DoD efforts to reduce the resource footprint of installations offer several benefits, but may incur risks as well. In addition, climate change may pose significant, if longer-term, environmental risks to both military and secured industrial installations. This paper will provide a survey of these issues and how they have heightened the profile of environmental factors in installation security and management.

This paper will provide a brief survey of the efforts of the US military to reduce energy, water, and waste footprints of military installations, which has accelerated in recent years. These efforts, if successful, offer cost savings as well as increased security for these installations. However, significant challenges exist. For example, alternative energy technologies offer reduced vulnerability to oil price shocks; however, many of these technologies require rare earth element (REE) inputs, which are almost exclusively sourced, at the moment, from China. Shifting to "green" energy therefore may replace vulnerability to oil shocks with exposure to REE market manipulation. This is just one example of the complex questions that have emerged as the US military has pursued goals of sustainability and security in energy and water use at military installations.

In addition, DoD installations must assess the environmental risks posed by climate change. A number of climate-associated risks, including more powerful storms, altered precipitation patterns, and related shifts in wildfire and flood scenarios, have the potential to affect the security of these installations. This paper will also briefly survey these risks and efforts by the military to address them.

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4.1 Introduction: Overcoming a Legacy of Environmental Disregard

The job of securing the nation, although noble, is dirty. DoD installations at home and abroad until very recently were usually contaminated by heavy metals, toxic munition constituents (exploded and unexploded), spilled fuel and engine oil, a variety of solvents, air pollutants, and a variety of chemical pollutants [1]. Furthermore, the operation of these facilities continues to consume enormous quantities of energy and fresh water, and generates enormous amounts of waste. The management of these natural resource inputs and waste outputs may be unglamorous, but it is critical to the success and future effectiveness of the United States military.

Only relatively recently has DoD attempted to tackle these problems head-on. Durant notes that although successive presidents throughout the latter part of the 20th century called for increasing attention to air and water pollution associated with federal facilities, little tangible progress could be seen throughout the administrations of Truman, Eisenhower, Johnson, Nixon, Carter, and Reagan:

> Thus, by the time the Soviet empire dissolved in 1991, a series of presidents over the prior four decades had tried, to varying degrees and with little success, to create a corporate sense of responsibility in the Pentagon for ENR protection. Bequeathed to the post-Cold War era as a consequence was a regulatory regime that allowed the military needs of the Cold War to take precedence over ENR protection. (Durant, p. 36)

The emergence of the environmental movement in the United States in the 1960s and 1970s drew attention to waste and pollution generated by military activity, most notably through the highly visible problems associated with nuclear weapons development and the Vietnam conflict. The human and environmental costs associated with bomb testing and the use of Agent Orange gained wide publicity and sparked calls for change. The ability of the military to shield itself from responsibility for environmental impacts was beginning to erode as the Cold War wound down and other national priorities moved to the forefront of American consciousness.

Initially, environmental responsibility was advanced upon the military via the courts. The environmental movement of the 1960s and 1970s generated significant federal legislation that protected air, water, flora and fauna; however, the military was reluctant to apply these laws to its own work. Rounds of environmental litigation in the 1980s that targeted DoD put the military “on the defensive” [2]. Legal efforts to rein in DoD environmental damage increased in numbers and scale, as challengers are “increasingly confederated” and occasionally joined by other federal agencies impacted by DoD installations, whether by noise, air or water pollution, or ordnance issues [3]. However, DoD earned a reputation for fighting efforts to attach responsibility for environmental issues to military activities: Schmidt [4] quotes a Colorado state attorney general complaint, “DoD has a consistent track record in litigation going back decades for trying to get out of its environmental requirements.” DoD most often sought to avoid environmental regulation by relying various exemptions for sovereign immunity of federal facilities (until the Federal Facilities Compliance Act of 1992), according to Durant.

In recent years, however, DoD has begun a remarkable effort to reduce the energy and environmental footprint of its operations at home and abroad, ranging from installations to ships and aircraft and batteries. Some of this change has come after years of pressure from the executive and legislative branches, as DoD has begun to realize the costs of fighting rear-guard actions against regulation are higher than avoiding them. Some of this change, however, has apparently emerged from within.

Critically, this effort may reflect a new and evolving attitude. Rather than disregarding the importance of environmental impacts and resource footprints, as was evident in earlier decades, DoD appears to have attached new strategic importance to environmental issues. This normative shift holds enormous significance for the future of military strategy, operations, and tactics. Rather than seeking exemptions from environmental regulations, DoD may now accept management of energy, water, and waste footprints as a smart strategy to improve performance, manage costs, and increase predictability. This concerted effort reflects both the increasing costs associated with energy and resource consumption, as well as the security risks posed by dependence on high resource inputs.

The Obama administration acted to reinforce this effort, and will likely continue to advance DoD efforts to shrink resource footprints in its second term. In 2009, President Obama issued [5] Executive Order 13514, directing federal agencies to reduce their energy, water, and waste footprints, as well as to shift procurement towards sustainable and environmentally preferable technologies, designs, and materials. Performance evaluation was a key element of this effort, as the EO called for "continuous improvement" through regular reassessment and transparent disclosure. The 2011 DoD Strategic Sustainability Performance Plan (DoD SSPP) [6,7] accepted this challenge: "The Department not only commits to complying with environmental and energy statutes, regulations, and Executive Orders, but to going beyond compliance where it serves our national security needs." This recognition that environmental management may serve national security is a significant and new development.

4.2 DoD Energy Footprint

It is not surprising that DoD is working to reduce its energy consumption: annual facility energy expenses hover around $4 billion (a figure that excludes fuel for military operations; in 2010 DoD spent $13.2b on operational fuel). The great majority of this figure is energy that is used in buildings, to provide power, heating, and cooling ($3.9b); the remainder is fuel energy used in non-tactical vehicles ($0.2b, [8]).

Aside from the explicit costs of purchasing energy, the volatility of energy markets (in particular oil) makes planning and budgeting more challenging and increases the appeal of consumption management. Decreasing reliance on petroleum, through increased efficiency and/or alternative energy sources, reduces DoD exposure to price swings.

Facility energy is an appealing target for energy reduction, since fixed installations are less dependent on liquid fuels and can readily take advantage of electricity-producing alternative energy sources including solar, wind, and geothermal. In fact, approximately 80 % of DoD facility energy comes from electricity and natural gas [8]. Operational energy needs are much more limited to liquid fuel alternatives, and transport requirements are daunting [9]. Although electricity and natural gas prices are significantly lower than liquid fuels, reliance on grid-delivered energy creates vulnerability for DoD installations. This vulnerability increases the appeal of shrinking energy consumption and/or switching to locally generated alternatives.

4.3 DoD Water Footprint

DoD is the largest water consumer, by far, of all federal agencies – roughly 120,000 mGal in 2007, or 71 % of water consumed by the federal government [10]. In 2010, DoD water intensity was 56.3 gal per square foot (total building gross square feet was 1.81 billion) [11].

Although it may seem omnipresent, in fact water is another necessary resource for DoD functioning. Furthermore, water is a critical resource, without which many DoD functions would be compromised. The Army Water Security Strategy [12] states:

> The availability of useable water is of strategic importance to all levels of the Army enterprise. Having continued access to adequate water resources and the ability to delivers treated water efficiently is *obviously essential* for ongoing and future Army missions. But a widely favorable water supply situation *cannot be assumed*. ([13], p. 8, emphasis added)

Furthermore, the DoD SSPP points out that problems associated with water supply are already emerging, as water shortages in the American West have forced DoD installations to aggressively curtail consumption. Predicted climate shifts may increase water scarcity.

4.4 DoD Waste Footprint

Although it easily overshadowed by the flashier issues of energy and water, the problems of waste – solid, hazardous, and human – are another significant area of reform at DoD.

The late 1990s saw the recognition that pollution prevention was preferable to *post facto* remediation and expensive clean up. Executive Order 13101 [5] stated in 1998, “It is the national policy to prefer pollution prevention, whenever feasible. Pollution that cannot be prevented should be recycled; pollution that cannot be prevented or recycled should be treated in an environmentally safe manner.”

However, DoD continues to produce significant amounts of waste. The Army has the largest waste footprint; approximately 2300 thousand tons of solid waste and construction debris in 2006, with a diversion rate of 59 % [14]. The Air Force is the next largest, producing nearly 2000 thousand tons of waste and diverting 64 % [14]. DoD has made progress in reducing its hazardous waste footprint: in 1995, DoD disposed of 345.4 million pounds of hazardous waste, but by the early 2000s the annual disposal of hazardous waste was around 130 million pounds. Much of this rapid improvement occurred within the Navy, which is the largest generator of DoD hazardous waste. The Navy cut its hazardous waste footprint by half in 2 years, and by two-thirds after 7 years (DEP).

4.5 Efforts to Shrink DoD Resource Footprints

4.5.1 Energy

The 2007 Energy Independence and Security Act contained several provisions that targeted energy consumption. This legislation set goals for energy intensity reduction (energy intensity is energy consumption per square foot), energy efficiency, sustainable design and construction, procurement, and vehicle fleet efficiency [10].

In addition, Executive Order 13514 also directed federal agencies to reduce energy intensity, increase use of renewable energy, reduce carbon inputs, alter supply chains and staff travel activities to reduce carbon intensity, and achieve zero net energy in new federal buildings by 2030. This Executive Order also tasked the Office of Management and Budget with preparing periodic scorecards to evaluate the progress of federal agencies towards these goals.

DoD is moving towards implementation of its broad goals for reducing energy consumption. Through the Installation Energy Test Bed initiative, pre-commercial emerging energy technologies are being deployed throughout DoD installations, in order to test their performance and advance commercialization. Test Bed projects are used to shrink the DoD energy footprint in several ways: improve building efficiency, store energy, generate renewable energy, and design building energy systems.

The DoD Defense Installations Strategic Plan [15] lists Objective 4.3: “Reduce reliance on fossil fuels to meet facility and non-tactical vehicle energy requirements.” The priorities listed include shifting towards renewable energy, both purchased and generated on-site; reducing energy use; focus on lifecycle energy costs; and using aggregate bargaining power to reduce energy costs [15]. Specific installation-specific actions include building retrofits, high-efficiency HVAC systems, double-pane windows and efficient lighting, new roofs, and energy management control systems [16].

However, the OMB scorecards reflect less-than-outstanding progress towards these goals. In 2011, OMB red-flagged DoD progress in reducing energy intensity, indicating that DoD had reduced energy intensity by less than 12 % compared with

2003 [17]. In 2012, this metric was again red-flagged. In 2011, OMB scored DoD progress in adopting renewable energy in facilities as "yellow"; in 2012 this score was red-flagged [16].

However, DoD is in the process of bringing new renewable facilities online, as well as working to reduce building energy intensity. Five new renewable energy projects were approved in FY2012, and are expected to be online by 2014. Furthermore, the FY2013 DoD budget includes $1.1 billion for energy efficiency, including lighting, boiler plants, and building envelope upgrades [16].

4.5.2 Water

Water is another major resource input to DoD installations. Although not as scarce as oil, water is becoming a limited resource in some areas, affecting DoD practices. In the western United States, arid conditions have led to conservation and reuse measures at DoD installations [11]. The Army Water Security Strategy identifies long-term concerns relating to water: supply and access to water sources, cost of water, risks associated with water (contamination), increasing demand by other users, and uncertainties associated with climate [13]. Mindful of these issues, as well as in response to legislative and executive pressure, DoD is striving the decrease the water footprint of its installations.

The DoD Strategic Sustainability Performance Plan lists three major goals related to decreasing the water footstep of DoD installations: reducing potable water consumption intensity, reducing industrial and irrigation water consumption, and maintaining pre-development hydrology of large development/re-development sites [11]. DoD aims to reduce its potable water consumption intensity by one-quarter by 2020 (from FY2007 levels), and by 2010 had gotten about halfway to this goal. The goal for industrial and irrigation water reduction is more modest – 20 % by 2020 (from FY2010 levels), and this effort will build slowly through the latter half of this decade [11]. These goals are a result of federal water efficiency requirements, including Executive Order 13512 (2009) and the Energy Independence and Security Act of 2007.

According to the OMB scorecards, DoD has been successful in these efforts. Both 2011 and 2012 OMB scorecards award DoD "green lights" for their on-track efforts to reduce potable water intensity, and indicate that DoD will successfully reach the targeted 26 % reduction by 2020 [16, 17].

4.5.3 Waste

Executive Order 13514, introduced earlier, called upon federal agencies to prevent pollution and reduce waste through minimizing generation, diverting solid waste and construction materials, reducing paper use, minimizing toxic and hazardous materials, and increasing composting. Agencies were directed to divert at least half of their non-hazardous solid waste and construction/demolition debris by FY2015. In addition, agencies were required to shift to 30 % postconsumer fiber paper for printing and writing [18].

These efforts are of particular importance given the long history of pollution and contamination associated with military installations and operations, as well as the historic reluctance of the military to incorporate environmental issues into planning. To cite perhaps the most prominent example, following the 1970 suspension of aerial spraying of defoliants during the Vietnam conflict, the US Air Force was left with 1.5 million gallons of Agent Orange at Vietnamese air fields and nearly another million gallons awaiting shipment from the United States [19]. Reflecting the widespread attitude at the time, the military saw the environmental regulations that governed the cleanup process as “a waste of time and energy” [19].

In 1990, Congress approved the creation of the Strategic Environmental Research and Development Program (SERDP), tasked with developing technology and identifying research that address “environmental restoration, hazardous and solid waste minimization and prevention, hazardous material substitution” and energy, and share this information across DoD, DoE, and private organizations (U.S.C. 172 § 2901).

DoD is also working to clean up already-contaminated installations. The Defense Installations Strategic Plan lists Objective 3.3, “Restore contaminated property to a condition that is protective of human health and the environment, and sustains mission capability.” DISP acknowledges that past military operations exposed DoD installations to contamination. Cleaning up these sites and minimizing future pollution offers several benefits: restoration can make contaminated lands once again useful, as well as demonstrate DoD environmental stewardship, enhance relationships with local communities, and help ensure access to test and training areas (DISP).

In addition, the SSPP lays out objectives for minimizing waste and pollution associated with DoD assets: minimizing solid waste and construction debris (50 % and 60 % respectively, by FY2020); reducing paper used for printing; and recovering biogas from 10 landfills or wastewater treatment facilities (by FY2020). The SSPP also establishes goals for the reduction of toxic chemicals, including electronic waste and pesticides.

4.6 The Benefits of DoD Efforts to Reduce Inputs and Increase Efficiency are Many

4.6.1 Cost Savings

Many of the resource-replacing systems that DoD is deploying at installations will pay for themselves over time through cost savings. By taking into account the full lifecycle costs of installation systems, DoD will lower costs by switching to more efficient and alternative technologies [16].

Furthermore, benefits come in a variety of non-financial measures. Increasing the energy independence of DoD installations will reduce vulnerability and improve security. The DoD Strategic Sustainability Performance Plan (SSPP) states that shrinking DoD resource footprints can advance the DoD mission:

> The Department recognizes that many key issues facing DoD can be addressed through smart investments that improve sustainability as well as promote the mission, such as using energy and water more efficiently, acquiring more energy from renewable sources, designing buildings for high performance, reducing the use of toxic and hazardous chemicals, and optimally managing solid waste. [11]

In addition, DoD recognizes that installations "offer an ideal test bed" for emerging energy technology, offering a platform for assessing the "technical validity, operating costs, and environmental impact" of pre-commercial technologies [11]. The Installation Energy Test Bed program was established in 2009, to test out new technology in DoD installations, in order to "reduce risk, overcome barriers to deployment, and facilitate wide-scale commercialization" (SERDP, Installation Energy). By giving emerging technologies a crucial boost through the Test Bed program, DoD will reap future benefits, as the most successful technologies move out into the wider market at more accessible prices – including purchase DoD-wide if appropriate.

On the topic of waste, DoD learned harsh lessons about the unintended costs of chemical use, most famously from the tragic consequences of its use of Agent Orange during the Vietnam conflict. It now recognizes that costs associated with hazardous and toxic materials include compliance and cleanup, associated litigation and health care, and total lifecycle costs of weapons and facilities [11]. Although some hazardous materials are critical to DoD readiness, the need to manage, track, dispose of, report, and ensure safe practices associated with these materials imposes a significant burden. The time and direct costs associated with these management practices can be avoided by reducing use and switching to less dangerous materials when possible. Cost benefits in terms of avoided liability are another area of potential savings from decreased chemical inputs to DoD installations.

4.6.2 Security Benefits

As global terrorism emerged as a major threat to the United States, DoD strategy shifted accordingly. This pivot brought more attention to the security risks associated with resource dependency. The 2006 [20] QDR stated that non-state enemies could focus their attacks on "food, water, and power supplies; and information, transport, and energy networks" among other targets. Securing these systems, as well as insulating DoD installations from the effects of these attacks, is therefore a critical element of security planning.

The reliance of domestic installations on an aging electrical grid, as well as natural gas lines, creates an area of vulnerability that all elements of the armed forces recognize. The US Marine Corps' Expeditionary Energy Strategy states bluntly, "this dependence leaves us vulnerable to accidental or intentional energy and power disruptions and places our mission-critical operations at risk." [21]. In addition, a 2008 Defense Science Board Task Force Report on DoD Energy Strategy found that "critical national security and Homeland defense missions are at an unacceptably high risk of extended outage from failure of the grid." ([22], p. 3)

Therefore, reducing energy consumption and intensity offers security benefits to DoD installations. Increased on-site energy generation, from solar panels, wind turbines, and other systems, combined with decreased energy demand, can move installations towards true energy independence. In the event of catastrophic grid failure, either as the result of natural disaster or deliberate attack (cyber or kinetic), DoD installations would still be able to perform their critical national security role.

Reducing water consumption likewise reduces vulnerability to water-associated risks. These can include explicit attacks, like deliberate contamination of water supplies or cyber or sabotage attacks on water infrastructure, or accidental crises related to natural events or disasters. Many systems are dependent on water availability, including firefighting, healthcare, food supply, and others, and would therefore suffer from water denial events [13].

4.6.3 Other Benefits

Efforts to reduce the environmental footprint of DoD installations burnish DoD's image in the public eye. The push for more efficient and alternative energy solutions has been splashed throughout national news outlets, and has received largely positive coverage.

Particularly in light of long, costly, and unpopular involvements in Iraq and Afghanistan, recent well-publicized "greening" efforts by DoD provide an alternate, more positive narrative for public consumption. DoD has worked to raise the profile of these efforts: the creation of the "DoD Sustainability" website in 2009 enabled DoD to publicize "greening" actions, along with the online DENIX – Defense Environmental Network and Information Exchange.

Cleanup at DoD installations also earns positive public attention, as well as feathering the cap of DoD personnel. For example, "Energy Source", the publication of the Defense Energy Support Center [23], published a four-page spread in its April 2010 issue on the wildlife that thrive in and around DESC Pacific installations. Noting that DoD and the commercial petroleum industry "must work hard to ensure their activities do not harm the environment", the article goes on to describe the variety of wildlife that uncontaminated installations can support, including moose, otter, fox, and birds (with photos). Such positive attention counteracts the legacy of pollution from earlier decades.

4.7 Efforts to Shrink Footprints may Carry Risk

However, as DoD works to reduce its energy, water, and waste footprints, its efforts may incur other vulnerabilities and costs. Shifting to new technologies that manage resource inputs brings new dependencies. In addition, military installations, as well as secured industrial installations like nuclear power plants, must assess the environmental risks posed by climate change. A number of climate-associated risks, including more powerful storms, altered precipitation patterns, and related shifts in wildfire and flood scenarios, have the potential to affect the security of these installations.

4.8 Rare Earth Minerals and DoD Security

For example, as DoD builds in new energy-efficiency technology to replace carbon energy sources, it is becoming increasingly reliant on rare earth elements (REE). This class of materials is required for the construction of solar panels, wind turbines, electric vehicles, batteries, and a variety of other emerging energy technologies [24].

Approximately 98 % of REE production occurs in China, which has demonstrated its willingness to use REE access as a tool of foreign policy. In 2011, the price of REE shot upwards almost 500 % after China restricted exports (Washington Post). In addition, China temporarily suspended REE exports to Japan in retaliation for a maritime dispute [25].

In the wake of the dramatic movement of REE prices in 2011, President Obama brought the United States into a WTO dispute alongside Japan and the EU, challenging China's policies on REE exports. The US argues that China is illegally restricting REE exports and using its market dominance to pressure foreign companies to relocate to China tin order to access REE; on the other hand, China points to tightened environmental standards as justification for its curtailed exports [25]. Furthermore, Congress directed the Secretary of Defense to assess DoD vulnerabilities to REE scarcity and develop a plan to address these issues [26].

A GAO report concluded that it could take up to 15 years to rebuild a REE supply chain in the United States, and would encounter several challenges, including cost, patent acquisition, and technological requirements (GAO, 10-617R). The US was the global leader in REE production and manufacture roughly between 1960 and 2000, but the primary US mine, Mountain Pass in California, was closed as a result of environmental pollution and REE processing facilities closed as well.

The GAO report noted, "Defense systems will likely continue to depend on rare earth materials, based on their life cycles and lack of effective substitutes." In addition to energy-efficiency technologies like wind turbines, solar panels, and batteries, REE are used in modern computers, lasers, radar systems, avionics, satellites, and other critical defense systems (GAO, Grasso).

Although the US and other countries are moving to open (or reopen) rare earth mines, the mining process for REE is highly polluting. In addition, the processing component of the REE supply chain is also dominated by China. In order to achieve REE independence, the US needs to develop processing facilities in order to ensure that US-mined REE ore does not need to be shipped to China for processing. In the meantime, DoD is working to build REE stockpiles to protect defense-related technology needs (GAO, Grasso).

Until more sources of REE are available on the global market, China will continue to dominate the market and the price of REE may continue to oscillate in unpredictable ways. The increasing interest of DoD in energy-efficient technologies may increase DoD exposure to REE-related vulnerability.

4.9 Other Associated Risks

The budgetary climate can also pose risks to the environmental security of DoD installations. The Army Water Security Strategy noted there is "systematic underfunding of the Army-owned waste and wastewater systems"; this situation has led to increased reliance on utilities privatization projects as the Army's preferred strategy for upgrading utilities infrastructure. However, the AWSS states: "Relying on connections to external utilities exposes the installation to the vulnerabilities associated with those utilities and introduces concerns about how an installation will function in a situation that requires it to be self-sufficient for an extended length of time."

In short, moving towards privatization of water systems may enable DoD to shrink its water footprint at lower cost, but it brings with it dependency and vulnerability. The higher upfront costs (but lower lifecycle costs) of renewable energy technology or waste-reduction technology can pose a challenge for DoD planners, particularly in the current era of continuing resolutions and budget cuts. Longer-range planning can better accommodate the timelines associated with shrinking energy, water, and waste footprints.

4.10 The Unknown Elephant: Climate Change and DoD Installations

The effects of a warming climate pose risks for DoD installations. The 2010 QDR recognized this challenge: "DoD will need to adjust to the impacts of climate change on our facilities and military capabilities . . . must complete a comprehensive assessment of all installations to assess the potential impacts of climate change on its missions and adapt as required." ([27], p. 85)

Specific problems that may result from climate change include: sea level rise, increased frequency and severity of storm events, heat events and wildfires, formation of ozone, alteration in disease vectors, species distribution shifts, and melting permafrost in the Arctic [11]. In addition, the effects of these changes may be more severe in combination – for example, more severe hurricanes, in combination with higher sea levels, could produce significantly greater devastation [12].

In addition, climate change may interact with other, human, global disruptions to create security problems. The 2008 National Defense Strategy notes, "The interaction of these [demographic] changes with existing and future resource, environmental, and climate pressures may generate new security challenges." [28] The Center for American Progress recently released a report linking climate change impacts to the 'Arab Spring' political disruptions in Egypt, Syria, and Libya. That very real security problems may flow from environmental origins does not discount their significance.

While working to reduce the energy, water, and waste footprints of DoD installations, managers must also incorporate the potential impacts of climate change into their planning. Anticipating the consequences of sea level rise, for example, will enable DoD to manage the necessary adaptations in a timely and efficient manner, rather than being forced to respond in a crisis scenario to flooded coastal installations. The Army Water Security Strategy states that climate change is "widely expected" to increase flooding events, which may "disrupt the function of pumping stations and treatment plants", and urges the Army and DoD to assess climate change-associated vulnerabilities.

It is not clear what may result from the concentration of CO_2 in our atmosphere. However, a CNA [29] report, "National Security and the Threat of Climate Change", co-signed by 11 retired generals and admirals, concludes its introductory statement with this conclusion: "The increasing risks from climate change should be addressed now because they will almost certainly get worse if we delay." This simple statement summarizes the reasons for action – no one knows for certain what the future holds, but it is almost always better to prepare for the worst and hope for the best.

An organization as vital to the very existence of the United States as the Department of Defense cannot take threats lightly no matter where they originate. Throughout the Cold War, DoD prepared the nation for possible nuclear war against the Soviet Union. Thankfully, this war never came. Yet no one questioned the enormous expenditure of resources devoted to the effort. Until scientists can provide a more accurate forecast of how the increasing concentration of CO_2 in the atmosphere will affect global conditions, DoD must incorporate their worst-case scenarios into plans for the future.

4.11 Conclusion: On the Right Path?

The US military has transformed itself in the two decades following the end of the Cold War. The close of the Cold War marked the end of 50 years of intense focus and strategic effort to defeat an existential threat – first Germany and Japan, then the Soviet Union. During these decades of militarization, the external threat was so overwhelming that concerns about energy dependence and pollution seemed trivial, simply distractions that weakened the US focus on victory. That attitude gradually began to change following the emergence of the environmental movement in the 1970s, as well as the public outrage that followed revelations about the use of Agent Orange in Vietnam (and the Vietnam conflict in general).

Efforts to reform DoD approaches to environmental issues emerged during the administration of George H. W. Bush, as efforts to clean up installations, reduce pollution, and minimize waste gained steam [2]. These efforts continued during the Clinton years; Durant describes a "fundamental perestroika in US military thinking and operations" in the 1990s that included the incorporation of environmental security into national security strategy [3].

Although some critics pointed to resistance to environmental regulation as proof of DoD cultural intransigence [1], it may be that recent strategic [30] advances have managed to alter the culture around natural resources in DoD. The 1995 Defense Environmental Report does not mention the strategic benefit of shrinking resource footprints of DoD; the issue is simply framed as "good neighbor" behavior: "It is not our duty merely to be good stewards of the environment; we owe our forces, families, and communities an environment that is free from hazards and degradation. That is what environmental security is all about." (William J. Perry, Secretary of Defense, Introduction).

These motivations were laid out in the 1993 [31] Report on the Bottom-Up Review conducted by Secretary Les Aspin:

> Environmental concerns are an integral part of US national security policy because of the effect that environmental conditions have on economic and political stability, because of the growth in environmental costs as a share of the national security budget, and because of the loss of public trust caused by military noncompliance with environmental laws and regulations. (p. 99)

However, recent language incorporates benefits of more central concern to DoD: "DoD's pollution prevention investments have the potential to reduce costs Department-wide." [33]. A 2001 Defense Science Report [32] was titled, "More Capable Warfighting through Reduced Fuel Burden", clearly indicating that some elements in the Pentagon were beginning to see potential operational and tactical benefits from shrinking footprints. However, this new view did not take hold easily or immediately. A follow-up DSB report in 2008 on the same topic noted, "The recommendations from the 2001 DSB Task Force Report, 'More Capable Warfighting through Reduced Fuel Burden' have not been implemented" ([22], p. 3).

Broader recognition of the multilevel benefits that flow from reduced energy, water, and waste footprints spread through DoD in the 2000s, driven partly by Congressional pressure and partly from internal leadership. In recent years, all of the services have released plans that address the requirements of EO 13514 and the Strategic Sustainability Performance Plan. Reducing energy, water, and waste footprints now are strategic goals that offer benefits in terms of cost savings, increased security, and reduced exposure to liability.

It can be assumed that these efforts will continue in the future, as technological capability improves DoD ability to shrink its installation footprint further and as institutional commitment to improvement diffuses broadly through a younger generation of security leaders. Although challenges will persist, the US military has demonstrated time and again its ability to overcome insurmountable difficulties in pursuit of greater comprehensive security for the US and its allies. The problem of energy, water, and waste footprints is far from our greatest challenge, and offers significant strategic, operational, and tactical benefits across many security sectors.

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Chapter 5
Sustainability Awareness and Expertise: Structuring the Cognitive Processes for Solving Wicked Problems and Achieving an Adaptive-State

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Abstract The term, "wicked problem," describes the intractable nature of social policy and planning problems that are complex, engender multiple and often irreconcilable stakeholder views, have no definitive formulation, no solution algorithm or single best solution, little tolerance for imbalances or judgment error, and no single repository of expertise from which trustworthy solutions might emerge. This also describes problems of *sustainability* and reflects a consistent theme that emerges from the last four decades for business, science and society – the need to improve understanding of complex systems and their interactions, incorporate non-expert knowledge and public values, improve communication between expert and lay groups, and foster deliberation between business and public groups with competing deontological views.

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We posit that a structured approach to problems of sustainability integrating (a) influence modeling, (b) assessments of sustainability, uncertainty, challenges and values, (c) multi-criteria decision analytics, (d) data visualization, and (e) building social capital can effectively address wicked problems. Rather than reductively "solve a problem" this approach results in a new, strategic *managed-resiliency* and persistent *adaptive-state* of coevolving capabilities we call Sustainability Awareness and Sustainability Expertise. Within this sustainability framework stakeholder communities make *better* versus *right or wrong* decisions and Sustainability becomes a practice versus a result.

5.1 Introduction

The longevity, resilience, and success of businesses and communities can be a result of their strategic and tactical decision making. In theory, decisions in for-profit corporations are guided by maximization of financial returns for shareholders and in communities by the maximization of wellbeing for residents. However in practice, the relation between organizational decision-making and long-term profitability or wellbeing is far from clear, demonstrating a lack of what we call *sustainability awareness*.

For example, recent financial engineering and business practices in the U.S. banking industry that seemed profitable at first, eventually resulted in bankruptcy or liquidation of formerly venerated investment banks (such as Lehman Brothers and Bear Sterns). Similarly, over-investment in the US corn ethanol industry in the aftermath of Hurricanes Katrina and Rita was projected to be profitable, but instead resulted in the bankruptcy of some of the newest, largest, and most efficient production plants in the world [1]. Likewise, many U.S. cities, once a stable locus for meeting basic wellbeing needs of their residents are now finding themselves on pathways that are financially unsustainable and unable to foster the development of their next generation of residents, leaving them in dire straits. For example, in Rochester, NY several urban support systems are failing city resident: *food system* – 54 % of youth are food insecure[1] (more US corn now used for ethanol than for food),[2] *health system*– 20 %[3] of students start life in neonatal intensive care; *education system* – the Rochester public schools graduate less than 50 % of overall students and only 9 % of African American males.[4] Meanwhile, comprehensive strategies for addressing sustainability issues directly challenging both businesses

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[1] Childhood Poverty: Retrieved from: http://www.democratandchronicle.com/article/20120920/NEWS01/309200049/Census%20Rochester%20childhood%20poverty.

[2] Corn: Retrieved from: http://www.extension.iastate.edu/agdm/crops/outlook/cornbalancesheet.pdf.

[3] Neonatal: Retrieved from: http://www.nycourts.gov/ip/access-civil-legal-services/PDF/4th-Dept-Testifying-Witnesses.pdf.

[4] Black Males: Retrieved from: http://www.schottfoundation.org/urgency-of-now.pdf.

and communities, such as climate change,[5] are lacking, even while the frequency and effects of major environmental disasters mount.

Partly as a result of this uncertainty, and partly because of the need to satisfy multiple stakeholder groups and manage disparate risks, decision-making in corporate organizations and communities is governed by more complex moral principles than profit or wellbeing maximization alone – particularly when confronted by questions of *sustainability.*

The term sustainability derives from the Bruntland Commission [2] report *Our Common Future*, which emphasizes careful stewardship of environmental resources to support longer-lasting economic activity and social wellbeing in developing countries. However, the understanding of sustainability has evolved since then to encompass diverse issues of human and environmental wellbeing, longevity, reliability, resilience, and innovation [3]. The challenge presented by sustainability transcends the technological or analytical paradigm of normal, industrial-age science Seager et al. [4]. Norton [5] characterizes sustainability as a *wicked problem*, which refers to the critique of scientific expertise originally put forth by Rittel and Weber [6] identifying the essential characteristics of problems in social planning that defy reductionist analysis, including crime, health care, and public education. Each case revolves around difficulties of problem formulation (e.g., is crime a problem of law enforcement, social decay, education, mental illness, or lack of economic opportunity?), nonrepeatability (every wicked problem is unique), lack of consensus, and open-endedness ([4]. See also [7]). In response, Rittel [8] proposed what he termed "second-generation design," which placed far greater emphasis on public participation, non-expert knowledge, incorporation of stakeholder values, and deliberative discourse. This emphasis has subsequently been repeated in the literature of risk analysis [9], especially with regard to adaptive, iterative strategies that include opportunities to incorporate new knowledge, continuously reformulate problems, and respond to new situations.

Consistent themes emerging over the last four decades are the need to: improve understanding of complex systems (specifically systems of systems and the paradigms driving their interactions and emergent behaviors), incorporate local knowledge and public values, improve communication between expert and lay groups, and foster deliberation and mutualistic cooperation between business and public groups with competing value systems. Nonetheless, there is little guidance in the scientific literature regarding how different deliberative approaches and analytic aids can be structured toward these ends in a *sustainability* context. That is, the typical approach to sustainability in business, policy-making, planning, or design has been an ad hoc combination of methods and tools that depend largely on what is familiar or readily available to participants, deployed in a single instance of strategic planning, problem-solving or policy formation. In addition, these approaches typically focus on limited, reductive *indicators* of "sustainability" versus

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[5] Climate Change: Retrieved from: http://climate.nasa.gov/evidence.

the long-term health of a whole system. This lack of appropriate analytical structure and cognitive tools is consistent with a pre-existing mental model that, until recently, did not recognize sustainability as a wicked problem.

This paper summarizes some of the concepts essential to this problem recognition, and describes the preconditions and processes necessary for individuals, businesses and communities to achieve what we term *sustainability awareness* – a necessary step to improving sustainability.

5.2 Barriers to Resolution of Sustainability Problems

Because it is a wicked problem, traditional problem-solving paradigms (including science-based) do not function effectively in seeking sustainability. More specifically, problems of sustainability present significant challenges related to complexity, boundaries, competing value systems, and a lack of experience, expertise or analogs. Failure mechanisms include:

- *Complexity.* Mental models and decision heuristics developed for simple or static systems often fail in the case of adaptive or emergent phenomena. Hidden feedback loops at multiple scales across temporal and spatial dimensions (i.e., large and small, slow and fast) lead to apparent chaos and uncertainty, and require the development of new analytic paradigms. Individuals and organizations typically have little education or experience for understanding interrelated systems at either the fundamental level of ecosystem dynamics, social processes, and thermodynamic constraints or the consequences of the technological systems they introduce within this context. The qualitative and quantitative complexity and the amount of available data is overwhelming – especially where there is no structure, cognitive framework, or recognizable pattern to identify and adapt to what is more sustainable [10, 11].
- *Lack of shared awareness of problems and solution outcomes.* All sustainability problems in business, science, society, and government must ultimately be resolved within a sociopolitical arena requiring a shared awareness among stakeholders of the issues, impacts, and risks involved. Without an effective interpretive process to create this awareness, conflicting ideologies, narrow belief systems, and competing political agendas will dominate the debate. Therefore, stakeholders and decision-makers cannot begin to define the causal relationships of sustainability problems, evaluate solutions, recognize associated challenges or deal with the appropriate distribution and communication of the exposure and risks among affected stakeholder groups.
- *Difficulties formulating or defining sustainability problems or solutions.* In contrast to wicked problems, tame problems can be solved based on an agreeable definition of measurable outcomes. The tame problem-solving process is refined by experience into tacit heuristics and explicit expertise for quickly framing problems, discerning differences from past experience, and identifying solution

paths. This approach works when metrics and value judgments are defined by simple, singular dimensions (such as cost-benefit analysis) that can result in the identification of a *right* or *best* answers. However, when solving sustainability problems, the notion that societal or individual wellbeing can be defined in simplistic terms (such as economics) has long been discredited [12, 13] and no single answer can be considered exclusively *right* – all potential solutions are only relatively better or worse. What remains are complex, incommensurable metrics across multiple dimensions, with no definition of optimized wellbeing or system health, stakeholders with limited understanding, and no agreed upon overarching objective.

As a result of these issues, individuals, businesses, scientists and policy makers must resort to ad hoc determinations of what tools, knowledge, and computational power to apply, within the limits of time and resources, in a process of *continuous adaptation*. Todd and Gigerenzer [14] refer to this as *ecological rationality*. The concept of continuous adaptation may sound familiar to those having experience with continuous improvement quality programs and, empirically, we observe that companies that excel at quality (such as Toyota and GE) are often leaders in sustainability. Moreover, quality management programs have been extended to sustainability management, as evidenced by the International Standards Organization's (ISO) standards 14000 and 16000, which attempt to systematize continuous improvement of environmental and social sustainability. Nonetheless, prescriptive problem solving approaches, such as total quality, are too rigid to support the organic nature of wicked problems of sustainability, because these problem/solutions relationships *co-evolve* in complex ways.

There are several major differences that undermine the analogy between continuous improvement in quality and the continuous adaptation required for sustainability.

- Quality in manufacturing emerges from managing systems and processes that may be complicated (in the sense of having many components or details), but are not *complex* (in the sense of exhibiting emergent properties).
- Prescriptive quality is absolute and clearly defined by metrics; while sustainability is relative and metrics only provide an indication of systems status.
- In bounded situations like discrete manufacturing, potential quality solutions can be tested off-line; while wicked-problem solutions are one-shot operations that can only be tested through implementation in real systems and thus subjected to unintended consequences and a series of iterations.
- Prescriptive quality has a zero defect goal and endpoint; while sustainability solutions evolve such that the solution to one problem may create a new problem, without endpoint.

The tension between prescriptive "zero defect" quality, and a holistic, performance-oriented "quality" is even present within the quality movement, especially in software, where influencing the human system of production itself constitutes a "wicked problem".

Because sustainability *is* a wicked problem, we posit that there is no simple, formulaic solution for achieving it. Rather, sustainability will be the result of a series of adaptive decisions, which people, organizations, and societies make using familiar cognitive processes, albeit in an unfamiliar context. Improving short- and long-term sustainability is about how to better understand, support, and manage these decision-making processes and monitor the impacts of change and uncertainty about consequences, while continuously replanning as both individuals and organizations. Even relatively small decisions can be important, because in highly complex information environments, small details can quickly magnify into large variances in outcomes, as in the "butterfly effect" [15]. Therefore, decision-making processes need to be effective across the spectrum of vision, strategy, tactics, operations, and individual activities. *It is the cumulative impact of these small and large decisions over time that predominantly defines a business or community's sustainable performance, resiliency, and evolutionary-adaptation. Because sustainability is a wicked problem, we propose that it is better addressed by supporting this repeated, heuristic decision-making, to co-evolve "sustainability awareness"* versus *seeking a particular solution formula.*

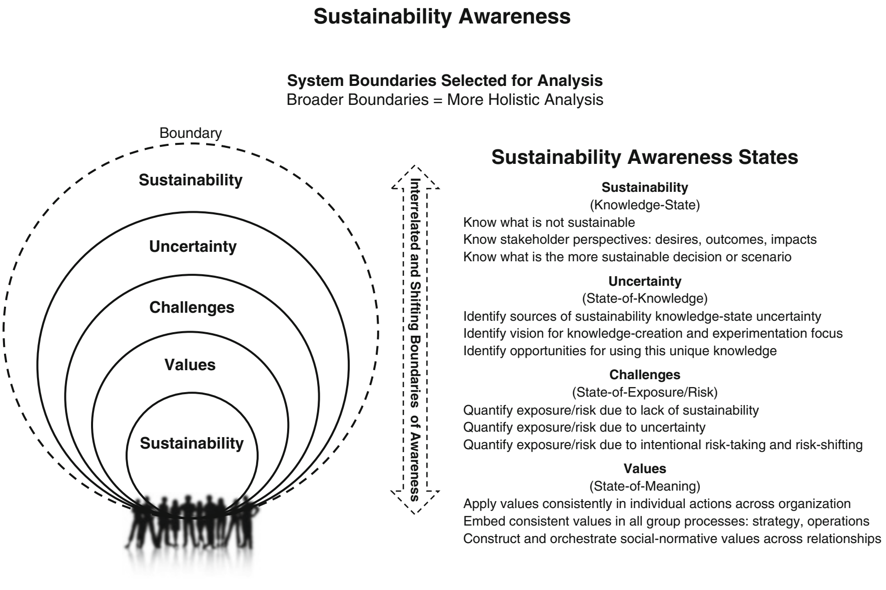
5.3 Sustainability Awareness

A pre-requisite to sustainable decision processes is a condition we are calling Sustainability Awareness (SusA). This is a situational, comprehensive, adaptive, and facilitative state for both rapid and deliberative decision-making involving value judgments of what is *better or worse* (i.e., recognizing what is more sustainable), rather than correct or incorrect. To achieve SusA, an individual or organization must navigate the iterative process of sense-making and mental modeling appropriate for sustainability, and apply these to interpretation and understanding of observations of current conditions. Lastly, they must be able to project that understanding into near, mid, and long-term futures. We assert that to support these processes SusA requires the collective achievement of conscious understanding in four categories:

- A *knowledge-state* as the current system sustainability status and the direction of current trends that results from achieving all three levels of situation awareness as it applies to sustainability – i.e., perception, comprehension, and projection (discussed later). Relative to the latter, it focuses on an integrated, real-world diversity of spatial and temporal influences relating to social systems (including economic and political constructs), ecological systems (including human health), and technological systems and the constraining parameters of all three of these, such as thermodynamics.
- A *state-of-knowledge* as the uncertainty associated with the sustainability knowledge-state. This informs the organization vision for what new knowledge needs to be created [16, 17] and guides the collection, categorization, and experimentation performed, including those as a self-experimenting society, in order to reduce uncertainty and become more sustainable.

- A *state-of-challenges* as the total exposure and risk due to lack of sustainability, amount of uncertainty, and intentional risk-taking and risk shifting to others.
- A *state-of-meaning* as the degree to which an individual, business or community has sufficiently thought through their values (a reflective exercise) and can consistently apply them (and their subset, ethics) as they pursue goals formulation, decision-making, and performance evaluation. This is further refined as "moral-knowledge-state" (discussed later) as it achieves the expertise (responsible, self-directed learning process) to construct, apply, and articulate a comprehensible unification of various requirements into a consistent values position of socially-normative judgments.

Because sustainability is impossible to define definitively, due to *contestability, fluidity*, our *ignorance* of the causal relationships underlying its complexity, and the other challenges described above, we propose a simple guide for addressing these four states, through "mutually reinforcing practices," summarized in Exhibit 1.



Sustainability Awareness States

Sustainability
(Knowledge-State)
Know what is not sustainable
Know stakeholder perspectives: desires, outcomes, impacts
Know what is the more sustainable decision or scenario

Uncertainty
(State-of-Knowledge)
Identify sources of sustainability knowledge-state uncertainty
Identify vision for knowledge-creation and experimentation focus
Identify opportunities for using this unique knowledge

Challenges
(State-of-Exposure/Risk)
Quantify exposure/risk due to lack of sustainability
Quantify exposure/risk due to uncertainty
Quantify exposure/risk due to intentional risk-taking and risk-shifting

Values
(State-of-Meaning)
Apply values consistently in individual actions across organization
Embed consistent values in all group processes: strategy, operations
Construct and orchestrate social-normative values across relationships

Exhibit 1

5.3.1 Co-evolution

Because addressing sustainability requires co-evolution of solutions with problems, SusA also includes the cognitive processes for maintaining awareness in the evolving operational states of "sustainability":

- *Structures and Frameworks* to integrate the complex combination of sustainability principles, concepts, data, information, and influences into new mental models and effective decision-making processes.
- *Influence Modeling* to understand system causal relationships to outcomes by embracing the explicit and tacit knowledge of experts and stakeholders across a wide spectrum of experience and expertise, and by capturing an understanding of the feedback structures that maintain the system paradigm and generate long-term system behavior trends.
- *Sustainability Analytics* to merge sustainability principles, concepts, data, and information with stakeholder perspectives and values into understandable comprehensive assessments of current and future sustainability. Ideally, these are presented using an intuitive graphical visualization to compare the outcomes and impacts of options under consideration. This cognition aid combines with the user's new mental models of sustainability to create the SusA of better versus worse outcomes. It also facilitates recognizing the impact of these outcomes on resiliency and adaptation for the purposes of formulating vision and strategy, and executing performance, decision, and wicked problem analyses.

5.4 SusA and SusE Cognition Building Blocks

Achieving SusA depends on a synthesis of many cognition building blocks in a process that is variously sequential, simultaneous, or iterative. An interrelated capability that guides this process and is concurrently developed during it is Sustainability Expertise (SusE). This represents the ability of individuals, organizations, and communities to create and apply SusA and to perform as an expert to improve sustainability through vision and strategy creation, performance analysis and decision-making, wicked problem solving, and special cases evaluation (e.g., climate-change risk). SusE is continuously evolving through the iterative cycling between assessments of situations to create SusA and the application of SusE in decision-making, etc. Through this organizational process of actively creating contexts (Mogi 2003 cited by Ichijo and Nonaka [17], p. 16), the bounded rationality [12, 13, 18] of individuals is expanded. Tacit and explicit knowledge are shared and its "truth" established through the social interaction of the participants, which is a dynamic process of justifying personal belief regarding a "truth that is never fixed" ([17], p. 17). It is thus objectified so that it can be shared externally and utilized for improving the sustainability of the organization. This is an implementation of the knowledge-spiral process described by Ichijo and Nonaka ([17], p. 17; [16]) as the essence of the knowledge-creating firm. The constitutive elements to the co-evolution of *SusA* and *SusE* – the cognitive elements in a knowledge-spiral specific to sustainability – are presented in Exhibit 2, followed by a description of each.

Our research suggests that a state of knowledge, uncertainty, challenges (exposure/risk) and meaning (values), sustained through frameworks of thought,

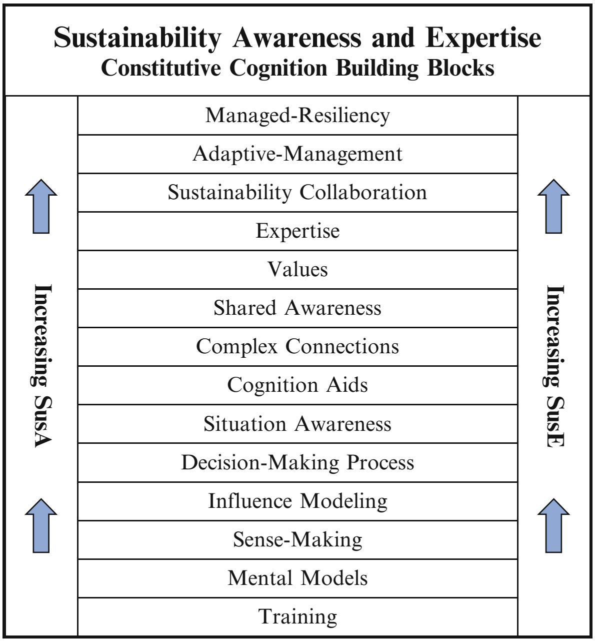


Exhibit 2

influence modeling, and analytics across stakeholders can support co-evolving assessment of sustainability issues, development of solution scenario options, and implementation of projects. Our initial focus was an 18 month Urban Agriculture and Community Gardening Feasibility Study [19] for the City of Rochester, NY, involving 676 stakeholders and experts exploring the benefits of urban agriculture and community gardening on individual and community wellbeing. In this particular situation, “the stakeholders and experts identified and mapped 248 influence relationships, summarizing incommensurable metric outcomes into indexes. The result is a qualitative and quantitative system model that represents a shared understanding of the impacts of urban agriculture that can be used to assess the benefits and potential unintended consequences of specific proposals or projects” ([19], p. 5). The seven wellbeing system impacts identified were: *financial, employment, education, health, public safety, ecosystem, and sense-of-community*.

This project’s context and subject matter focus had several benefits as a prototypical model for initiating stakeholder involvement in the development of a sustainable city, including:

- *Learning environment* for community residents to understand the principles and concepts of sustainability through collaborative exploration of the issues that arise at the intersection of three primary interrelated systems: ecological, social, and technological. This also includes cross-scale functionality provided

through the respective embedded subsystems: health; economic, education and governance; and infrastructure and engineering,
- *Participation relevance*, as the food system is something people care about, because it is both critical to survival and its food chain provides the most fundamental relationship between species, and
- *Sustainable city focus* for developing and experiencing scalable methodologies that combine stakeholder experience and expert knowledge in system assessment and decision-making and developing local and regional policies for improving sustainability.

The following are our empirical observations while using this process for stakeholder involvement in developing SusA and SusE and improving a subsystem of a sustainable city:

- *Undefinability of Sustainability* was accepted by stakeholders as true, and the concept of approaching it as a better versus worse decision, rather than right or wrong, made the process believable for participants.
- *Stakeholder Education* revolves around building the influence model, which is an affective, learner-centered and project-based process, but is useful only as long as it is focused on the specific influences familiar and interesting to participants. The model captures and retains group experiential history, which facilitates continuous updates, with the opportunity to dig deep into layered influences. Because stakeholders tended to have narrow interests, after the initial framing sessions we had to individually pursue smaller groups (or even individuals) to get to the deeper causal levels.
- *System Boundaries* are primarily related to the local sustainability issue being discussed, which parallels stakeholder interest. Stakeholders are comfortable and knowledgeable in discussing only those influence relationships they experience directly or know indirectly affects them. Regional and global research falls primarily to the organization facilitating this process and is inserted into the model with stakeholder concurrence, but only as it relates to a local influence relationship. We did not see evidence that stakeholder interest would ever be broad enough to develop universal solutions for all aspects of a sustainable city and would therefore need to be done in segments of stakeholder interest that could be subsequently stitched together as a qualitative sustainable city model. A quantitative city model would probably not be very useful for decision-making.
- *System Indexes* are high level, situation specific and identifiable only after the qualitative modeling progresses to the point that they emerge. Index relevance is sequential; first to coalesce a shared awareness among participants, agreement on the system context and most importantly, focus attention on impacts, second to help anchor an understanding and appreciation for specific causal chains and feedbacks within the model, and third to identify current and future unintended consequences. Later, when quantified, these indexes become notional indicators of better or worse system outcomes. We found that, because society has historically associated wellbeing primarily with economics and partially with education, meaningful metrics were not available for holistic systems. But this

was not a significant shortcoming because ultimately, improving sustainability comes down to determining metrics associated with specific causal relationships (of interest) and then focusing on finer granularity as knowledge deepens (as with the quality analogy). Abstract, high level indicators effectively abandon all knowledge of the system's internal functioning. (See *anticipation* later).

- *Multi-Criteria Decision Analytics* incorporating uncertainty in both stakeholder preferences as well as solution outcomes is integral to the SusA and SusE process. We also found this useful in support of a Department of Defense (DOD) project focused on decisions to drive ultra low energy military bases [81]. Relative to the community setting, we hypothesized that it could be used to make better and less contentious public decision-making and developed a software-supported evolutionary planning and decision-making application for dispositioning vacant city lots and creating a green belt ([19], pp. 278–283); however, while it appealed to individuals possessing domain knowledge, it appeared to be too complex conceptually for general public interest without additional education and usage experience.
- *Decisions and Funding* both occurred during the feasibility study process. Decisions were made and over $300,000 (combined state, city and foundation sources) was committed to fund one of the participants, Rochester Roots, to: (1) develop Phase I of a new Healthy Urban Food System Model, (2) refine an experiential education model, and (3) design a one and a half acre community Learning Environment and 12,588 sq. ft. Learning Center.
- A commitment to achieving SusA starts with training to achieve a holistic and comprehensive system view of a situation.

5.4.1 SusA Training

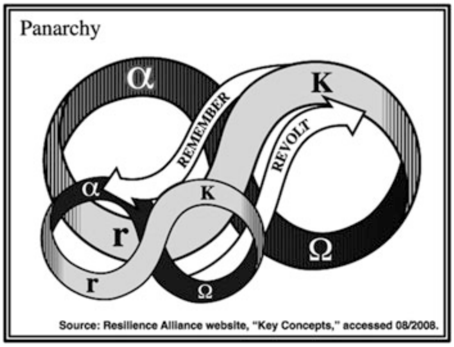
Similar to other transformative organization processes, such as continuous improvement quality, SusA requires its own language and tools, and a foundational understanding of sustainability principles, concepts, taxonomy, and metrics. SusA is predominantly skill in observing systems and their sustainability issues, which includes perceiving their driving paradigms, embedded processes, dynamic relationships, and "nested tiers of variables that interactively affect how other variables help or do not help to explain outcomes" ([21], p. 15186). Because this perception involves pattern recognition and is aggressively shaped by expectancy, which may be distorted due to framing biases [21, 22], training for open-ended system exploration needs to be designed to improve recognition of emergent system behavior patterns and reduce observer framing biases. This includes preparation in *theories* of system adaptation and transformation, *concepts* for explaining the attributes of system behaviors that may be observed, and *principles* of expectation. In order to begin orienting the reader to sustainability thinking, examples of each follow: theory of *Panarchy,* concept of *resilience,* and principles of *anticipation*.

5.4.1.1 Panarchy

Panarchy, its Greek origin translating as “rules of nature”, is a theory describing “how variables at different scales interact to control the dynamics and trajectories of change in social-ecological systems” ([23], p. 431). This explains how abrupt changes in ecosystems and other complex systems occur as a result of the interaction of slow, broad variables with smaller, faster variables. Empirically this is top-down (hierarchical), with the larger slower constraining the smaller faster. It has three ingredients: (1) subsystems of adaptive cycles at specific scales, (2) dynamic systems at different scales, and (3) coupling of these across scales at key phases of the adaptive cycle. It is the redundancy of cross scale functionality that provides much of the resiliency in ecosystems. The adaptive cycle has four phases:

- *Exploitive phase:* rapid colonization of recently disturbed areas in an arena of scramble competition, ecosystem resilience is high.
- *Conservation phase*: material and energy are accumulated and stored, slower growth, and exclusive competition. Toward the end of this phase the system is stable, but its stability is local and narrow resulting in a brittleness (usually internal due to high connectivity and accumulated capital) that leaves it vulnerable to small disturbances that can push its accumulated capital into catastrophe.
- *Creative destruction phase*: disturbance influences the established structure, thus releasing the accumulated ecological capital.
- *Reorganization phase*: little local regulation and stability, so vulnerable to changing stability domains.

In an example derived from Austin [24], consider a call center providing product or customer support. The larger system, seeking “efficiency” in terms of costs manages individual agents to call completion rates. This creates a hard coupling between the containing system intentionally pursuing its goals and the individual agents, each a subsystem pursuing its own goals. Agents adapt to this influence by hanging up on calls without resolution, which in turn has a coupled influence back into the larger system. The eventual resulting collapse is obvious. Failing to recognize humans as intentional, adaptive systems themselves is the theme of Austin’s work, and conversely a recurring source of errors in both management and policy formation.


Panarchy

Source: Resilience Alliance website, “Key Concepts,” accessed 08/2008.

5.4.1.2 Resilience

Resilience is understood very differently in sustainable ecosystems and social-ecological-systems (SES) versus how it is commonly addressed in engineered systems (though possibly not in the future?). This can be seen from seven perspectives below:

- *Intentionality*: Engineered systems are designed with intentionality, with resiliency assuming consensus on priorities, models, interpretations and acceptable actions, plus accuracy of observation, measurement, and communications. In contrast, evolving SES resiliency encounters these (priorities, models, etc.) as questions which emerge as new system states that appear after unanticipated perturbations. "Resiliency" in SES is therefore an emergent property related to self-organized behavior of those systems over time.
- *States*: Engineered systems design for only one state (set of functionalities) and therefore, define resilience in terms of recovery back to that steady state (equilibrium) following a shock, i.e., rate of change, speed of recovery, or magnitude of shock [25]. In contrast, ecosystems can have multiple regimes (states or stability domains) each representing a qualitatively different set of structures and dynamics, and therefore, define resiliency as the magnitude of a disturbance that effects the controlling variables (including feedback loops) sufficient to cause a regime shift. The defining characteristic of adaptive resiliency is that the system continues in some recognizable form, rather than a return to the previous state.
- *Optimality*: Engineered systems are intended to operate at an optimum. Hence, the introduction of the term resilience to indicate the amount of disturbance that a system can absorb without departing from a near-optimal state. In contrast, ecosystems have no optimality principle. Because both systems are operating far from thermodynamic equilibrium when change occurs, they can transform rapidly and dramatically and exhibit high nonlinearity and non optimal dynamics (potentially driving further transformation).
- *Stability*: Resiliency in engineered systems, which are designed to operate within well-defined boundaries, is typically a design property that does not self-evolve and emphasizes negative feedback loops to remain near equilibrium at the designed system state. Adaptation is only a result of successive design iterations resulting from engineering/social interactions, effectively outside the system of interest. In complex ecosystems, resilience is an emergent property of the system's self-evolution and emphasizes positive feedback loops. When successful, these systems occupy a trajectory of states where each may last only briefly but leads to a subsequent state that is similarly generative. In resilient ecosystems, stability in the engineered system sense is a property to be avoided. This is because stable systems are unlikely to be adaptive and more likely to experience catastrophic failure when design limits are exceeded. From a food web perspective, which is the most fundamental relationship between species, when a top predator becomes too proficient, the system can become unstable and result in the rapid decline or extinction of that species. The ecosystem can then

only be restabilized from the bottom up [26]. The system state changes radically, but on a trajectory of survival.

- *Resiliency Planning*: Engineered systems under normal circumstances operate within consistent human scales of planning and operation. In contrast, the controlling interactions of ecosystem's behavior, biotic and abiotic processes, can have distinct temporal and spatial scales that may be far larger than those commonly used by humans for management and planning. Also, unlike theories of engineered system behaviors in response to exogenous events, anthropogenic alterations of ecosystems can result in novel changes for which existing theories are insufficient.
- *Monitoring*: System assessment and monitoring functions to detect failure (lack of resilience) of engineered systems are designed-in control features that can be accessed locally (even for global systems, such as communications). However, for ecosystems, natural disasters strike across scales – up to planetary; therefore, to be understood they may need integrated local, regional, national, and global perspectives across short, medium and long term temporal observations (potentially decades). This raises other issues of cross-scale integration, communications, management, policy, and leadership, that in turn raises one of the biggest concerns of our culture, "whom to trust in the knowledge domain" for the technical details ([27], p. 204).
- *Recovery Planning*: The dynamics following the failure of limited engineered systems can be predicted and their management planned, based on factors that have been incorporated into the design (including cascading failures). In contrast, the dynamics of complex adaptive systems, for example following natural disasters, have high degrees of uncertainty and unpredictability, due to their evolutionary, adaptive, and cross-scale nature. Management systems have lacked data to monitor and test ideas about these system dynamics across scales.

It is worth noting that social resilience has the characteristics we assign to ecological versus engineered resilience. Key components of social resilience are engagement, trust, and learning, with the latter facilitated by stakeholder recognition of uncertainties, monitoring and evaluation. The most difficult issues to deal with are those whose consequences will be realized over a long time frame (10–50 years) over broad scales ([28], p. 426, 436). Seen in this light the consistent failures of engineered-resilience approaches to creating sustainable social systems only make sense.

Seager [29] proposed addressing the two systems, social and technological, as linked within an *industrial ecosystem* and applying the science of *industrial ecology* to improve their combined interrelationship with the ecosystem based on the natural analog [plus human intentionality]. He raises two issues with using this analogy: (1) natural systems use closed material loops of various time scales, and in some instances, recycling of low-quality industrial waste streams may be counterproductive by actually increasing thermodynamic resource consumption and (2) natural systems are highly energy intensive, with only 0.015 % energy transformation efficiency ([30], cited in [29], p. 23). Therefore, the industrial economy may need to best nature on both to sustain development.

5.4.1.3 Anticipation

One way to enhance the perception of emerging sustainability threats is to benchmark examples in high reliability organizations (HRO), such as better nuclear power plants, nuclear aircraft carriers, air traffic control, and wildfire teams. These organizations operate in an unforgiving social and political environment, the potential for error can quickly cascade into catastrophe, and the scale of consequences precludes experimentation. Weick et al. [31] point to these as harbingers of adaptive organizational forms, with cognitive infrastructures that enable simultaneous adaptive learning and reliable performance. These embody cultural processes of mindfulness with a quality of attention to suppress tendencies toward inertia and reveal unexpected threats to wellbeing that can escalate out of control – a capability to see the significance of weak signals and respond vigorously. Research by Weick and Sutcliffe [32] into HRO system inquiry behaviors indicates that, while not necessarily spotting discrepancies any more quickly, "they understand their meaning more fully and can deal with them more confidently" (p. 45).

They describe three principles/practices of *anticipation* that create a mindfulness focused on comprehension of emerging threats and reducing interfering comprehension factors:

- *Preoccupation with failure* heightens awareness (expect the unexpected) to look for weak signals that could be a precursor to the emergence of a gradual, interconnected threat. It heightens sensitivity to what systems are being counted on not to fail, while also cautioning that success at this process can result in overconfidence/complacency, reduced safety margins, and elimination of redundancies.
- *Reluctance to simplify interpretations* focuses mindful attention on context, categories, and expectations and is based on the assumption that the diagnostic value of weak signals is lost when those are lumped into crude, general categories, such as those masking deviation: vague verbs (impact, affect, determine), adjectives (slow, sufficient, periodic), and phrases (as soon as, if required, when directed) (p. 58).
- *Sensitivity to operations* focuses on operating details with mindfulness on "expectable interactions with a complicated [and] often opaque system" and "to respond promptly to those unexpected" (p. 59). This does not differentiate between the value of qualitative versus quantitative information as both are important when trying to detect the unexpected and to overcome the mindlessness of routines and overestimation of operations soundness.

As a "wicked problem," management and organization training also requires developing complexity thinking and includes using comprehension aids, such as influence modeling and personal cognitive mapping. The latter can also be used by instructors to identify students' knowledge and how it is being mapped to long-term memory [33]. Finally, as a social process, training for sustainability awareness requires teaching metacognition in order to recognize cues of information overload and confusion.

Because sustainability is a practice of consensus and coevolution, this collective preparatory knowledge then needs to be applied in domain-specific wicked problem solving exercises requiring values tradeoffs (discussed later) – essentially a practice of the kinds of thinking and collaboration involved in a coevolving sustainable state. Exercises should emphasize development, verification, and modification of SusA. These include exercises for recognizing and understanding antecedents, mental simulations that project actions into the future, organization of information for decisions (versus data flows), recognition of critical factors distinguishing more versus less sustainability, and expectancies, potential unintended consequences (consequences of decisions across broad interconnected wholes that occur much later in time [34]), and contingencies associated with a course of action [35]. Of particular emphasis are exercises that build strength in and comfort with ongoing evolution, where decisions are not final, but enable the next step – that keep the game going. This practice builds social resilience in relationships, trust and communication, and also motivates interest, which can be applied to generating further building blocks. For example, working with anticipation (resilience, Panarchy) in city, base and similar systems can create interest in the mental models at play.

SusA & Decision-making limitation: Training can form a familiarity with the taxonomy and processes for creating SusA; however, it does not in itself create the new mental models and SusE for achieving sustainability.

5.4.2 Mental Models

Challenged by "The weakness of a strong solution in a weak organization." ([36], p. 100) training participants may be guided to ask what mental models, sense-making, & etc. are blocking progress. Humans can only know what they have learned to hypothesize – *imagine* – which is grown and refined through experience as they intentionally project their bodies through time and space to explore an infinite world in search of desired future states [37]. Therefore, to make sense of complex situations and create a basis for decision-making, humans must generate hypothetical "descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states" that collectively form what is called a *mental model* [38]. These models are a set of well-defined, highly organized, yet dynamic knowledge structures developed over time from experience and stored as patterns in long-term memory [39].

Neurophysiology can now demonstrate how these neurodynamic activity patterns are formed and modified in the process of experiencing the environment (i.e., modification of a category of synaptic cluster – a learning process). Patterns representing prototypical states of the mental model are referred to as *schemata* or experiences. These categories of patterns store an individual's representation of reality. Cues from the environment invoke these to form the basis from which a situation is assessed, interpreted, and an appropriate decision is developed.

Since the human brain has strong pattern recognition capability, an expert can quickly access past schemata to assess a situation by matching it to previous experience and noting the important differences. However, in the case of sustainability assessment and decision-making, there is a dearth of appropriate mental models. This results in several issues.

- *Difficulty breaking out of personal experience.* People seek data in light of their current operating context and the decisions and goals they are trying to achieve. Thus, mental models drive the decision-maker's information seeking behavior. Without an accurate mental model of sustainability, people seek data that reinforces their personal experience versus data leading to accurate mental models.
- *Difficulty interpreting relevance of data.* Since mental models bias what information is attended to and how it is understood (through anticipatory shaping of the sensory cortices [40]), new information is not recognized or absorbed as quickly and is subject to distortion. Decision quality may also drop, as cues relevant to the decision goal may be missed. This is difficult to recognize because new data are interpreted in light of an existing model, exacerbated by the fact that decision-makers often ascribe inappropriately high weighting to past system states when predicting future system states [41, 42, 43].
- *Difficulty absorbing and relating data to an "unknown" paradigm.* Working memory is stressed by the relative novelty of the sustainability vocabulary and paradigm, which results in reduced listening and reading comprehension and negates the *automaticity* associated with well-practiced domain jargon and experience. Word recognition and decoding skills are thus degraded, resulting in a "bottleneck" in working memory that impedes the flow of thought and hampers comprehension. This becomes a critical issue for leaders who need to continuously and quickly absorb significant amounts of contextual background information to help structure, frame, and guide organization perception, knowledge-creation, and decision-making processes.
- *Difficulty making assessments*. Based on ignorance relative to knowing what is sustainable in distant time and space, there are no unequivocal decision-rules and therefore, the sustainability assessment capabilities of business and policy decision-makers remain below Dreyfus's "novice" classification of expertise [44]. They cannot use the common practice of domain "experts," which is to bring a familiar and well-practiced process or approach from long-term memory into the working memory "workspace" as the starting point of the decision process. As a result, each situation assessment and decision to be performed is novel, and therefore, more cognitively complex process, requiring more attentional resources than are potentially available in the finite working memory ([41], 2000).

SusA & Decision-making limitation: Creating new mental models of sustainability to solve the above constraints contributes to, but does not create awareness of a situation or make sense of it per se.

5.4.3 Sense-Making

Sense-making is the process of assessing history and interpreting the meaning of present situations for an individual, team, organization, or society. This is defined as "a motivated, continuous effort to understand connections (which can be among people, places, and events) in order to anticipate their trajectories and act effectively" ([45], p. 71). This process is initiated when an individual (or organization, etc.) recognizes the inadequacy of his or her current understanding of events. It is an active, two-way process of filtering data into a frame (i.e., a mental model) and fitting a frame around the data [46]. This is analogous to Rittel's observation of a wicked problem and solution evolving together. The personal experience of this process is the basis of Piaget's theory of learning [47], describing the creation of new knowledge, and Satir's change model [48], which maps the emotional experience of a change in world view. Because there is no end point, a successful sustainability initiative establishes a community engaged in ongoing learning from experience, in line with Kolb [49] or Piaget. Sustainability issues are a perspective from which to start this inquiry.

> *SusA & Decision-making limitation*: Sense-making has two limitations. First, it will not generate the forward perspectives desired for quality decisions (Endsley 1994), since by definition it is a backward focused process identifying reasons for past events, and second, it results in a limited understanding of problems/solutions that involve other stakeholders because it primarily incorporates perspectives relevant to the observer.

5.4.4 Influence Modeling

Influence modeling is a collaborative process among stakeholders for developing a compact graphical and mathematical representation of a decision situation that models a problem or process *qualitatively* and *quantitatively*. It starts with creating a shared understanding from a system-level perspective by mapping the dependencies of the situation and exploring the underlying processes and secondary or hidden influences and outcomes. (Other, related terms are "systems thinking" for the practice, and a "diagram of effects" for the instrument.) The deeper this process progresses, the more objective the questions become relative to individual causal linkages, resulting in a more objective evaluation and shared awareness. The relationships developed are then quantified probabilistically, to aid decision-making. These metrics and models also facilitate the post implementation assessment and inform subsequent iterative strategies of problem reformulation for further adaptation and resiliency.

When addressing wicked problems, whether performing social planning, evaluating the impact of potential new technologies, or addressing climate change, influence models allow stakeholders and experts from multiple perspectives to more clearly represent and communicate the qualitative components of their understanding of open interacting systems. This facilitates better anticipation and collaboration and as a result, reduces the potential for unintended consequences, which may otherwise ripple through a network of systems. It is through building these models that participants are also able to improve their focus on *goals formulation* and through the increased granularity more accurately and precisely define the desired outcomes (e.g., wellbeing, job creation, economic viability, reduced carbon footprint and energy use, public safety, healthy food supply, improved human health, etc.).

Conversion of influence diagrams into quantitative models further clarifies deliberation, argumentation, and planning processes and avoids imbalanced solutions focused on single nodes in an influence network. The span of interacting systems under consideration can be increased easily, as any model can be considered as a sub-module within a larger influence model. Multiple sub-modules can be constructed by independently operating groups while remaining seamlessly and quantitatively linked. The result is a large and inclusive qualitative and quantitative influence model that internalizes previously externalized impacts. Outcomes with unintended consequences can thus be deduced ahead of time and by monitoring metrics after implementation, new issues can be more quickly recognized and addressed.

When the quantitative relationships between nodes are expressed as probabilistic or stochastic relationships rather than deterministic ones, a *Bayesian Belief Network* (BBN) is the result. This is a modeling approach of artificial intelligence research directed at developing a decision-making support framework for problems involving uncertainty, complexity, and probabilistic reasoning. This expresses all the possible states of each node in the network and thus represents all possible worlds that exist in the system being modeled [50]. BBN's also use calculus and Bayes theorem to make statistical *inferences* and use observed events as *evidence* to update *beliefs* that certain future events will happen, but a detailed description of this is beyond the scope of this paper and readers interested in this aspect should refer to Wooldridge [50]. In application a populated BBN enhances SusA and SusE and is especially useful in challenging experts to articulate what they know and to enable decision-makers to make informed decisions before scientific knowledge is complete.

A refinement of the overall influence modeling process developed by Sustainable Intelligence is *Sustainability Gap Analysis*$^{\text{SM}}$ (SGA). SGA is applied with stakeholders during the model building using heuristics to spot potential imbalances, missed feedback loops and other potential gaps to source further questions about the influence model. SGA heuristics are focused on sustainability, and primarily rely on understanding of the three determinate interrelated systems that underlie all sustainability wicked problems: *Social Systems*, including social and economic viability, *Ecological Systems*, including human health, and *Technological Systems*. As well as the *Thermodynamic Constraints* (mass and energy) that challenge all three.

A second refinement developed by Sustainable Intelligence is the addition of a *Sustainability Implementation Assessment Model*$^{\text{SM}}$ (SIAM), which is designed to assist management in prioritizing the implementation of changes for increased sustainability. SIAM describes the dynamics of each node in the influence model and facilitates ranking from the perspectives of potential level of complexity involved, expertise involved (including interactional expertise, which will be discussed later), breadth of impact on the system, difficulty or inertia to be overcome, outcomes leverage, and optimization of total system impact based on resources available.

SIAM is very much in the spirit of "Places to Intervene in a System" in helping to select which of the many available actions to take to influence a system, and to a degree, what to expect. SIAM is both more explicit than Meadows [51] seminal work and directly focused on situation specific sustainability. These two prioritization perspectives (quantitative and qualitative) provide an excellent jumping off point for stakeholder groups to discuss implementation pros and cons, sharing explicit and tacit knowledge in the process of arriving at a plan of action, with potentially greater wisdom and chances of success.

A question sometimes arises as to the difference between influence modeling as a form of stakeholder engagement versus SWOT (strengths, weaknesses, opportunities, and threats), charrettes (group brainstorming to address issues or goals), and surveys. Basically, influence modeling addresses issues by engaging stakeholders in a holistic collaborative exercise to develop a system perspective based on their experience. Appealing back to Kolb/Piaget/Satir, this can result in changing the way they think about a situation (a precursor to behavior change); whereas, the other approaches are external to a system understanding by stakeholders and are generally agenda driven. The integration of the various approaches is most effective if the system perspective is developed first and then the other approaches (SWOT, etc.) used to develop solutions at specific nodes of the system. This improves the latter's targeting and effectiveness and reduces potential unintended consequences.

> *SusA & Decision-making limitation*: Influence modeling gathers and clarifies causal linkages and stakeholder perspectives; however, it also continues to add complexity that can lead to information overload in a traditional decision-making paradigm.

5.4.5 Decision-Making Processes

5.4.5.1 Naturalistic Decision Making

Since it has proven difficult to experimentally gain insight into real-world decision-making, the evaluative framework of *Naturalistic Decision Making* (NDM) was developed to empirically look at the way experts actually make decisions in naturalistic settings [52]. This approach falls within the realm of Simon's *bounded rationality* [12, 13], and we believe SusA and SusE fit into this relatively new and evolving field along with two other awareness-based, decision-focused disciplines: Sense-making, which we already discussed, and *Situation Awareness* (SA), which we will discuss later. However, these respective, process- and state- oriented approaches are focused on making *right* decisions; whereas, SusA and SusE are focused on making "*better* versus *worse*" decisions.

Three principles of the NDM classification summarized by Bryant [53] are:

- Decisions are made by *holistic evaluation* of potential courses of action, rather than feature-by-feature.
- Decisions are *recognition-based*, i.e., situation and pattern, versus exhaustive generation and comparison of alternatives.
- Decisions are focused on *satisficing* criteria (i.e., good enough), rather than a search for optimal solutions.

5.4.5.2 Heuristics

Also, within the framework of NDM is the study of *ecological rationality* which "focuses on uncovering the "adaptive toolbox" of domain-specific *simple heuristics* that real, computationally bounded minds employ, and explaining how these heuristics produce accurate decisions by exploiting the structures of information in the environments in which they are applied" ([14], p. 167; [18]). We believe this process, along with the three classification principles cited above, reflect the framework needed for understanding and evaluating sustainability decision-making, SusA, and SusE, and is why these fit within NDM.

Heuristic methods are strategies using readily accessible, though loosely applicable, information to guide problem solving and expand people's capacity for decision-making. These are especially needed in complex situations with incomplete information, i.e., wicked problems. Contrary to the normative ideal that good decisions follow the maximization of expected utility, the experimental evidence of NDM suggests people actually make decisions in an entirely different way. They rely on multiple simple *decision-heuristics*, not one general-purpose calculus of rationality [14]. As mental models for sustainability are developed, and businesses and communities gain experience managing for sustainability, there is an accompanying set of heuristic-based SusE assessment capabilities that begin to emerge and improve dispersed decision-making.

These *sustainability-heuristics* can be used to (a) more quickly and easily prioritize potential issues with a problem or proposed solution, (b) eliminate individual options (outranking) or identify improvements that need to be made before further consideration, and (c) make principled, accurate judgments, rather than producing cognitive biases. These include unique heuristics for individual situations, as well as, universal sustainability axioms or "rules of thumb." They can then be selectively applied throughout an organization or community to address sustainability as a natural extension of current heuristically supported decisions in the subset of the social system, economics – a far less complex and narrower domain. For example, companies have developed return on investment *hurdle rates* as a heuristic go-no-go before considering investments, as well as minimum *gross margin* and *overhead percentages*, *days receivables*, *inventory turns*, *growth rate*, etc., to aid in decision-making, financial modeling, and assessing the overall health of their business. In the case of sustainability, decision heuristics might include material content pounds/dollar profit, number of diverse perspectives/decision category, energy units consumed/dollar profit, gallons water/gallon finished product, and total exposure/total capitalization. Looking at coevolution of solutions and results, decision heuristics might include commitment to ongoing information collection, experimentation, or education – once you stop working, you're left with only the decision made so far.

> *SusA & Decision-making limitation*: The framework of NDM and heuristics can be useful in simplifying otherwise complex sustainability assessments and conforming decision-making processes with sustainability strategies, and thereby, expanding the participation in these processes; but for improving sustainability their development and application rely on the quality of the awareness and expertise creating and applying them, including the ability to project future outcomes and impacts of situations or scenarios.

5.4.6 Situation Awareness

In 1995 Mica Endsley pioneered a formal description of the process for understanding a situation, Situation Awareness (SA) [41], shown in Exhibit 3. Unlike the loosely defined process of Sense-making, which we discussed earlier, SA identifies three sequential levels of awareness an individual must achieve to reach a defined *knowledge-state*. SA was first recognized by the military in developing cockpit dashboard designs that enable fighter pilots to deal with the increasing complexity and compressed decision time-envelope of aerial combat. These SA driven designs are used as cognition aids that allow pilots to instantaneously project situations into the near future, and make quality decisions.

Situation Awareness

- Level 1: *Perception* of elements (status, attributes, dynamics) in an environment (within time, space)
- Level 2: *Comprehension* of the meaning (related to pertinent operator goals) of these elements.
- Level 3: *Projection* of the action of the elements in the near future.

Exhibit 3

SA applications are predominately linear, of one time scale, and contained within manageable spaces. In these situations, a single visual presentation of a situation as a "state" snapshot can be a sufficient representation to cue an expert to access appropriate schemata via pattern recognition for an accurate and instantaneous SA. Compared with SA, SusA requires the ability for a decision-maker to (1) comprehend the interaction of nonlinear dynamic systems of multi-temporal and multi-spatial dimensions and (2) interact or elicit the cooperation of others that may be operating with a different understanding or set of objectives. This means that obtaining SusA is more iterative and deliberative – i.e., more social – than in SA. Nevertheless, the SA model is a useful point of departure for understanding SusA, and three analogous levels of achievement may similarly be described.

- *Level 1: Perception* requires embracing the dynamics of living and engineered systems (including impacts of closely-coupled social, ecological and technological systems), which are ambiguous and extremely complex, requiring consideration of orders of magnitude greater breadth, diversity, and quantity of elements. This results in *boundary* selection decisions that are complex and conflicted and may need to be altered within the perception process versus simple and rigid for SA. In order to understand causality, the *time-envelope* must include interrelationship history (versus exclusively the present) and can extend generations into the future (versus seconds or minutes for the jet fighter example); the s*patial-scale* dimensions may include the earth and its surrounding atmosphere (versus several cubic miles of airspace). Consequently, the perception requirements of SusA may severely tax the sensory ability of a large organization that wants to stay in touch with interconnected social, ecological and technological systems bound by parameters, such as thermodynamic constraints.
- *Level 2: Comprehension* of meaning is more complex in SusA than SA due to (1) ignorance of what is sustainable in the long term, (2) the magnitude and complexity of the perceptual matrix of elements and their temporal and spatial outcomes and impacts for the ecosystem and various stakeholders, (3) the multiple and conflicting values-systems (and assumptions) that need to be addressed and harmonized and (4) the inclusion of diverse stakeholder goals that may extend decades into the future.
- *Level 3: Projection* for SA has a significant inertial component, due to the short timeframe, and is therefore more deterministic and easier to know; however, for SusA, this is better understood as *anticipation* and is most problematic due to the interaction of feedback loops caused by multiple interrelating systems (many on a global basis). These feedback structures generate long-term system behavior, which can remain latent until triggered by external inputs, shocks, or the tipping point of a natural resource service and can result in *emergent properties and apparent chaos*. This makes prediction of the future significantly more difficult and uncertain; especially, as a decision alternative's *temporal* considerations can extend to *trans-generational* impacts.

> *SusA & Decision-making limitation*: The process for achieving the single knowledge-state of SA can be a good conceptual process analogy for achieving SusA; however, the supporting cognition aid (i.e., cockpit dashboard) described is inadequate for achieving the three knowledge states required for SusA and applying SusE.

5.4.7 Cognition Aids

The magnitude, breadth, and interrelatedness of the information that must be understood to achieve SusA and apply SusE requires cognitive assistance via information visualizations incorporating simplifying analytics. System characteristics that are challenging for both cognition and cognition aids include:

1. *System incompressibility*: In complex systems, everything is connected to everything else, directly or indirectly, thereby making it difficult to disaggregate the contribution of individual components from the behavior of the whole. Conversely, it is difficult to aggregate constituent elements without losing important interactions, thus defeating the human cognitive strategy of "chunking." Because they are incompressible, any representation of complex systems less complex than the system itself, must lose some of the system's aspects [54]. This results in a significant limitation of any investigative or descriptive methodology dealing with these systems. This is the case for all complex system modeling even including advanced agent-based predictive computer modeling. This and other, similar limitations are why knowledge of uncertainty is a first-class element of SusA – the problems are so hard that keeping our uncertainty front and center is an indispensible part of understanding. Investigation is further confounded by the interaction of feedback loops, mostly hidden, with each other, which create complexity and emergent properties [55]. Feedback and other causal loops make prediction based on the elements intractable, and a full understanding of overall system behavior impossible. However, an imperfect attempt at managing the system is still required to form a basis for SusA as well as observing *stable abstractions* [56], which are the novel properties of the emergent system, independent of its components. The challenge of complexity thinking is the ability to recognize these emergent properties, and maintain the tension between our pretension that we know something, and knowing we know nothing for sure [54].
2. *Networked causality*: For systems thinking, boundary selection is problematic and forces a compromised representation of a non-compressible system. Just because a boundary is selected for the purposes of analysis does not mean that it is correct for creating SusA or applying SusE. The appropriateness of boundaries can also be time dependent, which may be significant in assessing sustainability and interactions with natural systems like watersheds, ecosystems, weather systems, or etc. Finally, all boundaries are transient given enough time. This highlights a fundamental complicating aspect of most wicked problems – the logical boundaries of various perspectives to a given problem do not coincide (e.g., physical, economic, environmental, span of control, or social boundaries). Therefore, any boundary selection is somewhat arbitrary and will most likely change within the SusA creation process as one solution begets another problem. Additionally, as Karl North highlighted, "compartmentalized scientific knowledge has created strong habits of boundary rigidity, with its resultant pattern of solutions that fail. Moreover, boundary rigidity often produces *bounded rationality*, where solutions that will fail actually are logical within the

limited perspective of the problem solver" ([34], p. 11). More sustainable system solutions require an endogenous focus that looks within the whole; and so for inquiry, expand boundaries as necessary to embrace additional externalities.

3. *Temporalities extremes*: Surviving in a rapidly changing and complex environment of interacting systems, experienced as chaos, requires a focus on the present, because different responses to even tiny perturbations can have significantly different long-term consequences. Leadership and management must adjust approaches that tend to focus on driving future goals and reducing apparent chaos. These approaches must in the short-term perceive and recognize early signals and implications of current and pre-emergent issues and respond by formulating new responses to opportunities. Simultaneously, at the other end of the temporal spectrum, long term natural system and multi-generational impacts must be anticipated (e.g., climate change), and used to influence current decisions.
4. *Conflicting values*: Stakeholders frequently assign conflicting, even mutually exclusive meanings to data and information. Yet these values need to be understood and appreciated for the system dynamics and sustainability insight they collectively bring. Stakeholders must also recognize that the value systems of today determine future technology developments and influence social changes.

5.4.7.1 Information Visualization

Information visualization can help focus stakeholders on the relevant sustainability issues and aid the cognition processes required to create SusA and apply SusE. This is done through (1) selection and structure of knowledge, (2) presentation of data and other information within an expertise-designed inquiry and decision-making framework, and (3) interactive computation support and relationship analytics. These visualization tools enable users to increase the quality of the four knowledge states comprising SusA, *sustainability, uncertainty, challenges,* and *values* and to identify, qualify, and quantify opportunities to enhance sustainability. The tools can also structure collaborative information among organizations (e.g., businesses and communities), such that opportunities to mutually enhance their individual cash flow and wellbeing may be more easily recognized, quantified, and realized (mutualism).

5.4.7.2 Information Visualization for SusA and SusE

Visualization's power lies in its ability to connect with user's mental models and elucidate a situation's causal relationships that underlie sustainability and decision scenario outcomes and impacts. Three perspectives of these relationships need to be developed for holistic SusA and SusE:

1. *Qualitative*: The qualitative perspectives are best presented as an integrated causal map developed through influence modeling. This significantly increases awareness of stakeholder perspectives and interactions.

2. *Quantitative*: The quantitative perspective is built by assigning mathematical formulas to the qualitative model, which enables prediction and scenarios testing.
3. *Analytical*: The analytical perspectives start with comprehensive sustainability assessment frameworks for the four states of SusA. These views and their underlying content can then be manipulated by a user to intuitively *pursue an analysis goal* without losing focus, or *follow changing analysis goals* as insights emerge.

5.4.7.3 Analytical Decision-Making

Davenport highlights that analytical organizations need a combination of human and computational perspectives and that analytical decision-making is at the intersection of individual and organization capabilities [57]. This intersection can be maximized by information visualizations that (a) support holistic collaboration, (b) build human and social capital, (c) facilitate rapid or deliberative decision-making processes, (d) relate SusA to plans, goals, and scenarios, operationalizing from the knowledge states and (e) allow sensitivities from various perspectives to be explored. The latter includes:

1. *Values Analysis*: Multiple stakeholder values-systems are applied to data and information to *articulate* comparative outcomes and impacts relative to those perspectives, highlight differences and temporal dependencies, and harmonize conflictual relationships.
2. *Causal Analysis*: Causal relationships to individual outcomes are ranked and explored so that influencing relationships, including “feedback causality” of reinforcing and balancing feedback loops, can be more clearly understood by all stakeholders.
3. *Scenarios Analysis*: Outcomes of multiple scenarios having multiple incommensurable metrics are ranked according to the values-weightings assigned to their individual components. Individual scenarios are tested to determine the sensitivities of future outcomes, impacts, uncertainty, and exposure to various influences and boundary selections.
4. *Uncertainties Analysis*: The interrelatedness and impact of the uncertainties of outcomes, exposure, expert estimates, and stakeholder perceived preferences is presented in order to investigate how scenario rankings change when these are modified. In certain cases this can result in achieving better outcomes with less investigative time and cost.

5.4.7.4 Analytics for Decision-Making

Analytics is a subset of business intelligence and is playing an increasing role in defining competitive advantage in business, healthcare, and sports and can also provide significant cognitive support for sustainability assessments and decision-making. It can be used to quantitatively assemble, integrate, and simplify the presentation of complex information, including technologies, life cycles, and value chains, to decision-makers, teams, and communities. This enhances their *cognitive agility* in deliberating, reflecting upon, and rationalizing conflicting tradeoffs and values across incommensurable metrics, multiple causal influences, and disparate stakeholder views. It also enables users to differentiate among decision scenarios through real-time application of various stakeholder values mosaics (discussed later) and manipulating multiple combinations of spatial, temporal and other boundary selections and weightings of sustainability metrics.

Because the holistic system perspective needed to assess sustainability requires that data and information be gathered, integrated, and consolidated from a variety of systems and sources, simple visualization aids are not enough. The visualization aid's presentation capabilities must be augmented with further cognition support for complex quantitative analysis and data mining by incorporating *analytics* [58].

5.4.7.5 Visualization Design

The visualization design must capitalize on the pattern recognition capability of the human brain, which exceeds that of computer models in speed and robustness in detecting minute but highly significant pattern fragments [59]. Also, studies show that *experts* are most effective when they can explore data [45]; therefore, data presentation must provide clear visibility to underlying relationships and support analytical drill downs, or if fused, the underlying algorithms must be accessible. This is what distinguishes this cognition aid from an expert system: it assists the expert with the structuring and framing of the sustainability analysis of a wicked problem and provides interactive computational analytics, but leaves the expert to formulate the decision and its expressed values.

5.4.7.6 Accessibility

Analytic visualizations embed important aspects and objectives of SusA and SusE within the visualization (e.g., baselines, scenario data and information, and heuristic insight and guidelines) [60]. The technology provides individuals, with differing capabilities, skill levels, and experience, greater accessibility to SusA and SusE, which increases diversity and collaboration. It also simplifies replicating these processes from individuals to teams to organization-wide and community levels and helps to build an analytical organization culture.

Research indicates that analytical workers have higher levels of business acumen than non-analytical workers and have shown a greater and often more nuanced understanding of their company's strategies, goals, and core capabilities, as well as the impact of external forces on their organizations [57]. Integrating a sustainability analytic capability with an organization's existing digital infrastructure can further accelerate organization-wide SusA/SusE usage and knowledge-flow. This capability can be further leveraged by providing browser based tools, available on a location-of-use and time-of-need basis [61], for all activities involving performance analysis, decision-making, and wicked problem solving.

> *SusA & Decision-making limitation*: Cognition aids can facilitate a better understanding of information available to create SusA, support the application of SusE, and facilitate a deeper understanding of sustainability issues; however, they are constrained by the limits of information, what users choose to seek, and ignorance of what will be sustainable forever.

5.4.8 Complex-Connections

In order to reduce sustainability ignorance, businesses and communities need to develop the capability to recognize, appreciate the implications of, and expand their *complex-connections* to the networked causality of the environment within which they operate [7]. Then, driven by an urgency of mild paranoia [62], they must identify uncertainty, quantify challenges of emerging threats and risks, and recognize the latter's *corollary*, as opportunity for adaptive-innovation. While this process can involve significant technical analysis, it is currently lead by social processes. These processes can be enhanced by, among other things: (1) flexible, nonhierarchical organization structures, (2) diverse human capital that recognizes information relevance to build a clear understanding of the organization's vision, strategies, information, and values, and (3) an environment of trust and caring that develops social capital and ensures free communication of information in all directions.

> *SusA & Decision-making limitation*: Complex-connections access more data, information, and societal knowledge and expertise; however, most wicked problems involves problem-solving as teams or communities (including as collaborators), which requires development of shared SusA and sharing of SusE among participants.

5.4.9 Shared Awareness

Extending SusA and SusE capabilities from individuals to the level of a team or community consciousness is significantly more complex. It differs in each of these social structures in both character and requirements, and relies on an understanding of the influences of social capital.

5.4.9.1 Team SusA

For teams, it is sufficient for SusE to only be represented in individual roles. However, SusA is dependent upon team members possessing SusA relevant to their job roles and shared SusA on those aspects of the situation common to the needs of each member, similar to SA [63]. When teams intend to operate at the *improvisational level*, SusA requires group *tacit knowledge* that includes team member anticipation of each others' actions based on an accurate mental model of other team members' expected behaviors (Weick 2008). This later aspect includes understanding team-members values-construct and how that will be applied to sustainability issues (discussed later). Team members require this to effectively deal with the uncertainty of their peers' potential actions or what Erden et al. refer to as "multiple-contingency" [64]. This level of SusA capability develops as teams work together over extended periods of time and, ideally, span multiple projects ensuring that they have sufficient shared experiences and knowledge of one another to achieve a high state of group tacit knowledge.

5.4.9.2 Community SusA

Team SusA is insufficient for situations that engage communities. Because all wicked problems are social, their solutions involve community input and participation; the scope of this stakeholder community defines the scope of available action, and the unit capable of taking action. Community SusA and SusE is significantly more difficult to achieve than within teams. Unlike teams, which are defined as groups of interdependent people with a common goal, communities (or collaborating organizations) do not necessarily have a common goal, and may believe themselves independent or even at odds. Therefore, a team or core community group organizing a sustainability initiative scoped for a larger community must project potential futures at that scope. Further, while the team or group may have their own preferences and priorities, to enlist a community they must also be seen as honest brokers, recognizing as legitimate even outcomes they, themselves dislike, if they address the priorities of others in the community.

Communities can be defined by various boundaries: geographic, cultural, organizational, interest (e.g., professional), intention (e.g., common social, political or spiritual interests), identity (e.g., race, sexual preference), etc. These can be nested (e.g., multiple ethnic groups within a geographic boundary), and their dynamics can be described, albeit differently, from various disciplinary perspectives: biology, sociology, psychology, anthropology, social philosophy, business and communications, ecology, etc.

Communities (or sub-communities) can operate as a cohesive functional unit to support their own sustainability within the context of a larger *social system*. A formal example includes the early settlement houses formed in the late 1800s to help arriving immigrants deal with the new society they were joining, which wasn't always supportive of them [10]. Therefore, achieving SusA and SusE requires awareness of both the dynamics of this system's construct and its perceived dependencies to sustainability. A structured approach for assessing this system can be based on the most broadly used approach for understanding a sense of community (SOC), the Sense of Community Index (SCI) proposed by Chavez et al., which includes analyzing four elements: membership, influence, integration and fulfillment of needs, and shared emotional connection [65].

Another aspect of community sustainability, especially when it involves nested sub-communities, is its ecological dynamics as described by Hollings as a Panarchy (discussed earlier in Training). This is a system of small, fast systems nested within larger, slower systems [66]. This concept is also reflected in Stewart Brand's observation: "The combination of fast and slow components makes the system resilient, along with the way the differently paced parts affect each other. Fast learns, slow remembers. Fast proposes, slow disposes. Fast is discontinuous, slow is continuous . . . .Fast gets all the attention, slow has all the power" ([67], p. 75). Woody Tasch extends this to his description of a robust and adaptable civilization as a series of fast to slow levels, "Fashion, Commerce, Infrastructure, Governance, Culture, and Nature" (p. 75).

5.4.9.3 Social Capital

Social capital can be thought of as a durable web of social dyadic and group relationships. The dynamics of the network can, in many cases, be the largest single determinant of SusA and SusE in businesses and communities. Depending on its application, social capital can either limit or expand SusA awareness, because it is often driven by homogenous or heterogeneous network ties. The latter outcome can be best achieved when social capital formation is managed from a holistic perspective of sustainability principles, values, and concepts. Cofield observed that the virtue of social capital lies in its ability to describe action in a social context and to explain the way action is shaped, constrained, redirected, and thus mobilized [68]. Therefore, this potentially addresses a component of one of the most troublesome sustainability issues: the ability to create workable solutions in a public setting. Relative to decision-making, this increased ability to describe social action also increases the ability to anticipate outcomes and uncover social feedback loops that might otherwise be hidden, thereby reducing unintended consequences.

Cofield's research into the formulation of social capital at the micro-level identified *social currency* to be the social system reflecting individual actor's intention, vision, and purpose (based on their existing mental models) that acts as the *social operating agent* for social capital formation [68]. In addition, she explained how social currency is a critical determinant in the maximization of human potential, and further, based on four principle elements, why social capital works in instrumental and expressive actions not accounted for in other forms of capital, such as in personal economic and human capital: (1) flow of information and resources, (2) influence on decision-making, (3) social credentials and connections, and (4) reinforcement of identity and recognition.

Based on this recognition, SusA can be increased by intentionally embedding structures and cognitive processes in businesses and communities that create *sustainability-oriented* social currency flows across all social dimensions (including race, ethnic cultures, economic strata, political influence, and opportunities environment). This results in increased *structured social capital* that facilitates information sharing, collective action, and decision-making through established roles and social networks supplemented by rules, procedures, and precedents. This is further enhanced by the increased *cognitive social capital* that is built to better articulate and embrace diverse values, attitudes and beliefs and cross-cultural/racial trust. From a sustainability perspective, social capital can also reduce information uncertainty by spreading knowledge and making the behavior of others more predictable, increase productivity of individuals and groups to improve economics through trust that builds speed and reduces costs, and according to the World Bank, is critical for economic prosperity and for development to be sustainable [69, 70].

> *SusA & Decision-making limitation*: A team or community's shared SusA, including an understanding of social capital formation, lacks significance until meaning is attached.

5.4.10 Values

SusA detached from meaning has no purpose. Because the meanings of knowledge and information emerge through social interactions among intentional beings [37], SusA involves the unique values-system lenses of stakeholders and communities as they pursue goals formulation, decision-making, and performance evaluation processes. When developing SusA, values are expressed by the *selection of boundaries* and *relative-weightings of metrics* (or criteria) to be used for assessing a situation and subsequent judgments to resolve short and long term temporal linkages and to harmonize the conflictual relationships that arise. These selections also result in the technologies that will become available in the future and represent the co-evolution of solutions with problems. These solutions arrived at by communities (with divergent values) converge upon the things they can agree on (versus their differences). For example, simplistically, environmentalism may contain the very divergent values perspectives that human activity is always a disruption to "the environment" to be minimized or eliminated, or that the environment is valuable to the extent that it supports humans and human activity. Either values perspective can lead to environmental strategies to "Live More Lightly on the Earth" despite their adherents valuing this choice for very different reasons.

In order to effectively and consistently apply sustainability values and its subset, ethics, an individual, business, or community has to have thought through these as a reflective exercise and arrived at a *state-of-values-knowledge*. This requires cognitive faculties and adjudication capabilities that understand values in order to make these judgments, a process of evaluating evidence within the process of making a decision. The broadest philosophical perspective for consideration of these value judgments is metaethics, which steps back to ask about the assumptions, commitments, and issues that emerge as a result of an abstract debate about morality, without taking a stand on the issues themselves. This offers a neutral background against which competing moral views can be identified and discussed [71].

However, even with all these tools, relative to neutrality, it must be remembered that: "there is nothing which is both a value, directing our actions, and objective" (Anas in [72], p. 281). Thus, values seeking in a sustainability-seeking community really uses these thinking tools to find common ground. One participant wants a sustainable outcome for the benefit of the people in it, while another for the reduced perturbation these same people put into an ecosystem. Values exploration in creating SusA and SusE – when it's working – leads to a community of partially-divergent values that's acting together in aid of the things they agree on.

> *SusA & Decision-making limitation*: Developing and applying values brings meaning to data and information; however, decision-makers may lack the expertise needed to be effective.

5.4.11 Expertise

Per Hubert Dreyfus [44], expert knowledge is developed through training and experience, is situational, and progresses in five sequential and universal stages from novice through expert. In the case of sustainability, expertise is rare, constantly changing, and needs to be an organization-wide capability: both general and role-related. Therefore, this expertise cannot be purchased; an organization must develop it for themselves. Furthermore, solving wicked problems requires external expertise, with examples of this including lay knowledge, values, and interests, nongovernmental organizations' (NGOs) resources, and knowledge contained in social networks.

By their very presence, individuals, businesses, and communities already exhibit a certain level of past survival expertise and potentially relevant future sustainability expertise as well. However, these personal life and organization histories represent *embeddedness* that will significantly affect their future acquisition of new knowledge. It will be both a help and hindrance in developing new mental models and expertise needed for present and future sustainability [72].

5.4.11.1 Expert Decision-Making Process

Dreyfus describes understanding the processes used by experts to access and apply their expertise as being inaccessible, even to the expert themselves [73]. Therefore, we turn to using NDM's empirical orientation discussed earlier; within this framework Klein and Hoffman [74] were able to make several useful observations of the characteristics of experts' decision-making processes. In general, they found that experts are

- Driven by experience-tied knowledge that is domain and context specific, able to make fine discriminations, and notice when something is missing that would be expected and the potential implications;
- Sensitive to semantic (logical conditions of truth) and syntactic (systemic relationship of the elements) content;

- Evaluating options sequentially or screening them against a standard versus each other and selecting or rejecting based on compatibility with situation;
- Learning perceptually, so that a focus on isolated variables shifts to perception of complex patterns- while some of this may be deliberative and analytic, it primarily relies on various forms of pattern matching, versus a concurrent choice among available alternatives;
- Visualizing how a course of events will unfold and form expectancies, and notice when these do not materialize;
- Using a forward-chained reasoning from existing conditions, versus backward-chained reasoning from a goal; and
- Integrating their individual acts and judgments into overall strategies, including the ability to form new strategies when required.

Training and models of expert-decision making can make these modes of thought available to a sustainability-seeking community, to apply.

5.4.11.2 Collective Expertise

Because the fundamental principles, concepts, and processes for enhancing sustainability are universal, they can be captured and applied organization-wide through modeling, heuristics, and analytics and visualization structures of the decision-making processes. These are a collective-expertise that evolves as an organization improves SusA and SusE capabilities. These are not expert systems, which are formulaic and rigid in solving predefined problems, or with collective intelligence systems, including web 2.0, which facilitate accessing a spectrum of individual expertise on an ad hoc basis versus applying a structured sustainability analysis framework to solve a problem.

5.4.11.3 Values-Expertise

The application of values gives meaning to data and information as discussed earlier. This becomes expertise with the achievement of the ability to construct and apply a comprehensible unification of various requirements to arrive at a consistent values position of judgments that can be well articulated. This is the *state-of-meaning* of an individual, business, community, or government. According to Anas, "becoming moral is a process of learning in which we all start as pupils or apprentices, and where it is up to us to become experts" (Anas in [72], p. 281). Appreciation for its subtler aspects, and that some parts are emergent, will only come through experience. The requirements of moral behavior, thus the moral state of actors may be industry and situation specific, and thus impossible for external "experts" to know, especially when latent impacts of activities may only be suspected initially or known tacitly to experiential experts or company insiders. In these latter cases, information may be intentionally hidden by vested interests, not recognized as relevant, be considered company-impolitic or irresponsible to express, [75] or have temporally dependent impacts, which start to emerge as anecdotal customer complaints or suspicions (e.g., asbestos, tobacco, thalidomide).

5.4.11.4 Interactional Sustainability Expertise

H. M. Collins and Robert Evans differentiated three forms of expertise with the introduction of their tripartite model, *no*, *contributory*, and *interactional expertise* [76]. Understanding the distinctions is necessary when it comes to designing organizations for increased sustainability. The latter interactional expertise is a critical attribute for change agents, as this enables them to provide organizational cognitive capability for cross-disciplinary effectiveness. Agents require the intersubjective linguistic fluidity across multiple fields in order to facilitate their interaction with field "contributors" (i.e., professionals with the contributory expertise needed to create new knowledge in their field) and through that interaction cause the "contributory expert" to reassess his or her own practice [72]. In the case of sustainability the agent needs a solid contextual understanding of sustainability principles, concepts, and efficacy.

When interactional expertise is combined with an understanding of sustainability and the processes of SusA and SusE it becomes what we call *interactional sustainability expertise*. With this ability, a change agent can stimulate among contributory domain experts the creation of new understandings of ways individual disciplines can contribute to the advancement of the broader, cross-disciplinary problem solving challenges for advancing sustainability; this is opposed to the narrow advancement of knowledge exclusive to their field. This can enhance an organization's knowledge-creation processes and collaboration, and foster co-production of expert-knowledge that advances sustainability, while building a process that is proprietary and difficult for competitors to duplicate. This latter is reinforced by the broader *emergence of interactional expertise*, which Michael Carolan [77] observed. As the contributory experts begin to recognize the "incompleteness" of their knowledge and ways of knowing, based on the limits of their epistemic orientations, they are thereby motivated to develop interactional expertise for themselves in order to reach across domains, a process that then has the potential for exponential expansion of sustainability oriented expert-knowledge within an organization.

Carolan's study also highlighted the need for interactional expertise to intercede in the conflict in the agricultural industry between two groups representing two types of contributory expertise, (1) organic farmers that place importance on mutable, fluid, and local knowledge, which is practical, and (2) conventional farmers that focus on commodified, universal, and highly generalizable knowledge, which is abstract [77]. The authors of this paper also observed this issue among farming participants in the 2009–2011 Rochester, NY Urban Agriculture Study, which involved groups of organic farmers, traditional farmers, non-organic hydroponic and aeroponic farmers, and universities representing both traditional commercial agriculture versus organic focuses. In this case, we observed that participants had different objectives and some perceived they had competing interests, with little incentive to collaborate (at least initially) to achieve a greater level of collective expert-knowledge.

Another form of interactional expertise, which is required for building and acquiring SusA at individual and community levels, is interracial and intercultural competency. This is critical to creating trust in order to form micro-level social currency, which is fundamental to developing and accessing human and social capital, discussed earlier [68], and the bonding and bridging social capital networks (social networks between homogeneous and heterogeneous groups of people, respectively) discussed by Putnam [78]. This is increasingly needed as communities and countries, such as the U.S., become more racially and culturally diverse (in terms of empowering more diversity in influencing decisions), which otherwise works to undermine the levels of trust fundamental to social currency and accessing the SusA knowledge embedded in social capital networks.

Wexler [42] describes how the acceleration of globalization of cultures, especially the proliferation of the U.S. culture to the youth of other cultures, unintentionally undermines interfamilial trust in other countries. Neuroscience now shows how a person's early brain development, when it is highly plastic, is culturally shaped by their environment. In later years, as neuroplasticity is reduced, but the surrounding cultural environment continues changing, a cognition gap (reduced comfort level) arises. The fit between the older brain's neural architecture (shaped by an earlier culture) is not as effective in relating to the new cultural environment, thus triggering affective neural circuits that elicit a threat response resistant to change (maintaining an environment to which their brain is better adapted). In many cultures around the world, the resistance to change as a result of this affective response [79] is as extreme as parents disowning their children if they marry outside their culture. Reyna et al. [80] describe with their Fuzzy Trace Theory the neuroscience basis for the difference between younger and older brain learning, reasoning, and decision-making processes: younger brains use "verbatim" information (data) and in certain situations can actually make more rational decisions, older brains rely on the "gist" (meaning) of earlier experiences applied to the new situation.

5.4.11.5 Applying SusE

SusE can be applied to all business and community activities, and is a process that is enhanced by a management information system tailored to support sustainability performance analysis, decision-making, and wicked problem solving, thereby fostering the emergence of interactional expertise. As with all such organizational information systems, by intention or not, this system becomes the embodiment of the organization's *intention, aspirations, purpose* [62]. There is also the opportunity to include the organization's sustainability vision, i.e., what new knowledge needs to be created [16], what resiliency needs to be built to effectively manage sustainability challenges, and values construct.

Through this system, much of the control benefit of a traditional hierarchical organization structure can be retained, while a more sustainability oriented hybrid social-organizational structure is employed that enables essential human capital by fostering social currency and capital [68]. This supports self-organizing, autonomous team knowledge-creation, adaptive-innovation, and execution activities while influencing these activities strategically, tactically, and operationally. The latter influences are accomplished through a coherently focused sustainability information structure that collects, aggregates, and synthesizes assessments of sustainability, uncertainty, challenges and values with underlying data support. Such a framework would naturally remain extensible across boundaries. Properly orchestrated through this system, CEO and community leadership's impact is augmented within a nonhierarchical environment. This becomes a distributed institutional intelligence and expertise to effectively absorb information through its complex-connections to the environment and respond with adaptive-innovation that is in concert with corporate and community vision and values.

5.4.11.6 Replicating SusA and SusE

Extending SusA and SusE capabilities and interdependent processes and activities organization-wide is best done using a replication process. This approach, unlike duplication, can be organic and evolutionary in nature and uses the processes of proliferation as a strategic opportunity to learn from each new instance of implementation, and thus continuously improves SusA and SusE capabilities. Their essential business model qualities and replicable information endowment, the "Arrow core", are discovered and refined through an experiential-learning process of exploration and "doing" into a working example or *guiding template* [81]. Its consistency is maintained as a result of being embedded within the structured knowledge and collective-expertise processes of a sustainable intelligence system, such as described earlier, that assists in establishing and monitoring local decision-making practices. This guiding structure and framework with its codified knowledge is incrementally updated through new learning experiences and analogous to Klein's and Freeman's observations of the human brain updating its mental model frames or synaptic clusters, respectively.

Replication of SusA and SusE as a knowledge-creation and application process starts with proliferation throughout an organization to its employees and self-organizing teams, and for increased leveraging of this knowledge-asset; it is then extended to relationships across boundaries. For businesses this can include subsidiaries, supply chains, outlets, and franchisees and for communities it can be applied to neighborhood governance, economic development and comprehensive planning processes. Winter and Sulanski highlight that this requires the capability to recreate complex, imperfectly understood, and partly tacit productive processes with different human resources every time, facing in many cases resistance from proud, locally autonomous agents.

From an adaptation viewpoint the knowledge transfer involved is both (a) *broad in scope* to impact organizational context of the target organization or team to better align it with its environment and (b) *narrow in scope* to primarily address internal details of knowledge already transferred (e.g., specifications, technology, etc.). Another adaptation analogy is the development of memories forward through time of the human brain, which carries parallel information as both the verbatim "data" (process to be replicated in this case) and "gist" or emotional memory of the experience [80]. A good example of a corporation that did the former well, but not the latter, is Starbucks. As they expanded they did not carry forward the "customer experience" portion of their model, and as such customers dropped and finally the original founder, Howard Schultz, had to return as CEO to reignite the original model's customer "experience" of their visit, which is what brought them back.

The value to sustainable competitive advantage offered by replication of SusA and SusE to a company increases with its ability to exploit knowledge through its intensive use, is eroded with delay, and is difficult for competitors to imitate. The latter is because replicators have the advantages of (1) superior access to the template, which involves tacit components that are only transferred through hands-on experience, (2) experience and specialized investments to facilitate replication that combine to make it cost effective and with a greater net present value, (3) other firm level replication advantages, aside from the core knowledge transfer, (4) a social entity committed to and experienced in the replication task and benefiting from its history, and (5) conventional firm-level advantages that are closely aligned and complementary to the knowledge-based advantages (Winter and Sulanski). While generally thought of as applying to retail outlets or franchises, in the case of SusA and SusE processes, a replication strategy has a similar strength in leveraging knowledge to more effectively reach large markets, and can additionally drive excess returns through its role in adaptive-innovation and enhanced long-term sustainability.

> *SusA & Decision-making limitation*: At this point the system perspective and processes for SusA and SusE are established, along with their sub processes for social capital development, emergent interactional expertise, knowledge-creation, and adaptive-innovation. What remains is for these to be expanded through engagement in societal processes.

5.4.12 Sustainability-Collaboration

SusA and SusE can be expanded through participation in *sustainability-collaborations* that include members from all sectors: business, not-for-profit, and government/community and is the meta-social context within which wicked problems are ideally evaluated and resolved. The participants should be mutually committed to utilizing their collective SusA and SusE to address some significant societal issue (research, problem, or policy oriented) with the goal of reaching consensus on a system representation of the problem.

The influence modeling discussed earlier is an ideal tool for this initial step of the process because of its ability to (1) accelerate sharing of experience (truth) and building of social capital, (2) allow members' representatives to move in and out of the process as appropriate without losing continuity of the process, (3) engage experts or new participants on an as-needed basis to fill-out missing experience or societal representation, and (4) capture an evolving record of the accumulating knowledge that can be shared and continuously improved.

Once this problem statement has been collectively defined within a system context it can be used for two purposes. The first is assigning appropriate societal members to develop solution scenarios that can be tested against the model to arrive at consensus on a satisficing solution, and the second is sharing the information with others for potential insight into related issues or linking the model to other models for solving other problems.

Recognized success in this process has three additional potential impacts: it can change the system-level understanding of participants in profound ways that (1) leads to beneficial changes in behavior, (2) serves as a cultural template for future collaboration, and (3) builds community human and social capital, including the potential to operate at the improvisational level (jazz metaphor discussed earlier for teams).

> *SusA & Decision-making limitation*: The twelve cognition building blocks discussed so far allow *sustainability-collaborations* to have the ability to continually improve SusA and SusE. By following a vision for knowledge-creation and an experimentation focus, they can generate, or be open to, new knowledge; which if they allow to impact them, allows adaptation to a new knowledge-state, with a potentially deeper SusA understanding of values and moral knowledge. However, understanding isn't enough, which leads to theories of action as cognitive building blocks supporting SusA and SusE.

5.4.13 Adaptive-Management

Based on the recursive-learning nature of sustainability problem solving and its continuous sustainability-collaboration and adaptive-innovation processes, organizations and communities are becoming experimental knowledge societies, as described by Gross and Krohn [82] – where conventions and norms are increasingly replaced by decisions made based on expert knowledge and situation-specific experience – i.e., analogous to SusA and SusE.

These societies develop through "experimental performance" and thus require the ability to assess the outcomes of their self-experimentation and make decisions for the next experiment from the unique perspective of observers within an experiment (this includes sociologists, scientists, stakeholders, etc.). This contrasts with the traditional external separation of scientists, planners and policy-makers from their experiment, where they attempt to manipulate variables without facing dilemmas of ethical constraint. SusA and SusE are intentionally created from an inside-the-experiment perspective, deliberately sensing and learning from both the intentional and unintentional self-experimentation. Most important, the learners and the designers are the participants within the experiment.

This brings us back to the quality analogy; quality control provides the knowledge to assess and improve in-process decision-making, based on its understanding of that relationship to expected outcomes, post-processed to rigorously assess and reduce any discrepancy. In active quality programs, participants drive this evaluation. This is similar to the Gross and Krohn [82] description of sociological research related to Hull House, a Chicago settlement house in late 1880s and the "social laboratory" (i.e., societal self-evolution processes) of the surrounding community. They took a special interest in understanding "the linkage between knowledge-informed strategic action or institutional planning and methodically guided observation of practical development" (p. 86).

Similarly, SusA must provide a concurrent assessment and alignment of decision-making processes, tradeoffs and anticipated sustainability outcomes, while refining their stochastic linkages to societal perceptions, preferences, and actual improvement in sustainability outcomes. SusA and SusE are real-world, adaptive-knowledge-state perspectives that frame a system understanding, while facilitating participant interactions so that every party feels heard, involved, and understood. In addition, SusA and SusE may "use" conventional expert backgrounds and training but do not "require" conventional expert backgrounds or significant training to participate. This framework works in conjunction with on-the-ground adaptive-management tools, such as those used within processes to define and develop infrastructures for managing society's relationship with the ecosystem, including adaptation under climate change [83].

Cities and military installations involve significant physical infrastructure. Since infrastructure artifacts have lasting impacts, unintended consequences for sustainability and adaptive-states can occur, and the broader SusA and SusE pre-framing of projects may help avoid these situations. Other tools (versus frameworks) that help with this kind of insight include multi-criteria decision analysis tools. An example is SMAA-TY, which is embedded within the SusA and SusE processes and supports the societal reasoning process and deliberative management decision-making tradeoffs. It also has the capability to drill down and explore combined uncertainties in stakeholders' preferences (*values*), performances of proposed solutions (*knowledge*), and government policies as rules (*process)* input for decision-making [84]. The concept of combing values, knowledge, and process with uncertainty as a decision kernel mechanism is a useful construct for deconstructing influences for teaching and improving sustainability decision-making.

In addition to decision-making influences/tradeoffs/process/assessment being inseparable, so is the identification of the more sustainable pathway options that the outcome will enable an organization to pursue. (See next section.) The starting point of pathways is unique to an organization's circumstance in relationship to the system in which it resides and those at adjacent scales above and below (Panarchy model of evolution dynamics). SusA and SusE need to frame this starting position so that its sustainability is realistically anchored within this larger systems context. SusA and SusE and their integral decision-making processes are the capacities and behaviors that both define and limit an organization's point-in-time adaptability, which we call its *adaptive-state*. See Exhibit 4. The development of SusA requires generation of this intentional perspective in order to support on-the-ground adaptive management activities and systems.

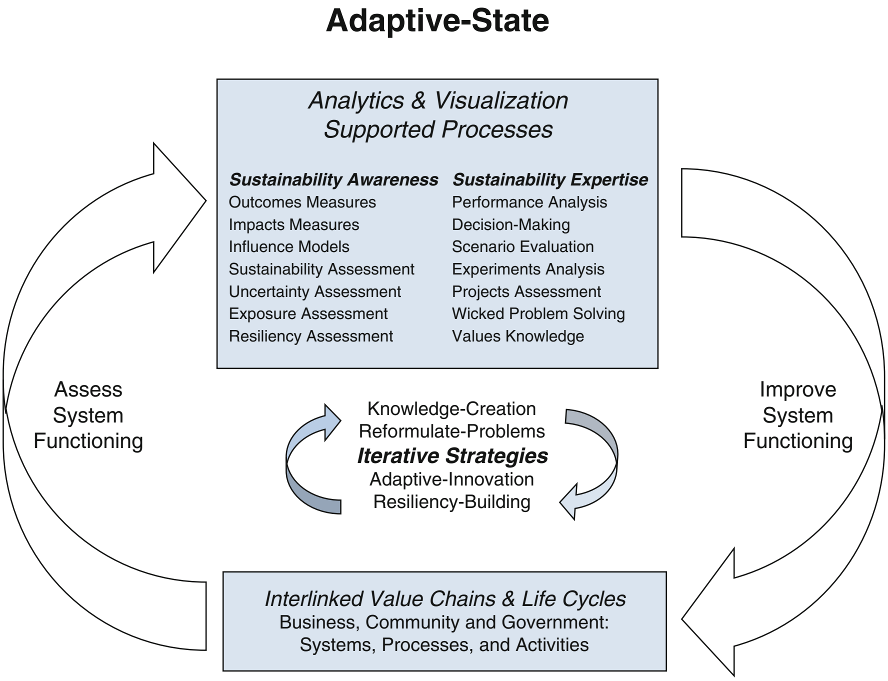


Exhibit 4

> *SusA & Decision-making limitation*: Adaptive-management systems operating within a SusA and SusE adaptive-state context can guide real-time operational responses to events as they occur. However, the available choices from which to select these responses, the holistically defined cost of those options, and the ability to retain functionality to unanticipated events are determined by the resiliency-state (capacity) of the organization. Managing this requires an additional and final dimension of SusA.

5.4.14 Managed-Resiliency

Traditional engineered resiliency means return to the prior internal state after encountering perturbations from within a known envelope. Also, traditionally, an engineered system is allowed to fail – achieve an undesirable internal state or even collapse and disappear – after encountering situations outside the anticipated envelope. Adaptive resiliency means the generation of a new state with additional options after encountering any perturbations that may come along. The adaptive system's internal state can be anything as long as it always offers further options for evolution; hence, the meta-state capability of ecosystems discussed earlier. Managed resiliency brings in intentional human action. *Managed-Resiliency* means an active human element within an evolving system deliberately chooses adaptive resiliency when faced with a choice.

Sustainability training uses examples and simulations to make this distinction apparent, building an intuitive sense for adaptive versus engineered resilience and comfort with scale-shifting along the way. For example, the dynamic stability of a sailboat is an example of adaptation as its orientation self-adjusts to changing sea conditions. Changing the boat's configuration is a different kind of adaptation, both intentional and occurring on a different timescale. In both cases, the adaptation satisfies the goal of sustainability, by keeping the boat sailing with many options of environment, configuration and later adaption still possible. Even so, there may be sea conditions that break the boat, illustrating that on one scale the boat is adaptive, while on another it is not. The sustainability training discussed earlier presents these conundrums, supported by the applicable models, tools, and physical understandings, so students can practice consciously being part of an adaptive system, actively managing its resilience.

By breaking resiliency, and specifically managed-resiliency, out as a separate cognitive building block of SusA, we are highlighting its strategic importance, as distinct from adaptive-management. This allows important issues to be addressed that otherwise get brushed aside by the traditional economic framing of strategies that reward optimization of short term goal seeking. Yet, it is exactly the kind of resiliency issues that were avoided in strategic discussions that have been the source of the sudden systemic collapse of major companies, industries and ecosystems and now the failure and bankruptcy of communities and cities as well.

There are several distinct differences between adaptive-management and managed-resiliency:

- Adaptation indicates what's doable now; resiliency highlights possible pathways for future evolution.
- Adaptive-management responds to "event" issues (storms, floods) in time-frames determined by attention or response times; managed resiliency responds to system qualities based on system cycle, reaction and tipping point time-frames that may extend across decades (ex. climate change).
- Adaptive-management responds to indicators of system status; managed-resiliency responds to dynamic system influences.
- Adaptive-management is tactical and operational; managed-resiliency is strategic.
- Adaptive mindset trades off resiliency to optimize and solve short term problems and maintain stability; resiliency mindset looks for generative choices. These can work counter to each other as evidenced in managed ecosystems, where control and reduced variability produced less resiliency ([23], p 10, Holling 1986). Also, resiliency itself can look sub-optimal, e.g., is a weed sprouting from long-dormant seed after a fire an example of resiliency? As a step toward recovery of the soil and foliage system, yes, while in terms of production of cash crops, no.

- Adaptive-management has a direct and observable relationship to intentionality that results in clear paths for its development; managed-resiliency has a much less intentional linkage because it must respond to unanticipated exogenous events and is an emergent property that isn't recognizable until it responds.

Resiliency-building is generally thought of as adding cost (e.g., redundancy) to the development and operation of processes. However, using larger temporal and spatial boundaries can alter this assumption, as these additional costs may be offset by savings in adaptive-management processes and be far less than the alternative costs of decaying life-supporting services or sudden infrastructure and institutional systems collapses (examples of all three were highlighted in the introduction).

5.4.14.1 Whole-Systems Engineering

Improving resiliency of technological systems starts with recognizing that their development processes and adaptive and resilient capabilities are inextricably interconnected with the social and ecological systems with which they interact. These systems both self-evolve and co-evolve together – their adaptive-management and managed-resiliency are interdependent. Next, we must recognize that unchecked optimization in the presence of ever-greater coupling makes things fragile. From Rome's collapse [85] to "brittle" software, or modern supply chains and food networks, purging reserves from all actors (optimization), while assuming ever more correct behavior from others (coupling), propagates surprises or malfunctions through the whole system. These system properties – coupling and brittleness – are more pronounced with larger, longer-lived systems. Only a climax-forest established and optimized, coexisting with salmon runs could be impacted by hydroelectric dams downstream (loss of nitrogen replenishment from carcasses after the spawn), with a social impact on local logging.

Dealing with this level of highly evolved complexity requires recognizing and understanding system features and control mechanisms different from those of bounded, single systems. This will necessitate a fundamental shift in the way whole-systems engineering is conceived and taught as a discipline for participating in the development of more sustainable Technological Systems. Curriculums might be expanded to include:

- *Robust yet fragile (RYF)* as a *feature* of engineered systems optimized for high performance in the midst of environmental uncertainty. Generic, modular configurations are "robust" to common perturbations, but especially "fragile" to rare events, unanticipated changes in the environment, and flaws in the design, any of which can cause sudden catastrophic failure [86]. Through close-coupling with no reserves and common failure modes among elements, failures tend to propagate through the whole system.
- *Biomimicry* as a development *approach* that looks to nature for solutions to adaptation and resiliency problems, including more recently, gene regulating

mechanisms as an "organizing principle guiding layered control systems in biology that balances energy, efficiency, component performance, and scaling." ([87], p. 6)

- *Protocol-based architectures (PBAs)* as an architecture to facilitate elaborate regulating *control* systems to coordinate and integrate diverse function creating coherent, global adaptation to large perturbations ([87], p. 4)... "each layer in the protocol stack hides the complexity of the layer below and provides a service to the layer above" (p. 6) – e.g., the internet. Isolating elements from failures that impact other layers.... Different layers iterate on different subsets of the decision variables using local information, yet their shared protocols allow diverse and robust edges to adapt and evolve, as long as they have appropriate (and typically hidden) layers of feedback control (p. 8)... This system-level recovery operates horizontally – the Internet recognizes censorship as damage and routes around it. And vertically – the most ubiquitous example is load-balancing. In both cases, protocol-based architecture allows local *adaptation* without impacting the rest of the system, by in effect creating a shearing layer as in building architecture that allows adaptation ([88], pp. 12–23). These processes mimic the way protocols allow for evolution in ecologies described by Doyle [87]: "In natural environments fitness and selection is highly stochastic and accidental, and protocol-based architectures "facilitate variation" that while random in origin, can be large, structured, and most importantly, highly likely to be adaptive" (p. 10).
- *Social-Technical Co-Evolution* as a *strategy* in which innovation and adaptation does not reside solely within technology design. "In technical evolution, as against species evolution, there is indeed much room for processes of creative combination and synthesis" of a "confluence" of development channels ([89], p. 133). For example, the SCOT Program, which is an interdisciplinary framework for social studies inquiry into the social construction of technology (SCOT) can provide historical insight into the time dimension of technological systems. Borrowing an analogy from architecture: "The unit of analysis isn't the building; it's the use of the building through time. Time is the essence of the real design problem" ([88], p. 13.).

5.4.14.2 Alternative Strategy Paradigm

Lastly, as highlighted in our introduction, improving the longevity, resilience, and success of businesses and communities relies on reducing the gap between expectations of strategic and operational decisions and their real world financial and wellbeing outcomes. Nonaka and Zhu [90] describe strategy and suggest pragmatism,

> "In a pragmatic world, strategy is about how firms, in fact, managers, orchestrate material-technical assets, mental-cognitive capabilities and social-normative relationships in a

> timely, appropriate manner so as to create and capture value. We make our way in a world full of complexity, ambiguity and uncertainty; strategy is purposeful action to get fundamentals right, promote situated creativity and realize common goodness" (p. xvii)

and identify the need for an alternative to strategy as optimization of bounded systems of concerns.

> "Managers and citizens have learned the hard way that, in their own interest and that of their children, it is imperative to *engage strategy consciously, purposefully, collectively* . . . and join the ongoing collective search for an alternative strategy paradigm" (p. xix)

We propose that a deliberate managed-resiliency, using the frameworks presented here, makes a compelling candidate for this alternative strategy, better aligned to complex adaptive systems – the "wicked problems" of sustainability. For communities choosing to engage sustainability-strategy more consciously and holistically, resilience provides a focus and rubric for guiding decisions. We believe that organizations can evolve and improve wellbeing more effectively by linking the strategic intentionality influencing the development of human *social and technological systems*, to be aligned with the ecosystems' instinct-based strategy of non-intentionality to self-evolve. SusA & SusE as elaborated here provide knowledge to frame and tools to manage "state" alternatives and goals within this triad of social, ecological and technological systems. In real time they are tools supporting adaptive-management, seeking sustainability through managed-resilience.

5.4.14.3 Social Systems

The education, training and use of the cognition building blocks of SusA and SusE cultivates the participating social system. Tools, habits and social capitol developed in creating SusA and SusE reflect and apply to – participating – in the sustainable evolution. Even heuristics and decision strategies explored as Cognitive Building Blocks, apply to the training itself, providing practice before applying to the larger context. These include three themes of Weick in support of Gigerenzer's "satisficing" solutions under bounded rationality:

- Broad repertoire of actions and experience, the ability to recombine fragments of past experience into novel responses, emotional control, skill as respectful interaction and knowledge of how the systems functions. Weick (2007, p. 3, [91]).
- Keeping errors small and improvising workarounds to keep the system functioning. (Weick, p. 14).
- "If your organization has to fight fires, you need resilient groups that are capable of improvisation, wisdom, respectful interaction and communication." Steve Jackson paraphrasing of Weick's Harvard Business Review Article (in [36, 78], p. 123).

5.5 Limits of SusA and SusE

As organizations develop their ability to operate sustainably within the complex systems of their environment, they, likewise, become a more complex system. Diversity and boundaries expand to connect to and interpret the environment, and organizational hierarchy is diminished to facilitate self-organizing teams and processes, sometimes referred to as autopoiesis. The collective *human and social capital* dynamics of an organization's employees interacting among themselves and the environment (as opposed to exclusively executive leadership and management) emerges to become the primary vehicle thus resulting in a more organic connection to the environment and to sustainability. In essence, human and social capital becomes the chief mechanisms for creating SusA and provides the SusE to initiate, formulate, and implement adaptive-innovation responses at all organizational levels and employee capacities.

This process essentially *leverages entropy* (complexity and chaos) to enhance adaptability. The entropy of this adaptive-state will continue to increase (less the finite entropy reductions available from reduced energy and material content as put forth in the Brundtland Commission's sustainable development guidelines in 1987) as an organization's organic connection to its environment becomes, in the process of improving, more complex and closely coupled. However, the limit is approached as for both management and employees, the complexity and chaos of managing for sustainability and their organization begins to become synonymous, and they face similar perceptual limitations in their ability to understand each. Likewise, as the emerging systems' complexity continues to rise, it may reach a theoretical point beyond which system robustness decreases and certain types of uncertainty increases as postulated by Carlson and Doyle. This limitation may be as significant a factor of sustainability in both biological and designed systems as the "conservation principles" (matter, energy, entropy, and information) have been in the past [92, 93].

To counteract this, decision-making process improvement needs to focus on practical simplification and support of SusA and SusE. We suggest that improvements can be best made by focusing on the development of cognitive aids, such as visualization-analytics and sustainability heuristics, perfected using the evaluative framework of Naturalistic Decision Making. Combining these with influence modeling, creating nonhierarchical organizations and developing social capital can help mitigate the trend toward increasing complexity: as individuals, teams, and communities are enabled to autonomously address single causal relationships that are within their *direct experience*, and are supported by an information system that frames the assessment of evolving sustainability, which we call a *Sustainability Framework*.

5.6 Conclusion

Sustainability within a complex, chaotic, and rapidly changing world requires continuous adaptation – resilience understood as preserving a system's options in unknown futures versus consistent return to a defined preferred state. While in the latter a designed city would remain the same until it collapsed in the former, a resilient sustainable city would remain recognizably present as a city generations hence, but won't be the same city it was when it began.

In this context Sustainability Awareness (SusA) and Sustainability Expertise (SusE) are strategic capabilities that, through a process of iteration allow complex, adaptive systems to sustain their existence, through evolving their state. SusA and SusE, shaped by real-world stakeholder experience, sustainability expertise and collaboration capabilities allow people in complex systems to create and apply new knowledge within the decision-making process to build resiliency and foster adaptive-innovation. These processes are interrelated and co-evolve as they pursue "*better*" decisions rather than "*right* versus *wrong*" decisions, evaluate outcomes and impacts, and then reformulate problems for further adaptive decisions, all performed by the impacted stakeholder community, in their context. The cumulative impact of these learnings and decisions – small and large – produce sustainability over time.

SusA is assessed by the four constitutive states of SusA – sustainability, uncertainty, challenges (exposure/risk) and values. These are not universal, reductionist indicators, but rather properties of the system and community of interest. Changes in this state over time represent an organization or community's pathway toward increasing or decreasing sustainability.

SusA and SusE as described here improve the "cultural ways of seeing" embedded within our social and technological systems to improve the sustainability of any given ecosystem – all individuals, organizations, communities, and governments, regardless of economic, social, organizational, or global status. It is within this awareness framework that businesses, communities, cities or intentional systems like military bases can frame their operational A*daptive-Management* behaviors and seek pragmatic strategies for *Managed-Resiliency*. This framing side-steps the unsolvable "wicked problems" of designed ecological sustainability to allow iterative satisficing over the long-term.

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Part II
Water

Chapter 6
Sustainable Water Resources Management: Challenges and Methods

M.C. Hamilton, W. Goldsmith, R. Harmon, D. Lewis, B. Srdjevic, M. Goodsite, J.H. Lambert, and M. Macdonell

Abstract This chapter provides findings of a working group from the NATO conference on Sustainable Cities and Military Installations, whose purpose was to identify the emerging challenges and methods in water resources management. The chapter identifies several themes of sustainable water resources planning, including: (i) the triple net zero concept of water, energy, and materials; (ii) risk, uncertainty,

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and future scenarios as multiple planning criteria; (iii) interactions within and across multiple spatial and temporal scales; and (iv) application of the second law of thermodynamics to ecological systems.

6.1 Introduction

Sustainable use of water resources has become a topic of critical importance for humans, with implications for society, health, economic development, ecosystem function and services, and other aspects of the human environment. Globally, freshwater resources are under increasing pressure from both development demands and anticipated impacts of climate change. Fresh water comprises only 3 % of global water, approximately 87 % of which is not readily accessible for use and development. While the global availability of fresh water is finite, human demand for this life-sustaining resource continues to grow such that at present an estimated more than two billion people are affected by a shortage of water [1]. The driving forces and pressures on water resources include both naturally occurring and human actions. Anthropogenic driving forces include population growth; demographic change, including migration from rural to urban areas; increases in the standard of living; competition among multiple users; land-use changes; and pollution of water resources [1]. Natural variability along with uncertainties in the human environment can make it difficult to predict water resource demands. In general, the systems for managing water that have been created throughout the developed world have been designed and operated under the concept of stationarity [2]. This situation reflects the fundamental idea that fluctuations in natural systems occur within an envelope of fixed variability. Within the water resources community, stationarity implies that any hydrometeorological variable (such as rainfall, snowmelt, or runoff) has a probability density function that is invariant over some finite time domain and whose statistical properties (e.g., mean, standard deviation, correlation structure) can be estimated from an adequate length of historical record. Based upon this concept, water resources infrastructure has been developed and operated by empirical rules for evaluating and managing risks to water supplies, waterworks, and floodplains. If non-stationarity becomes the new paradigm as a consequence of climate change, the robustness and resilience of water systems would be severely challenged and could ultimately create substantial economic regret that has been not accounted for in current systems.

Water issues of concern include adequate supply (for drinking, sanitation, agriculture, and other uses), quality (including salinity), and habitat degradation. Each of these issues already impact many locations across the globe. The availability of fresh water is a critical factor for environmental security and stability, and it is essential to the development of sustainable strategies for managing water resources. Progress is being made in a number of key areas, and more is needed. These areas include: (i) designing and implementing the triple net zero concept for systems of sustainable water, energy, and materials; (ii) integrating risk, uncertainty, and future scenarios as multiple planning criteria; (iii) addressing interactions within and across multiple spatial and temporal scales; and (iv) applying the second law of thermodynamics to ecological systems. Highlights for each of these areas are presented below.

6.2 Triple Net Zero Concept of Water, Energy, and Materials

The energy/water nexus is an important issue that has taken on new urgency as concerns have grown about competing demands for limited resources. Energy can account for 60–80 % of water transportation and treatment costs and 14 % of total water utility costs [3]. Much of water resources development in the U.S. took place during the twentieth century in an era of both low energy and low water prices. Subsidized rural electricity increased agricultural production in irrigated areas and encouraged the use of irrigation in areas without direct access to surface water. Energy demands for potable water systems include requirements for pumping, transport, treatment, and desalination. Recent estimates indicate that approximately 40 % of water use in the United States is for energy production; with agriculture representing the second highest use category. The energy-related uses of water include thermoelectric cooling, hydropower, minerals extraction and mining, fuel production (fossil, non-fossil, and biofuels), and emission controls. Most of this total is associated with non-consumptive use, i.e., as cooling water for power generation plants; the total consumptive use is much lower, at 3 %. Over a number of decades, trends away from once-through cooling and toward closed-loop cooling have reduced the ratio of total water withdrawals to energy produced from 63 gallons per kilowatt-hour (gal/kWh) in 1950 to 23 gal/kWh in 2005 [4].

The implementation of renewable energy technologies is a way to meet increasing energy demand, reduce climate impacts of burning fossil fuel, and decrease dependence on imported sources of energy. Some renewable energy options require little, if any water. However, the water requirements should be considered for each renewable energy development activity. Solving one resource problem can affect another if all implications are not considered through comprehensive evaluations such as systems analyses. As an example, using irrigation to produce biofuel crops has been estimated to consume 15–30 times more water than it takes to produce a gallon of gasoline [5].

Lack of water can also affect energy production. To illustrate, Hoover Dam’s 17 turbines that are responsible for generating 2080 megawatts (MW) of hydropower; however, they cannot operate at full capacity when the waters of Lake Mead drop below certain levels because insufficient flow can damage the turbo generators. In fact, Lake Mead has not been full during recent years due to drought conditions that began in 1999 [3]. Similarly, certain methods of natural gas extraction such as hydraulic fracturing or “fracking” require the injection of large quantities of water to break up deep rock formations and release the gas for subsequent recovery. As another example, water needs for solar energy development can be substantial [6].

Given such interrelationships, it is evident that we cannot continue to consider water, energy, and waste issues separately. This understanding has motivated the U.S. Army and many other organizations to pursue the "triple net zero" concept, which is focused on (1) creating buildings, campuses, cities, and other facilities and communities that produce as much energy as they consume; (2) limit consumption of fresh-water resources and return water back to the same watershed so as not to deplete groundwater and surface water resources of the region in either quantity or quality; and (3) reduce, reuse, and recover waste streams with a goal of zero landfilled wastes [7].

As highlighted from the recent U.S. Army overview of its net zero program (available online), the approach is comprised of five interrelated steps: reduction, re-purpose, recycling and composting, energy recovery, and disposal. Each step is a link towards achieving net zero. To achieve this goal, installations must first implement aggressive conservation and efficiency efforts while benchmarking energy and water consumption to identify further opportunities. The next step is to utilize waste energy or to "re-purpose" energy. For example, boiler stack exhaust, building exhausts and other thermal energy streams can all be utilized for a secondary purpose. Co-generation recovers heat from the electricity generation process. The balance of energy needs can then be reduced, with the goal of meeting those needs with renewable energy projects. The net zero water strategy balances water availability and use. To achieve a net zero water installation, efforts begin with conservation followed by efficiency in use and improved integrity of distribution systems. Water is re-purposed by utilizing grey water generated from sources such as showers, sinks, and laundries and by capturing precipitation and storm water runoff for on-site use. Recycling discharge water for reuse can reduce the need for municipal water, exported sewage or storm water. Wastewater can be treated and reclaimed for other uses or recharged into groundwater aquifers. The components of net zero solid waste include reducing the amount of waste generated, re-purposing waste, maximizing recycling of waste streams to reclaim recyclable and compostable materials, recovering waste materials to generate energy as a by-product of waste reduction, and working towards eliminating the need to landfill material. Strategies include considering waste streams when purchasing items, reducing the volume of packaging, reusing materials as much as possible, and recycling the rest.

In April 2011, the U.S. Army designated five net zero energy installations, five net zero water installations, and five net zero waste installations with one integrated net zero installation for pilot demonstrations. These installations are working to achieve Net Zero by 2020. They are expected to become the centers of energy and environmental excellence, showcasing best practices and demonstrating effective resource management. An additional 25 installations in each category are expected to be identified in FY14 to achieve net zero by FY2030. The U.S. Army is collaborating with others, including the U.S. Environmental Protection Agency, to promote these concepts. The lessons learned by the U.S. Army and its collaborators in the quest to implement and achieve triple net zero installations (and other communities) can be leveraged by other agencies worldwide.

6.3 Risk, Uncertainty, and Future Scenarios as Multiple Planning Criteria

Significant innovations in the management of environmental and infrastructure systems have resulted from the adoption of a holistic systems-based approach [7–32]. Extending from the preceding discussion, a key part of the triple net zero success lies in creating a culture that recognizes the value of sustainability measured not just in terms of financial benefits, but in benefits to human health, quality of life, relationships with local communities, environmental and ecological aspects, and the preservation of options for future generations [7]. Water planners must consider interrelated impacts of water management strategies with energy, economic growth, land development, agriculture, and others, so the use of multiple planning criteria becomes increasingly important. Because effective water resource management will involve collaboration of stakeholders across many geographic scales, including local, regional, and national planning organizations, a participatory approach that integrates multiple values and perspectives is crucial. A wide range of multiple criteria analysis approaches have been applied to a variety of water resource management initiatives, including water policy evaluation, strategic planning and infrastructure selection [33–36]. Clearly defined objectives and criteria for implementing water management policies and projects have been shown to increase stakeholder engagement and consensus [36, 37].

A vital component of developing sustainable strategies is the use of scenario analyses to assess vulnerabilities. In considering sustainability planning and climate change, these scenario analyses involve assessing the extent to which climate variability and change, acting together with other stressors such as shifting land-use patterns and rapidly industrializing nations, can impact water, energy, and other systems. Recent work has integrated scenario planning with multicriteria analysis for the prioritization of initiatives that comprise management of environmental and infrastructure systems [7–25]. In risk assessment, scenarios can be used to represent what can go wrong in the most basic sense [38]. Scenario planning enables the characterization of possible threats and opportunities related to a system that can span technology, climate change, economic, regulatory, socioeconomic, ecological, and other aspects. Unlike forecasting, scenario planning does not typically include calculation of probabilities [11]. Although it is not possible to fully characterize potential futures, scenario planning can help reduce the uncertainties to a reasonable number of states that may matter most to decision making. The ultimate aim is for the decision maker to be able to define strategies that are robust over a range of different possible outcomes [39]. Furthermore, scenario planning enables the observation of joint impacts of various uncertainties and simultaneous changes in various variables, and it uses subjective interpretations beyond the reach of objective analysis [40]. Two elements of these collective risk-uncertainty-scenario approaches that are relevant to water resource management have long been recognized [41]. First, multicriteria decision analysis provides an appeasing allocation of shared resources by enabling the involvement of a variety of stakeholders in the decision process. Second, the multifaceted nature of water resource management problems makes it harder for decision makers to simultaneously process different information. The characteristics of multicriteria analysis approaches can help decision makers process information such that all encompassing criteria and factors are considered [39].

In integrated scenario planning with a multicriteria analysis approach [7–15, 29], scenarios are introduced that can increase the importance of some criteria while decreasing the importance of others. A change in the importance of a criterion is reflected by a change in its weight, as captured by either a decrease, no change, or an increase. New weights then represent the weights of the criteria given that a particular scenario is observed. Each scenario is represented by a unique set of criteria weights. The expert is not asked to reweight the criteria, but rather to assess whether the importance of a criterion increases, decreases, or stays the same. Results from this type of analysis can identify scenarios that indicate management alternatives that are robust across scenarios, and, perhaps, more importantly, this analysis can identify scenarios that are most disruptive or influential to the ranking of alternatives to which decision-makers should apply additional modeling, information-gathering, and other resources.

6.4 Interactions Within and Across Multiple Spatial and Temporal Scales

Historically, the planning and management of water resource projects have been compartmentalized for one or more purposes (e.g., flood control, navigation, water supply, energy supply, transportation corridors, and others). However, due to interdependencies on both the temporal and spatial scales for water resources, management requires an integrated, holistic approach. As noted by [53], mismanagement of natural resources may occur when there is a temporal or spatial mismatch between the scale of the management and the scale of the process being managed. Further, technological advances in spatial science and innovations in statistical methods have resulted in models that provide estimates of water supply and demand at increasingly fine spatial and temporal resolutions. Previously, water demand forecasts were made using available data such as water price, household income, and city-scale climate factors. Now, access to rich spatially explicit data allows for the incorporation of local-scale factors that may also be important in predicting water demands, such as the influence of urban zoning, building density and area, vegetation, and landscaping. Understanding the influence of urban design, land-use planning regulations, and other property characteristics on water consumption will be important for policy makers attempting to integrate land and water management planning for sustainability.

Social, economic, climatic, hydrologic and other variables are continually interacting to create a complex system where it can be difficult to gauge the effectiveness of policies to improve sustainability. This recognition has lead to a recent increase in the development and implementation of dynamic models capable of incorporating the multiscale interactions between human and natural systems that are in contrast to conventional static time series and econometric models [53]. Several examples of dynamic models are offered, including those developed to capture how water consumption decisions and behaviors are affected by urban form and housing [42], changes in price [43, 44], conservation policies [44, 45], and climate change [46].

Two types of dynamic modeling methods commonly used to examine complex, dynamic water systems are agent-based models (ABMs) and system dynamics models (SDMs). ABMs have been described as gaining popularity for water demand modeling because of their ability to (1) incorporate both spatially and temporally explicit data, (2) model bidirectional relations between individual human agents and the macrobehavior of the social or environmental system being modeled, (3) capture emerging patterns at higher scales of the system that result from interactions at lower levels, and (4) blend qualitative and quantitative approaches ([53]; [42, 47, 48]).

SDMs provide another method for understanding the dynamically complex problems that underlie water resource management. These models facilitate the examination of behavior patterns over time and of how a system responds to interventions [49]. The foundation of system dynamics is the notion that the behavior exhibited by a system is due to the structure of the system and the relationships, interactions, and feedbacks among the key variables within the system. The process of building a system dynamics model fosters an awareness of the elements that create feedback and delay within a system and thus can improve resource management policy making. For example, Beall et al. [50] used a participatory system dynamics model to improve collaboration among stakeholders, enhance scientific understanding, and promote a long-term future-focused management of aquifer resources in Idaho’s Palouse Basin (in the northwestern United States).

Continued research in modeling complex interactions of human and natural variables at multiple temporal and spatial scales will be important to achieving the goal of water sustainability. The increased availability of data on multiple spatial and temporal scales, including from remote sensing tools, can help analysts identify and quantify the factors that influence water supply and demand to help guide planning decisions. Insights from this research can be used to create policies aimed at reducing demand and designing appropriately scaled infrastructure that will be resilient to uncertain nonstationarity conditions that could result from climate change.

6.5 Second Law of Thermodynamics to Ecological Systems

The second law of thermodynamics is fundamental to all real processes involving energy and material transformations. The second law states that any internal change in a closed system moves the system closer to thermodynamic equilibrium. A state close to equilibrium is known as one of high entropy, where there is a uniform distribution of energy and matter. A low entropy system, on the other hand, is one that contains high use potential or stores of energy. The concept of the second law of thermodynamics and entropy is applicable to interdependent human and ecological systems. Rees [51] provides examples of low-entropy natural capital such as forests, grasslands, marine estuaries, salt marshes, and coral reefs, arable soils, aquifers, mineral deposits, petroleum, and coal deposits that represent highly-ordered self-producing ecosystems or rich accumulations of energy/matter. Examples of high-entropy systems include eroding farmlands, depleted fisheries, anthropogenic greenhouse gases, acid rain, poisonous mine tailings and toxic synthetic compounds that represent disordered systems or degraded forms of energy and matter with constrained or little use potential. The main thing connecting these two states is human activity operating through the second law, where human activity is a dissipative process that requires consumption of available energy and matter [51].

The goal of sustainability should be to achieve a harmonious relationship between the human environment and the ecosphere – one that maintains the long-term integrity of both [51]. In order to do so, we must strive to reduce entropy generation by avoiding generating large gradients and dissipating existing gradients in small steps, thus maximizing the productivity of each resource. Current water management practices often impose unnecessarily large gradients and dissipate those gradients in one or very few steps. For example, highly purified water that is produced through a significant investment of energy and materials is often used for low-quality end uses such as flushing the toilet, which dissipates that investment in one step. Future water management strategies should strive to align the quality of supply with the quality of demand. Another example of generating large gradients is the historical practice of U.S. flood mitigation policies, which have relied on structural measures such as dams, levees, floodwalls, and diversion channels, all of which require significant inputs of energy and materials to build and maintain. These policies have had a devastating effect on riverine ecosystems. Birkland et al. [52] reviews an extensive body of research that has documented the environmental costs associated with dams and other impoundments, regardless of whether such structures are used for power generation, irrigation, recreation, or flood control. The removal of natural riparian vegetation buffers that filter pollution and slow erosion and runoff into rivers, and the replacement of these natural features with built infrastructure. has degraded water quality, fragmented habitat, and caused additional habitat loss in the form of upstream and downstream changes in sediment, decreased diversity of fish and other aquatic flora and fauna, and increased susceptibility to invasive species [52]. Future policies should focus on methods that work in harmony with nature, to restore natural systems including modifying dam operations, reopening water access to natural floodplains, restoring riparian vegetation and habitat, using infiltration and natural buffers to treat storm water, and reestablishing natural dunes along coastlines and barrier islands [52]. Such approaches can reduce the creation of unnecessary gradients by working with natural processes rather than trying to control them, thus saving valuable human and natural capital.

6.6 Summary

Water resource planning is vital to sustainability at multiple scales, and to be effective it must be integrated with interrelated sustainability goals for energy and materials. The future of water management will require that agencies breakdown "stovepipe" management of natural resource and infrastructure systems. Interactions within and across spatial and temporal scales must be considered when developing and maintaining water infrastructure. Solutions will need to address short-, mid- and long-term needs and benefits, and multiple planning criteria will play an important role in improving the overall desirability of various projects and evaluating alternative solutions. Approaches that explicitly address risk and uncertainty will be essential anchors of effective sustainability programs, along with scenario analyses that can be used to develop management strategies that are robust to a variety of uncertainties. Fostering communication and engaging a variety of stakeholders will be important to achieving the objectives and goals highlighted above, including to develop the criteria and envision the future scenarios that will underpin sustainability initiatives. It will be increasingly important to develop and implement pilot projects and other demonstrations that engage citizens, resource managers and policy makers to achieve collective sustainability goals.

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Chapter 7
Innovative Group Decision Making Framework for Sustainable Management of Regional Hydro-Systems

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Abstract This paper proposes innovative group decision making framework for the sustainable management of regional hydro-systems. It is based on the Analytic Hierarchy Process (AHP) philosophy and two conceptually different models of treating decision making problem in group framework without and with consensus. Typical hydro-system in Serbia is used as a case study to demonstrate how different aggregation schemes influence resulting group decision(s). Different from our earlier work (Srdjevic and Srdjevic, Sustainable use and development of watersheds. Springer, Dordrecht, pp 201–213, 2008), here the group of twelve individuals participated in evaluation of five water uses of the hydro-system. Weight of each decision maker in the group is defined according to his/her demonstrated consistency and used as an input to the aggregation process to derive group decision(s). Differences in ranking water uses obtained without consensus and with consensus indicated importance of selecting proper aggregation scheme. We recommend application of a consensus based aggregation method because each participating individual has a 'vote' which counts in the final decision, so dominance is at least reduced (if not fully excluded), and finally, the final decision is expectably acceptable for all participants at the end of process.

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7.1 Introduction

Decision making in modern times usually assumes participation of a number of individuals or parties, i.e. participants in a group. In further text terms ‘agents’ and ‘stakeholders will be used regarding specific contexts. Agents are people coming from public sector, water users, delegates from local municipalities and else. They usually have different background in education, gained knowledge, attitudes and interests.

Long term planning of water resources development within multipurpose regional hydro-systems in developing countries (e.g. Serbia) is faced with problems such as a lack of financial funds for investment and annual operation and maintenance of facilities, conflicting interests of water users upstream-downstream, and transition scenarios related to national economy and possible frequent changes in political system. Given available information about one of such systems, existing and perspective water users and other parties, all with exposed interest in development and maintenance of the system, we propose the two conceptually different models of participative decision making. The first one directly aggregates individual judgments of participating agents at all levels of the problem hierarchy, without any further influence of agents on the decision process, once they have completed their judgments. The other model is based on building consensus. Reaching an agreement of involved decision makers is achieved in iterative manner, again without their direct participation. In each step (iteration) judgments are changed in strictly defined mathematical manner, for only one decision maker, namely that one who is most far from the group decision obtained in previous step. Such consensual approach is in many case realistic because it does not imply discussion or other ‘means’ of direct communication between agents which is typical, e.g., for political scenarios of decision making in developing countries.

In developing both participatory models, emphasis is put on how to treat different interests and priorities of involved stakeholders, how to model decision making process itself, and how to provide instruments (mainly institutional) for monitoring the decision implementation and the effects of the decision(s) made. We adopted a realistic approach and propose to associate weights to agents according to their demonstrated consistency in assessing and evaluating decision elements: ‘less consistent’ means ‘lower weight’ (of the agent within a group).

The Analytic hierarchy process (AHP) [1] is selected as supporting multicriteria decision making tool to create unique framework for implementing the two aggregating concepts in deriving so-called group decision from number of individual judgments elicited from participating agents. The AHP has been widely used in water related group decision making [2–5] and it is applicable in both with/without consensus scenarios. For both cases we demonstrate how to apply developed algorithms in group assessment of an importance of different regional hydro-system’s purposes. A regional system Nadela in Serbia, described in detail in Srdjevic and Srdjevic [6], has been selected to demonstrate influence of different aggregation schemes on related group decision(s). A short description of the system is replicated here from Srdjevic and Srdjevic [6], and complemented with innovative approach to creating a group of stakeholders (agents), managing the decision making process, and deriving ranking of system's purposes in two various consensual contexts.

7.2 Nadela Hydro-System and Participants in the Decision Making Process

Regional hydro system Nadela in Vojvodina Province in Serbia is named after Nadela central 83 km long canal passing from north to south where it confluences into the Danube river (Fig. 7.1). There are irrigation systems and industrial facilities in the Nadela basin and main purposes of the system are recognized as drainage, industrial water supply, collecting used waters, irrigation, and other purposes. Key stakeholders (participants) in the decision making process are identified by the Public Water Management Company Vode Vojvodine, responsible for global water management in the Province. A meeting was organized with 12 invited representatives from farmers association, industry and small and medium irrigators. Participants are briefed on main problems related to long term planning and management of the system. After they reached agreement on a methodology which will be used to assess existing conflicts between interest parties, the AHP based methodology has been adopted by a group to support their decision making.

7.3 Participatory Decision Making

7.3.1 Hierarchy of the Decision Problem

The participants are explained how to act in the decision-making session aimed to reaching a group decision about ranking the purposes of the system and strategy that will ensure well balanced system use and satisfaction of prescribed system purposes and users' expectations, but also that will respect defined system capacity and wider interests of a society. A discussion helped to elaborate the most important decision making issues and to define a global goal as to identify priorities (i.e. ranking) of system's purposes. Three criteria and five defined purposes of the system are adopted as evaluation filters that will apply at later stage for detail assessment various management strategies. A criteria set on the second level of hierarchy included three main aspects of the water management within the region and set as a criteria set: (1) Economic, (2) Social, and (3) Ecological. Five different purposes of the system are set on the third level of the hierarchy as follows: (1) IR (irrigation); (2) DR (drainage); (3) UW (used waters); (4) IS (industrial supply); and (5) OP (other purposes).

Fig. 7.1 Regional hydro-system Nadela

For the sake of completeness, the lowest (fourth) level has also been defined, represented by four alternative management strategies for the 10-year period 2011–2020. Strategies are adopted after justification provided by the PWMC Vode Vojvodine and participants' notion of global importance of different water uses. This level is described in more detail in [6] but not elaborated hereafter.

7.4 Materials and Methods

7.4.1 The AHP Method: General Overview

The AHP is a multi-criteria decision making method which requires a well structured problem, represented as a hierarchy. At the top of the hierarchy is a goal. The subsequent levels usually consist of the criteria and sub criteria, while alternatives lie at the lowest level of the hierarchy. The AHP determines the preferences among the set of alternatives by employing pair wise comparisons of the hierarchy elements at all levels following the rule that at a given hierarchy level, elements are compared with respect to the elements in the higher level by using the fundamental importance scale [1]. After all judgments are made, the local priorities of the criteria, sub criteria and alternatives can be calculated using the logarithmic least square method (*LLS*) [7], or any other also well known methods [8, 9]. At the end, synthesis consists of obtaining the overall priority vector of alternatives with respect to a goal by multiplying local priority vectors of alternatives by the priority of their parent nodes and adding for all such nodes [10]. After synthesis has been done, the highest value of the priority vector indicates the best ranked alternative. If *LLS* is used for prioritization, consistency of the decision maker is measured using the geometric consistency index (*GCI*) [11].

7.4.2 Assessments in AHP Manner

Much of research work has been reported concerning a very important point of the AHP method: (1) creating a judgment matrix by the decision maker by performing pair wise comparisons of decision elements with respect to an adjacent element in the upper level (e.g. criterion or goal); and (2) performing prioritization by which weights of judged elements are computed.

Sticking to that, here we demonstrate how assessment of hydro-system's purposes can be achieved if only two-level hierarchy is considered with goal (ranking) at the top, and purposes of the system at the bottom. Once this simple hierarchy has been created, participants were asked to evaluate purposes of the system only and directly, i.e. not to use criteria explicitly like in standard AHP, but implicitly assuming their synergistic influence when assessing purposes against the global goal: which ranking of purposes can be considered as most desirable for the group. In other words, each decision maker compared purposes by keeping in mind importance of economic, social and ecological aspects of system's management. Then the weights of purposes are computed by the LLS prioritization method and their ranking was straightforward.

To summarize, assessment of system's purposes in AHP manner consisted of two steps: (1) creating a set of judgment matrices by involved individuals; and (2) deriving the group decision in two possible ways as will be described below.

7.4.3 *Deriving a Group Decision Without Consensus of Participants*

In AHP-group decision making applications there are two methods that have been found to be the most useful for aggregating individual preferences. The first one is aggregation of individual judgments (AIJ), and the second one is aggregation of individual priorities (AIP) [12].

Here we stick to the first aggregation scheme where elements of the group matrix are obtained as weighted geometric means of all corresponding entries from individual matrices:

$$a_{ij}{}^{G} = \prod_{k=1}^{m} (a_{ij}{}^{(k)})^{\alpha_k}, \ (i, j = 1, \ldots, n) \tag{7.1}$$

In formula (7.1) n is the number of decision elements involved in pair wise comparisons while the judgment matrix is created, k stands for the number of decision makers, $a_{ij}{}^{(k)}$ for the judgment for kth decision maker, α_k for the 'weight' of kth decision maker within the group, and $a_{ij}{}^{G}$ for the aggregated group judgment.

7.4.4 *Deriving a Group Decision with Consensus of Participants*

Group consensus can be built with the following algorithm [13]:

Step 1 Let $z = 0$ and $A_z{}^{(k)} = (a_{ijz}{}^{(k)})_{nxn} = (a_{ij}{}^{(k)})_{nxn}$.

Step 2 Let $w_z{}^{(c)} = (w_{1,z}{}^{(c)}, w_{2,z}{}^{(c)}, \ldots, w_{n,z}{}^{(c)})$ denote group weights calculated using the LLS from group matrix $A_z{}^{(c)} = (a_{ij,z}{}^{(c)})_{nxn}$. Matrix elements are:

$$a_{ij,z}{}^{(c)} = \prod_{k=1}^{m} (a_{ij,z}{}^{(k)})^{\alpha_k}$$

where z denotes iteration number.

Step 3 Calculate cardinal consistency index for each matrix ${A_z}^{(k)}$:

$$GCCI({A_z}^{(k)}) = \frac{2}{(n-1)(n-2)} \sum_{i<j} (\ln({a_{ij,z}}^{(k)}) - \ln({w_{i,z}}^{(c)}) + \ln({w_{j,z}}^{(c)}))^2$$

If for each k condition $GCCI\ ({A_z}^{(k)}) \leq GCCI_{\max}$, is satisfied, then go to Step 5. Othervise, continue with Step 4. It is recommended in the literature that for 9 dimension matrix, $GCCI_{\max} = 0.37$.

Step 4 Elements of the matrix with the highest value of *GCCI* of the *k*th decision maker are corrected using the following equation:

$$a_{ij,z+1}^{(k)} = (a_{ij,z}^{(k)})^{\theta} \left(\frac{w_{i,z}^{(c)}}{w_{j,z}^{(c)}} \right)^{(1-\theta)},$$

where $0 < \theta < 1$. Then return to Step 2.

Step 5 End. Output of the algorithm consists of the corrected matrices, number of iterations to reach consensus and group matrix with the final weights of the decision elements.

7.5 Solving the Decision Problem in Participatory Framework

In this paper, we introduce an objective treatment of 12 decision makers (participants in the group) and aggregation of their individual judgments according to their demonstrated consistency *GCI* while evaluating purposes of the Nadela system, Table 7.1. Details of how *GCI* was calculated can be found in related literature [11]. Note that decision makers' weights in column (3) are obtained by normalization of *GCI* reciprocals in column (2).

The final group decision *without consensus* is presented in Table 7.2. Weights of system's purposes are calculated using formula (7.1) from Sect. 7.4.3.

Purpose with the highest weight is irrigation and can be considered as most important purpose of the Nadela hydro-system. Drainage and used waters are ranked as second and third, having the similar weights as the first ranked irrigation. Remaining purposes considered as 'other' are significantly less important then aforementioned purposes.

After the application of the algorithm described in Sect. 7.4.3, group consensus is obtained as presented in Table 7.3.

If consensus aggregation scheme is applied, rankings of all alternatives except the last ranked (OP - other purposes) are changed. First ranked alternative is now drainage (DR), followed by irrigation (IR) and industrial supply (IS). Used waters (UW) is now ranked as fourth.

Table 7.1 Consistency and corresponding weights of decision makers within the group

Decision makers	GCI (1)	1/GCI (2)	α (3)
DM1	0.750	1.333	**0.033**
DM2	0.344	2.905	**0.072**
DM3	0.420	2.381	**0.059**
DM4	0.547	1.827	**0.046**
DM5	0.255	3.928	**0.098**
DM6	0.448	2.230	**0.056**
DM7	0.481	2.077	**0.052**
DM8	2.113	0.473	**0.012**
DM9	0.443	2.259	**0.056**
DM10	0.397	2.520	**0.063**
DM11	0.166	6.038	**0.150**
DM12	0.082	12.150	**0.303**

Table 7.2 Group decision without consensus

Purpose of the system	Weight	Rank
IR	0.285	1
DR	0.267	2
UW	0.225	3
IS	0.178	4
OP	0.046	5

Table 7.3 Group decision with consensus

Purpose of the system	Weight	Rank
IR	0.274	2
DR	0.288	1
UW	0.182	4
IS	0.212	3
OP	0.044	5

7.6 Main Conclusions and Recommendations

Participative decision making in managing water resources is not only necessity but it is also demanded by the Water Framework Directive [14]. As a developing country in transition, Serbia still does not have defined guidelines that will help practitioners to fulfill this demand in real life problems of managing water resources.

In order to build a group decision framework for the sustainable management of regional hydro-systems, we propose use of the AHP well established multi-criteria decision making method and acclaimed supporting tool in group decision-making frameworks. We also identify two different models of participative decision making. One model enables direct aggregation of individual judgments of participating agents at all levels of the AHP's problem hierarchy. The other model reaches the consensus between involved decision makers in iterative and strictly defined mathematical manner. In both models, importance of the decision maker in the group is defined according to his/her demonstrated consistency.

Application of the models on selected case study showed that selection of one or the other model influences the group decision and ranking of evaluated system's purposes. Also, weights of some purposes significantly changed, which can be important in the case of allocation of financial support to specific management actions.

We believe that a consensus based approach is more applicable in sustainable water management. We find it more fair than the other one because each agent has a 'vote' which counts in the final decision, dominance is at least reduced (if not fully excluded), and finally, the final decision is expectably acceptable for all agents at the end of process. The final outcome of the process is a decision with legitimacy for real-life implementation.

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Chapter 8
Future Water Availability, Sustainable Dryland Agriculture, Desertification and the Second Law of Thermodynamics

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Abstract Sustainable use of water and the future of food production have become topics of critical importance over the last decade. In northern and remote communities and arid zones around the globe, water scarcity, the rising cost of energy and food shortages have come to the forefront in discussions of sustainable development. Food production has become the biggest water user across the globe as industrial agriculture uses about 70 % of the total freshwater withdrawn each year (World Economic Forum, Managing our future water needs for agriculture, industry, human health and the environment. Discussion document for the world economic forum annual meeting, Davos, Switzerland, 2008). Expansion of the world's deserts in many regions may be a canary in the coal mine that is signaling our unsustainable approach to these challenges. This chapter looks at the growing problem of drought, desertification and food shortages, suggesting a systems approach that relies on the 2nd law of thermodynamics and looks at the potential of using ecosystems as a guide to development of sustainable solutions to these looming challenges.

8.1 Introduction

Sustainable use of water and the future of food production have become topics of critical importance over the last decade. In northern and remote communities and arid zones around the globe water scarcity, the rising cost of energy and food shortages have come to the forefront in discussions of sustainable development. Expansion of the world's deserts in many regions may be a canary in the coal mine that is signaling our unsustainable approach to these challenges.

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Desertification has become a high profile environmental problem affecting millions of humans on a global scale [1–5]. It has been described as a persistent trend toward development of desert like conditions in vulnerable drylands, often referred to as arid or semi-arid zones, which results in a catastrophic loss in primary productivity, a devastated ecosystem and significant hardship, loss of livelihoods and potential loss of life. Each year across the globe more than 30 million acres of productive land degrade into desert [18].

Drylands are arid and semi arid lands whose productivity, expressed as plant production, is primarily limited by water availability in the root zone, due to naturally occurring low rainfall and high evaporation losses [5]. They include tropical grasslands and savannah/woodland, the warm desert and semi-desert, temperate grasslands, tundra communities, and cold desert biomes [6]. Presently they make up 41 % of global lands and support as much as 35 % of the earths human population [3, 7].

Drylands unto themselves are viable and sustainable ecosystems capable of supporting a complex web of life. Many important food crops originate from drylands. Indigenous crops and fruits from drylands are known for their resistance to disease, stress, and adaptability and are valuable sources for plant breeding. They contain a significant endowment of plants and animal species, including micro-organisms. Arid land species exhibit a wide range of morphological, physical, and chemical adaptation to their harsh environment [6].

These lands are coming increasingly under pressure and, with the exception of Australia where most economic activity is confined to coastal areas, continents like Asia, Africa and even North America have rapidly growing populations in these arid and semi-arid areas. Far northern communities are expected to expand as arctic regions open up due to climate change and the rush to exploit fossil fuel and mineral reserves. Today 1.5 billion people depend for their food and livelihoods on land that is losing its capacity to sustain vegetation. It has been estimated that half of today's armed conflicts can be partly attributed to environmental strains associated with dryland degradation [8].

Presently most developed nations have the economic capacity to adapt infrastructure to accommodate this growing population pressure, however, in poorer nations, the implications for increased poverty, loss of security and violence are significant. The economic effects of desertification are felt most by these vulnerable populations [9]. Even so the threat of climate change and increasing costs related to fossil fuels continue to put pressure on all water users and the future presents significant challenges.

8.2 The Importance of Water Availability to Sustainability

Until recently, in most developed countries, water has been taken for granted. Abundance invariably produces wasteful habits and water is no exception. Once through water and wastewater systems common in the developed world are extremely wasteful and users seldom pay the full cost of water. Water is critical for both economic development and for life itself. In spite of its obvious importance, water has been treated as an almost valueless commodity.

The conflict over water occurs on many levels. All species compete for available water in ecosystems while on a human scale conflicts have historically occurred between individuals and between nations. Competition for water is growing and many believe it will become as critical for survival as competition over energy.

Around the world food production has become the biggest water user. Industrial agriculture uses about 70 % of the total freshwater withdrawn across the globe each year [10]. Clearly the current systems are using more water than can be sustained.

8.3 Causes of Desertification

The issue of desertification came to prominence in the early 1970s in part due to the prolonged drought in the Sahel region of Africa, which led to the starvation of more than 200,000 people as well as mass migration out of affected areas [3].

This event significantly raised the profile of this issue on a global scale and led to a number of international actions in response. The United Nations Plan of Action to Combat Desertification was one early attempt to co-ordinate international science and policy to solve a global environmental problem [3].

By 1992 it was evident that this and other efforts had failed to slow the progress of desertification and as a result a more concerted and focused effort was initiated at the Earth Summit in Rio de Janeiro in 1992. This resulted in the initiation of the United Nations Convention to Combat Desertification, a convention signed by 193 countries, and brought into force in 1996 to combat desertification and mitigate the effects of drought, through national action plans and long term strategies, using a science based approach to policy making and action.

Environmental change, particularly variability and distribution of rainfall can move a dryland toward desert like conditions through effects on natural biodiversity as well as rain-fed crop production and vegetation, resulting in soil degradation and reduction in ecosystem services.

In addition and at times in response to these effects, conditions can be exacerbated by a wide range of political and socio-economic factors including land management strategies, local practices, macro economic factors and law policies [9, 19].

It remains a part of the debate to what extent desertification is human induced at a local level and to what extent climate change is responsible. The fact remains that as human populations continue to expand in arid zones, vulnerable drylands are coming under increased agricultural pressure. In many cases climate change will exacerbate these challenges.

In addition to local rainfall variability which can lead to drought like conditions, land degradation caused by mono-cropping, overgrazing or improper irrigation can lead to soil crusting, soil erosion or lowered water tables further leading to a reduction in the capacity of the agro-ecosystems to absorb environmental shocks. Understanding the causes of desertification can lead to development of new ideas about sustainable food production and sustainability in general.

8.3.1 Agricultural Drought

Sledgers and Stroosnijder [11] have developed a framework for Agricultural Drought which differentiates between meteorological drought, soil water drought and soil nutrient drought.

Meteorological drought (limited precipitation) directly effects the development of drought like conditions while soil water drought and nutrient drought can indirectly increase the vulnerability of a region to drought and therefore accelerate a region toward desertification.

Meteorological draught is very difficult to mitigate on a local level. Altering rainfall patterns, either geographically, or seasonally is difficult although attempts at cloud seeding to induce rainfall have been undertaken with uncertain results in a number of jurisdictions. Climate change, due to global warming, may exacerbate local water shortages and therefore efforts to reduce GHG production may have a mitigating effect on the long-term trends. This is difficult to predict.

Soil water and soil nutrient drought, much of it anthropogenic and immediate in nature provide significant opportunities for intervention which may reduce local land degradation (desertification). Understanding and mitigating this challenge is critical to future food production and sustainable development.

8.4 The Ecosystem Approach and the Second Law of Thermodynamics

Desertification has been linked to many factors. The majority of the problem seems at least to have been exacerbated by application of conventional agricultural practices to sustain growing numbers of human beings on lands that are already short on carrying capacity and biologically available water and nutrients [4].

These practices have resulted in replacement of resilient, adaptable and productive ecosystems that have evolved over time to local arid conditions and are able to adapt and respond to extreme arid conditions [12]. Conventional industrial agricultural practices have stripped these ecosystems of their capacity to adapt and withstand even minimal environmental shock [11].

The term ecosystem is used to describe “a complex of plant, animal and microorganism communities and their non living environment, interacting as a functional unit”, [17]. Each element of the ecosystem provides services to the others to maintain soil moisture, soil organic content and increase availability of nutrients.

Ecosystems have come closest to sustainability, evolving with local conditions and establishing relative stability in terms of biophysical conditions on earth for close to 4.5 billion years. A look at ecosystems and the way they evolve to manage both energy and materials helps us understand how we can develop more sustainable and resilient approaches that minimize both soil water drought and soil nutrient drought.

Presently 80 % of global agricultural land is planted in annual crops which must be planted every year and require energy intensive cultivation [12]. These simplified systems have limited ability to cycle energy and nutrients and require constant inputs of water and energy to be sustained. By contrast, perennial crops mimic ecosystems and stay in the ground for many years developing complex microbial communities and deep root systems, the foundation required to prevent soil moisture and soil nutrient loss. Unlike monocultures of annual crops, ecosystems need no fertilizers, pesticides, herbicides or irrigation to remain healthy year after year [12].

Scientists are now looking at developing perennial grain crops that will bring modern agriculture closer to creating conditions similar to stable ecosystems with the potential to improve sustainability in arid zone agriculture [13]. Agroforestry is a trend in arid zone agriculture that includes a transition to intensified land use that has led to the planting or protection of a diverse mix of livestock, useful trees and crops [16]. Livestock numbers have been maintained, by development of more integrated livestock, arable cropland and marketing systems. Agroforestry has been used with some success in Africa and Asia [4, 14].

These approaches involve increasing the ability of food systems to cycle water, energy and nutrients. While still simplified when compared to natural systems they, have the potential to bring modern agriculture closer to the hierarchy of energy, water and material management necessary for sustainability.

8.5 Conclusion

The second law of thermodynamics is an expression of the universal law of increasing entropy, stating that the entropy of an isolated system will tend to increase over time, approaching a maximum at equilibrium.

Schneider and Kay [15] have proposed that in fact the ecosystem has evolved on earth as a direct response to the second law of thermodynamics “re-stated for open systems”, where the suns energy creates the gradient that drives the evolution and sustainability of ecosystems. Healthy and diverse ecosystems maintain the system at equilibrium with the external energy source. The complex web of life found in arid zones is a manifestation of this law.

It can be argued that the ability of global food production to provide sustainable nutrition to growing populations will be decided by the second law of thermodynamics and that the present system is not sustainable. As vulnerable ecosystems are replaced by modern agricultural practices the ability of the system to maintain biophysical conditions necessary for life decreases. To compensate for the lost efficiency and deteriorating condition of the agro-ecosystem, fertilizers must be added and water must be supplied through irrigation and use of various modern technologies. This approach requires constant and significant energy inputs. Additional energy input often comes from the use of non-renewable fossil fuels, which will further exacerbate climate change and meteorological drought.

Desertification may in fact be another “Canary in the Coal Mine”, a warning that agricultural practices can not operate outside of the second law of thermodynamics. Stable ecosystems are required to maintain the complex plant, animal and microbial communities to prevent erosion and maintain soil moisture and soil nutrients. Without this ability the system moves toward greater entropy and equilibrium, as if it where closed, with no ability to capture energy from the sun.

Without reference to the second law of thermodynamics “re-stated”, some scientists are now beginning to develop agricultural practices that create conditions mimicking ecosystems, dissipating energy, water and material resources in small steps, avoiding large energy gradients and reducing the need for additional energy inputs, building efficient and sustainable agro-ecosystems.

These practices provide lessons in all areas of sustainable development from water management to energy and infrastructure and may be transferable to much of our thinking about sustainable development. Avoiding large gradients and dissipating energy and materials in small steps improve the prospects for sustainable communities.

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Chapter 9
Multi-Criteria Evaluation of Groundwater Ponds as Suppliers to Urban Water Distribution Systems

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Abstract Freshwater for urban water supplies in growing cities is often secured through groundwater ponds. In the majority of Serbian cities, an increase in population creates a need for investments into new or reconstruction of existing distribution networks. We propose the use of two methods, the analytic hierarchy process and the consensus convergence model, as a group decision making framework for determining the importance of Novi Sad city ponds and deciding the optimal strategy of investing into the technical realization of infrastructure relying on the ponds. Three experts participated in the evaluation of three ponds using the following criteria set: capacity, water quality, cost of water, natural protection, recharging capabilities, technical accessibility, and environmental impact. Experts found the final result acceptable and the proposed methodology easy to understand and implement. They also agreed that the result can be used as a reliable basis for further economic analysis and feasibility studies.

9.1 Introduction

The majority of cities in Balkan countries with populations above 50,000 are facing the problem of providing the required quantity and quality of water for urban supplies. The water distribution infrastructure in the majority of Serbian cities of that size is on the tolerance edge because growing population provokes shortages

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in supplies and/or a decrease in water quality. In some cities a need for investment into a new or reconstruction of existing distribution networks has been recognized, waiting for proper financial funding. In order to provide money for re-investments, we recently assessed the three existing major city groundwater ponds in the City of Novi Sad, the second largest city in Serbia.

Analyses indicated an urgent need to explore reconstruction/development options. It was shown that capacities and overall performance of ponds, not only technical but also social-ecological, could be improved if proper structural and non-structural measures are applied. Groundwater ponds are all located very near the shoreline of the Danube River. Because the Danube passes almost through the city center, ponds are within the core city area and various risks exist in securing an adequate supply of both drinking and industrial waters that adheres to the required standards of quality.

The analytic hierarchy process (AHP) [1], a multi-criteria optimization method, is used in a group decision-making context to determine importance (mutual weights) of ponds and to indicate the optimal strategy of investment into the technical realization of infrastructures (distribution system) relying on the ponds, as well as into institutional measures to meet other urban social goals. Experienced experts in groundwater hydrology, urban water supply, and distribution network engineering participated in a group decision-making process. A consensus convergence model [2] is used to obtain, firstly, group weights of criteria and, secondly, the final priorities for the ponds.

It was made clear to the expert group that the underlying criteria for the development of their decisions was that sustainable and harmonized urban growth and reduce or minimize risks in the supply and quality of waters sourcing from ponds must be assured.

The expert team used the following set of criteria for evaluating ponds: capacity, water quality, cost of water, natural protection, recharging capabilities, technical accessibility, and environmental impact. In this paper we describe the created framework for straightforward evaluation and ranking of the groundwater ponds' capacities for supplying the City of Novi Sad, based on the simultaneous use of two methods: AHP and consensus convergence model.

This paper is organized in the following manner: after the introduction, basics of AHP and consensus convergence model are summarized, as well as the proposed solving methodology. The problem of selecting the best ground water pond and its solution are given in the next section. Concluding remarks end the paper.

9.2 Analytic Hierarchy Process

The AHP method requires a well-structured problem, represented as a hierarchy. At the top of the hierarchy is the goal; the next level contains the criteria and sub-criteria, while alternatives lie at the bottom of the hierarchy. AHP determines the preferences among the set of alternatives by employing pair-wise comparisons of

Table 9.1 Saaty's importance scale

Definition	Assigned value
Equally important	1
Weak importance	3
Strong importance	5
Demonstrated importance	7
Absolute importance	9
Intermediate values	2,4,6,8

the hierarchy elements at all levels; following the rule that, at given hierarchy levels, elements are compared with respect to the elements in the higher level by using the Saaty's importance scale (Table 9.1). Here, value 1 corresponds to the case in which two elements contribute in the same way to the element in the higher level. Value 9 corresponds to the case in which one of the two elements is significantly more important than the other. Also, if the judgment is that B is more important than A, the reciprocal of the relevant index value is assigned. For example, if B is felt to be notably more important as a criterion for the decision than A, then the value 1/7 would be assigned to A relative to B.

The results of the comparison are placed in so-called comparison matrices. After all judgments are made, the local priorities of the criteria and the alternatives are calculated from related matrices by using their principal eigenvectors, as suggested by Saaty [1]. Computing eigenvectors is usually called prioritization. Worthy to mention is that several other methods can be used for prioritization (e.g. see overview in [3]). Eigenvector is dominant in practice and is used here.

The synthesis is performed by multiplying the local priorities of the elements from one hierarchy level by the 'global' priority of the parent element, and then adding the global priorities for the lowest level elements [4]. The highest value of the priority vector indicates the best-ranked alternative.

9.3 Consensus Convergence Model

The central idea of the consensus convergence model (CCM) is assigning a weight to the decision makers' trust in the expertise of other epistemic decision makers working on the issue at hand [5]. The weight of respect, w_{ij}, describes the respect decision maker i has for the opinion or expertise of decision maker j, and $\sum_{j=1}^{n} w_{ij} = 1$ for the group of n decision makers.

Here we propose to use an adapted version of the consensus convergence model presented in [6]. The procedure is based on the original model introduced by Lehrer and Wagner [2] which uses the weights of respect assigned by each decision maker, and modified model defined by Regan et al. [6]. The later model proposes using the weights of respect based on the strength of differences in weights assigned to objectives by individuals in the group. In this model, we can assume that initial objectives weights of n decision makers are $p_1^0,\ p_2^0,\ \ldots,\ p_n^0$, and a metric that calculates the weights of respect is:

$$w_{ij} = \frac{1 - \left| p_i^0 - p_j^0 \right|}{\sum\limits_{j=1}^{n} 1 - \left| p_i^0 - p_j^0 \right|} \tag{9.1}$$

where i refers to the individual who is assigning the weights, j refers to the individual being assigned a weight, and n is the number of group members.

The weights of respect are used to create nxn size matrix W

$$W = \begin{bmatrix} w_{11} & w_{12} & \ldots & w_{1n} \\ w_{21} & w_{22} & \ldots & w_{1n} \\ \ldots & \ldots & \ldots & \ldots \\ w_{n1} & w_{n2} & \ldots & w_{nn} \end{bmatrix}. \tag{9.2}$$

If P is a vector of the weights of the initial objectives, the consensual vector of the objectives' weights is obtained by the iterative equation

$$P_c = WP_{c-1}. \tag{9.3}$$

The procedure is repeated until the values of the weights of the objectives in vectors P_c and P_{c-1} is equal within a tolerant error limit. Convergence is guaranteed if the weights of respect are constant throughout the iteration process for each decision maker [2].

This model is easily implemented and theoretically well grounded. It does not require that all members of the group reach agreement, often an imposible task in group decision making [6].

9.4 Solving Methodology

Solving methodology can be divided into four phases.

Phase 1 During the first stage, K experts (representatives from urban planning policy makers, hydrologists, engineers, etc.) are briefed on the basic assumptions of AHP and explained what they are expected to do. After the stating and hierarchical structuring of the decision making problem, they evaluate decision elements by using Saaty's scale (Table 9.1) in a pair-wise manner. This way, performance matrices of criteria versus goal and alternatives versus criteria are formed at the end of the first phase.

Phase 2 Evaluations of criteria regarding goal are transformed into K sets of weights of the criteria by applying the eigenvector method, as suggested by Saaty [1]. K sets of criteria weights are used as inputs in the CCM in order to achieve consensus among experts on the importance of the criteria. Consensual criteria' weights are obtained as a result of the second phase.

Phase 3 Using the performance matrices of alternatives versus criteria for each expert obtained in Phase 1, local priorities of alternatives are calculated also by the eigenvector method. Now it is possible to make an AHP synthesis for each expert individually. Local priorities of alternatives are multiplied with corresponding consensual criteria weights to obtain the final priorities of alternatives with respect to the goal. This way, K sets of final priorities of alternatives are calculated.

Phase 4 K sets of final priorities of alternatives calculated for each expert individually in Phase 3 are used as inputs in CCM, resulting in the final consensual priorities of alternatives.

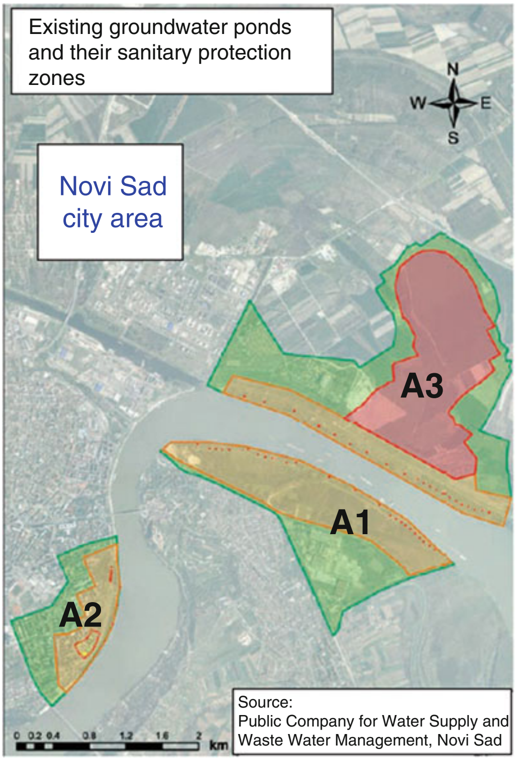
9.5 Evaluation of Groundwater Ponds in the City of Novi Sad

9.5.1 Phase 1

9.5.1.1 Groundwater Ponds as Alternatives

There are three major and two secondary groundwater ponds for supplying fresh water to the city of Novi Sad, capital of Vojvodina Province, Serbia [7, 8]. The major ponds are known as Strand, Petrovaradinska ada, and Ratno ostrvo. Those three ponds are in full 24-h operation. Their exploitation is supported on a temporary and intervening base by the two other ponds known as Kamenjar and Detelinara; for certain reasons these two supporting ponds were not considered in this study.

All three major groundwater ponds are located near the shoreline of the Danube River, Fig. 9.1. Since the Danube passes almost through the center of the city, ponds are within the core city area. Two ponds, Strand (A2) and Ratno ostrvo (A3), are located on the left river side 5.5 km from each other. Strand pond is more upstream and is located just near the University of Novi Sad campus. The third pond, Petrovaradinska ada (A1), is located at the opposite river side, approximately across the Ratno ostrvo pond. Earlier analyses hase shown that the capacities and overall performance of ponds, not only functionally but also on a social-ecological level, could be improved.



Source:
Public Company for Water Supply and Waste Water Management, Novi Sad

Fig. 9.1 Major groundwater ponds in the Novi Sad City area

9.5.1.2 Decision Makers (Experts)

Experts in groundwater hydrology, urban water supply, and distribution network engineering have been asked to assess ponds in order to determine the optimal strategy of investment into technical realization and into institutional measures to meet other urban social goals. Assessments of the first expert (hydro geologist) are mainly the same as reported in [7, 8]. The other two experts assessed the ponds from a different perspective which will be presented later on.

9.5.1.3 Evaluating Criteria

In order to compare characteristics of and rank the three major ponds, experts agreed on a set of criteria that should be used in the evaluation procedure. A short discussion led to the adoption of the following criteria: capacity, water quality, cost of water, natural protection, recharging capabilities, technical accessibility, and environmental impact.

The capacity of a pond is defined as the well's total installed capacity. Water quality is understood as a necessity for water treatment. The unit cost of water

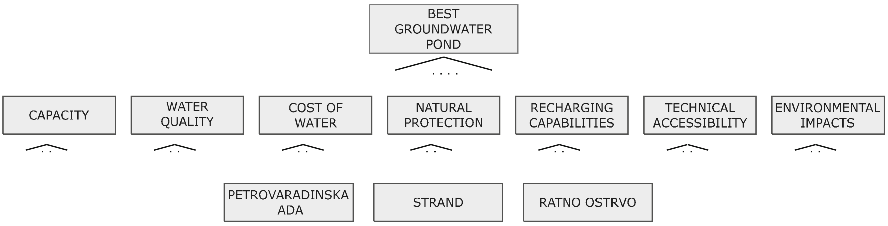


Fig. 9.2 Hierarchical representation of the decision problem

is defined as the cost of m^3 of the installed pump capacity. As far as the 'natural protection' criterion is considered, it was assumed, for example, that low-permeable layers such as clays or sandy clays should cover water-bearing layers with the underlying logic in evaluations by AHP: the more massive protecting layers are, the better natural protection of the pond is. Recharging capability aggregates both natural and artificial recharging possibilities that exclude any hazardous pollution. Technical accessibility of the pond is a global measure of technical characteristics of wells, pumps, local infrastructure, etc. Finally, 'environmental impact' is an important criterion that serves to include interrelations between ponds, water factories, societal interests and other environmental factors; certain psychological issues are considered to be included in evaluations under this criterion, too.

9.5.1.4 Hierarchy of the Problem and Solving Framework

The decision problem is therefore structured as the hierarchy presented on Fig. 9.2. An assessment of groundwater ponds is organized as a multi-phase group decision making process which combines: (1) standard AHP methodology to derive priorities of decision elements in the hierarchy based on assessments performed individually by the experts; and (2) consensus convergence model (CCM) for aggregation of individual priorities at both the criteria and alternatives' level based on iterative improvement of mutual respect between participating experts in the group.

9.5.1.5 Assessing the Problem by Experts

Experts were briefly introduced to AHP method and its basics, and used Saaty's scale first to compare in pair-wise manner criteria with respect to a goal. Tables 9.2, 9.3, and 9.4 show comparison matrices Criteria versus Goal filled by Experts 1, 2, and 3, respectively.

Note that names of criteria are shortened as follows: Capacity – CAPA; Water Quality – QUAL; Cost of Water – COST; Natural Protection – PROT; Recharging Capabilities – RECH; Technical Accessibility – ACCE; and Environmental Impacts – ENVI.

Table 9.2 Comparison matrix criteria versus goal: Expert 1

	CAPA	QUAL	COST	PROT	RECH	ACCE	ENVI
CAPA	**1**	1	2	1/3	2	5	5
QUAL		**1**	7	1	2	4	5
COST			**1**	1/4	1/5	1	3
PROT				**1**	1	5	3
RECH					**1**	7	4
ACCE						**1**	3
ENVI							**1**

Table 9.3 Comparison matrix criteria versus goal: Expert 2

Criteria versus goal

	CAPA	QUAL	COST	PROT	RECH	ACCE	ENVI
CAPA	**1**	1/4	2	2	1	5	1
QUAL		**1**	5	3	5	5	2
COST			**1**	1/3	1/3	2	1/5
PROT				**1**	1	3	2
RECH					**1**	3	3
ACCE						**1**	1/5
ENVI							**1**

Table 9.4 Comparison matrix criteria versus goal: Expert 3

Criteria versus goal

	CAPA	QUAL	COST	PROT	RECH	ACCE	ENVI
CAPA	**1**	1/5	5	1	1	1/3	2
QUAL		**1**	1	1	1/3	1/3	1
COST			**1**	2	1/3	1	2
PROT				**1**	1/5	1/2	1
RECH					**1**	1/2	3
ACCE						**1**	3
ENVI							**1**

The next step is performed so that each expert filled-in seven more matrices in the same manner as for criteria versus goal. Again, elicited preferences are based on Saaty's scale from Table 9.1; that is, experts expressed their judgments of alternatives (ponds) quality values versus each criterion as given in Tables 9.5, 9.6 and 9.7.

Recall that alternatives are as follows: A1 – Petrovaradinska ada; A2 – Strand; and A3 – Ratno ostrvo.

Table 9.5 Comparison matrices alternatives versus criteria: Expert 1

CAPA

	A1	A2	A3
A1	**1**	2	1/2
A2		**1**	1/3
A3			**1**

QUAL

	A1	A2	A3
A1	**1**	2	1
A2		**1**	1/2
A3			**1**

COST

	A1	A2	A3
A1	**1**	1/4	3
A2		**1**	5
A3			**1**

PROT

	A1	A2	A3
A1	**1**	4	2
A2		**1**	1/5
A3			**1**

RECH

	A1	A2	A3
A1	**1**	3	4
A2		**1**	2
A3			**1**

ACCE

	A1	A2	A3
A1	**1**	1/3	2
A2		**1**	3
A3			**1**

ENVI

	A1	A2	A3
A1	**1**	1/4	3
A2		**1**	5
A3			**1**

Table 9.6 Comparison matrices alternatives versus criteria: Expert 2

CAPA

	A1	A2	A3
A1	**1**	2	1/3
A2		**1**	1/2
A3			**1**

QUAL

	A1	A2	A3
A1	**1**	3	2
A2		**1**	1
A3			**1**

COST

	A1	A2	A3
A1	**1**	1/2	4
A2		**1**	6
A3			**1**

PROT

	A1	A2	A3
A1	**1**	5	4
A2		**1**	1/5
A3			**1**

RECH

	A1	A2	A3
A1	**1**	3	5
A2		**1**	2
A3			**1**

ACCE

	A1	A2	A3
A1	**1**	1/5	3
A2		**1**	4
A3			**1**

ENVI

	A1	A2	A3
A1	**1**	1/5	3
A2		**1**	4
A3			**1**

9.5.2 Phase 2

The weights of criteria for Experts 1, 2, and 3 are calculated by the eigenvector method from matrices in Tables 9.2, 9.3, and 9.4. The resulting values are presented in Table 9.8.

Then consensus convergence model (CCM) is applied for each criterion to obtain consensual group weights. For illustrative purposes, we present herein how the consensual weight for criterion CAPA is derived. The first step in the CCM

Table 9.7 Comparison matrices alternatives versus criteria: Expert 3

CAPA

	A1	A2	A3
A1	**1**	2	1/3
A2		**1**	1/3
A3			**1**

QUAL

	A1	A2	A3
A1	**1**	2	3
A2		**1**	1/2
A3			**1**

COST

	A1	A2	A3
A1	**1**	1/3	2
A2		**1**	4
A3			**1**

PROT

	A1	A2	A3
A1	**1**	5	1
A2		**1**	1/5
A3			**1**

RECH

	A1	A2	A3
A1	**1**	4	5
A2		**1**	3
A3			**1**

ACCE

	A1	A2	A3
A1	**1**	1/3	2
A2		**1**	3
A3			**1**

ENVI

	A1	A2	A3
A1	**1**	1/5	2
A2		**1**	5
A3			**1**

Table 9.8 Weights of criteria as obtained for each expert individually

Criterion weight	Expert 1	Expert 2	Expert 3
CAPA	0.188	0.139	0.143
QUAL	0.240	0.362	0.150
COST	0.058	0.051	0.105
PROT	0.238	0.130	0.077
RECH	0.187	0.150	0.218
ACCE	0.051	0.037	0.239
ENVI	0.037	0.131	0.068

application was to calculate the weights of respect (Eq. 9.1) using the initial individually obtained weights of this criterion given as a first row in Table 9.8. That is, the vector of the initial criterion's weights is $P_0^{CAPA} = [0.188, 0.139, 0.143]$.

In the first iteration, the matrix of respect, formed from calculated weights of respect for the given criterion,

$$W^{CAPA} = \begin{bmatrix} 0.344 & 0.327 & 0.329 \\ 0.323 & 0.339 & 0.338 \\ 0.324 & 0.338 & 0.339 \end{bmatrix}$$

is multiplied with the initial vector P_0^{CAPA} to calculate a new vector of criterion CAPA weights.

$$P_1^{CAPA} = W^{CAPA} \cdot P_0^{CAPA} = \begin{bmatrix} 0.344 & 0.327 & 0.329 \\ 0.323 & 0.339 & 0.338 \\ 0.324 & 0.338 & 0.339 \end{bmatrix} \begin{bmatrix} 0.188 \\ 0.139 \\ 0.143 \end{bmatrix} = \begin{bmatrix} 0.157 \\ 0.146 \\ 0.149 \end{bmatrix}.$$

Table 9.9 Consensual weights of criteria

	CAPA	QUAL	COST	PROT	RECH	ACCE	ENVI
Consensual weights of criteria	0.149	0.238	0.079	0.123	0.190	0.134	0.083

Table 9.10 Final priorities of alternatives for each expert (with applied consensual weights of criteria)

Alternatives	Expert 1	Expert 2	Expert 3
A1	0.394	0.445	0.418
A2	0.318	0.326	0.310
A3	0.284	0.225	0.267

As the terminating condition, we have set that the difference between elements of vector P_c^{CAPA} should be smaller then 0.001. This condition is not fulfilled for the vector P_1^{CAPA} and the procedure of multiplying the matrix of respect with the new vector P_1^{CAPA} is repeated.

$$P_2^{CAPA} = W^{CAPA} \cdot P_1^{CAPA} = \begin{bmatrix} 0.344 & 0.327 & 0.329 \\ 0.323 & 0.339 & 0.338 \\ 0.324 & 0.338 & 0.339 \end{bmatrix} \begin{bmatrix} 0.157 \\ 0.146 \\ 0.149 \end{bmatrix} = \begin{bmatrix} 0.151 \\ 0.149 \\ 0.149 \end{bmatrix}$$

Again, the difference between P_2^{CAPA} elements is higher then 0.001 and so it was necessary to perform a new iteration.

$$P_3^{CAPA} = W^{CAPA} \cdot P_2^{CAPA} = \begin{bmatrix} 0.344 & 0.327 & 0.329 \\ 0.323 & 0.339 & 0.338 \\ 0.324 & 0.338 & 0.339 \end{bmatrix} \begin{bmatrix} 0.151 \\ 0.149 \\ 0.149 \end{bmatrix} = \begin{bmatrix} 0.150 \\ 0.149 \\ 0.149 \end{bmatrix}$$

Consensus is finally reached in the fourth iteration

$$P_4^{CAPA} = W^{CAPA} \cdot P_3^{CAPA} = \begin{bmatrix} 0.344 & 0.327 & 0.329 \\ 0.323 & 0.339 & 0.338 \\ 0.324 & 0.338 & 0.339 \end{bmatrix} \begin{bmatrix} 0.150 \\ 0.149 \\ 0.149 \end{bmatrix} = \begin{bmatrix} 0.149 \\ 0.149 \\ 0.149 \end{bmatrix}$$

and the value of 0.149 is declared as the consensual weight of criterion CAPA.

Consensual weights of other criteria, as given in Table 9.9, are obtained in a similar way as the described one.

9.5.3 Phase 3

Comparison matrices presented in Tables 9.5, 9.6, and 9.7 are also processed by the eigenvector method to compute the local priorities of alternatives versus criteria for each expert.

Table 9.11 Final consensual priorities of alternatives

Alternatives (ponds)	A1	A2	A3
Final consensual priorities	0.427	0.318	0.255

Then, local priorities of alternatives are multiplied by the consensual weights of criteria from Table 9.9 to come up to the final individual priorities of alternatives. This is a standard AHP synthesis with the only difference being that the same, group-wise, consensual weights of criteria are applied for each individual expert. The final result of this phase is presented in Table 9.10.

9.5.4 Phase 4

The final consensual weights of alternatives are calculated in a similar manner as the consensual weights of criteria were. By applying the CCM after several iterations the final consensual (group) priorities of alternatives are derived as presented in Table 9.11.

Results in Table 9.11 show that the pond A1 – Petrovaradinska ada is identified as the most sustainable (‘best’) groundwater pond through consensus of the three experts. At the same time, computed weights of all three groundwater ponds as major city suppliers of fresh (drinking) water are considered as possible indicators of global efforts, finances, and other actions that could be allocated to the ponds in order to preserve safe water supply in hazard situations.

9.6 Conclusions

Making a decision on investing in new or reconstruction of existing distribution networks is a complex task that requires involvement of experts from various fields and, if possible, their consensus. We have proposed simultaneous and interconnected use of two methods (AHP and CCM) for evaluating three groundwater ponds of the City of Novi Sad, Serbia.

The three participating experts found the proposed methodology easy to understand and implement. They also unanimously agreed that the final result is acceptable and can be used as a good basis for further economic analyses and feasibility studies.

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Chapter 10
Pilot Study of Contaminants near Station Nord, a Military Airbase and Research Station in NE Greenland

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Abstract There are very few studies of contaminants in waters, sediments and air in the vicinity of high Arctic military bases. This pilot study was commissioned by the Royal Danish Air Force and conducted around Station Nord, a small remote Danish Air Base and military station in northern Greenland, with the aim of determining the importance of local sources versus long range transport of contaminants. Trace metals (including As, Hg, Cd and Pb) were measured in freshwater and marine sediment cores, seawater and air within 3 km of the base. Concentrations of trace metals (including As, Hg, Cd and Pb) were analysed in the marine and freshwater sediment cores. Furthermore, air pollutants were measured to quantify emissions from local point sources compared to long range transport. All trace metals except As showed low concentrations in both a lake (Sommersøen) and in the sea (the Wandel Sea). As was found to be higher than expected both in marine and lake sediments. The concentrations of certain heavy metals were higher than would

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be expected from an undisturbed remote location. At present, there is not yet enough information to distinguish between local sources and long range transport as concentrations were found to be higher than expected both in marine and lake sediments. Some of this could be explained from the lithology but a major part of the variability remains unattributed and needs further study, though it is certainly possible that the concentrations were due to local sources and rubbish disposal practice.

The measurementof atmospheric pollutants upwind from the Station demonstrated a minor influence of local sources and the observed levels can be explained by long range transport. Monitoring of atmospheric pollutants in the high Arctic should be continued to assess the long term trend of load of pollutants to the Arctic environment from the atmosphere. The decision has been made in 2013 to expand the capabilities of Station Nord as a high Arctic research station with facilities supplementary and complementary to those found at other High Arctic Stations such as Alert, Canada; Thule, Greenland; Spitsbergen Norway, and Barrow, Alaska; therefore we describe in detail the Research Stations' surrounding area and pertinent environmental data.

10.1 Introduction

Due to its remoteness and lack of significant industries, there have been long standing perceptions that the Arctic is a pristine environment, free of pollution. However, when the Arctic is examined for pollution, for example, its fragile ecosystems and sensitive fauna, numerous examples have appeared which show the Arctic to be vulnerable to pollution transported from the industrialized regions at mid-latitudes or emitted from anthropogenic activities taking place in and around the Arctic [1–4]. For example, radar sites in the Arctic, both those which are abandoned and those which are still in operation have been shown to be among the more serious sources of Arctic pollution, and they have been linked to emissions of PCBs [4]. The outpost under present consideration is one of the small military bases (stations)

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established throughout the high Arctic during the cold war. With the end of the cold war stations have closed, especially along the Canadian Defence Early Warning (DEW) radar line (see e.g., [5]). Those that remain operational provide a gateway to places in the high Arctic not accessible by ship. Some (e.g. Station Nord, and Alert) of these bases have a formal operational mandate to support scientific research (all of them in some way or another have or continue to do so), and thus become natural staging areas for high Arctic research; research that is greatly needed to understand some of mankind's greatest challenges concerning global processes; the global warming (which has the greatest effects in the Arctic) causing changing terrestrial and marine ecosystems, and contaminations in marine and freshwater sediments as well as atmosphere [6]. Station Nord in NE Greenland (81°36′ N 16°40′ W) provides scientific value to circumpolar monitoring because data have been acquired from monitoring of air pollutants since 1989 [7–11]. Station Nord is together with Alert (Canada) one of the only permanent continuously operated environmental monitoring sites located north of the polar front and within the marine cryosphere.

Base operations can and will impact the environment, however, there are few peer-reviewed articles dealing with quantitative information about contamination from small outposts to the surrounding environment and what can be learned from this human interaction with pristine environments.

In the present pilot study, heavy metal concentrations in sediments, as well as air pollution at the Danish military air field and high-arctic outpost, Station Nord (Figs. 10.1 and 10.2a, b) is presented. The field work was conducted in spring 2002 and reported as a technical report to the Danish Military [12] who have since released it to the public. Over 10 years after, there is still a lack of knowledge in the peer-reviewed literature on local impacts. Therefore it is important to reanalyze and publish the technical data from our report, analyzed in light of the state of the art knowledge. This is crucial due to the role and potential of outposts in Arctic in understanding global processes.

10.1.1 Area and Station Description

Station Nord (described in Danish by the Danish Military at http://forsvaret.dk/GLK/Station%20Nord/Pages/default.aspx accessed February 10th, 2013 with the pages linked from this page) is the second (after Alert) most northern, permanently manned station in the Arctic. It is located in the farthest north-eastern corner of Greenland on the north–south oriented peninsula Prinsesse Ingeborg Halvø on a 20 × 15 km^2 lowland plain. It is funded and outfitted with the logistic equipment and services as a major international platform for scientific studies focused on the Arctic cryosphere, nature and interaction with humans. Future plans include even operation of Unmanned Aerial Vehicles as environmental monitoring platforms (http://scitech.au.dk/en/current-affairs/news/show/artikel/aarhus-universitet-bygger-forskningsstation-i-nordgroenland/ accessed February 10th, 2013). The

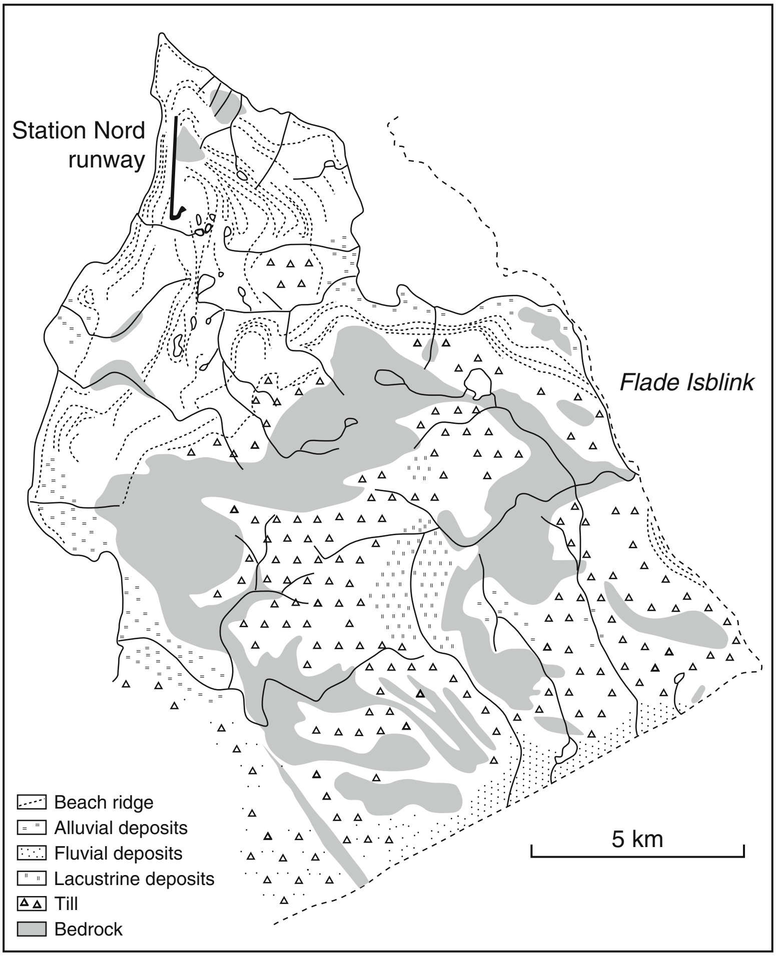


Fig. 10.1 Geological map of the Station Nord area. Simplified from an unpublished map compiled in 1994 by S.A. Schack Pedersen and used with his permission

operations at Station Nord are closely allied with those at Thule Air Base in North-western Greenland and with the Danish Greenland Dog Sled (*Sirius*) Patrol Headquarters at Daneborg, south of Station Nord on the Northeast coast of Greenland. It is an important logistic site for many scientific research activities in the Greenlandic National Park, Northeast Greenland, and thus provides a different type of data set than other Arctic stations.

The Station Nord plain is comprised of Quaternary raised marine silt, beach shingle and glacial deposits [13]. The Quaternary deposits are underlain by rocks of Permian age. Our field team (Goodsite, Skov and Feilberg) noted in August, 2001, that the active layer, above the permafrost was shallow, approximately 8–10 cm

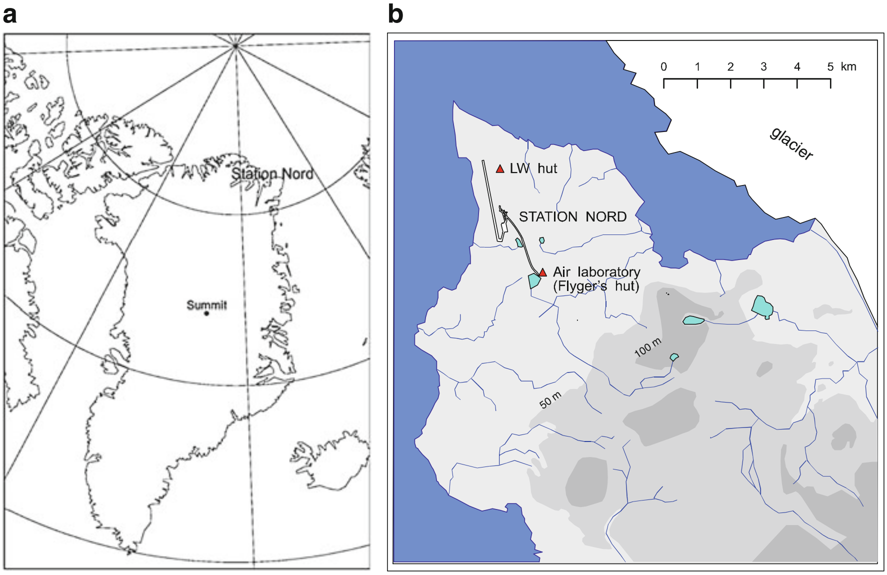


Fig. 10.2 (**a**) Map of Greenland showing the location of Station Nord. (**b**) The position of the air monitoring site at Station Nord. The regular AMAP site is located at Flyger's hut. From 1989 until 1995 the measurements where performed at Long-Wave hut (*LW*)

(though no formal study to our knowledge has been carried out to establish the depth). The plain borders on the north to Wandel Sea, the west to *Flade Isblink*, a local ice cap (presently being used for ice-core studies) to the east and south.

Håkansson et al. [14] described the bedrock geology of the peninsula, and Pedersen [15] compiled a geological map of the peninsula see Fig. 10.1. Funder and Abrahamsen [13] described the Holocene palynology of the region with cores taken in the summer 1979 from lake Sommersø (located next to the ground level atmospheric monitoring station, Flyger's hut, see Fig. 10.2b), the lake where we took core samples in this study. Finally, Bay and Fredskild [16] described the vegetation which was classified as Arctic polar desert.

10.1.1.1 Water Bodies Around Station Nord

Two shallow fresh water lakes are used as water supplies, water being pumped into tanks and trucked into the station. One of the lakes (Vintersø) has an outlet with intermittent flow (primarily at snow melt) to the Wandel Sea, located approximately 300 m south of the runway. There is not any hydrometric data for this flow – but it may be significant during snow melt. Sommersø lies approximately 2 km SW of the station. It is at the end of a gravel access road next to the Department of

Environmental Science, Aarhus University's Air Monitoring Station "Flyger's hut" (opened 1995, closed June 2002 and reopened in January 2006 – now significantly funded for future monitoring, see link above) located at its northwestern shore. The lake surface elevation is approximately 25 m a.s.l.. Sommersø is triangular in shape, with side lengths of 300 m, corresponding to a surface area of approximately 6.7 ha. This is of course variable, given that it has an inlet from the northwest, draining a small nearby pond, and is the catchment for various smaller drainage channels in the upland. Also since its topographical location in a kettle hole between raised beach ridges [13], assures it as a catchment for melt water. Funder and Abrahamsen [13] found the mean sedimentation rate to be 0.53 cm/year and the maximum depth of the lake to be over 10 m in the summer 1979. They sampled approximately 50 cm long cores from a depth of 3.5 m. The cores show frost shattering indicating effects of freezing (photographs and discussion in [13]).

10.1.1.2 Climatology

The climatology of the station is described in detail by Cappelen et al. [17] and is based on observations from 1961 to 1990. The main results are summarized here. The climate is dry with a mean yearly accumulated precipitation of 188 mm. The sun stays above the horizon for 148 days and below the horizon for 133 days. The snow free period is generally from late July through early September, but snow cover has persisted during cool summers. The provisional normal average air temperature was −21 °C with an average of 336 provisional normal average days with frost ($t_{min} < 0$ °C). The minimum temperature recorded is −51 °C and the absolute maximum air temperature is 17 °C. Calm weather with a wind speed ≤ 1.5 m/s prevails about 30 % of the time, but most of the time moderate winds are seen. The provisional normal average wind speed is 4 m/s. Winds are generally from the south-south-western 30° sector centered at 210°, i.e., from the Greenland ice sheet blowing over the station towards Wandel Sea. The winds can be cold katabatic or warm adiabatic (foehn) winds. The cold snow surface results in a persistent and strong, low level inversion that helps maintain calm wind conditions. Evidence of this stability is seen at Station Nord with the service members at the Station reporting a provisional normal annual average of 58 % of the time that the ground level visibility is greater than 50 km (estimated simply by their ability to see a mountain range at least 50 km away from the Station or not). Cyclonic storms with wind speeds at 20–30 m/s do occur, blowing in from the sea or along the coastline from the north-northwest. The above conditions suggest that it may take decades for terrestrially deposited material (which was a standard waste disposal practice) to decompose, and smoke from open burning will in general be blown out to sea as well as with dust and other transportable matter from the station. The dust is formed as a result of both natural (aeolian, hydrological or frost/thaw processes) as well as anthropogenic (traffic, construction, flight operations etc.) activities. All the roads and the runway are graded gravel and the runway is resurfaced every summer.

10.1.1.3 The Military Station Nord

Station Nord was opened in 1952 – taking through 1956 to fully establish the facilities (see the Danish Military description as linked to above) as a Danish weather station and emergency runway (Originally 1,700 m since shortened to 1,300 m). It remained open until 1972, when it was closed and left unused until the Danish Military acquired it in 1975 after determining that it was the best place for its Northeast Greenland operations in the 1974 mission "*Brilliant Ice*"; reopening it on 5 August 1975 with a crew of 5. The amount of activity and assigned personnel has varied at the station; summer months often being the most active with numerous technicians to repair facilities. When it was first established it was operated by approximately 30 service members. Today, a permanent crew of 5 men is assigned to keep the station running and the runway open. The three primary missions of Station Nord are: (1) monitoring and maintaining a presence in NE Greenland (2) keeping the 1,300 m long gravel/snow packed runway open (includes fuel stocks of jet fuel, JP-8 (aviation kerosene) and diesel for generators, and (3) supporting scientific research. Annual resupply missions are still given the operational name *Brilliant Ice* to honor the mission that resulted in (re)establishing the station, and provide an excellent period to fly in and out of the Station from Thule Airbase, Greenland.

The military station itself has an average elevation of 30 m a.s.l. with a gentle slope to the coasts. The gravel/ice runway which is kept open year-round is oriented approximately north–south parallel with the north-western shoreline of the peninsula. The station is a gateway to the national park of NE Greenland and a support base for the Danish dog sled patrol *Sirius*. Research support for scientific expeditions is available through collaboration with Danish or Greenlandic governmental agencies, Universities or NGOs operating in the Arctic. Station Nord is powered by an electrical generator which uses Arctic diesel.

For understanding any historical pollution signals that might be investigated, it is important to note that prior to the Danish military taking over the base, three types of fuel were used at Station Nord: motor fuel (gasoline) as well as jet fuel (JP-4) and diesel (as described below). Later, through the end of the 1980s and the beginning of the 1990s there were two different types of fuels used: Arctic diesel JP-8 and jet fuel. Since the beginning of the 1990s the station has only used Arctic diesel (JP-8), which can be used for jet motors, diesel driven vehicles and generators as well as heaters. The fuel is flown in yearly in a fuel lift period, with a cargo plane outfitted with refueling tanks.

JP-8 was exclusively utilized until the beginning of the 1990's when it was virtually excluded. The polyaromatic hydrocarbons (PAHs) trace from this type of fuel oil should therefore be limited since then. The fate of JP-8 in the environment is described in detail in the US Agency for Toxic Substances and Disease Registry (ATSDR) 1998 report and in Dean-Ross et al. [18]. Similar ATSDR reports are available for other jet fuel types (including JP-4) as well as the inorganic substances examined in this study. Peer reviewed studies are available for the fate of JP-5 [19] and JP-4 and other fuels [20]. Many of the stations are fuelled with stocks from Thule Air Base and thus the local contamination profiles of PAH will likely follow fuel stocks supplied from Thule Air Base.

Building large high Arctic stations require an aerial bridgehead and flying in of all supplies and fuel to run the station and refuel the aircraft. Due to logistical costs associated with bringing in equipment and fuel, only items that are vital to the station are brought, including fuel. Planes generally return any waste that cannot be combusted-though in the past, waste could also be deposited in an area known as the "dump" until it could be removed. Solid waste is burned in an open dumpster, with the ash subsequently spread. Grey wastewater is allowed to run into the environment. Empty steel fuel drums were historically dumped into the ocean where they decomposed. However, dumping drums into the ocean is not permitted under Danish and Greenland law thus the Danish military has not dumped anything into the sea since acquiring the base. There has been a solid waste accumulation point, the "dump" which was between the runway and the shore. This practice has since stopped and the "dump" since has been systematically remediated. For historical purposes only, it is noted that at the time of this pilot study, there were approximately 40,000 empty drums (as approximated by station personnel) accumulated along at the 500 m × 300 m dumpsite. Drums were also found washed up all along the peninsula and on nearby islands, from *Flade Isblink* to many kilometers into Denmark's Fjord, now the dump has been completely remediated i.e.it has no longer directly impacts on the area. Protection against spilled fuel is already considered by the Danish military however, in the event of a spill e.g., Mohn et al. [21] demonstrated that bioremediation is possible in the Arctic, and this possibility should be considered for all high Arctic station pollution response protocols.

10.2 Methods and Material Studied

The project was designed and funded as a pilot project for contaminant screening with the purpose of establishing the presence of, and preliminarily quantifying inorganic and organic contamination to the terrestrial, marine and freshwater environment surrounding the station. Fieldwork was carried out in a 9-day period, during lulls in the air sampling campaign, from 13 to 22 April 2002. Prior to this time, only a cursory walk-through survey could be performed in August, 2001.

Due to the lack of data and pre-survey to select the best suitable sampling sites and the difficulty to do so in the Arctic spring with snow and ice cover, a strategy of sampling in transect was adopted. Sediment cores were processed in the field and subsamples transported to the researchers institutions for later analyses of inorganic compounds (analyzed in the top cm of the core, a cm slice from the middle of the core and the bottom of the core) and organics (determined by combining 3 slices of the cores; i.e. The top 3 cm, 3 cm near the middle and the bottom 3 cm of the cores).

Atmospheric samples were likewise collected at Flyger's hut and at the Long-Wave hut (LW hut), see Fig. 10.2a, and sent to the Department of Environmental Science in Denmark for analysis. As we did not have the funding for dating or proper analyses of organics in the core, the organic data is not treated or presented due to the uncertainty associated with it. The inorganic data should be analyzed with the consideration that the core profiles were not dated. All data collected was presented to the Danish military [12]. The interested reader is welcome to request this technical report from the author, but the scientific team has scientific issues with the method used to obtain PAH/organic data, and it is our opinion that it should not be used for further scientific analyses.

10.2.1 Marine Sediments

Cores were collected at three sites: S3, S2, and S1 located respectively 250 m (6 m water under the ice), 750 m (7 m water under the ice) and 1,000 m (12 m water under the ice) from the land break. The distance and direction from the land break is in a continuation from the end of the access trail leading to the open burning container site at the dump. The distance to the three stations was established by clocking with a snowmobile and snow machine trip counter. Direction and distance were additionally established by a hand-held GPS, and verified by compass, with reverse cross section to the Station Nord control tower as an additional plotting control.

Cores were successively labeled as C1, C2 . . . for each site. Each core was sliced and bagged in the field as later described. Thus, for example: the top first centimeter (sediment water interface) cut from the second core, located at the coring site 250 m from the land break is called: S3C2 0–1. The sites had approximately 95 cm of snow covering 1 m thick ice. At the station 750 m from the land break (S2) the ice was 1.3 m thick. The depth to the sea floor is the free water plus the ice thickness. The ice at the 1,000 m site S1 was soft and was shoveled down to approximately the last 10 cm of ice and then used an ice drill. Depths were established with a metal measuring tape and sinker. We used a modified HON-Kajak gravity corer with plexi-glass coring tubes [22], washed on station in the water. This type of coring system should have been sufficient for obtaining 50 cm long cores; however we were unable to obtain cores more than 20 cm long, as we hit firm sediment. The cores were cut into 1 cm slices in the field and the slices stored in nylon bags for organic analyses and polyethylene (PE) bags for inorganic analyses. Bristle worms (polychaetes) were present in the top 2–3 cm of the marine sediments, with this section appearing bioturbated with worm burrows. We did not observe any freeze thaw damage to the cores from Wandel Sea, which is in agreement with the water depth. The cores all smelled of sulphur and the sediment was greyish green. The top (bioturbated) section had a more brownish hue.

Surface snow was taken in acid washed Teflon bottles, rinsed three times in surface snow from the site. Seawater was sampled similarly, prior to coring. Bottom water was sampled by expunging the water above the core in the sampling tube, also into a Teflon bottle. Sea ice slush was sampled similarly as snow.

10.2.2 Freshwater Sediments, Snow and Ice

Coring sites and samples from Sommersøen were marked in the same fashion as the samples from Wandel Sea but instead of S we used L. A total of 10 small diameter holes were drilled in transect across the freshwater lake "Sommersøen" where the depth to the bottom was measured in an attempt to locate the deepest part. No site with water deeper than 6 m was identified (corresponding to a depth of approximately 7 m when the ice melts). We cannot rule out that we did not find the deepest part of the lake or if manmade drainage or overflow channels dug to protect the station's installations have affected the depth of the lake since 1979. We found shallow areas (near the shoreline) to be 2–3 m deep around the edges of the lake. Samples were collected at three sites parallel to the north shore.

10.2.2.1 Air Samples

Near the northern end of the runway, measurements of particulate bound inorganic pollutants, heavy metals, sulphur dioxide, ammonium, nitrate and sulphate were carried out at the LW hut (see Fig. 10.2b) from August 20, 1990 until March 9, 1998 [9] within the framework of the Arctic Monitoring and Assessment Program (AMAP). From May 1, 1995 and onwards the same species were measured at the atmospheric monitoring station, Flyger's hut (see Fig. 10.2b). Therefore ground level atmospheric measurements exist for both the north- and south-side of Station Nord for a 4 year period which allow for a comparison of local impact from flight traffic with long range transport of air pollution to the station.

Samples were taken with a filter pack system sucking 40 $\mathrm{l\ min^{-1}}$ through the system. The filter pack was equipped first with a particle filter, then a series of filters impregnated with various substrates to collect specific gases [10]. A long time series of particle-associated compounds and gas phase species were measured [10]. Later on ozone and gaseous elemental mercury have been measured [11].

Among the compounds measured with the filter pack method was particulate sulphate. It was collected on the particle filter (the first filter) and gaseous sulphur dioxide was collected on a KOH impregnated filter placed after the particle filter. After sampling over a week the filter pack was transported to the Department of Environmental Science's I laboratory where the filters were analyzed. Both compounds were analyzed by ion chromatography with a method that was EN 17025 accredited from 2000. The detection limits are 0.06 and 0.45 μg S/m^3 for respectively sulphate and sulphur dioxide and the uncertainty is estimated to be within 15 % on a 95 % confidence interval as established through parallel measurements over several months for both species.

10.2.3 Loss on Ignition and Porosity

Loss on ignition (LOI) is an estimate of the percentage organic matter in sediment, determined by igniting a known mass of dried sediment at 550 °C for 15 min. The fraction of mass lost by ignition is assumed to represent the organic content of the sample, and is calculated based on masses of sediment before (m_t) and after (m_i) ignition:

$$\% \text{ LOI} = 100\,(m_t - m_i)\,.m_t{}^{-1}$$

where

m_t = total mass of sample
m_i = inorganic mass of sample (remaining after ignition).

The organic matter in sediments is comprised of very fine particles that will, like clay particles, sorb contaminants. The organic carbon in organic matter, often estimated at about 50 % of % LOI, will sorb most of the organic contaminants, including PAH. Many Holocene lake sediments (gyttja) in Greenland have LOI values of about 10–50 % [23]. Values below this are typical of minerogenic-rich sediments, whereas values over 20 % or higher indicate a productive water body.

Porosity is a measure of the pore volume in sediment samples and is an indication of the amount of clay, silt or sand in a sample. A sample with high porosity (0.95) has a high fraction of clay (or organic) particles with large pore volumes between them, whereas a sample with porosity of 0.8 or less is sandy, with a relatively smaller pore volume. All contaminants will have a higher affinity for smaller particles, especially if they are organic. Porosity measure is based on differences of wet and dry weights of sediments [24], assuming densities of water (1 g cm^{-3}) and dry sediment particles (2.45 g cm^{-3}) using the formula

$$\text{Ø} = [1 + (m_s/\,(2.45\,m_l))]^{-1}$$

where

Ø = porosity
m_s = mass of solid fraction
m_l = mass of liquid.

10.2.4 Inorganic Analyses

The samples were analyzed between September 1 and December 11, 2002. The samples were kept at the Department of Environmental Science in Roskilde and were prepared for analyses in their laboratory.

The samples were analyzed using EN 17025 accredited methods where they were dissolved in concentrated nitric – and hydrofluoric acid at 140 °C in Teflon bombs under pressure (The Loring and Rantala method). Then they were diluted to app. 50 g. Cadmium, lead, nickel, arsenic, and chromium were determined by Zeeman-Graphite furnace atomic absorption. Zinc, aluminium, iron, lithium, and copper were determined by flame atomic absorption. Hg was determined by cold flameless atomic absorption after reduction with boron hydride using a Perkin Elmer flow injection mercury analyzer, after dissolution in nitric acid.

As a control of the quality of the analyses two certified reference materials were analyzed in parallel with the samples. The uncertainties of the analyses were found by participation in inter-calibration. The uncertainty of the method is shown in Table 10.1.

10.3 Results and Discussion

10.3.1 Porosity and Loss on Ignition in the Marine and Fresh Water Samples

Porosity measure of sediment Wandelhavet marine cores S3C1 and S3C3, and Sommersøen lake sediment core L1C1 are shown in Fig. 10.3. The measurements should be considered nominal, since they were not immediately performed after sampling, but they were important to make in order to establish if the cores could be dated with lead isotopes, and to have an idea of the adsorption capacity of the cores.

The porosity values of the marine cores are very similar and vary from 0.75 to 0.8 in both cores and show that the material has a sandy texture, though experience in this research group varies with respect to this observation. For example, porosity of approximately 80 % corresponds to a water content of about 62 % (which is high for arctic marine sediments, and generally indicates a silty or clay like sediment). Correspondingly, the measured lithium concentration is high (50 %), indicating a fine grained sediment as well. The loss on ignition (LOI) values for the marine sediments is low (5 %), quite normal for marine sediments and consistent with a porosity of 0.8 Hermanson [25, 26]. However, we found only one core in both papers with a porosity lower than 0.95. The gritty taste of the basal sections of the cores after field sampling as well as the observation that the cores slices easily crumbled at the laboratory affirms the conclusion that they are sandy and we would expect comparatively low concentrations of anthropogenic contaminants associated with these sediments (see next sections).

Table 10.1 Accredited 95 % confidence limits expressed on a dry weight basis for the analyses

	Biological material			Sediment		
Element	Method no	Concentration independent uncertainty mg/kg	Relative uncertainty[b] %	Method no	Concentration independent uncertainty mg/kg	Relative uncertainty[b] %
Hg	**65**	0.005	25	**15**	0.05[a]	25
Cd	51 and *52*	0.005	25	1 and *2*	0.01[a]	25
Pb	53 and *54*	0.05	25	3 and *4*	1	25
Zn	*55*	1	12.5	*5*	10	12.5
Cu	56 and *57*	0.2	25	6 and *7*	2	25
Cr	70 and *71*	0.2	25	20 and *21*	10	25
Ni	62	0.2	25	12	10	25
As	63	0.3	25	13	5	12.5
Se	**67**	0.1	12.5			
Li				9 and *10*	10	12.5

[a] The numbers are very close to the detection limit defined as five times the noise on blanks

[b] Determined by participation in proficiency testing

The analytical error must in 95 % of the cases be less than the sum of the two errors. There is no upper limit for the analyses.

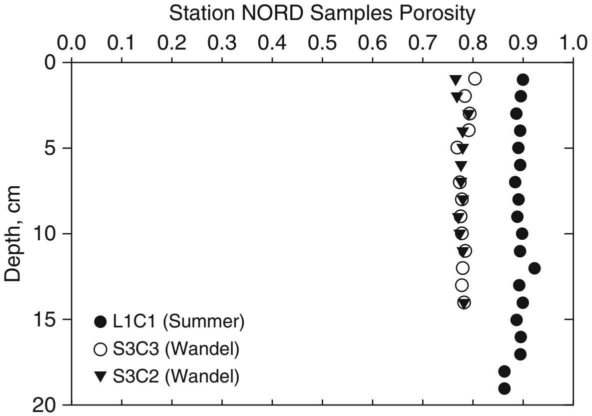
Method number in italics: Flame AAS

Method number in bold: Flow injection hydride method and flow inection mercury system.

Method number underlined: Graphite furnace AAS

The determination of Co is not an accredited analysis but is performed in the same way as Ni. The sensitivity for Co is better than for Ni (85 %)

Fig. 10.3 Porosity in sediment samples



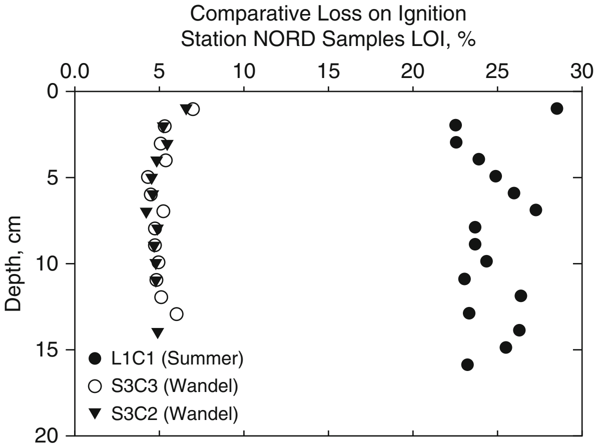


Fig. 10.4 Percent loss on ignition (LOI, %) in sediment samples

The porosity of Sommersøen core L1C1 is much higher; approximately 0.9 throughout the length of the core, indicating that, under similar contaminant inputs, it would contain higher amounts of trace metal and organic contaminants. The % LOI values from these cores show a more distinct contrast (Fig. 10.4).

The marine cores Wandelhav S3C2 and S3C3 both have similar values and shape with about 5 % LOI reduction through the cores. These values suggest a low level of biological productivity in the water, or small amount of organic matter being washed into the ocean from nearby streams which is normal for arctic marine sediments. Concerning contaminants, the effect of low %LOI is similar to low porosity: contaminant sorption will be low. The lake core, L3C3 from Sommersøen, is again much different. Its %LOI values range from about 22 % to 28 % at the surface. There is not any apparent core length LOI trend, suggesting that oxidation of sediment organic matter below the surface does not occur on a large scale, perhaps related to low dissolved oxygen levels at the sediment/water interface during winter ice cover. These higher %LOI values suggest that contaminant sorption to these sediments would be greater and are different than those previously measured by Funder (1988) who recorded decreasing values over the bottom 15 cm of his core, from approximately 30 % to approximately 10 % suggesting a dynamic type of sedimentation in the lake.

10.3.2 Heavy Metal Analyses

10.3.2.1 Marine and Freshwater Comparison

The metals in marine and lake environments (see Tables 10.2 and 10.3) show a few significant contrasts and at first glance, the levels of metals in the marine sediments seem within normal ranges for the Arctic, except for arsenic, which is rather high. However, as shown above, there are significant differences in porosity and LOI between the lake and marine sediment. Any comparison should take this into consideration. Comparable amounts of trace elements in marine and lake sediments suggest that the marine environment is receiving much more contamination due to the fact that much of it is not retained in the marine sediments. The marine cores, even though sandy and low in organic matter, show systematically higher concentrations of Hg, As, Cr and Pb than the lake sediments, suggesting that the inputs of these elements to the marine environment are quite high. Each of these elements is influenced by industrial and other anthropogenic activities, and could be linked to disposal or other anthropogenic activities at the dump and/or from atmospheric deposition. Since the lake is located away from most Station Nord activities, it likely receives contaminants mostly from the atmosphere, though anthropogenic activity cannot be ruled out as a source without a complete survey of the lake. The lake sediments show much higher concentrations of Cd than the marine sediments, which may indicate that atmospheric inputs are high. The comparatively low concentrations in the marine sediments is very likely due to low contaminant sorbing ability of the marine sediments, which again suggests that similar or higher concentrations observed in the marine cores result from very large inputs from a contaminant source.

By using the lithium concentration to normalize the concentration of elements in the sediments, the trace elements can however, be compared with values reported in an AMAP sediment study [27]. This comparison shows that all values for the marine sediments are within expected ranges except for arsenic, which is high, and cadmium, which is low. Chromium and nickel are not treated in the report, but it can be seen from comparison with values reported by Loring and Asmund [28], that they are within ranges of uncontaminated Greenland sediments, outside of tertiary volcanic areas. Loring et al. [29] show in a diagram that an As/Li ratio of 0.5 is normal. Enrichments, with ratios of up to 3 can be found at some locations near nuclear test areas. The ratio at Station Nord is 1, twice that of [29].

Table 10.2 Results on a dry weight basis (ppm) for cores from Wandelhav

Lab. ID nr	Core nr-stn. Nr.	Dist. from dump m. from shore	Depth in Cm Below surface	Hg mg/kg	Cd mg/kg	Zn mg/kg	Fe %	Cu Mg/kg	As mg/kg	Li mg/kg	Al %	Pb mg/kg	Cr mg/kg	Ni mg/kg
25121	C1-S1	**1,000**	**0–1**	0.036	0.034	75.4	4.65	21.99	59.14	53.49	8.44	17.6	97.0	42.7
25121	C1-S1	**1,000**	**0–1**	0.040	0.052	73.6	4.63	54.34	59.63	51.65	8.48	17.9	108.5	38.9
25121	C1-S1	**1,000**	**14–15**	0.031	0.015	81.0	4.36	24.09	71.57	53.55	10.55	19.7	108.1	38.5
25121	C1-S1	**1,000**	**14–15**	–	0.017	78.3	4.34	23.28	67.75	50.54	11.01	19.3	107.6	40.6
25124	C2-S1	**1,000**	**0–1**	0.036	0.092	69.5	7.11	20.09	55.56	46.64	7.65	17.1	91.5	42.5
25124	C2-S1	**1,000**	**13–14**	0.033	0.020	75.1	3.97	22.74	45.78	50.17	7.40	19.3	105.3	37.3
25129	C3 – Ref	**1,000**	**0–4**	0.036	0.033	88.1	3.85	28.16	49.60	57.02	7.05	19.3	117.0	40.6
25129	C3 – Ref	**1,000**	**0–4**	0.036	0.030	89.4	3.81	28.75	46.70	58.82	7.05	19.5	115.1	44.7
25122	C1-S2	**750**	**0–1**	0.035	0.032	68.5	3.62	20.16	42.59	42.99	9.15	17.2	105.7	38.2
25122	C1-S2	**750**	**7–8**	0.045	0.024	88.3	2.68	21.59	69.93	59.32	10.41	19.2	115.2	46.8
25125	C3-S2	**750**	**0–1**	0.038	0.030	68.4	3.73	20.61	40.38	43.05	5.97	17.1	93.3	40.2
25125	C3-S2	**750**	**13–14**	0.037	0.011	72.8	3.08	18.19	32.75	53.60	8.10	18.2	115.6	29.9
25123	C1-S3	**250**	**0–1**	0.038	0.053	68.9	3.32	20.84	34.80	43.43	9.02	16.6	95.4	45.8
25123	C1-S3	**250**	**10–11**	0.028	0.035	74.6	3.70	23.19	36.71	48.60	9.33	18.0	114.4	52.2
25126	C3-S3	**250**	**0–2**	0.042	0.040	78.9	3.55	22.58	41.64	51.16	8.75	17.7	110.0	42.1
25126	C3-S3	**250**	**12–13**	0.037	0.021	76.4	3.26	23.75	30.13	51.03	8.82	18.3	125.4	37.9

Table 10.3 Results on a dry weight basis (ppm) for cores from Sommersøen

Lab.	Core nr-	Dist. from dump m.	Depth in Cm Below	Hg	Cd	Zn	Fe	Cu	As	Li	Al	Pb	Cr	Ni
ID nr	stn. Nr.	from shore	surface	mg/kg	mg/kg	mg/kg	%	Mg/kg	mg/kg	mg/kg	%	mg/kg	mg/kg	mg/kg
25127	L C2	**Lake**	**0–1**	0.026	0.135	73.3	1.66	21.56	9.50	36.57	6.13	14.0	68.0	34.3
25127	L C2	**Lake**	**0–1**	–	0.130	74.9	1.69	21.93	7.80	36.32	5.41	14.3	69.3	34.7
25127	L C2	**Lake**	**13–14**	0.018	0.143	61.9	1.48	17.84	7.56	31.57	3.99	11.0	59.4	29.9
25128	L C3	**Lake**	**0–1**	0.014	0.138	64.9	1.49	19.69	8.36	32.01	4.00	11.2	63.2	31.6
25128	L C3	**Lake**	**6–7**	0.019	0.030	66.5	1.81	19.44	18.10	29.80	3.32	10.6	49.2	33.7

The marine samples taken in this study have absolute As concentrations ranging from 30 to 72 ppm (see table for uncertainties). Comparing these with values reported by Siegel et al. [30, 31], arsenic ranges from 6.9 to 22 ppm and in other reported studies from the central NW Barents Sea, up to 69 ppm. Siegel et al. [30] conclude that sediments they measure suggest an "incipient pollution problem" especially with respect to Hg and As. Thus comparing absolute As concentrations together with the enriched ratio in our samples from the Wandel Sea mean that we have at least an incipient pollution, if not a mature anthropogenic impact. We do not have the necessary data to conclude if this impact is local or from long range transport since long range transport, given the circulation with waters from the Barents Sea cannot be excluded; but it is logical that what we are measuring is probably a local anthropogenic signature.

The sediment samples taken in this study have absolute Hg concentrations ranging from 28 to 45 ppb (see Table 10.1 for uncertainties). [29] find in their study that Hg ranges from 31 to 140 ppb, which is a higher range than those reported in other studies. Our results show an Hg range surprisingly lower than any of the other studies. In the marine sediments the low concentrations for these elements may be explained by the physical properties of the sediments.

With respect to the freshwater samples, the As concentration is high, compared with other elemental inputs to the lake. We do not know what the source of As is to the sediments. If it is atmospheric then levels for other elements would be correspondingly higher in Sommersøen. As in sediments may correlate with Al [32], the correlation in all of our Wandel Sea samples is $R^2 = 0.225$ and significant on a 90 % confidence interval, suggesting that the geogenic variability in the lithology of the sample is a significant contributor to the observed levels of As. Anthropogenic sources are likely the dominant source of the measured As enrichment, explaining the remaining 77.5 % of the variability. However, none of the traditional target heavy metals Hg, As, Pb and Cr show clear gradients neither vertically (through cores) nor horizontally (across the transect of the sites).

10.3.2.2 Air Samples

From 1995 to 1998 filter pack sampling at two sites were carried out; One site was north of the station, the LW hut and the other was south of the station, the Flyger's hut. The results from these measurements have previously been published [9, 10]. Results for sulphate and sulphur dioxide from 1989 to spring 2010 have a strong seasonal variation with a minimum concentration during summer (Fig. 10.5). In late autumn the concentrations start to increase, reaching a maximum during January – February. Thereafter the levels decrease again to a minimum during summers. Sulphur dioxide is seen to precede sulphate each autumn and first "disappears" during spring as sulphur dioxide is photo-chemically transformed to sulphate in the arctic atmosphere [10, 33]. The weekly concentrations of the compounds were plotted against one another at the two sites. In Fig. 10.6 the results for sulphur dioxide are shown as typical results. There is a very strong correlation with an

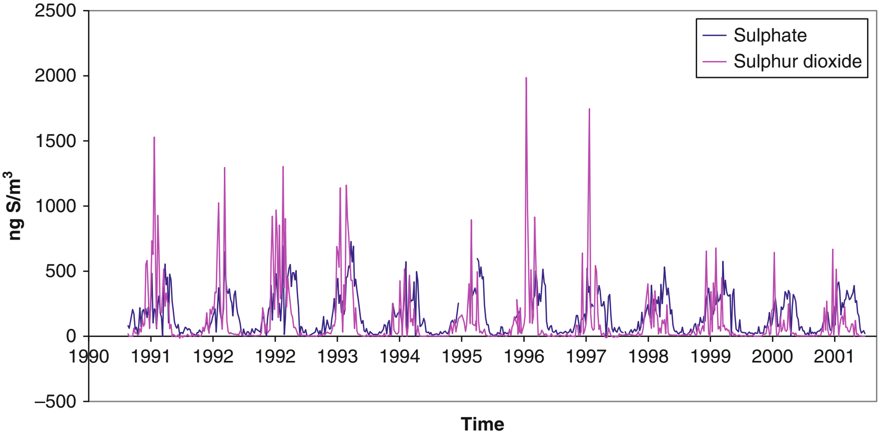


Fig. 10.5 Weekly average concentrations of sulphate and sulphur dioxide in the atmosphere at Station Nord, North East Greenland

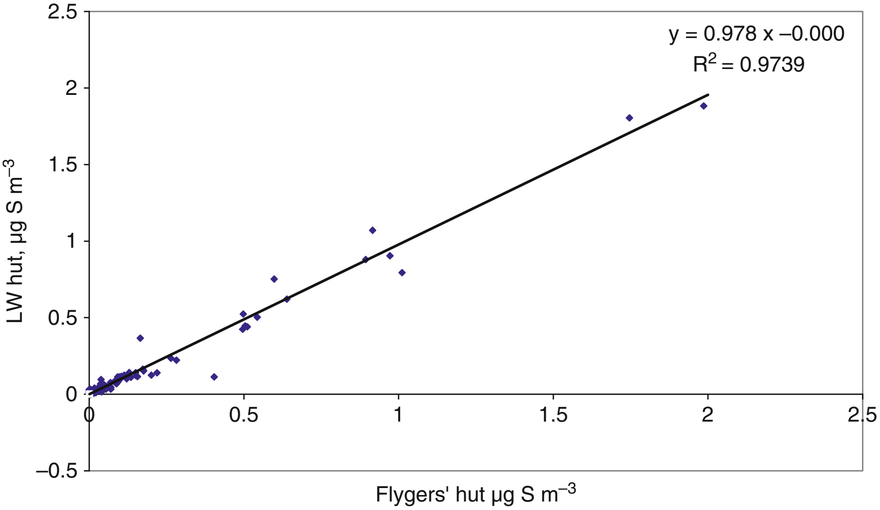


Fig. 10.6 Comparison of sulphur dioxide concentrations at LW hut and at Flyger's hut, unit is µg S/m^3. The regression line is obtained by orthogonal regression

intercept close to 0 and the slope for all compounds was close to 1. Therefore there is negligible influence of the station on weekly average values of sulphur dioxide. Similar can be deduced for the elements measured heavier than Al, sulphate, nitrate and ammonium. NOx measurements spike as expected when local traffic is near the measurement station. Hg^0 and O_3 are measured as well at the station and are published elsewhere [11]. Therefore local combustion or use of fuel as a source of pollution is of minor importance for the air quality at the site.

10.4 Conclusions

In the present paper we have measured heavy metals in sediment cores in the Wandel Sea and Sommersøen Lake close to Station Nord. We also present data on the air quality acquired simultaneously north and south of the Station. We have described the station so that future studies may refer to the historical environmental parameters that are presently known about the station for consideration in future studies.

The concentrations of certain heavy metals were higher than would be expected from an undisturbed remote location. At present, there is not yet enough information to distinguish between local sources and long range transport as concentrations were found to be higher than expected both in marine and lake sediments. Some of this could be explained from the lithology but a major part of the variability remains unattributed and needs further study.

The measurement of atmospheric pollutants demonstrated a very minor influence of local sources and the observed levels can be explained by long range transport. Monitoring of atmospheric pollutants in the high Arctic should be continued to assess the long term trend of load of pollutants to the Arctic environment from atmosphere.

Understanding the impact of human operations in the Arctic is important given the expected expansion of such activities as sea routes open in the future and the natural dynamics in the Arctic change with a changing climate and changes in sea and terrestrial ice cover. We must establish baselines with respect to contamination from local effects now, to better understand how to mitigate and adapt in the future and to enhance our understanding of global processes. As it is commonly the Military operating these stations and given the growing importance that military presence will have in the high Arctic, it is necessary for the military operating remote stations to be aware of the environmental impact that their activities will and might have, and for the military leaders and base commanders to continue to promote scientific collaboration and activities at their stations.

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Chapter 11
Sustainability of Water Supply at Military Installations, Kabul Basin, Afghanistan

T.J. Mack, M.P. Chornack, and I.M. Verstraeten

Abstract The Kabul Basin, including the city of Kabul, Afghanistan, is host to several military installations of Afghanistan, the United States, and other nations that depend on groundwater resources for water supply. These installations are within or close to the city of Kabul. Groundwater also is the potable supply for the approximately four million residents of Kabul. The sustainability of water resources in the Kabul Basin is a concern to military operations, and Afghan water-resource managers, owing to increased water demands from a growing population and potential mining activities. This study illustrates the use of chemical and isotopic analysis, groundwater flow modeling, and hydrogeologic investigations to assess the sustainability of groundwater resources in the Kabul Basin.

Water supplies for military installations in the southern Kabul Basin were found to be subject to sustainability concerns, such as the potential drying of shallow-water supply wells as a result of declining water levels. Model simulations indicate that new withdrawals from deep aquifers may have less of an impact on surrounding community water supply wells than increased withdrawals from near-surface aquifers. Higher rates of recharge in the northern Kabul Basin indicate that military installations in that part of the basin may have fewer issues with long-term

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water sustainability. Simulations of groundwater withdrawals may be used to evaluate different withdrawal scenarios in an effort to manage water resources in a sustainable manner in the Kabul Basin.

11.1 Introduction

Military installations in Afghanistan currently (2012) rely on groundwater for a significant portion of their water supply [1]. The Kabul Basin is host to several military installations of Afghanistan, the United States, and other nations, including the Bagram Airfield in the north and the International Security Assistance Force (ISAF) compound in the city of Kabul. The sustainability of the region's principal aquifer systems is largely uncharacterized, and an improved understanding of the water resources of the region can aid in the effective management of water resources [2]. The city of Kabul (Fig. 11.1), with a population of approximately four million people, also depends solely on groundwater for drinking water supplies. The sustainability of water resources in the Kabul Basin is of concern to military planners and Afghan water-resource managers owing to the region's water needs for a growing population and for potential mining activities.

Investigations by the United States Department of Defense Task Force for Business and Stability Operations (TFBSO), the U.S. Geological Survey (USGS), and the Afghanistan Geological Survey (AGS) indicate that copper deposits immediately south of the Kabul Basin have the potential to provide considerable economic opportunity to Afghanistan [3]. Understanding the water resources of the Kabul Basin is necessary for the military installations in the Kabul Basin but also for the social and economic sustainability of Kabul and Afghanistan. Collaboration between the USGS[1], TFBSO, and AGS and scientific investigations conducted under agreements with the United States Agency for International Development (USAID) have led to improved understanding and management of water resources in the Kabul Basin. This chapter examines the methods of investigation, particularly chemical and isotopic analysis of water resources, and simulations of groundwater flow that have contributed to the assessment of water-resources sustainability in the region.

11.1.1 Site Descriptions

For this study, the Kabul Basin is defined as the drainage area to the valley holding the city of Kabul, which extends about 40 km north of the city. The basin is bordered to the west by the Paghman Mountains and to the east by the Kohe Safi Mountains (Fig. 11.1). This area excludes the drainages outside the valley.

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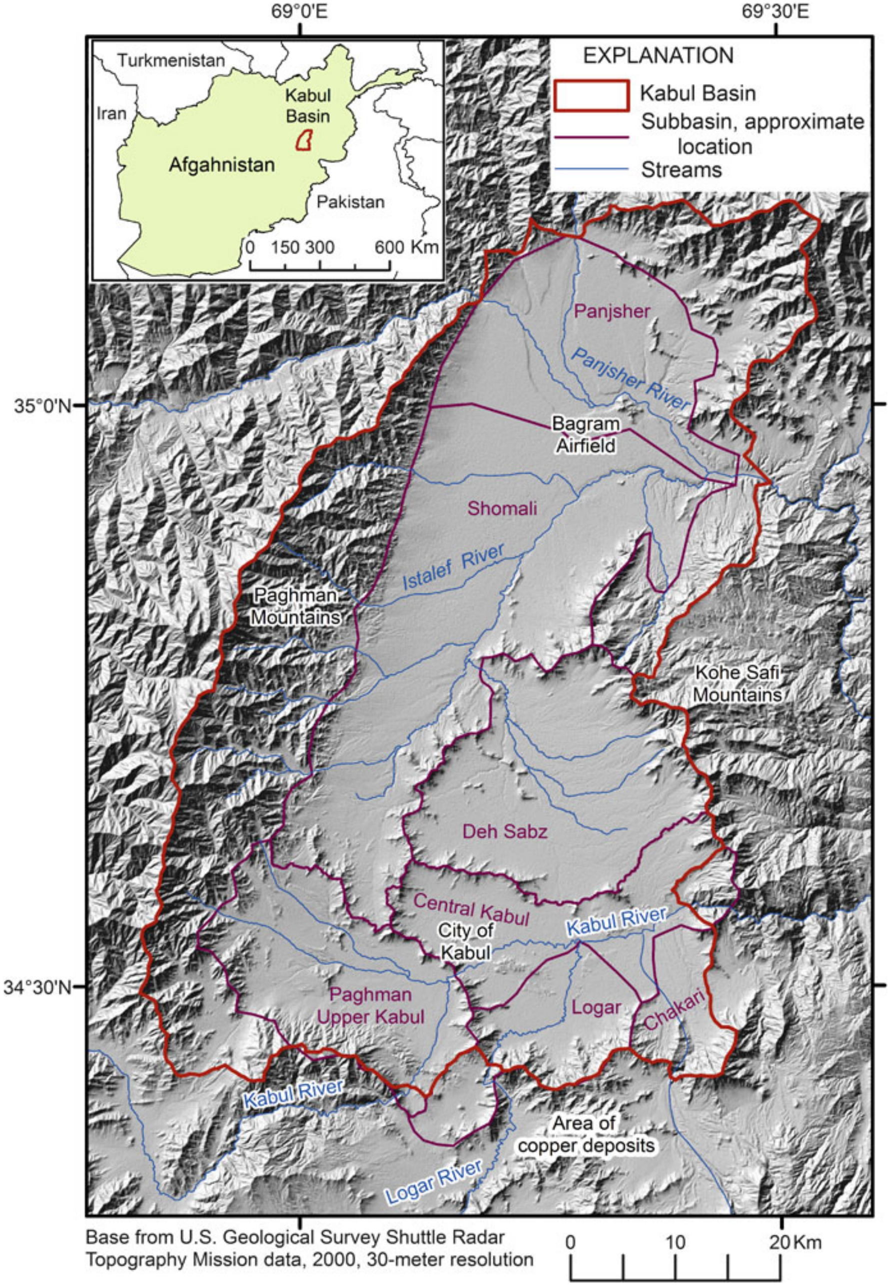
[1] This study is a product of the U.S. Geological Survey Afghanistan Project: http://afghanistan.cr.usgs.gov/.



Base from U.S. Geological Survey Shuttle Radar Topography Mission data, 2000, 30-meter resolution

Fig. 11.1 The Kabul Basin, Afghanistan, with major geographic features and approximate subbasins

Subbasins of the Kabul Basin are formed by interbasin ridges and river drainage divides (Fig. 11.1). Several military installations within and adjacent to the city of Kabul are in subbasins that compose the southern Kabul Basin; the Bagram Airfield is in the northern Kabul Basin. An economically significant copper deposit is immediately south of the Kabul Basin [3].

The primary aquifer in the Kabul Basin is a surficial sedimentary aquifer in the bottom of the basin (Fig. 11.2). The underlying semiconsolidated sediment is a less used aquifer, and the sedimentary and fractured metamorphic and crystalline bedrock of the surrounding mountains and interbasin ridges are the least used aquifers in the Kabul Basin. Alluvial fans have developed on the flanks of the mountains surrounding the subbasins and on the interbasin ridges. Deposits in the central plains include alluvium and loess sediment, typically less than 80 m thick, that overlie semiconsolidated conglomerate sediment up to 1,000 m thick (Fig. 11.2). Studies that have investigated aquifers in the southern Kabul Basin include those by Myslil et al. [4], Japan International Cooperation Agency [5], Lashkaripour and Hussaini [6], and Houben et al. [7].

The collection of climatic data in Afghanistan ceased around 1980, and few climatic data are available for Kabul until about 2003. The mean annual precipitation from 1956 to 1983 was estimated to be 312 mm [8]. Evaporation rates are high relative to annual total precipitation – approximately 1,600 mm/year – and thus net groundwater recharge by precipitation in the Kabul Basin is essentially zero on an annual basis. During the late 1990s and early 2000s, little or no precipitation occurred in several years, and in 2001, only 175 mm of precipitation was reported for Kabul [9]. For water years[2] 2004–2011, precipitation measured at the Kabul Airport was above average in 2005 and 2007, below average in 2004 and 2008, and average in other years (Fig. 11.3; [8]).

11.1.2 Water Resources

11.1.2.1 Surface Water

A network of 12 streamgages (Fig. 11.4) were operated within and adjacent to the Kabul Basin for various periods from 1959 until 1980 when the streamgages were discontinued. Historical streamflow records were compiled and entered into USGS databases [10, 11] to enable calculation of historical base flow and recharge characteristics per unit area. Larger snow accumulation in northern drainages resulted in an average annual runoff of 0.020 $m^3/s/km^2$ for the northern stations compared with 0.004 $m^3/s/km^2$ for the southern stations [12].

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[2] Afghan water years are from September 1 of the previous year through August 31 of the water year referenced.

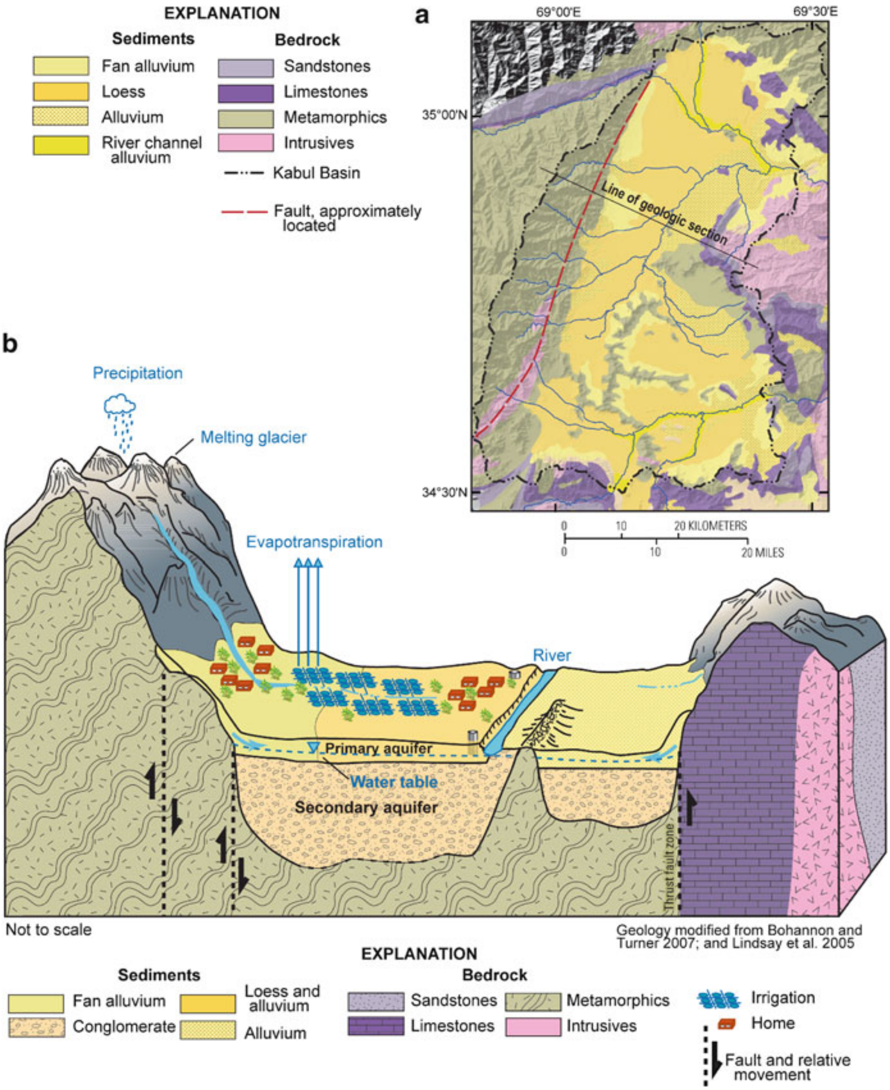


Fig. 11.2 Generalized surficial geology and cross section and schematic diagram of the Kabul Basin, Afghanistan

11.1.2.2 Groundwater

The AGS has operated a monthly water-level-monitoring network of more than 69 wells to better understand groundwater levels (Fig.11.5) in the basin since 2004 [13]. Due to declining groundwater levels, some wells have been removed from the network, and 66 wells were used in this study. The Danish Committee for Aid to Afghan Refugees (DACAAR) has 10 wells in the Kabul Basin that were monitored

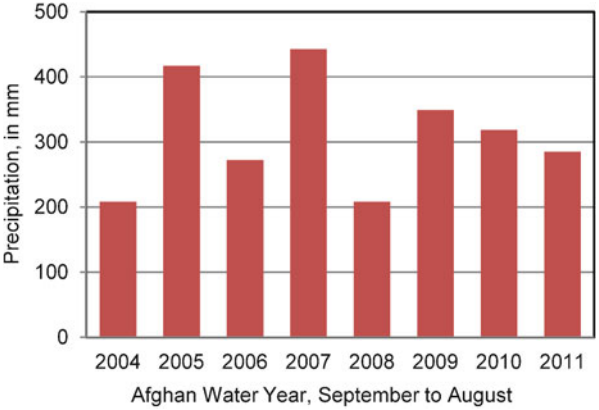


Fig. 11.3 Annual precipitation at the Kabul Airport, Afghanistan, between September 1, 2003, and August 31, 2011

for about the same period [14]. The AGS studied water-levels in wells in the Kabul Basin that ranged in depth from 4.9 to 30 m and generally were equipped with hand-operated or electric pumps. The DACAAR network wells are likely similar to the AGS wells.

Groundwater levels in parts of the Kabul Basin have declined substantially as a result of periods of below-average precipitation and increased water use during the 2000s. By 2007, groundwater levels in rural areas in the Kabul Basin were rising in response to an increase in precipitation to more average rates relative to antecedent drought conditions (Fig. 11.3), while groundwater levels were declining in the city of Kabul as a result of increased water use [12]. Groundwater levels in some areas of the Kabul Basin have been rising since 2004, such as at AGS monitoring well 20 near Shomali in the northern part of the basin (Fig. 11.6a). By contrast, groundwater levels in the city of Kabul have been declining. For example, AGS monitoring well 167 in the Central Kabul Subbasin indicated a 3-m decline in groundwater level from 2004 to 2007; however, from 2007 to 2012, the decline was about 15 m (Fig.11.6b).

Groundwater levels in the Kabul Basin were assessed using the seasonal Kendall test [15, 16] to determine whether trends were evident. The slope of trends in groundwater levels is depicted in Fig. 11.7 and indicate where groundwater levels show no trend (slopes near zero) or levels are significantly rising (negative slope) or declining (positive slope). Between 2004 and 2012, groundwater levels rose in 16 wells; the median groundwater level rise was 0.31 m/year, and rises generally were greater near streams in the northern Kabul Basin. Between 2004 and 2012, the median groundwater level decline observed in 19 wells was 0.76 m/year, more than twice the median rate of groundwater level rise.

Groundwater level declines occur primarily in the urban areas of the Kabul Basin (Fig. 11.7). Declines also tend to increase with greater distance from recharge sources, such as rivers or mountain fronts (the basin area adjacent to a mountain). The measured groundwater level trends are consistent with groundwater flow model

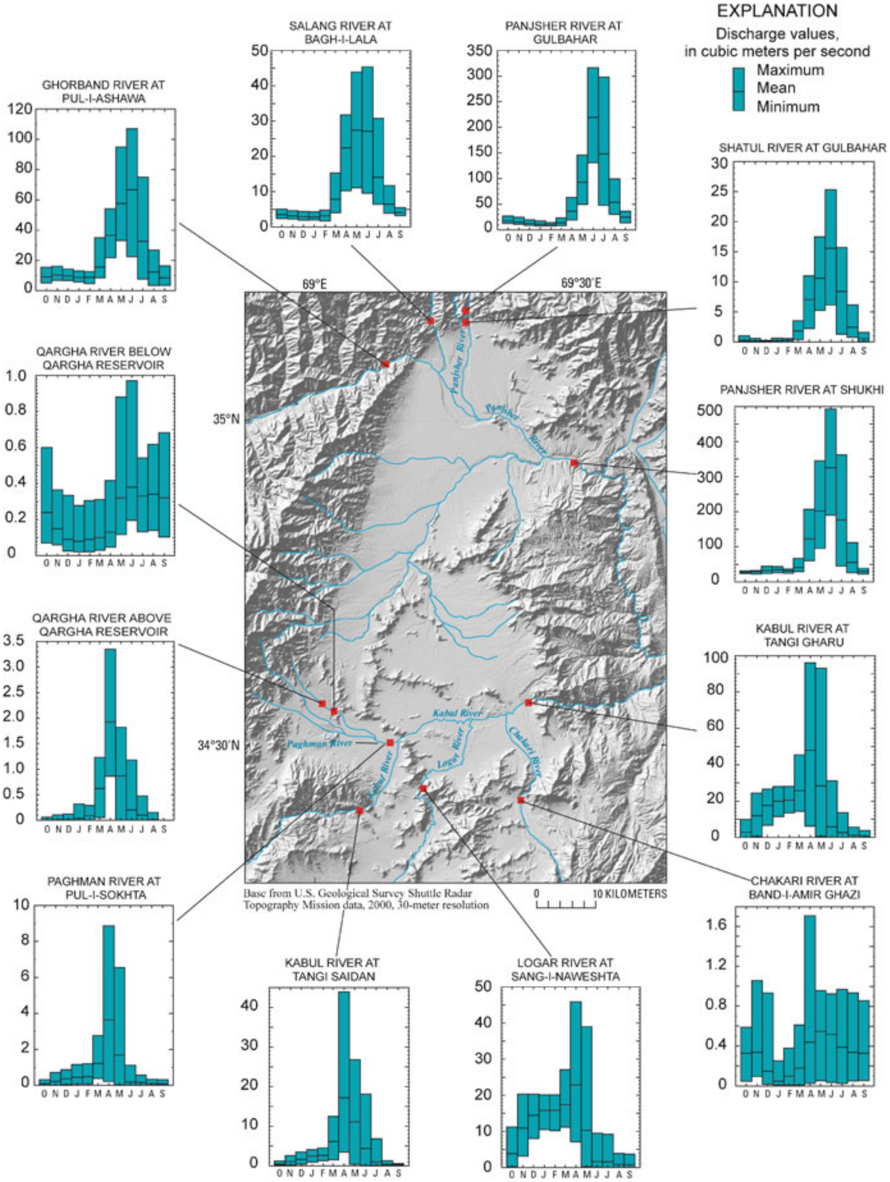


Fig. 11.4 Maximum, minimum, and mean monthly discharges at 12 streamgages in the Kabul Basin between 1959 and 1980

simulated drawdowns resulting from increased withdrawals in and around the city of Kabul [12]. Model simulations indicate that groundwater level declines may affect military facilities and government agencies in the city, all of which depend on

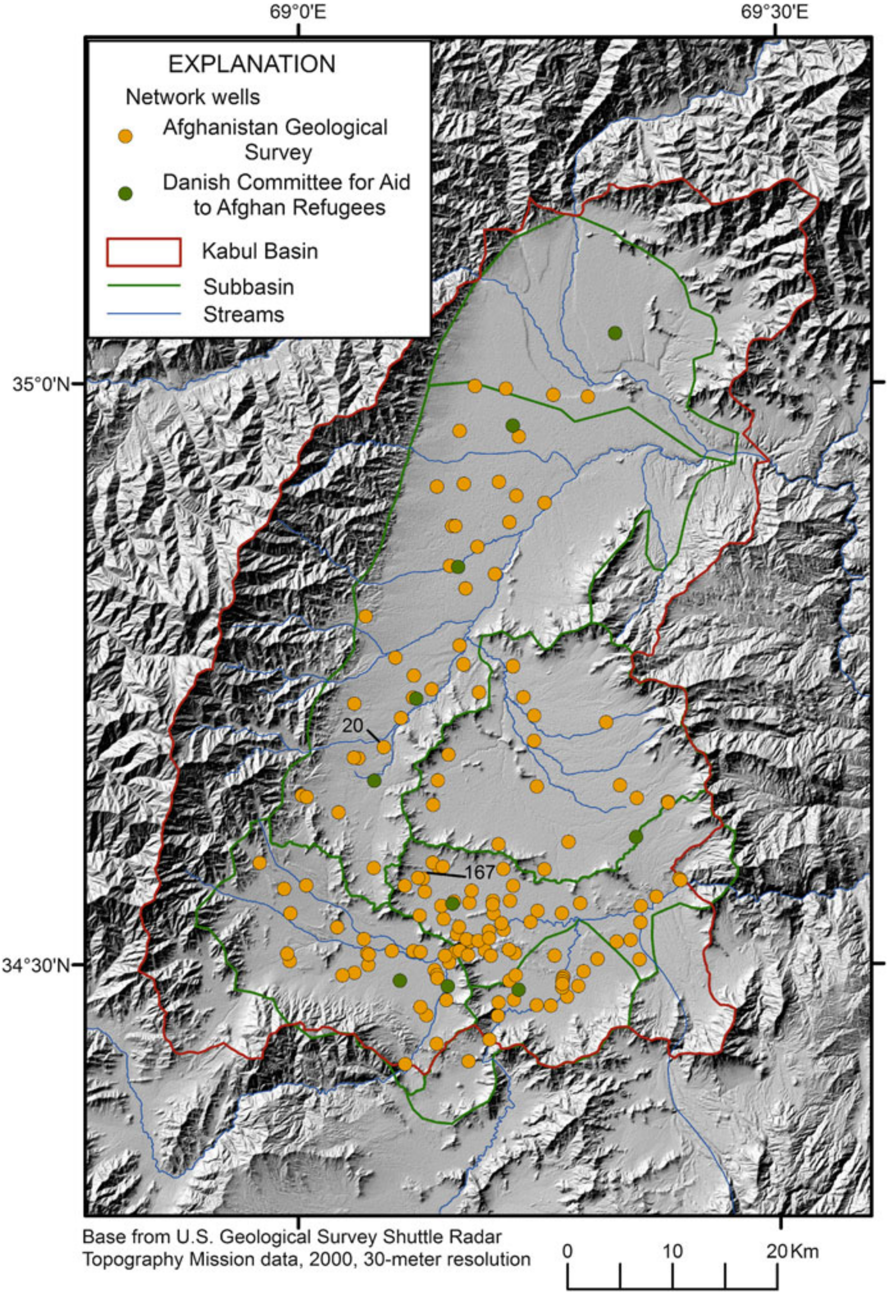


Fig. 11.5 Location of wells in the groundwater level monitoring network in the Kabul Basin, Afghanistan

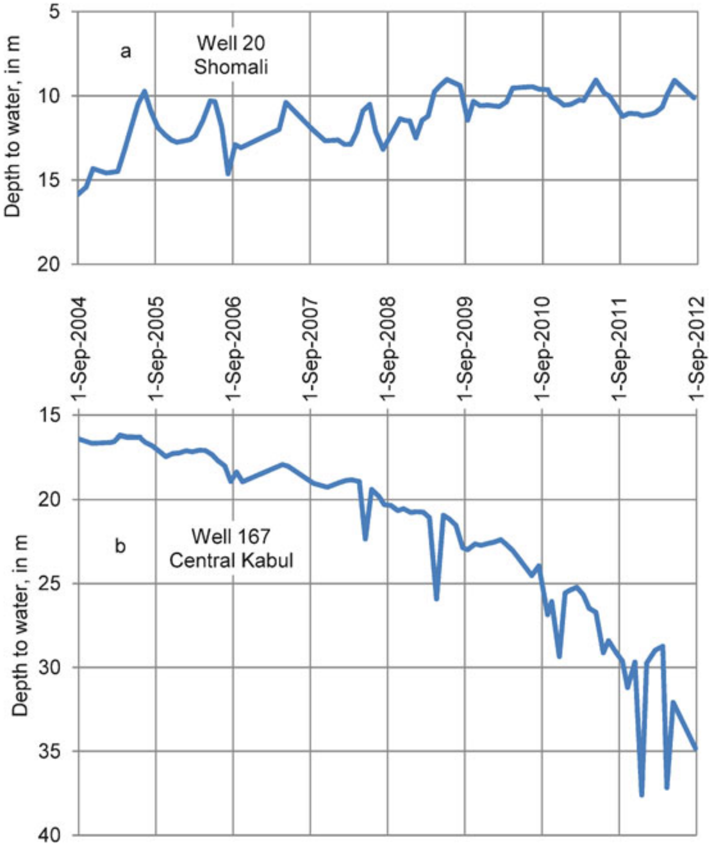
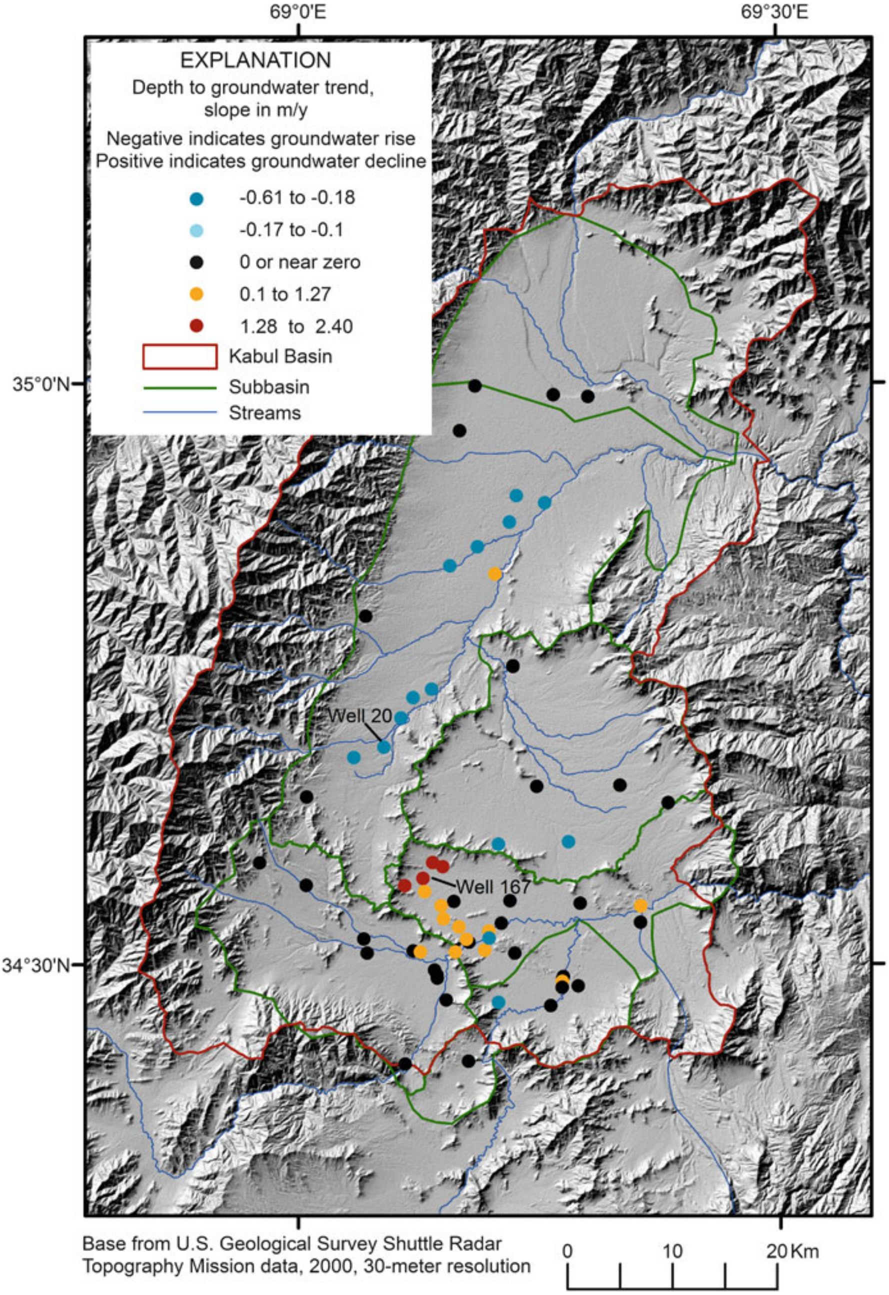


Fig. 11.6 Monthly groundwater levels (measured as depth to water) from September 2004 to September 2012 at (**a**) well 20 in Shomali in the northern part of the basin and (**b**) well 167 in the Central Kabul Subbasin in the southern part of the basin in the Kabul Basin, Afghanistan

groundwater for supply. By contrast, the northern Kabul Basin, which contains the Bagram Airfield, is less populated, receives more recharge [12], and groundwater levels have generally been rising between 2004 and 2012 (Fig. 11.7).

11.1.2.3 Water Quality

Concentrations of several chemical compounds were elevated in the city of Kabul and surrounding areas relative to less developed areas, suggesting anthropogenic contamination. Water-quality constituents and properties that indicated effect of urbanization included specific conductance, hardness measured as alkalinity, and concentrations of nitrate plus nitrite, bromide, magnesium, sodium, potassium, chloride, arsenic, boron, nickel, and zinc. Median values of specific conductance in groundwater ranged from 51 μS/cm near the Kohe Safi Mountains (Fig. 11.8)



Base from U.S. Geological Survey Shuttle Radar Topography Mission data, 2000, 30-meter resolution

Fig. 11.7 Groundwater level trends from 2004 to 2012 in the Kabul Basin, Afghanistan

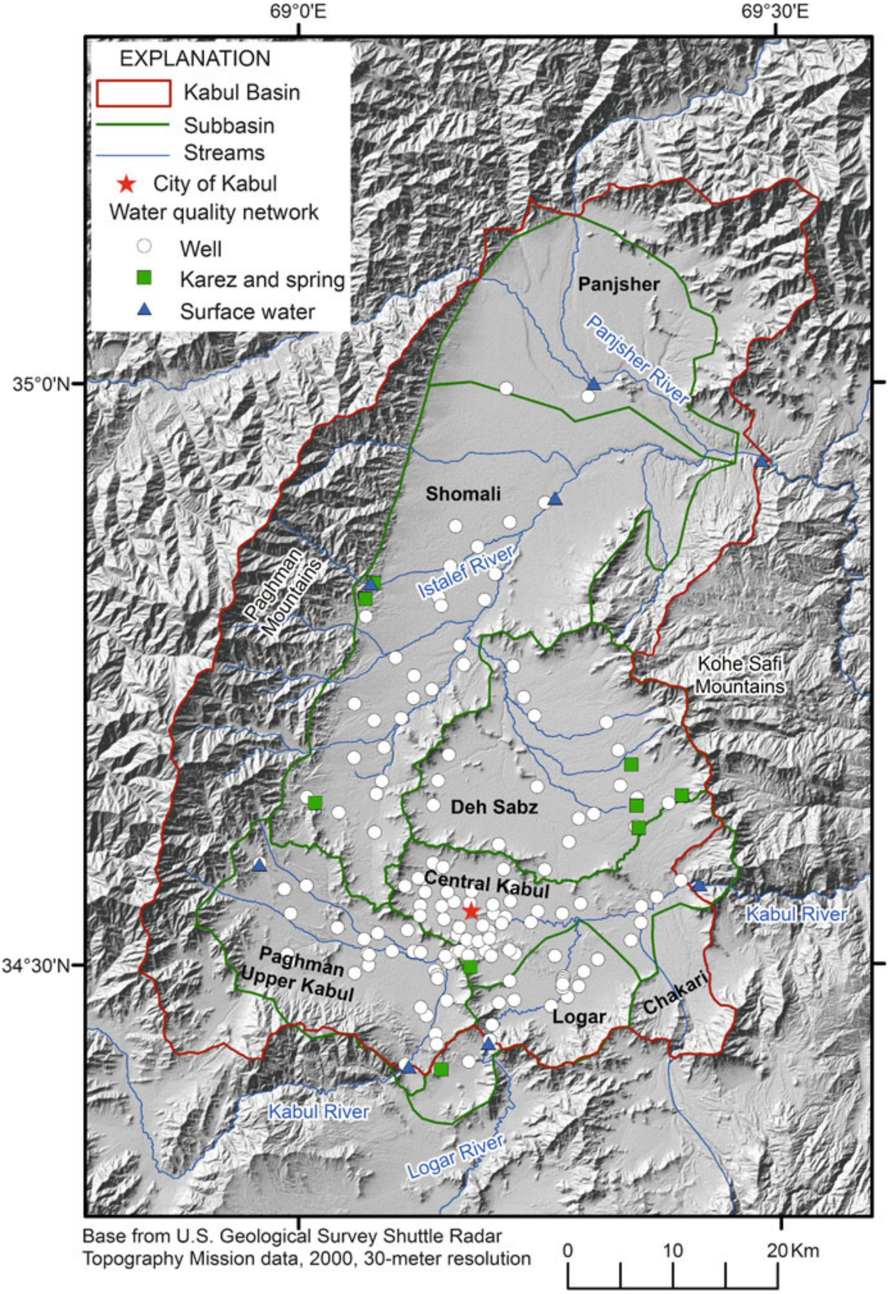


Fig. 11.8 Water-quality sampling network in the Kabul Basin, Afghanistan

to 1,177 μS/cm in the city. The most notable concern for water quality was the presence of bacteria; total coliform and *E. coli* were detected in nearly all the groundwater samples in the basin. These indicators may be the result of poor sanitation and poor well construction.

11.1.3 Sustainability Considerations

Sustainability considerations in the Kabul Basin include the supply of water to shallow wells and the effects of potential climate change on water supply.

11.1.3.1 Shallow Wells

There are many shallow wells in the Kabul Basin that provide potable water to communities near military installations. Between 1997 and 2005, DACAAR and other nongovernmental organizations (NGOs) installed approximately 1,500 shallow wells in the Kabul Basin, with a median depth of 22 m. About 1,000 of these wells are in the three subbasins that include the city of Kabul [17]. About 25 % of the NGO wells that have a reported status in the city of Kabul were dry or inoperative compared with about 20 % basinwide. Groundwater declines of 4–10 m occurred in the city of Kabul during the drought period of 1998–2002 [18, 19]. With an improving standard of living, per person water-use rates and other water uses in the Kabul Basin likely will increase from current rates as will the likely number of dry shallow wells.

11.1.3.2 Climate Trends and Predictions

Although few data are available for comparisons, previous (1961–1991) and recent (2003–2007) mean monthly temperatures indicate a general warming trend throughout the year [12]. The largest change has been an increase of 5 °C in the month of February. Vegetation trends from remotely sensed data indicate that the large increase in February temperatures is likely to have been consistent from 1992 through 2002 when temperature data are missing. The rate of change has been about 1 °C for every 5 years since the early 1960s; although variable, the temperature continues to be higher than past measurements. Trends of this kind are expected to continue throughout the twenty-first century, particularly in mountainous regions [20], including Central Asia. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) described twenty-first century projections of climate under various scenarios of greenhouse-gas emissions. An increase in surface temperatures in mountainous regions around the world is predicted fairly consistently by global models. In temperate mountainous regions, the snowpack may respond rapidly to small increases in temperature. These changes could reduce the snowpack thickness and affect the timing and magnitude of snowmelt because, as warming increases, a greater fraction of precipitation will occur as rainfall. Modeling by Milly et al. [21] projected a 20–30 % decrease in runoff for Afghanistan by 2050 as a result of climate change. The implications for water resources at military installations and elsewhere in the Kabul Basin may be a reduction in the amount of water available for supply.

11.2 Methods for Framing a Conceptual Model of Sustainability

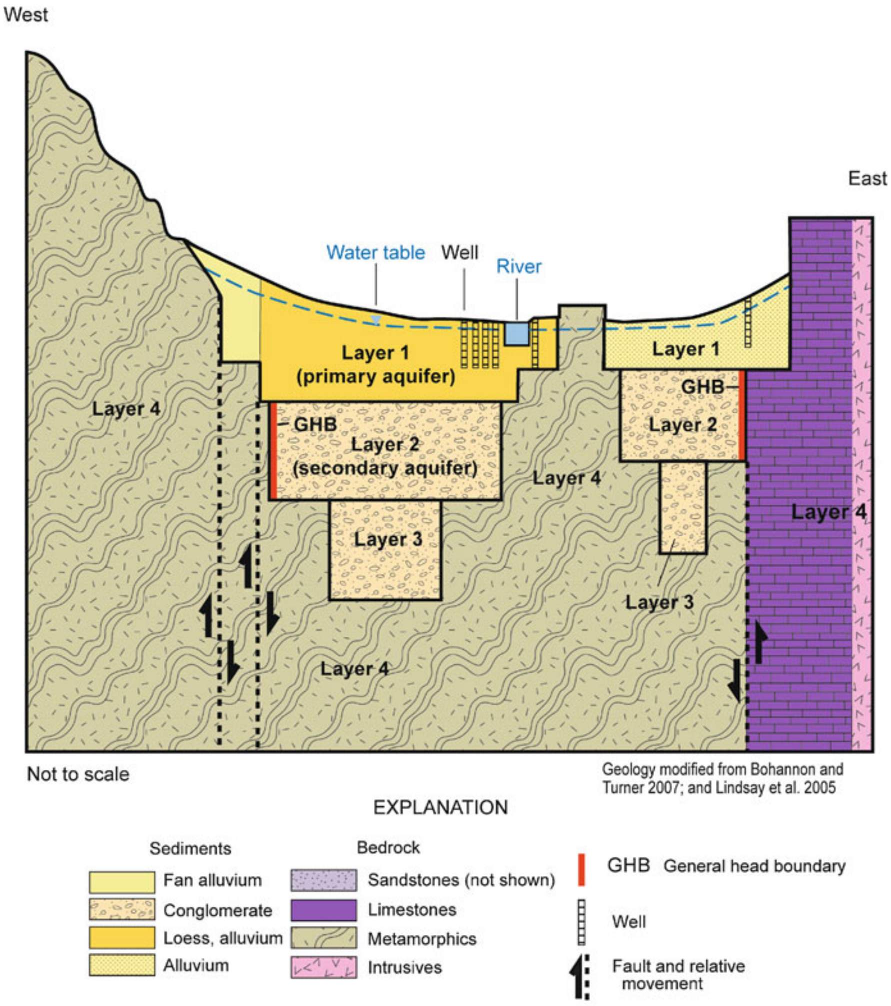
11.2.1 Chemical and Isotopic Analyses of Water Quality

Surface-water and groundwater samples were collected from May 2006 through July 2007 and analyzed for (1) stable hydrogen and oxygen isotopic composition, (2) major- and minor-element chemical composition (30 elements), and (3) dissolved-gas composition (nitrogen, argon, carbon dioxide, oxygen, methane, helium). The apparent age of the sampled groundwater was estimated using chlorofluorocarbons (CFCs) trichlorofluoromethane (CFC–11), dichlorodifluoromethane (CFC–12), and triclorotrifluoroethane (CFC–113), tritium (3H) content, and carbon 14 (14C, two samples). Chemical constituent or isotopic composition samples included 80 groundwater and 76 surface-water samples. Mass fractions (picogram of constituent per kilogram of sample) of CFC–11, CFC–12, and CFC–113 were measured at 35 wells between May 2006 and June 2007, 6 springs in May and June 2006, and 14 surface-water sampling sites in February and June 2007. Samples were collected in a variety of settings, locations, and depths to help identify the source characteristics of groundwater recharge. Detailed descriptions of the chemical and isotopic methods of USGS–AGS water-quality investigations in the Kabul Basin are presented in Broshears et al. [22] and Mack et al. [12].

11.2.2 Conceptual Model and Groundwater Flow Simulation

A conceptual model of the Kabul Basin was designed to assess the regional groundwater flow system, including shallow unconsolidated sediment, deep semi-consolidated sediment, and bedrock aquifers, using MODFLOW-2000 [23, 24], a steady-state finite-difference groundwater flow model; the modeling analysis incorporates information provided by isotopic analyses. The lithology was grouped by major hydrologic characteristics (primarily hydraulic conductivity) from surficial geology [25, 26] to form general geohydrologic zones (Fig. 11.9).

The model area was subdivided into a grid of 400-by-400-m cells, aligned with the primary axis of the Kabul Basin, and divided vertically into four layers



Geology modified from Bohannon and Turner 2007; and Lindsay et al. 2005

The west and east side of the section approximately coincide with the watershed boundary for the Kabul Basin shown on figure 1.2.

Fig. 11.9 Generalized hydrogeologic representation, including numerical-model layers, of the Kabul Basin, Afghanistan

(Fig. 11.9). Layer 1 represents the primary surficial aquifer, consisting of unconsolidated sediment typically less than 80 m thick; layers 2 and 3, each 500 m thick, represent the secondary aquifer, consisting of semiconsolidated conglomeritic sediment and bedrock; layer 4 is 1,000 m thick and represents the underlying bedrock at depth. Flows into and out of the model area included major streams, areal recharge from precipitation, inflows (head-dependent boundaries) at mountain fronts, leakage in irrigated areas, and domestic and commercial water use.

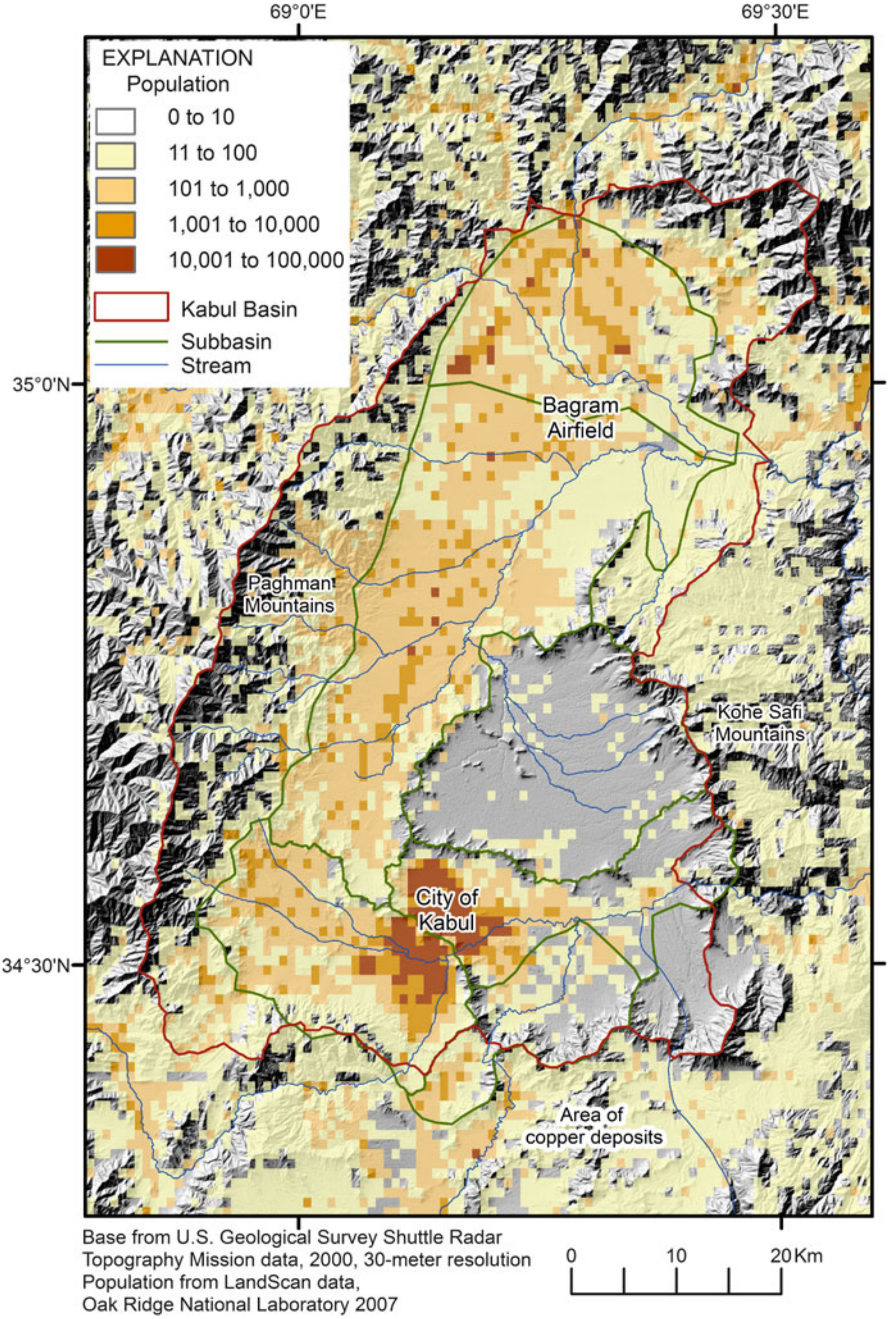
Water use in the model can be grouped into two major categories: (1) combined municipal and domestic use and (2) agricultural irrigation. Municipal and domestic use was estimated using an assumed annual average per person water-use rate of 30 L/d (11 m^3/year) in rural areas and 40 L/d (15 m^3/year) in the city of Kabul applied to a 2005 regional population distribution estimated by the Oak Ridge National Laboratory [27] LandScan project. The estimated population by 1-km grid cells ranged from 0 to 10 in rural areas to about 62,000 in the city (Fig. 11.10). Populated areas indicate where water is or has been available from karezes (a historical water supply system that accessed the water table), streamflow diversions, or shallow groundwater wells.

Currently (2012), there are few waste water systems in the Kabul Basin; waste water is discharged in leach fields on site or, in many cases, residents use nearby drainage ditches. Agricultural water use was estimated by an energy-balance method and remotely sensed temperatures [28]. Agricultural water use occurs primarily in northern subbasins and to lesser degree in the southeastern subbasins and is almost entirely supplied by karezes and streamflow diversions (Fig. 11.11).

Steady-state groundwater flow in the aquifer system was simulated using mean annual inflows and outflows (Table 11.1). The groundwater flow model was calibrated to recent (2007) water levels and historical (pre-1980s) stream flows. Because of limited streamflow data suitable for calibration, the model is considered to provide a conceptual understanding of the groundwater flow system and probable flow conditions rather than a fully calibrated understanding. The general structure of the groundwater flow model is shown in Fig. 11.9. Total base flows, river inflows, estimated upland drainage, and estimated direct recharge were compared with outflows at the Panjsher and Kabul Rivers from the northern and southern basins, respectively (Fig. 11.4, Table 11.1). The total inflow to the northern subbasins is about five times the total inflow to the southern subbasins. Detailed discussion of the numerical representation, simulation of inflows and outflows, and model limitations are provided in Mack et al. [12].

In the lower altitude areas near the centers of the subbasins, the simulated groundwater levels (Fig. 11.12) were generally within 10 m of the observed levels and generally matched regional measured levels. Larger errors were apparent near the valley walls where some simulated levels were much lower than the observed levels. Groundwater flow conditions are often difficult to represent accurately near valley walls or other areas with large contrasts in hydrogeologic environments. Although levels simulated by the model may not be accurate at a local scale, the model can be used to simulate the regional groundwater flow system and the effect of natural and anthropogenic stresses on the system.

Simulated groundwater levels (Fig. 11.12) illustrate the effects of recharge to the surficial aquifer due to leakage from the perennial streams that drain into the valley from the Paghman Mountains. Additionally, the amount of streamflow entering the northern Kabul Basin, which contributes leakage on irrigated areas, is much greater than the streamflow entering the southern Kabul Basin (Table 11.1 baseflow in; Fig. 11.4). Chemical analyses indicate that mountain-front recharge adjacent to



Base from U.S. Geological Survey Shuttle Radar Topography Mission data, 2000, 30-meter resolution
Population from LandScan data, Oak Ridge National Laboratory 2007

Fig. 11.10 Estimated population distribution in the Kabul Basin, Afghanistan, in 2005 (Data are from Oak Ridge National Laboratory [27])

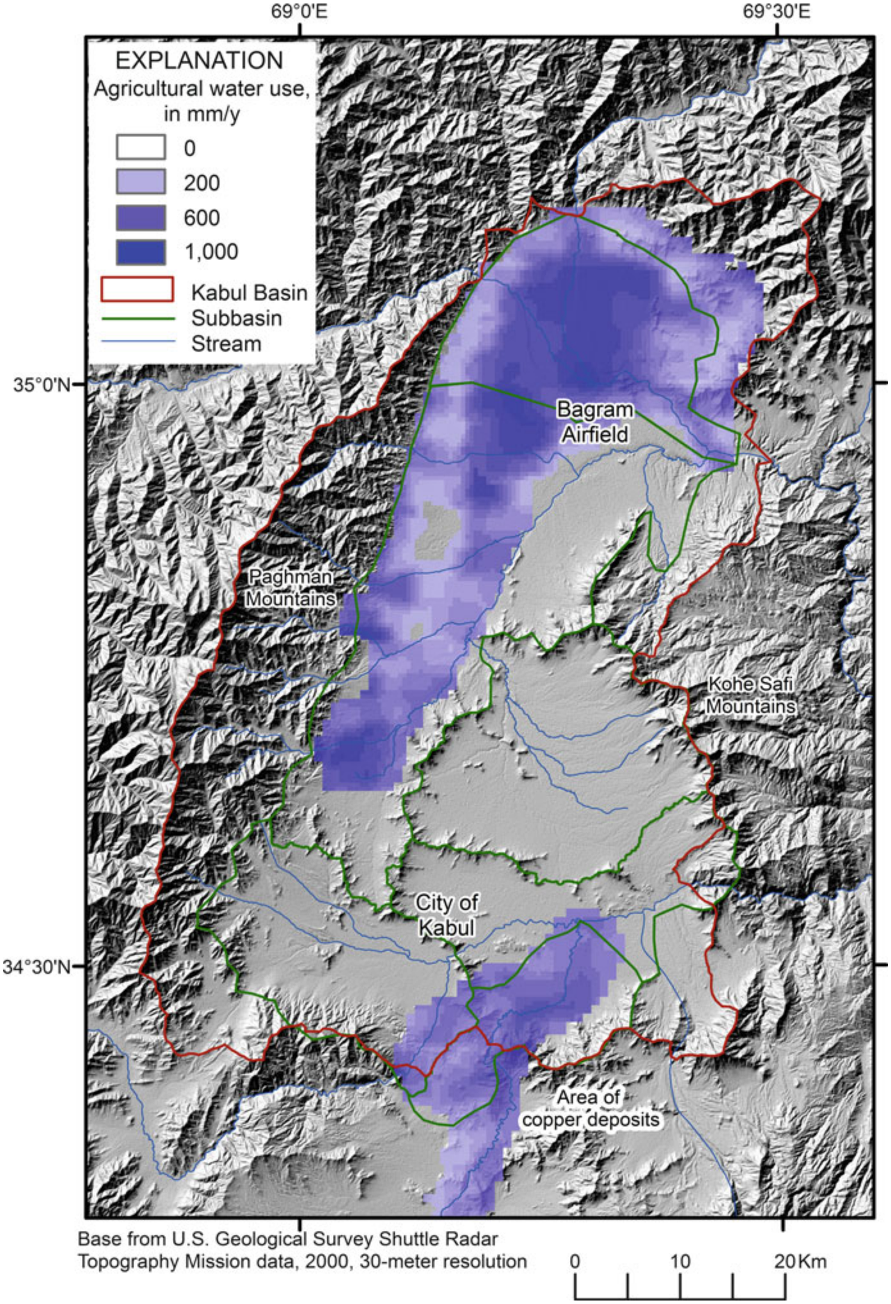


Fig. 11.11 Areas of agricultural water use in the Kabul Basin, Afghanistan

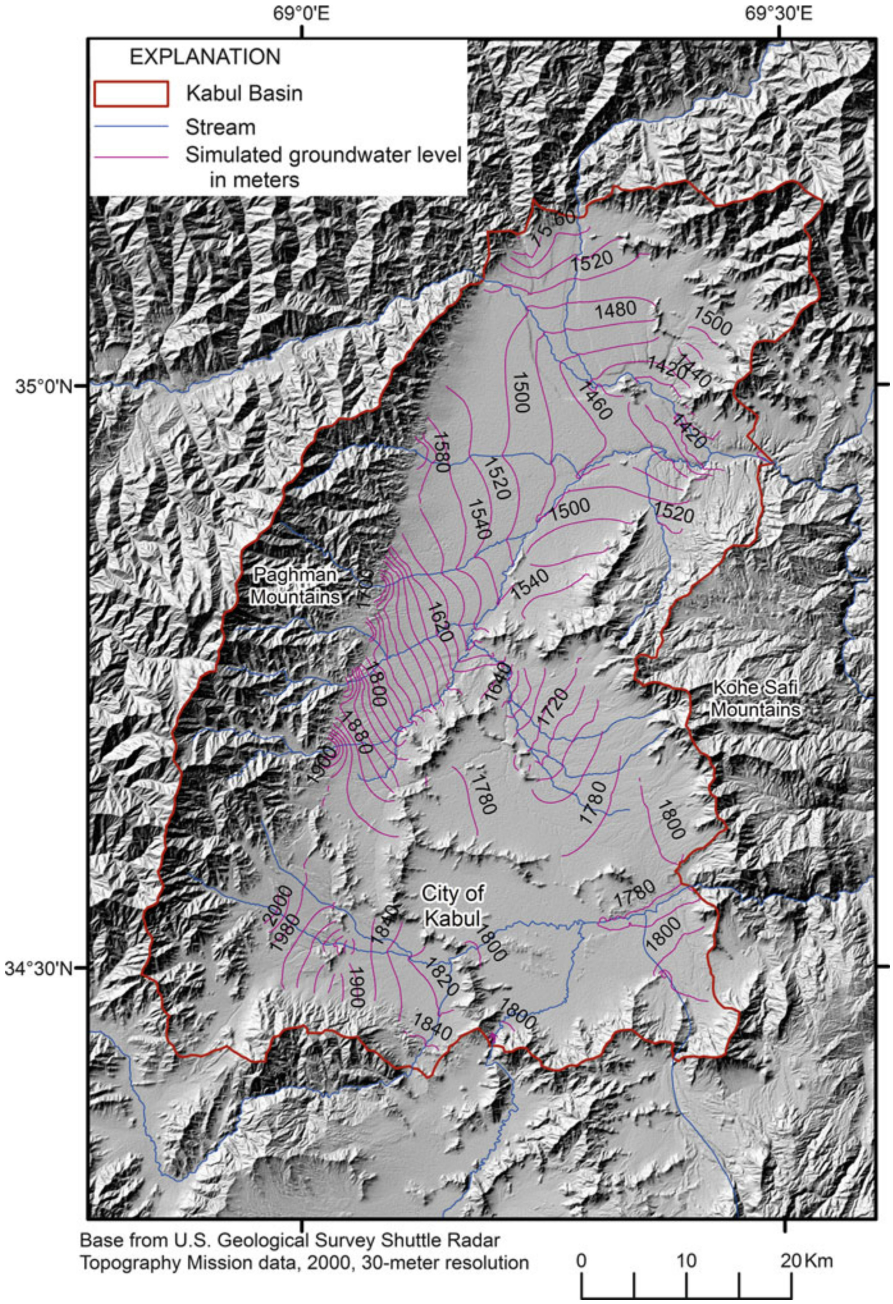
Table 11.1 Annual mean balance of water in the (a) northern and (b) southern subbasins of the Kabul Basin, Afghanistan

Flow	Drainage area, in km^2	Recharge rate, in m^3/day
a. Northern subbasin areas (Panjsher River and Shomali subbasins)		
Inflow:		
Base flow:		
Gorband River	4,032	1,775,435
Salang River	435	837,178
Panjsher River at Gulbahar	3,538	3,723,924
Shatul River	202	290,461
Recharge at a rate of 0.00067 m/day	–	–
Upland drainage from Paghman Mtns.	321	468,686
Direct recharge on subbasin surfaces	1,698	1,940,571
Total inflow	–	9,036,256
Outflow, base flow at Panjsher River at Shuki	10,857	6,150,398
Difference between inflows plus recharge and outflow[a]	–	2,081,599
Inflow as a percent of outflow[a]	–	134
Loss, estimated evapotranspiration	700	915,422
b. Southern subbasin areas (Paghman, Central and Upper Kabul, Logar, and Chakari subbasins)		
Inflow:		
Base flow:		
Paghman River	424	49,524
Kabul River at Tangi Saidan	1,663	303,903
Logar River	11,461	690,416
Chakari River	302	25,744
Recharge at a rate of 0.00067 m/day	–	–
Direct recharge on subbasin surfaces	780	891,429
Total	–	1,589,587
Outflow, base flow at Kabul River at Tangi Gharu	14,556	1,078,018
Difference between inflows plus recharge and outflow[a]	–	511,569
Inflow as a percentage of outflow[a]	–	147
Loss, estimated evapotranspiration	110	51,547

Flows and rates are accurate to no more than two significant figures; data are shown unrounded for computational purposes only

[a] Because of changes in storage, unknown components in the water balance, and inflows and outflows being annual mean values, inflows do not necessarily equal outflows

the Paghman and Kohe Safi Mountains is an important source of recharge to the Kabul Basin (Fig. 11.12). The stratigraphy of the Paghman Mountains comprises metamorphic rocks, which generally have relatively low groundwater storage and transmissivity. Because there are a number of faults along the western mountain front of the Kabul Basin, along the Paghman Mountains (Fig. 11.2), the bedrock is likely to be more highly fractured and to have higher groundwater storage and transmissivity than rocks elsewhere in the Kabul Basin.



Base from U.S. Geological Survey Shuttle Radar Topography Mission data, 2000, 30-meter resolution

Fig. 11.12 Simulated groundwater levels in primary surficial aquifer (model layer 1) in the Kabul Basin, Afghanistan

11.3 Application of Sustainability Analysis to the Kabul Basin

The effect of an estimated population of nine million [12] in the Kabul Basin in 2057 on water resources was simulated by increased domestic and municipal withdrawals in the surficial aquifers. Estimating the sustainability of water in the Kabul Basin requires estimating the balance of flow in the system through a combined use of numerical modeling and detailed isotopic analysis of groundwaters and surface waters. A general water balance consisting of mean base flows in and out of the rivers in the Kabul Basin was calculated for the northern and southern subbasin areas (Table 11.1). Chemical and isotopic analyses of surface water and groundwater help in characterizing the distribution of recharge to the upper aquifer and the source and age of water in the lower aquifer to improve the analysis of groundwater sustainability.

11.3.1 Chemical and Isotopic Analyses of Water

The samples most depleted in stable hydrogen and oxygen isotopic composition (^{2}H and ^{18}O) were those from the Panjsher River; this isotopic result reflects snow melt from high-altitude source areas. Samples from the Istalef and Paghman Rivers (Fig. 11.8) were most enriched in ^{2}H and ^{18}O; this result is consistent with the relatively low-altitude source areas for these rivers in the foothills of the Paghman Mountains west of the Kabul Basin (Fig. 11.1). None of the surface-water bodies studied were affected by significant evaporation.

Some groundwater had chloride concentrations as high as 1,650 mg/L, which is 10–50 times greater than that in surface waters. Had these chloride enrichments been caused by evaporative concentration, there likely would have been substantial enrichments in ^{2}H and ^{18}O. This finding that the surface water and groundwater chemical compositions were similar suggests that there was little evaporation prior to recharge. Mass concentration ratios of some of the dissolved solutes to dissolved chloride in groundwater were similar to the ratios in nearby surface-water samples. The similarities of the mass ratios of more conservative solutes (sodium, sulfate, manganese) with chloride in groundwater to the same ratios for surface water together with the isotopic data suggest a surface-water source (river and irrigation leakage) for many of the groundwater samples.

All the water samples analyzed from the upper aquifer, springs (essentially groundwater discharge), and surface water contained CFCs and tritium and can be considered young water (post-1945). An ^{3}H concentration greater than 0.5 tritium unit indicates waters that are post-1955 in age or waters that are mixtures of pre-1955 water with post-1955 water. The presence of CFC–11 or CFC–12 indicates waters that are approximately post-1945 in age or are mixtures of old (pre-1945) water with young water, and the presence of CFC–113 indicates post-1957 water or mixtures of pre-1957 water with post-1957 water. The median mass fractions of CFC–11, CFC–12, and CFC–113 in 41 groundwater samples (35 wells and 6 springs) were 309, 221, and 39 pg/kg, respectively. In unmixed samples (samples not diluted by mixing with old water), these median CFC volume fractions correspond to median groundwater ages of 30, 21, and 21 years, respectively (Table 11.2). Because most of the samples are pumped from open boreholes, the CFC mass fractions are likely measured in mixed water, and thus the age is referred to as the median or apparent age. Two ^{14}C samples collected from the top of the lower aquifer, which is used less commonly for water supply, indicate groundwater residence times of hundreds to thousands of years. The results indicate that groundwater in the lower aquifer is orders of magnitude older than that of the upper aquifer.

Groundwater samples from the upper aquifer generally are relatively young because they contain CFCs and tritium or are mixtures that contain some young water (Table 11.2). Most samples appear to be water infiltrated from streams and rivers within the past 30 years but the samples likely have been affected by mixing processes. Groundwater age generally increases with depth below the water table (Fig. 11.13). The observed depth-to-age gradients suggest infiltration rates, adjusted for an assumed porosity of 25 %, of 0.35–0.7 m/year. These rates are considerably greater than estimated basinwide recharge rates because the samples were collected primarily from irrigated areas where infiltration of surface water may locally contribute a large portion of the total recharge. However, the results for one sample near the Kohe Safi Mountains did not follow the general depth and age trend (Fig. 11.13). This sample was from a deep well at the eastern area of the Deh Sabz subbasin (Fig. 11.1) where there is likely to be relatively little direct recharge and no recharge from irrigation leakage. The anomalously young age of this sample suggests a relatively rapid source of groundwater inflow (mountain front recharge) from the adjacent Kohe Safi Mountains.

11.3.2 Sustainability of Groundwater Resources in the Kabul Basin

Based on analysis of projections from United Nations Population Division [31] and United Nations Economic and Social Commission for Asia and the Pacific [29], population growth and increasing per capita water use were estimated to result in about a sixfold increase in total annual municipal and domestic water use by 2057 [12]. For purposes of this analysis, the population distribution (Fig. 11.10) and the extent of and use of irrigation water were assumed to be the same as recent (2007) conditions.

A sixfold increase in water withdrawals from the upper aquifer and subsequent water distribution following current population patterns could cause many existing shallow wells to become dry. The simulated groundwater declines (drawdowns), ranging from 2 to 40 m, are largest in urbanized areas, particularly the center of the city of Kabul (Fig. 11.15). The mean depth of NGO-installed community supply

Table 11.2 Summary of average ages, percentages of young water, and percentages of modern water based on concentrations of CFCs, tritium, and carbon 14 in groundwater in the Kabul Basin, Afghanistan

				Average ratio-based ages and percentage of modern water[a]									
	Average piston flow ages, in years[a]			CFC-113:CFC-12		CFC-113:CFC-11		Average percentage of modern water				^{14}C[b]	
Groundwater subbasin or area	CFC–11	CFC–12	CFC–113	Age	Percentage of modern water from CFC–113	Age	Percentage of modern water from CFC–113	CFC–11	CFC–12	CFC–113	Tritium, in TU	Age	Percentage of modern water from $_{14}C$
Kohe Safi mountain front	30	21	20	20	95	11	84	55	81	67	6.1		
Paghman mountain front	28	23	21	23	77	17	71	85	86	68	12.0		
Shomali	23	21	19	15	87	14	81	86	88	81	13.5	300 2,800 0	84 58
Deh Sabz	33	28	24	20	61	16	80	38	52	40	7.6		
Central Kabul	34	28	26	17	66	18	65	63	394	39	8.4		
Paghman and upper Kabul	22	20	20	21	55	14	77	89	162	72	12.1		
Logar	27	21	21	22	92	14	75	65	79	67	10.4		

^{14}C carbon 14, *CFC–11* trichlorofluoromethane, *CFC–12* dichlorodifluoromethane, *CFC–113* triclorotrifluoroethane, *TU* tritium unit

[a] Averages of all samples that could be dated using CFCs

[b] From two samples collected at depths of 73 and 100 m

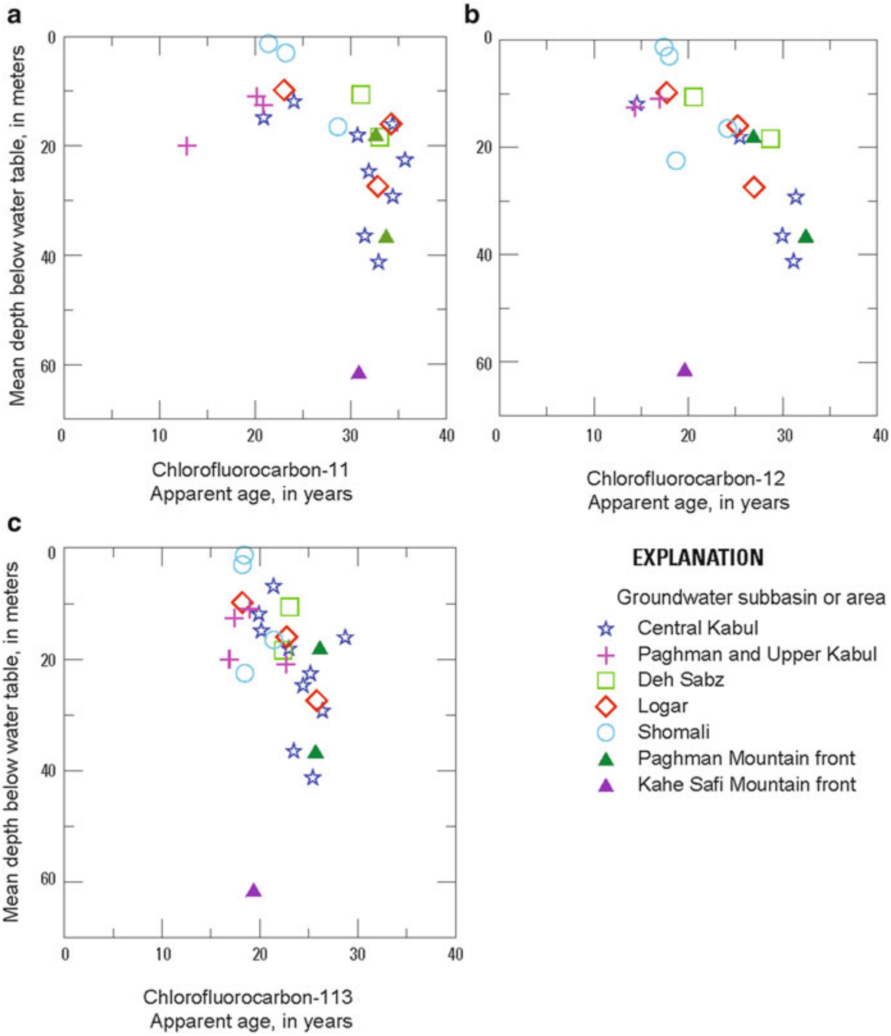
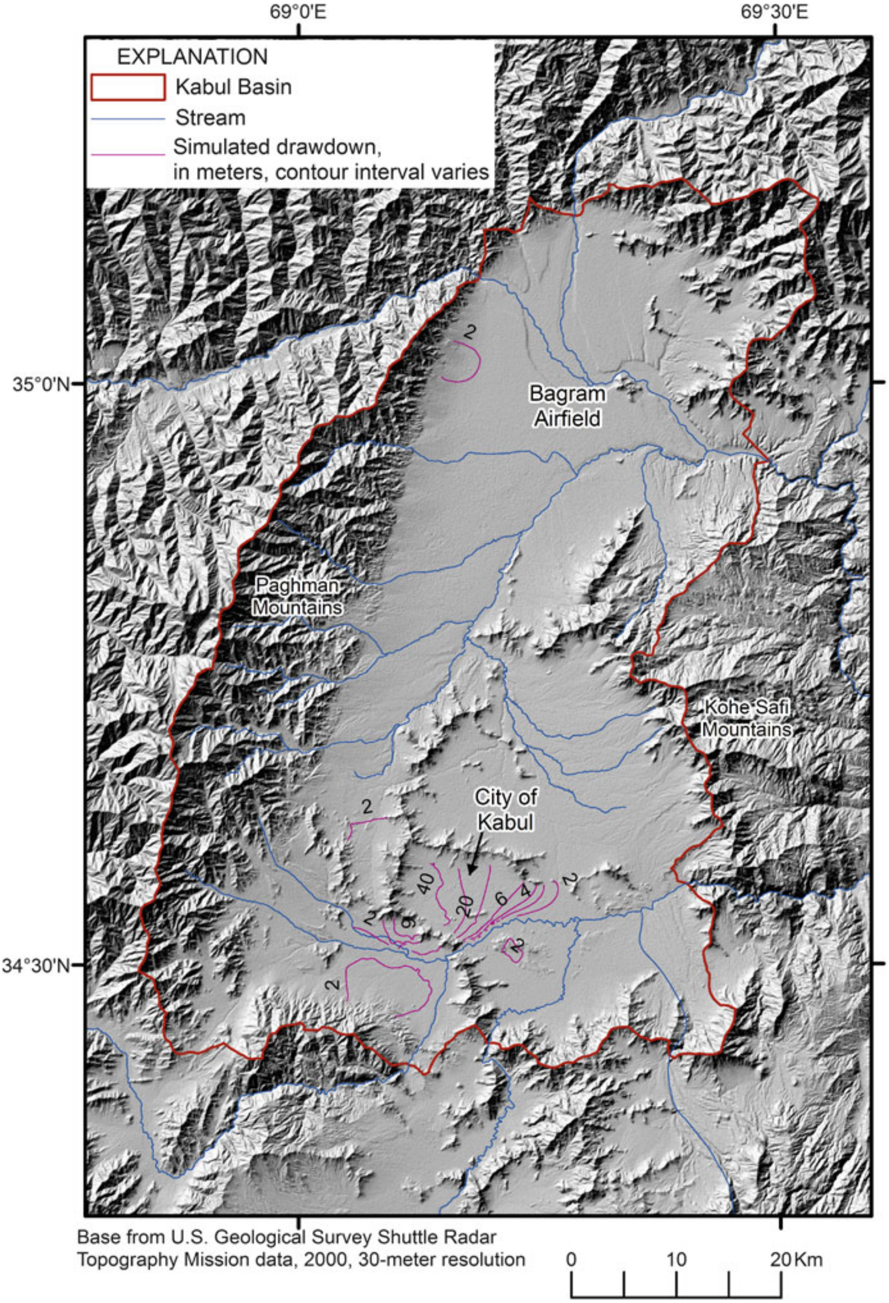


Fig. 11.13 Apparent (piston-flow) ages as a function of depth below the water table based on (**a**) CFC–11, (**b**) CFC–12, and (**c**) CFC–113

wells in the Kabul Basin is about 22 m, and the mean nonpumped depth to water in those wells is about 12 m. Therefore, on average, very little water (a column of about 10 m) is available for drawdown caused by pumping or seasonal fluctuations in water levels. Military installations in the city of Kabul and surrounding areas, which probably have deeper wells than community supplies, may also be affected by simulated groundwater level declines of 10–40 m (Fig.11.14). Military installations in the northern basins likely are less affected due to the greater water inflows in this area (Table.11.1).



Base from U.S. Geological Survey Shuttle Radar Topography Mission data, 2000, 30-meter resolution

Fig. 11.14 Simulated regional drawdown in the upper aquifer caused by a sixfold increase in water use in the Kabul Basin, Afghanistan

Future, more centralized water systems are likely to access water from the lower aquifer for additional water supplies and may not greatly affect water levels in shallow wells As an example, simulations of large groundwater withdrawals (10,000 m^3/day) from six hypothetical wells located in the top 100 m of the deeper conglomeritic aquifer indicate that individual large groundwater withdrawals likely do not substantially affect shallow wells (Fig. 11.15; [12]). However, multiple large withdrawal wells in the deep aquifer, particularly in the smaller subbasins around the city, would likely interfere with each other and collectively could affect water levels in shallow wells. Large groundwater withdrawals may be more sustainable in the northern areas of the Kabul Basin where recharge along the mountain fronts and from surface water inflows are greater. Withdrawals from the deep aquifer also may be free of the bacterial contamination that affects the shallow aquifer. However, groundwater in the deep aquifer, with ages of thousands of years and long flow paths, may have other water-quality characteristics unsuitable for supply, such as high dissolved solids and potentially trace elements, such as arsenic, manganese, and uranium. For example, in the southwestern United States, arsenic was found to increase with longer groundwater flow paths in similar, low-recharge, basin-fill aquifers [30].

11.4 Summary

Complex groundwater resource sustainability questions can be addressed with a hydrogeologic investigation using isotopic and chemical analyses and groundwater flow modeling. Groundwater levels in the Kabul Basin have declined considerably since the 1960s as a result of below-average precipitation in the early 2000s and increasing population and associated water use during the past decade. Declines of a few meters to more than 10 m have been reported between the 1960s and early 2000s for some parts of the Kabul Basin. Further groundwater level declines of more than 10 m have been measured in the city of Kabul in the past decade in areas of concern to military installations of Afghanistan, the United States, and other nations.

Basic hydrogeologic methods, including geologic mapping and water-level and streamflow-data analyses, were used to determine the primary characteristics of the Kabul Basin. Detailed chemical and isotopic information was used to assess the distribution of recharge and determine the likely sources of water in the Kabul Basin. Analyses indicate that much of the groundwater in the Kabul Basin appears to have recharged from surface water, either by infiltration of river water or irrigation leakage. Additionally, groundwater inflow at the mountain fronts is a source of recharge in those areas. The city of Kabul is distant from these sources of recharge and it is estimated that groundwater beneath the city is likely thousands of years old.

Simulated groundwater flow in the Kabul Basin, with the anticipated population growth and consequent sixfold annual water use increase by 2057, indicates that the sustainability of future water supplies may be of concern at military installations in and around the city of Kabul. An analysis of groundwater level trends from 2004

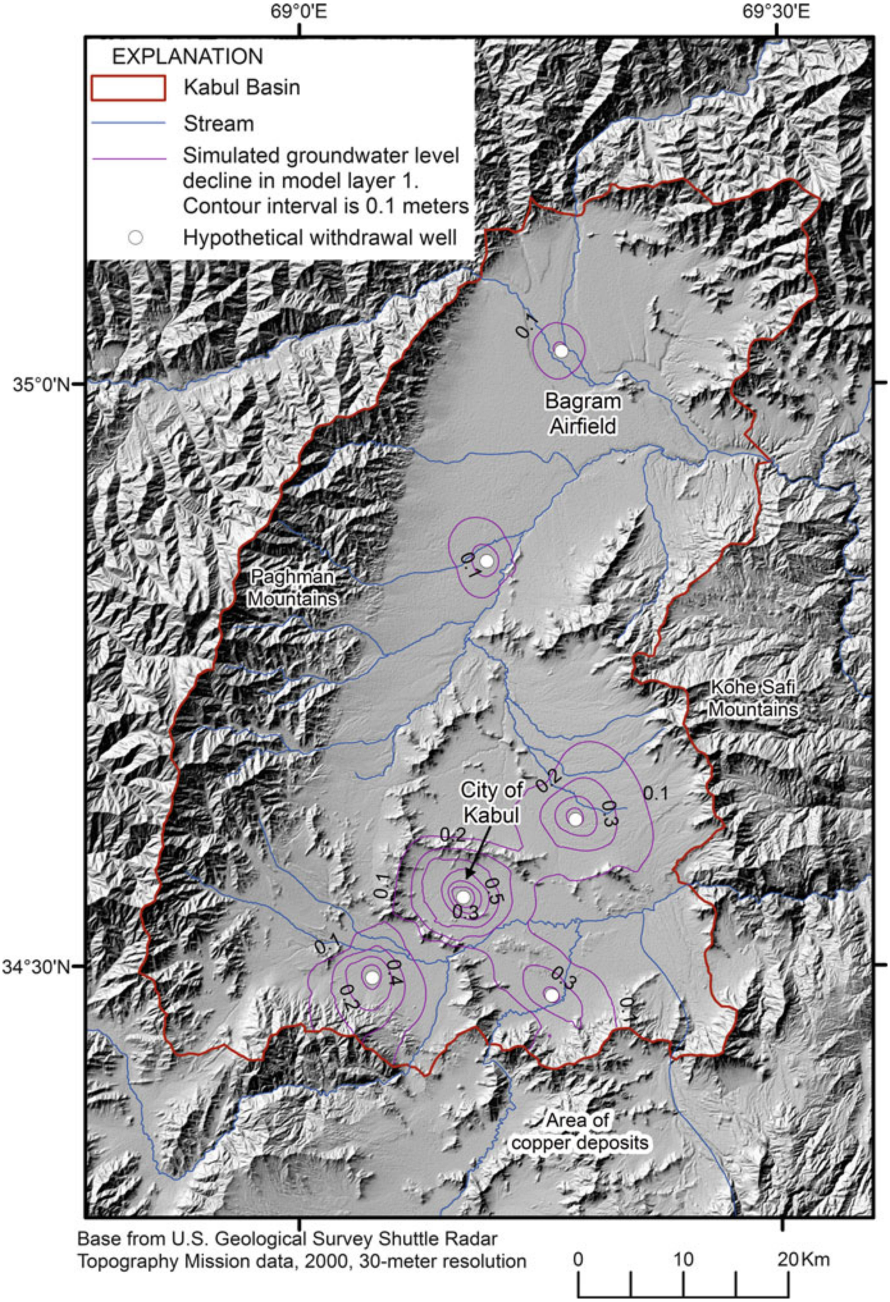


Fig. 11.15 Simulated drawdown in the primary surficial aquifer (model layer 1) by large withdrawals from deep aquifers in the Kabul Basin, Afghanistan

to 2012 produced results consistent with analyses using the groundwater model. The sustainability of groundwater is favorable in the area of the Bagram Airfield in the northern part of the Kabul Basin. Military installations in the Kabul Basin may develop a more secure water supply by completing future water-supply wells in the deeper aquifer, which is less responsive to potential effects of changes in climate and shallow withdrawals. However, careful evaluation and management of new withdrawals, along with monitoring climate trends and effects of other withdrawals, will be needed to protect existing water supplies for the surrounding communities. With uncertainties in the effects of potential climate change and population growth, models that simulate groundwater flow provide a tool for assessing alternate management scenarios for improving the sustainable use of water resources at military installations in the Kabul Basin, Afghanistan.

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Part III
Energy

Chapter 12
Sustainable Energy Pathways for Smart Urbanization and Off Grid Access: Options and Policies for Military Installations and Remote Communities

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Abstract Civilian and military communities alike must pursue innovative approaches to provide resilient, sustainable energy and water sources in the face of global challenges such as climate change, increasing population density, and ever more complex and vulnerable infrastructure systems. Equally compelling is the need for reliable energy supply to remote locations – whether they are military bases, humanitarian refugee camps or communities that have no access to electricity.

We emphasize technological pathways and options that do not rely on a long supply chain and those less reliant upon fossil fuels. To the extent possible, it is ideal to focus initially on highly efficient building, equipment, and infrastructure systems to reduce energy demand, and to harvest energy available on site through energy recovery processes and renewable power generation before applying other

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power sources. Meeting the needs of these communities requires a focus on the development of next generation transmission and distribution infrastructure, in coordination with effective local distributed generation. The concept of a smart energy network that integrates and exploits the power of information and communication technologies with advanced decision-making tools will be an important aspect of developments. Systematically engaging and building understanding amongst stakeholders – from decision makers and regulators, to utility operators, community leaders, and ultimately to community citizens – will be critical to building and sustaining portfolios that meet the diverse acceptability criteria for these next generation energy systems and technologies.

12.1 Introduction

12.1.1 The Functional Value of Sustainability: Local and Global Challenges, Military Requirements

Military installations, small communities, and forward military bases throughout the world face unique energy supply and management issues. Given the importance of military missions and risks associated with disruptive events, military communities and bases need secure energy supplies and resilient infrastructure. Small communities share similar needs to protect the welfare of inhabitants (in terms of quality of life and economic stability). Logistically, there are transportation costs and risks associated with traditional energy approaches, which typically involve extended supply lines.

Within the system/community itself, the failure of one critical infrastructure element due to energy loss could cascade throughout the entire community to affect other infrastructure assets, geographic regions, or economies [1]. These cascades, in turn, pose risks to human health and the environment (e.g., inoperability of functions such as sewage treatment, water purification, life support) [2]. For military installations, the loss of supporting infrastructure, including communications and surveillance capabilities, can render them unable to sustain missions such as training or force projection. Remote areas may lack trained maintenance personnel or access to necessary parts and materials for repairs, extending downtime and increasing risks to the community. A reliable and cost effective supply of energy (electrical, thermal, and transportation fuels) is therefore a critical need.

Paralleling these local challenges, the global dynamics of environmental and socio- economic factors, such as projected energy demands, population growth, and effects of climate change provide a compelling argument for sustainable, resilient solutions. The global energy challenge is constrained by several key factors: the forecasted exponential growth in global energy demand in the coming decades; the uneven distribution of population growth; the continued rise in greenhouse gas emissions from fossil-based energy consumption; and the consequential deterioration of the global environment coupled with stress on the climate system. Climate change must be a driver in the selection of a resilient energy strategy and inform decisions as they relate to future changes in climate, ecology, energy demand, and environmental regulations and policies [3].

The issues of energy access, security and affordability, as well as impacts of energy use on the environment and global climate system are all linked. The challenge of meeting future energy demand is made difficult by the scientific reality that the dominant way we produce energy today is altering our planet's climate and promoting social instability in many regions. More than 68 % of our global electricity supply in 2008 was produced by burning fossil fuels, primarily coal and natural gas, releasing 11.9 gigatons of carbon dioxide into the atmosphere. Most of this carbon dioxide will stay in the atmosphere for hundreds to thousands of years, acting as a greenhouse gas that warms the Earth and potentially disrupts the climate patterns to which our civilization has been accustomed for several thousand years ([3, 4, 74]).

The rhythms of sun and rain, calm and storms, heat waves and cold snaps that societies have taken for granted in the twentieth century are changing, and the long-term climatic impacts of unchecked fossil fuel burning could be severely negative. Warnings to this effect are now coming from the International Fund for Agricultural Development (IFAD), the United Nations World Food Programme (WFP), the Food and Agriculture Organization of the United Nations (FAO), as well as the United Nations Intergovernmental Panel on Climate Change (IPCC). These agencies warn that, if no action is taken, continued expansion and operation of fossil fuel infrastructure will lead to global warming of 2.4–4.6C by 2100 due to high levels of atmospheric CO_2 concentration. The environmental stress resulting from this will create ripple effects that have the potential to undermine the economic livelihood, food supply and security of millions of people [3, 4].

Given the vulnerabilities associated with the limited access to the resources available to larger, more well-connected communities, small, remote communities and installations have additional incentive to adapt to and also mitigate these global conditions. Modernization of the current carbon-based energy infrastructure will need to be synchronized with the requirements of growing demand, the daunting challenges of energy poverty (or achieving military missions while stationed in an energy poor region) and the need to limit or reduce carbon emissions.

In the United Stated, recent Executive Orders and Public Laws have mandated federal agencies to make impactful changes to their approaches of their management of energy, waste, and water to address financial, social, and local community interests. Additionally, the Quadrennial Defense Review (QDR) [5] highlights the military significance of managing waste, water, and energy in efficient and resource-conserving ways that achieve increasing levels of sustainability. Consistent with the challenges enumerated in the QDR, the US Army has begun to move towards a goal of complete Net Zero installations. This holistic approach to addressing energy, water, and waste at military installations is a force multiplier as it enables the military to appropriately steward available resources, manage costs, and provide a sustainable future for our Services. In order to achieve these Net Zero goals, DoD facilities need a means for simultaneously evaluating, designing, and implementing integrated systems that efficiently handle all aspects of the waste, water, and energy streams from energy generation to consumption, sewage, stormwater, greenhouse gas emissions, and solid waste. Installations often focus on each area in isolation, with little or no integration between energy, water, and waste goals.

12.1.2 What Is Energy Sustainability?

The term "sustainability" is often used, but there is not a single, agreed upon definition. For instance, United States Executive Order 13514 defines sustainability as efforts "to create and maintain conditions, under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations" [6]. Mihelcic et al. define sustainability as "the design of human and industrial systems to ensure that humankind's use of natural resources and cycles do not lead to diminished quality of life due either to losses in future economic opportunities or to adverse impacts on social conditions, human health and the environment" [7]. These definitions highlight the need to consider criteria above and beyond simple engineering attributes such as power-output and downtime. They point to a conception of sustainability that integrates environmental, social, and economic criteria in the context of long-term planning and quality of life.

While the concept of sustainability continues to evolve, at the core of sustainability is one key idea - meet the needs of the present without compromising the ability of future generations to meet their own needs. After almost two decades of debate, a consensus emerges around a few ideas such as inter- and intra-generational equity, resource maintenance and efficiency, precaution and adaptation, ecological system integrity and immediate and long-term integration. These are qualitative statements and considerations or high level descriptions of the main factors that should be considered in evaluations of sustainability. Thus, for practical application, a basic framework is necessary for identifying and evaluating a set of criteria based on the requirements of sustainability, specified and elaborated to respect the particular context. Coined by John Elkington, the "triple bottom line" (People, Planet, Profit) has been widely adopted by many organizations, including the U.S. Army [8]. The triple bottom line promotes the responsible use of economic, natural, and social capital [9], or in the case of militaries, it can be modified to substitute "Mission" for "Profit." Decision makers must therefore balance a vast array of (sometimes conflicting) criteria focused on the site-specific needs of the community, which is no simple task. Communities have different sustainability needs based on their unique goals, geographic locations, financial and natural resources, and cultures. In addition, the effectiveness of different sustainability approaches varies geographically (i.e., local, regional, global) and temporally [7]. There is no "one-size-fits-all" solution to sustainability and a sustainability strategy that is not aligned with the needs and goals of the community will be unsuccessful [10].

12.1.3 Reliability and Resilience

Reliability represents the goal of maximizing the probability that a system will perform, or that a resource will be available, when needed. The term typically relates to assurance of functions or capabilities whose failure would have significant consequences over short time frames. Military organizations focus on reliability to assure capabilities of mission critical systems and infrastructure, especially in the event of disruptive events such as natural disasters or attack.

According to the US National Science and Technology Council's Subcommittee on Disaster Reduction, resilience is "…the capacity of a system, community, or society potentially exposed to hazards to adapt, by resisting or changing, in order to reach and maintain an acceptable level of functioning and structure" [11]. Resilient systems are generally less likely to fail under upset conditions, and they degrade "gracefully," meaning that they continue to provide some level of service, even as conditions become more severe. It is a fundamental concept underlying the science of ecology and the process of natural selection which allows survival of the fittest under a range of potential conditions, including new or infrequent ones. The concept complements sustainability in order to preserve both local and global capabilities. However it is not a customary driver in conventional engineering design and operations decision-making, especially when initial cost is a primary focus.

Resilience is an important concept that spans an otherwise unsatisfied gap between notions of sustainability and reliability. The former tends to invoke general criteria in an effort to preserve resources and functionality over relatively long time frames. The polar concept of reliability seeks to protect specific capabilities or functions against failure due to discrete events, such as attack or natural disaster, generally focusing upon short-term protection of the specific function. Resilience is a holistic concept that involves deliberate integration of diversity into the system. Rather than protecting against specific threats or providing for emergency functions, resilient design identifies and reinforces the capabilities that are important to normal system function, while eliminating single-point or common-mode failures. Successful resilience-building requires both a collaborative approach (capturing the diversity among stakeholder perspectives), and systematic analysis to expose important dependencies and failure modes.

In practical terms, resilience naturally lends itself to a hierarchal approach. Local communities can build upon their understanding of system dependencies, including critical functions and resource relationships, to build stakeholder-informed portfolio solutions. Regional collaboration, in turn, enables consideration of social, environmental and infrastructure factors as an underlying texture for interaction among communities, and with national-scale structures, such as energy networks.

12.1.4 Energy Decisions and Decision Making AIDS

The effective selection and management of energy and other infrastructure assets is of crucial importance to small communities and installations. Selecting just one infrastructure asset may be difficult as there are numerous factors to consider, many of which have already been discussed. However, these energy infrastructure decisions are not made in isolation – they contribute to the overall portfolio of infrastructure assets of a community, including energy conversion, storage, and distribution assets, as well as water and other critical infrastructure. An optimal allocation of resources is difficult to achieve given the diversity of asset interdependencies, external stressors (e.g., uncertain climate change scenarios), and different costs (e.g., upfront, maintenance, operations) and benefits (e.g., human health, social welfare). Under budgetary and often legislative or regulatory constraints, difficult tradeoffs must somehow be evaluated to ensure that energy infrastructure investments deliver the "biggest bang for the buck" while simultaneously minimizing potential risks.

The quality of a decision may be evaluated by six elements: framing, alternatives, information, values, logic, and implementation [12] and Keisler extends this framework to portfolio decisions [13]. Portfolio-based approaches can provide a structured and high decision quality methodology for comparing and prioritizing interdependent energy assets for investment or repair under limited budgetary environments. Quantitative portfolio analysis tools based on product portfolio management and modern portfolio theory [14–17] can be applied to decisions about portfolios of infrastructure assets. Portfolio tools may also be used to manage the risks associated with a portfolio [71].

According to the National Research Council (NRC), sustainability is both a process and a goal. To guide the "process", the NRC recommends that impacts of trade-offs between alternative technologies be considered by using a "sustainability toolbox" [18]. Given the need to compare energy investments on difficult-to-monetize criteria such as environmental impacts and social welfare, simple cost-benefit analysis is not a sufficient tool to adequately prioritize alternatives. In addition, traditional economic analyses can break down under choices involving a large group of stakeholders, whose collective preferences are difficult, or impossible, to aggregate, leading to the need for a method that can incorporate the quantitative and qualitative aspects of complex policy choices [19]. Problems with high levels of complexity and uncertainty represent the most difficult class of problems to solve, for both laypeople and experts alike [20].

The process of making complex energy decisions requires the integration of quantitative and qualitative data, and if made on an ad hoc basis, is prone to yield suboptimal results. Multicriteria decision analysis (MCDA) is a tool that is well-suited to complex, multivariate decisions such as energy policy. MCDA can be defined as "an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter" [21]. Many distinct MCDA methods exist, and some methods may be better suited to different types of situations, but in general, all MCDA methods aim to structure the decision making process by comparing and evaluating different alternatives against multiple criteria through the construction of a grid-based decision matrix. Methods differ in their weighting and evaluation algorithms [21–23].

Numerous examples of applications to energy and infrastructure decisions exist where MCDA has been applied. For example, multi-attribute utility theory has been used to make decisions about selecting sites for nuclear power plant construction and nuclear waste storage [24, 70]. More recently, MCDA was combined with scenario analysis to select resilient energy infrastructure in light of future and emergent conditions [25, 26]. In Germany, a small village developed a plan to become a "bioenergy village" using MCDA to assess a set of sustainability criteria [27]. Reviews of MCDA methods for use in the context of energy decisions can be found in Løken [28], Hobbs and Meie[29], and Polatidis et al. [30].

12.2 Key Concepts

12.2.1 The Energy-Water Nexus

Energy and water tend to be strongly linked in practical applications, from cooling water used for various engines and boilers to the need to pump water for useful purposes. Engineers have long alluded to the relationship as the "energy-water nexus."

This principle will continue to grow in importance as population and environmental factors continue to intensify energy and water challenges.

High performance system designs necessarily involve integration and balancing of component system attributes to best satisfy performance requirements. In the context of developing sustainable, resilient community energy and water solutions, this principle is particularly relevant. For example, the design of local energy and water systems must mesh processes such as conversion, control, storage and distribution to take into account factors such as available resources; the scale and nature of community services required; cost factors; and waste stream management.

Hybrid energy systems integrate energy and water technologies in ways that optimize benefits associated with respective characteristics, and leverage resources to meet requirements. Cogeneration is a common hybrid system – using heat rejected from power generation to drive other processes, such as space heating or chemical processes. Applied more broadly, hybrid energy system concepts offer significant opportunities to improve performance across a portfolio of objectives.

12.2.2 Exergy and Energy Quality

Many laypeople and even some professional practitioners are accustomed to relying on the First Law of Thermodynamics for their basic understanding and conventional analysis of energy efficiency and overall energy management. This approach leads to a focus on managing the quantity of energy used, and can be useful to help identify measures to for reduced energy use. However, the Second Law of Thermodynamics focuses on energy quality, rather than quantity. First introduced in the literature in 1956 by Rant, exergy is defined as is the maximum amount of work that can be extracted from a physical system by exchanging matter and energy with large reservoirs in a reference state. This work potential is due to either a potential due to a force, temperature, or the degree of physical disorder. While energy is conserved, exergy can be destroyed. While there is a constant amount of energy in the universe, the amount of exergy is constantly decreasing with every physical process [31]. By analyzing and managing the exergy of a system, it is possible to identify more useful work that is possible, and to conserve and recovery energy in a way that minimizes reduction of exergy.

Minimizing the destruction of exergy can take the form in practice as managing energy quality and optimizing the conversion of energy from one form to another. Known as energy quality flow analysis, this new approach can be applied at any scale, from a single industrial process, to an entire global geological and ecological system [32]. On a level of interest to managers of remote cities and military installations, it can be applied to infrastructure components for power, water, and waste handling. Analysis reveals that integrated resource management practices can achieve synergistic energy, water, and waste management efficiencies in infrastructure operations while capturing resource streams previously "wasted" such as "waste" heat and "waste" water. Fundamentally, sustainable systems with low energy quality loss contain cyclical, rather than one-way processes. However, most infrastructure and other built systems are not designed this way, so a broad category of untapped opportunity for improvement exists. Cyclical infrastructure systems enable the capture of outputs from one process as inputs to another process, rather than allowing output value to be lost, thereby preventing exergy destruction. For example, an installation can design or retrofit sewage treatment systems to allow utilization of heat from sewage digestion for district heating and cooling, much like ground source geothermal systems (reducing greenhouse gas emissions and producing energy). Biosolids can be converted to compost for application as a soil amendment conducive to water conservation. In total, these types of systems can reduce water and energy demand over 50 %. While this approach appears to be a major departure from current infrastructure design, it essentially represents a systems-approach assemblage of existing technology, interconnected to function much like an ecosystem. Results from this approach include the possibility of substantial cost savings, and improved ability to meet or exceed EO 13514 requirements, while fulfilling mission objectives [73].

12.2.3 Energy Security

Energy security is a general concept of assurance that energy will be available to support important functions under a range of conditions. The term is used in diverse contexts and at varying levels. For example, national and international issues of energy availability focus on topics such as geopolitical dynamics, and national concerns such as energy infrastructure vulnerability. Within the military, energy security often serves as an overarching description for energy strategies at all levels. For example, the Army Energy Security Implementation Strategy (US [33]) describes that organization's approach in terms of five pillars:

- Reduced energy consumption
- Increased energy efficiency across platforms and facilities
- Increased use of renewable/alternative energy
- Assured access to sufficient energy supplies
- Reduced adverse impacts on the environment.

Traditional conservation concepts tend to focus on finite capacities of resources or systems, emphasizing preservation of resources for future use. In contrast, energy security typically approaches assurance of capacity against effects of disruptive events over shorter time frames; contextual discussions often invoke aspects of competition, conflict or reliability and resilience.

12.2.4 Resource Consumption

One of the challenges that we have when proposing technologically based energy solutions are due to the availability of materials [34]. Growth in human population has been accompanied by an increasing rate of consumption of natural resources [35, 36]. For several key resources, the use of materials and energy has increased faster than the population growth alone. For many fossil resources (energy, most metals and key elements), the rate of extraction is now so high that it can only with difficulty be further increased [37–41]. In many cases, known resources are dwindling, because prospecting cannot find more. Fossil fuels are arguably the most essential modern commodity that may become scarce during the coming decades [42, 43], but rare minerals and metals, used, for example, in technological instruments, are also not in unlimited supply [44]. New energy technologies, such as transistors, capacitors, electric car batteries, and thin-film solar cells therefore need to be developed according to the long-term availability of their key material ingredients. The limitation of resources will also affect wealth in the world, and peak wealth will follow peak energy and resources by some decades.

Sverdrup et al. [34] used burnoff rates, Hubbert curves and systems analysis to evaluate how long resources will last into the future. They conclude that with business as usual, burnoff rates will be so high that the resources (metals needed for technological advancement, fossil fuels, phosphorous for food production) will not last past this century. They concluded that with the prevailing one way-use paradigm, implying little or no recycling, the Earth cannot feed and sustain seven to nine billion people for very long. They show that there are some important end-times within 100–200 years from now, unless some paradigm changes have occurred. The paradigm change includes policy changes involving both convergence (efficiency, reduce losses, recycling) and contraction (population contraction, less intensive resource use, smaller extraction rates). It will be possible to feed and supply approximately 2.5–3 billion additional people on Earth if we carefully recycle most of the resources (90–95 % should be a target), making sure that we can keep enough material in the cycle, having low restocking demands, because of low losses [34]. They also conclude that bulk energy strategies are at present based on unsustainable thinking and still, quite inefficient use, and partly inadequate technologies. When it comes to public policies and strategic planning for the national states, a complete rethinking must take place in order to step away from self-destructing behaviour. To approach a sustainable situation in our world, recycling must be raised to levels between 80 % and 95 %. These are very challenging tasks both technologically and behaviourally.

12.3 Technical Solutions

12.3.1 Efficiency and Energy Use

It is tempting for planners to focus on novel ways of obtaining energy, such as wind, solar, geothermal, or even small scale nuclear power sources. It has long been recognized, however, that reducing demand is almost always much more cost effective than increasing supply. It can be argued that using less energy in general will always be more sustainable and secure than using more, as conversion inefficiencies and dependence on complex systems are decreased. Legislation and Defense policy can lead the way in promoting the adoption of sustainability goals and strategies, as demonstrated in the United States by the Energy Policy Act of 2005, the Energy Security and Independence Act of 2007, Executive Order (EO) 13423, and Executive Order (EO) 13514. The policy requirements of these documents are far reaching, including a requirement to eliminate fossil fuel use in new and renovated facilities by 2030 and to reduce overall facility energy use intensity by 30 % by 2015. Further, the U.S. Army's strategy for Net Zero seeks to establish eight installations that consume a net fossil fuel usage of zero by 2020 and 25 installations by 2030 [45]. The U.S. Army Net Zero Energy Installation program has evolved to use an optimization strategy that reduces energy loads first, minimizes distribution losses, and then considers alternative sources of supply-side energy, such as cogeneration, biogas, geothermal, etc.) pictured in Fig. 12.1.

What was truly novel in EISA 2007 was the focus on *source* energy. That is, considering not just the energy consumed at the end use (e.g., electricity, heating), but also the source of energy with accompanying conversion and transmission inefficiencies. A study of the five most commonly built facility types in the U.S. Army [46] found that by applying Energy Efficiency Measures (EEM) similar to those used in typical German Passivhaus-style buildings (e.g., efficiencies in air tightness, insulation, windows, mechanical systems, etc.), it was possible to

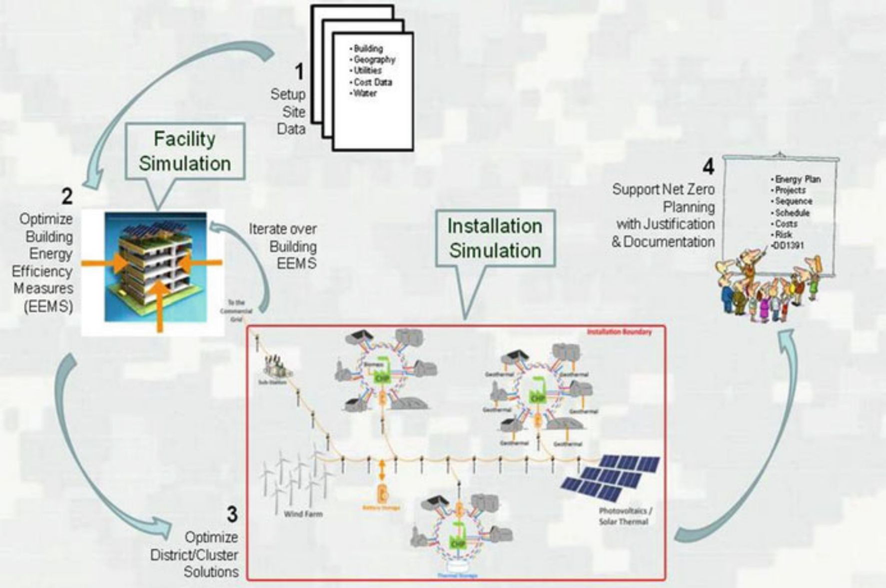

Fig. 12.1 Net Zero Energy Installations Optimization Strategy

reduce energy usage from 9 % to 80 % for each building type and across the 15 climate zones of the United States. Further, it was possible to achieve energy savings of better than 30 % over ASHRAE 90.1-2007 in all building types and for all climate zones. While intelligent application of EEMS can greatly reduce energy consumption in facilities, Net Zero Energy cannot be economically achieved without finding an optimum mix of cogeneration, tri-generation, renewable sources, or other advanced energy supply strategies. The good news is that many of the necessary technologies are available today.

12.3.2 Transmission and Distribution

Energy transmission and distribution networks are fundamentally important to reliability and resilience. The term, "transmission" is generally used in the electric power industry to denote moving electrical energy over large distances at high voltage. "Distribution" refers to moving and managing energy within a local area. While contemporary market forces focus upon energy sources and conversion processes, which largely determine the cost of energy delivered in the marketplace, the distribution system delivers (or fails to deliver) energy to the point of use. Distribution capabilities constrain delivery locations and rate, and represent potentially significant vulnerabilities - as well as the opportunity to provide for flexibility in operation and response to upsets.

Traditional energy transmission and distribution concepts involve simple delivery of energy resources to end users across geographically distributed locations. In the second half of the twentieth century, concepts of networked architectures began to emerge, especially in parallel with development of information networks. The twenty-first century is unveiling an era of “intelligent networks,” which merge information capabilities with various other domains, including energy. The term “smart grids,” for example, refers to electrical power networks that manifest capabilities to improve reliability or quality of service through automated functions such as balancing of load and demand, or by reconfiguring the network in response to disruptive events. Future evolution may extend network concepts across the traditional boundaries of energy domains (for example, electrical, chemical, electrochemical and thermal), such as the notion of “scalable energy networks” [47].

A Smart Grid is a modernized electric system that uses sensors, monitoring, communications, distribution system automation, advanced data analytics and algorithms for anomaly detection to improve the flexibility, security, reliability, efficiency, and safety of the electricity system. It increases consumer choice by allowing them to better control their electricity use in response to prices or other parameters. A Smart Grid includes diverse and distributed energy resources and accommodates electric vehicle charging. In short, it brings all elements of the electricity system – production, delivery and consumption – closer together to improve overall system operation for the benefit of consumers and the environment [4, 48]. Integrating all components of urban planning in the system – smart grids, electric vehicles, charging infrastructure, ICTs, natural gas network, distributed generation, and district heating/cooling networks – to meet the needs, of consumers, communities, municipalities and regions, is the concept of a Smart Energy Network. The Smart Grid’s cousin, the Micro-Grid, is an electric power network with distributed generation, controls, and storage designed to work over a relatively small area. Common agreement is that it is has a capacity lower than 10 MW that can be operated in an islanded mode [49], yet function as part of a larger grid or Smart Grid.

Thermal networks, although prevalent in Europe, are frequently overlooked in many parts of the world. A thermal network is one that distributes energy through pipes in the form of heat (hot water, steam, or cold water). As energy costs increase and an emphasis on emitting lower amounts of greenhouse gases and burning less fossil fuel builds, thermal networks are getting a closer look in many small communities. Barriers to thermal networks include high initial capital cost, thermal losses to the surrounding ground, and maintenance costs. The economics of thermal networks are highly sensitive to the energy density of the community. The higher the density, the lower the proportional thermal losses. When paired with co-generation (combined heat and power) or tri-generation (heat, power, and cooling), thermal networks can play a major role in increasing the efficiency of energy conversion, thus decreasing the use of fossil fuels. When feasible, the use of thermal networks adds flexibility to community energy systems by decreasing the requirement for larger equipment in individual buildings to meet peak loads (taking advantage of non-coincident peaks in the different types of buildings), enabling cost-effective and shared thermal storage, and providing a path for renewable technologies such as thermal solar and wind to distribute energy throughout a community.

No discussion of transmission and distribution would be complete without including losses. In both electrical and thermal networks, losses are incurred in moving energy. In the United States, annual electrical power grid losses during transmission and distribution are about 7 % [50]. These losses are significant when calculating the source energy required to satisfy any particular demand on-site. Experience has shown that losses in aged steam-based thermal systems can be much greater, sometimes approaching 30–40 %, due to poor maintenance, leaks, and thermal conduction to the ground. Modern medium-temperature hot and chilled water systems using new materials and pre-insulated pipe, however, experience much lower losses, on the order of 3–10 %. The overall trend has been away from steam-based thermal systems to either hot/chilled water systems or to complete decentralization.

12.3.3 Energy Conversion

Conversion is integral to nearly every energy process. Most energy harvesting methods involve conversion, for example, from photons (sunlight), kinetic energy (wind or hydro), or fossil fuels to electricity, hot water, or cold water. Energy storage devices for electricity usually convert electrical power to chemical, kinetic, pressure or thermal energy. Real-time distribution and management functions involve conversion, such as transforming, rectifying or inverting electrical power to facilitate transmission or control. Finally, end use devices involve conversion consistent with the function – be they electric motors, fueled burners, pneumatic tools or steam engines.

Although the First Law of Thermodynamics conserves total energy through conversion processes, some of the energy is wasted - usually in the form of heat. As noted in the earlier discussion of exergy, this phenomenon is inevitable because the Second Law dictates an increase in total entropy, or “disorder.” In simple terms, lower entropy equates to more useful energy – higher pressure, temperature or voltage. The greater the entropy increase, the more potentially useful energy is lost in the process.

Since every conversion reduces total utility, there is a fundamental advantage in minimizing conversion processes. This is one rationale for emergent experiments and pilots involving direct current (DC) electrical grids for localized applications such as buildings or small communities. Since solar panels, batteries, electronic devices and many types of efficient lighting operate on DC, the rationale avoids repeated inversion and rectification processes, which compound losses.

The bulk of electrical power worldwide is produced by “heat engines,” using heat from fossil, nuclear, or (rarely) solar sources to produce steam, which in turn is used to drive turbines. Generically, these systems are referred to as thermal power stations. The maximum efficiency with which a heat engine can convert heat to work (to drive an electrical generator, for instance) is limited by the Carnot efficiency, proportional to the difference between temperature of the source and the temperature of the sink to which the energy is rejected. This theoretical limit applies to steam turbines, gas turbines, combined cycles (gas turbine and steam), reciprocating internal combustion engines, Stirling engines, and any other heat engine. Other forms of energy conversion, such as fuel cells (chemical reaction) and photovoltaic solar panels (photoelectric effect) are not subject to the theoretical limit of the Carnot efficiency, but have their own limits. Practically speaking, this means that the efficiency of heat engines in converting heat energy to electricity is in the range of from 33 % (coal-fired steam plant) to 45 % (natural gas-fired combined cycle plant) [50]. A small part of the heat energy is lost to auxiliary equipment, but the majority of the remaining energy is in the form of lower exergy heat that must be either used in another way or rejected to the environment. The overwhelming practice in the much of the world is to reject the heat to the environment, meaning that up to 70 % of energy derived from fossil fuels and indeed most heat sources is lost during conversion, transmission, and distribution. Unless thermal plants are located geographically close to thermal loads that can use their low exergy output, economics dictate that the heat will be rejected. In the spirit of considering the energy-water nexus described previously, it important to recognize that thermal power stations that reject heat in this way are high users of water.

In cases in which there is a significant thermal load close to a thermal power plant, the low exergy heat that would otherwise be rejected can be used for heating, cooling, or industrial processes. Combined Heat and Power (CHP) is an approach where input energy is converted in an integrated approach to produce useful streams of output energy, usually electrical power and heat. The heat, in turn, can be used to produce chilled water with absorption chillers when economically feasible. The terms “cogeneration” and “tri-generation” are sometimes also used to label these CHP concepts. A well engineered system using CHP for electricity, heat, and cooling can achieve 75 % conversion efficiency compared to roughly 49 % for a Separate Heat and Power (SHP) system [51] that uses separate thermal power generation and dedicated boilers and chillers. The physics of energy conversion argue for locating smaller and cleaner thermal power plants close to communities where energy conversion can be done more efficiently by using the heat that would otherwise be rejected. The source of input heat energy can range from fossil sources (coal, petroleum, natural gas) to “renewable” sources such as biomass or solar thermal energy. Even conversion from coal to natural gas will result in significantly lower emission of greenhouse gases, although there are attendant environmental issues associated with modern methods of extraction. Modern CHP plants can be designed with fuel flexibility, so that they can burn natural gas and be switched to synthetic gas from biomass or municipal waste.

When energy conversion is deployed, exergy principles come into play: matching entropy levels across the process to minimize entropy increase. Low entropy sources, such as electrical power or very high temperature steam can be used to drive high energy processes, such as hydrogen production through decomposition of water.

Lower temperature fluids, such as exhaust from such low entropy processes, can still be used for higher entropy processes, such as space heating.

Finally, a discussion of what are traditionally considered "renewable" conversion technologies is in order. Wind energy, solar (thermal and photovoltaic), and hydroelectric technologies have unique economic and technological feasibility positions among energy conversion technologies. Both wind and solar technologies have become less expensive and more efficient in recent years due to technological advances and government policies around the world to promote their use. In general, without the use of government-led policy drivers, however, wind and solar are not financially competitive, except in remote applications. Recent advances in fossil fuel extraction technology have not helped the case for renewables, **unless** additional costs are considered with greenhouse gas generation, global climate change, and energy security. These are social and political considerations that are valued differently around the world. Despite these obstacles, renewables have an important position in moving to more sustainable communities if certain barriers can be overcome. In integrated analyses of community energy, water, and waste systems, renewable options should be included in alternative plans so that informed decisions can be made that take into account technical, economic, social, and political considerations.

Energy conversion can significantly impact sustainability and resilience. In order to maximize energy system efficiency and utility, designers must identify and optimize overall designs, considering conversion in conjunction with other functions of generation, storage, distribution and end use.

12.3.4 Storage

Renewable energy sources offer a great potential for producing energy on a large scale, suitable for sustainable cities and military installations, with low greenhouse gas (GHG) emissions. The challenges are how to capture these dilute, low energy-density, intermittent, variable and geographically dispersed energy resources where they are needed and when they are needed, at reasonable cost. Intermittency and variability are a substantial problem for modern electrical grid systems that have been designed primarily to accommodate constant, baseload energy from sources such as natural gas and coal-fired power plants, hydroelectric dams, and nuclear power.

A range of options exists for managing the intermittency and variability of renewable resources, each with strengths and weaknesses that differ across scale and situation. Not all storage systems can be applied to electric power utilities that integrate scalable renewable-based generation. When considering baseload integration, there are several critical storage metrics that need to be considered. A comparison of how capable each storage system is for grid application is shown in Fig. 12.2.

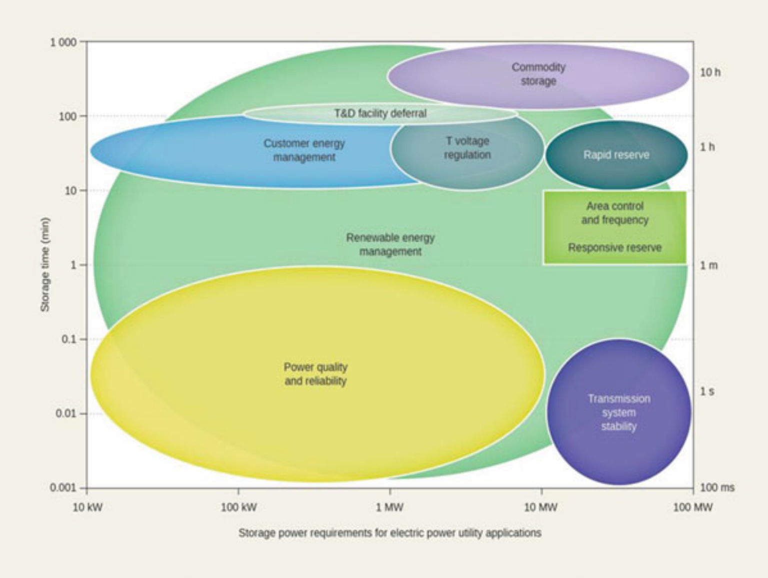

Fig. 12.2 Storage power requirements for electricity power utility applications (Adapted from [52])

Within the four main types of energy storage technology for large-scale grid applications (mechanical, electrical, chemical, electrochemical), electrochemical batteries and flow batteries in particular have the potential to address the intermittency and variability characteristics of renewables. In general, they possess a number of desirable features, including pollution-free operation, high round-trip efficiency, flexible power and energy characteristics to meet different grid functions, long cycle life, and low maintenance. Though less commercially advanced than other storage systems such as lead-acid batteries or pumped-storage hydroelectricity, electrochemical systems such as flow batteries promise considerable commercial value and an effective mitigation of intermittency. These technologies provide direct conversion between chemical and electrical energy, allowing for storage of any source of electricity.

Flow batteries work by storing energy as charged ions in two separate tanks of solutions. To discharge, the electrolyte flows to a redox cell where the electron transfer reactions take place at inert electrodes, producing electric current. The most attractive feature of flow batteries is that power and energy are uncoupled, a characteristic that many other electrochemical energy storage approaches do not have. This gives considerable design flexibility for stationary energy storage applications. The capacity can be increased by simply increasing either the size of the reservoirs holding the reactants or increasing the concentration of the electrolyte. In addition, the power of the system can be tuned by simply modifying the numbers of cells in the stacks, using bipolar electrodes, or connecting stacks in parallel or series configurations. The use of solutions to store energy makes recharging relatively easy through replacement of electrolytes – like refilling a fuel tank. Moreover, flow batteries do not suffer from reactions that can lead to deterioration, which means they could have significantly longer cycle lives than conventional batteries such as lead-acid and lithium.

One possibility of complementing the use of flow batteries is to couple them with Superconducting Magnetic Energy Storage (SMES) systems, which have the characteristics of fast response and high charge–discharge efficiency. Rapid discharge and response capabilities allow potential implementation of SMES in utility applications such as instantaneous load following, stabilization of system oscillations, spinning reserve capacity and so on. SMES systems have attracted the attention of both electric utilities and the military due to their fast response and high efficiency (a charge–discharge efficiency in excess of 95 %). As with flow batteries, the power utility integration characteristics of SMES denote constraints and limitations if they are deployed as stand-alone solutions; yet the combination of flow batteries with SMES has the potential to complement the comparative disadvantage of each technology [4, 53].

12.4 Social Aspects of Sustainability

12.4.1 Behavior and Judgement

The discussion up to this point has focused on technological and engineering solutions to the problem of achieving energy sustainability, but an important area that has not been addressed is how energy-related values, perceptions, judgments and behaviors of stakeholders influence decision making and long-term planning [54]. Stakeholders are any individual, group or organization that may affect, or be affected by, or perceive themselves to be affected by a potential risk (or opportunity). Decision makers are also stakeholders [55].

Stakeholders' beliefs and judgments of the acceptability of energy technologies and specific projects are driven by their underlying mental models. For example, some communities have always survived without electricity and therefore have different energy values, needs and priorities than more modernized communities. Energy- related decision making must include influences on consumer decision making on the acceptability and use of new technologies. Positive social judgment will enable the behavioral change needed to support widespread adoption of these technologies. Integrating stakeholders' mental models (described in the next section) to building social acceptability of new energy technologies – from energy production from solar, wind, biomass, new nuclear, and hydropower, to Smart Grids and electric vehicles – is critical to building and sustaining positive social judgment and behavior. At the policy, governance and regulatory level, insight into consumers' and stakeholders' values, interests and priorities, along with understanding of the key influences on their behavior and judgment – in short, their mental models – provides the requisite knowledge to shape policies, regulations, programs and communications to speed adoption and acceptance of the new energy technologies and foster and reinforce the behavioral change required for their success.

Through building awareness and providing opportunities for participation, decision makers can gain sustained public support in order to develop and successfully implement sustainable energy solutions and affect long-term behavioral shifts in stakeholders. It is ultimately the responsibility of decision makers to strike a balance between incorporating sustainable principles into legislation – making sure that a suitable institutional framework is in place beforehand which would support them – and managing the input of consumers and private industry.

12.4.2 Mental Modeling

The psychological phenomenon called "mental models" is well established in cognitive and behavioral psychology. Since the 1930s, scientists have been studying the mental models that people use to interpret and make decisions about a wide variety of topics. Over the past two decades, cognitive and decision scientists have created the research base needed to understand mental models in the complex, uncertain environments that many people, agencies, and firms face.

Mental Modeling$^{©}$, built on the foundational work in risk analysis and risk communications, is well-established in the fields of risk analysis and decision sciences [65, 66, 69, 72]. Mental models research is a method for generating the in-depth understanding of factors influencing decision making and behavior required to develop communications strategies, plans, and messages to effectively address people's current thinking on complex issues and enable them to make well-informed decisions and take appropriate action. A person's "mental model" can be thought of as a complex web of deeply, and often subconsciously, held beliefs that affect how an individual defines a problem, reacts to information, forms judgments and makes decisions. One's beliefs on the topic at hand may be complete and correct, or they may have gaps that are consequential to decision making and action. Decades of research and experience has shown that to effectively engage people through communications and enable changes in their beliefs and behaviors, one must first understand their mental models, then design strategies and communications to: reinforce what they know that is correct; address key knowledge gaps and misunderstandings; and reinforce judgments of credibility of the communications and their source. Mental models research allows discovery of critical issues and the identification of gaps and alignments among the values, perceptions, decisions and information needs of differing stakeholder groups.

Achieving favorable social judgment of an electrical power system project or new technology requires first understanding stakeholders' mental models then systematically building shared understanding among stakeholders of the benefits,

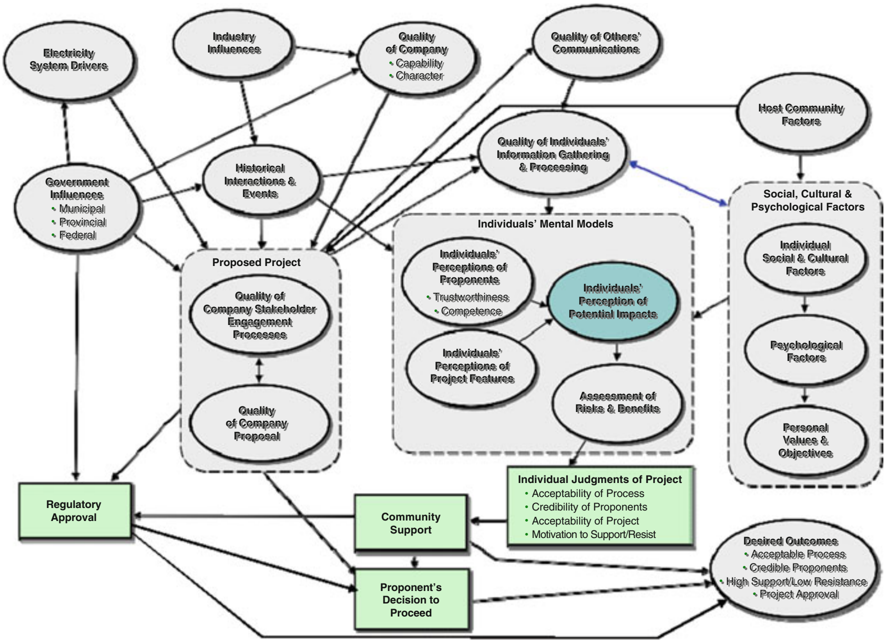

Fig. 12.3 An expert model

costs and risks, including how stakeholders value outcomes and make tradeoffs among them. Key steps in Mental Modeling are: (1) Characterizing the situation (typically in the form of an expert model); (2) Conducting mental models research to reveal in-depth how people make critical judgments and decisions along with their information needs and trust criteria; (3) With that insight, developing precisely focused strategies and communications for addressing the critical decisions, and; (4) Evaluating strategies and communications to ensure they perform as intended, pre- and post- implementation, on changing beliefs and behavior.

A recent assessment of the influences on social acceptability of electrical power systems [56] took a broad approach, from a global perspective, incorporating law, geography, psychology, and social sciences to better understand the factors that influence people's perceptions, decision making and judgments about electricity projects. These were characterized in-depth and used to define how the factors interact to form a "system" of influences that can be addressed by proponents and other systems planners at various stages of the planning process (Fig. 12.3). While the focus of this work was on siting new electricity facilities within a host community, it is applicable to effectively building and sustaining positive social judgment of the acceptability of new energy technologies and facilities – from wind farms and power plants, to transmission lines, to new green technologies for producing electricity, to electricity storage and Smart Grids.

Similarly, expert modeling can be scaled to depict the system at a higher level. As an example, a system model was developed for the Ontario Power Authority as it initiated its Supply Mix submission for the Government of Ontario [57], the first step in developing a comprehensive 20-year Integrated Power Supply Plan. The expert model provided the foundation for an effective, inclusive stakeholder consultation process which was essential to the preparation of Advice to the Minister on the appropriate supply mix to meet anticipated demand in the Province. The consultation process provided OPA professionals with insight into stakeholder interests and priorities with respect to various aspects of the supply mix challenge. In-depth understanding of the range of issues and underlying rationale of stakeholder and public judgment of the future supply mix for Ontario along with the degree to which stakeholders and others felt they had an opportunity to participate in the process in a meaningful way was critical to OPA's success and fundamental to the Province's decision making regarding energy policy.

12.4.3 Social Judgement

Any successful project requires social judgment on the acceptability of the project and its proponents. Social judgment refers to people's thoughtful, considered judgments about issues that matter to them. It calls for a careful weighing of options and the costs, risks and benefits which characterize them. Note the important distinction between social judgment and *public opinion*. Public, or mass, opinion can be thought of as people's top of mind, offhand, "no-sacrifice-for-me" views. Public opinion is often generated through structured surveys ("opinion polls"), asking people to consider hypothetical situations or scenarios with limited context, incomplete information and without consideration of a complex set of factors and tradeoffs.

Social judgment emphasizes coherence and integration of views. It calls for a fair weighing of pros and cons inherent in options and a reconciliation of them. Research and experience shows that, faced with a new power plant, transmission line, or new energy technologies, when given the opportunity, Canadian and U.S. stakeholders typically demonstrate in-depth thinking, thoughtfulness, richness and subtlety and "common sense." They express a need for relevant and credible information, and want to work through the consequences of various decisions, and how options may play out with respect to their interests and priorities and those of the larger community. Table 12.1 highlights the primary differences between social judgment and mass opinion.

The concept of social judgment provides a mutually respectful way to analyze the sources of conflict and seek common ground among the parties. Rather than invoking immutable personal properties (like hysteria or avarice), it frames the research needed to uncover differences in stakeholders' understanding and goals. By focusing on the situation, not the stakeholders, it avoids the interpersonal friction that can give the decision-making process an acrid life of its own. It identifies

Table 12.1 Social Judgment versus Mass Opinion (Source: [58])

Social judgment...	Mass opinion...
Is mature and stable	Is volatile
Emphasizes coherence	Emphasizes diversity
Relies on relevant and useful information	Relies on incomplete information
Looks like a fair weighting	Looks like a knee-jerk response
Involves a higher level of engagement in the issue or opportunity	Involves little or no engagement in the issue or opportunity
Thinking is based on the full context	Compartmentalizes thinking
Reconciles risks and benefits	Emphasizes risk
Understands and accepts consequences	Considers and addresses consequences
Emphasizes values and ethics; includes but goes beyond knowledge	Emphasizes knowledge, information, laws and rights

and expands the role for better data collection and communication. It offers the chance for fewer, but better conflicts – focused on actual differences, rather than imagined ones. It reduces the suspicions that stakeholders will bring to the next conflict. Using mental models to design strategies and communications to focus social judgment is key to addressing information that is relevant to the decisions at hand and useful for decision making, and can help people better understand issues and resolve ambivalence or confusion about them.

12.4.4 Social Friction

Social friction is the societal force operating on public planning processes, such as facilities siting within the electrical power system, which results from complex differences in perceptions, values, and capacity of interdependent stakeholders in that process.

"Not-in-My-Backyard" or NIMBY, and related terms, are not helpful and may even jeopardize constructive dialogue in planning or facilities siting. The primary reason is that they (most often pejoratively) focus, one-sidedly, on individuals or groups rather than the underlying issues (values, risks, benefits) that are at the crux of the range of perceptions often perceived in siting or other projects. They ignore the relationships between multiple stakeholders in the electricity system, including citizens, and their potential role in the successful resolution of the issue and opportunities related to the proposed project. Finally, such terms trivialize the interests and priorities of the individuals affected by the issue. Labeling stakeholders as "NIMBYs" is fundamentally disrespectful and must be avoided, if progress is to be made on building social acceptability of new energy technologies.

Social friction, on the other hand, indicates the broader issues of differences in values, understanding, and constraints facing multiple stakeholders in public planning. A physical term, friction is the force that resists movement between objects in contact. *Social* friction thus focuses on the interaction between stakeholders “in contact” (i.e., interdependent). Broad social engagement of all stakeholders is a critical component of a successful planning project and requires shared understanding of the project need, benefits, costs and risks, and how stakeholders value outcomes and make tradeoffs. Social friction may be a desirable force if it provides traction to “brake” planning or implementation from going forth without due deliberation on stakeholder considerations. It may be an undesirable force if it causes excessively slow or inefficient progression, or halts planning or implementation altogether.

12.4.5 Socio-political Aspects of Sustainable Energy Solutions

The previous sections addressed the influence of behavior and judgment on stakeholder acceptability of new energy solutions, as well as the available tools for understanding what influences social judgment and how effective decision-making and public engagement processes are in mitigating the impact of social friction. It is clear that the development of energy sustainable communities is not only contingent on technical innovation, but also on public support and clear political commitment. By taking into account the costs, risks and constraints associated with the implementation of new technological and engineering innovations, decision makers can make more informed choices when crafting policy, ensure acceptability among their constituents and effect long-term changes in behavior.

The ultimate success of decision makers – the public authorities at local, regional and national levels who have direct influence on the crafting of energy policies and regulations – and support for their energy strategies is bridging the gap between the differing attitudes of stakeholders, since a lack of knowledge on the part of the public can trigger skepticism and even spark protests against energy projects. It is therefore essential that lawmakers spread awareness and simultaneously integrate stakeholder concerns while incorporating principles of sustainability and environmental protection into the planning and eventual implementation of energy policies. Furthermore, the measures taken must also be economically efficient, given the fact that the global economic downturn has decidedly affected the feasibility of implementing new energy strategies which depend on costly technological innovations. The interdependence between these three factors – economic efficiency, social responsibility and environmental protection – is therefore the main task of decision makers and should be taken into account when developing and implementing sustainable energy solutions.

On the economic front, policy makers have a central role to play in finding a balance between efficiency and creating a favorable business environment which will attract investment. Furthermore, given the fact that energy is regarded as a strategic commodity and as such, the energy market has become heavily influenced by regulations and political decisions, appropriate energy mixes for meeting the needs of the community must be balanced with what is economically feasible. The technological innovations necessary to achieve these goals require huge investments. This means that a predictable and well-functioning framework must be in place that will secure commercial interests and attract private investment while safeguarding public interests at large by involving the participation of stakeholders. The costs of implementing sustainable energy solutions can also be minimized by reconfiguring existing institutions with incremental policy adjustments smoothing the transition and sustaining stakeholder acceptability. Ultimately, this combination of measures can facilitate market penetration of new energy innovations and ensure their acceptability by the public. In this way, energy policy will come to drive, and not only be driven by, the costs of technological innovations.

Ultimately, clear commitment on the part of decision makers is needed to achieve goals of sustainability at the political and regulatory level. Competing interests as well as the desire to maintain the status quo prevent the adoption of innovative energy technologies, while a lack of acceptability on the part of the public due to misinformation further compound the problem. It is through clear political support based on an understanding of the different values and perceptions of stakeholders as well as their participation in the planning and implementation of policy measures; the incorporation of sustainability concerns into all levels of policy planning; and the management of private sector and consumer interests that will allow decision makers to gain the support of their constituents and ultimately facilitate behavioral changes which will support a sustainable future.

12.4.6 The Regulatory Environment

In addition to the geographic, ecological, and social environment in which small settlements and installations exist, these communities also exist within a regulatory environment which may pose additional challenges and opportunities. For instance, at US military installations, various energy-related mandates (such as Executive Orders and Army's Net Zero initiative, discussed above) drive energy investment decisions by setting clear and measurable goals that installations must meet. For example, the United States DoD, acknowledging its reliance on fossil fuels, also recognized a growing concern for the natural environment and welfare of soldiers and civilians that is compromised and thus there has been a push for more sustainable practices [59]. The priorities outlined in the 2010 Strategic Sustainability Performance Plan published for DoD include: (1) investing in fixed installations using a three part strategy to reduce energy demand, apply micro-grid technologies, and increase the supply of renewable energy; (2) enhancing governance structures to ensure top level commitment and accountability; and (3) ensuring that all DoD Components are incorporating the concepts of sustainability into their doctrine, policies, and guidance documents. Specifically, eight goals are outlined in regard to fossil fuels, water resources, greenhouse gas emissions, waste management, toxics and sustainability management [59].

Small communities may have similar regulatory drivers. And while sometimes these regulatory forces can motivate communities and installations to achieve ambitious energy goals, they can also present challenges. The processes associated with licensing, siting, commissioning/decommissioning, environmental compliance, and other necessary actions can be complex, time consuming, and expensive. A project could get mired in legal and bureaucratic red tape and delayed for months or years. Residents within a remote settlement may not even know the regulatory or legislative requirements that govern their energy decisions, and incorrect decisions could result in cumbersome and costly delays.

The energy and sustainability strategy of the community or installation should be aligned with the regulatory environment in which the community exists. By making regulation a key aspect of the energy strategy, these communities can better adapt to, and influence, potential energy policies. This requires an understanding of the impacts of regulation on society and the economy, as well as the needs and motivations of stakeholders such that coalitions can be built [60].

12.4.7 Building a Business Case and Innovative Financing

Existing energy system business models impose significant barriers to achieving sustainability and resilience goals at all levels. Investors, especially in US markets, seek near-term return on investment – this favors technology solutions that represent small capital investments and short deployment (development/delivery/construction) times. While Government and communities may value longer-term sustainability and resilience goals, these institutions largely have withdrawn from the energy market, leaving investment, production and delivery to private (albeit regulated) industry. While privatization generally produces more cost-effective solutions and supports economic growth, the withdrawal of public institutions from the investment role has reduced their ability to advance long-term objectives. In order to make up for this decline, there is a need for new business models that enable sustainability and resilience to be factored into investment decisions, even as they foster economic growth. Stakeholder involvement and portfolio management have emerged in recent decades as viable approaches to address community issues, especially in the environmental sector (witness issues such as historic preservation, wetlands and fisheries in the US). New concepts that could be integrated into the marketplace could provide important reinforcing mechanisms.

Worldwide energy pricing is based almost entirely upon the attribute of quantity, with little consideration of factors such as quality (with the notable exception of fuels), availability or impacts/liabilities. This model makes it difficult to provide a resource stream to support investment in technologies that improve sustainability and resilience - despite the fact that these attributes provide value of great importance to society. As an example, US utilities generally are required to purchase renewable energy produced by homeowners, without respect to instantaneous need to meet customer demand. This factor, coupled with generous tax credits, is leading to significant private investment in solar and wind generating systems which, due to the extreme variability in those sources, can wreak havoc in a power grid in which stable control already represents a challenge.

One simple variation in the business model would expand upon the currently limited use of differential pricing (e.g., peak power premium) for electrical power. A local pricing structure ("feed-in tariffs") based upon variations in power line frequency (which actually reflects the balance between supply and demand in real time), could encourage investment in technologies that actually mitigate those instabilities. A customer who installs a large battery, for example, could buy less expensive power when line frequency is high (above nominal 50 or 60 Hz, indicating excess system capacity), and sell it back to the utility at a premium when frequency drops (demand exceeds supply). This concept, suggestive of spot trading of securities, would actually tend to stabilize, rather than destabilizing the system. Other business model changes might enable the market to naturally increase sustainability and resilience; more collaboration and analysis would be required to define such opportunities.

12.5 Putting the Pieces Together: The Case of Sustainable Mobility

12.5.1 Sustainable Mobility

Transportation is an integral part of modern living. The linkages between urbanization and mobility, from a sustainability point of view, are constrained by four factors: energy consumption, greenhouse gas (GHG) emission, population, and transportation infrastructure. Road energy consumption amounted to 1,698 Mtoe in 2010, and is expected to grow to 2,812 Mtoe by 2030, according to the International Energy Agency [61]. Transport is also an important contributor to the GHG emissions of cities, releasing 5,794 Million tonnes of CO_2 equivalent in 2010 which accounted for 13 % of GHG emission worldwide [62]. In addition, some five billion people, approximately 60 % of global population, are expected to live in cities by 2030. A rapid associated growth in personal vehicle ownership will exacerbate the problem of traffic congestion, especially in developing countries that lack adequate transportation infrastructure. These factors present immense challenge to the sustainable development of cities.

Fortunately, the expansion of cities provides opportunities. With good planning and governance, cities can deliver transport services more efficiently and with fewer emissions than less densely settled regions, simply because of their advantages of scale and proximity. In those with high densities that favor public transport, total transport energy consumption is four to seven times less than in cities with low densities. Improvements in how urbanization unfolds can have a significant positive impact on energy use and consumption, and these improvements are discussed below [4].

Transportation integration into the energy system – through electrification of transport, shifting away from personal ownership of vehicles, advanced information and communication technologies (ICT) integration, complemented by advanced transmission infrastructure enabled by superconductors – has the potential to realize personalized modes of low-carbon transport in cities.

The technology to make much of this vision a reality is either available now, or within reach. Infrastructures such as smart grids – allowing ICT to be interwoven with the electrical grid system, along with other enabling elements such as recharging stations – are emerging. Advancement in storage technologies is helping to overcome challenges such as high capital costs, the range anxiety of users, charging flexibility and integration issues.

12.5.2 Electrification of Transport

Recent efforts to reduce dependence on liquid fossil fuels for transportation have resulted in a significant push toward electrification. While other approaches such as biofuels, hydrogen, natural gas, light-weighting and next-generation internal-combustion engines have been pursued with limited success, electrification has presented itself as the option with the highest potential for impact on reduced greenhouse gas emissions and fossil fuel usage.

It is also an option that can effectively make use of existing infrastructure. The advent of several commercial vehicle models demonstrates the readiness of electric vehicles. In 2011, GM and Nissan began selling electric vehicles (EVs) to US drivers. Electric transport in the form of trains, subways, trams and streetcars is also already in use, with widespread acceptance and success. Advances in battery technologies have helped improve the performance and lowered the cost of other forms of electric mobility such as electric bicycles. Electric bicycles have a significant role to play in emerging economies in Asia, Latin America, and Africa, allowing the reduction of air emissions and vehicles occupying road space.

Electric vehicles and the smart grid are closely linked. An intelligent grid can be an enabler for electric vehicles (EVs) by maximizing charging flexibility; without the smart technology component, the grid may be a barrier to the adoption of electric vehicles. The wide adoption of EVs and expansion of recharging infrastructure will put stress on the electricity grid, not only from an increased energy consumption point of view but also from the perspective of information exchange. This means increased coordination among the divisions of the system to enable features such as plug-in hybrid vehicle (PHEV) control, vehicle-to-grid (V2G) control, and managing intermittent demand.

Conventional grid systems are not designed for those purposes; they are primarily a vehicle for moving electricity from generators to consumers. For effective integration of smart transportation, the grid will need to enable two-way flows of electricity and information, as new technologies make possible new forms of electricity production, delivery and use.

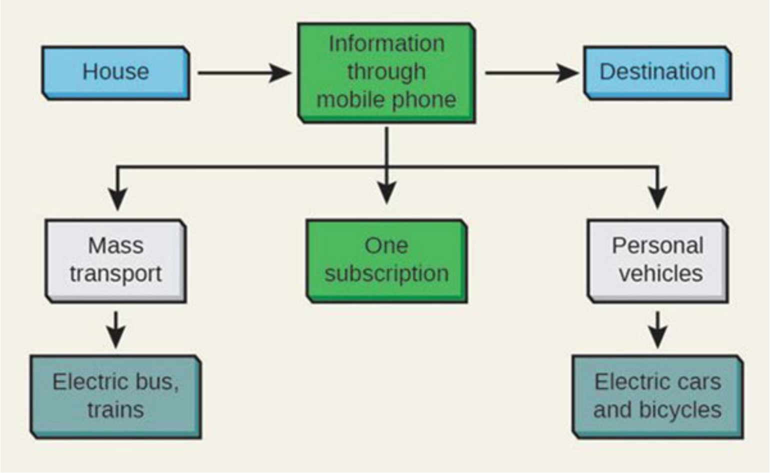

Fig. 12.4 Personalized access to mobility means not having to own transport vehicles [4]

12.5.3 *Personalized Access to Mobility and ICT Integration*

Behavior change will be vital, both for reducing demand overall and in particular, for personal vehicle use. In cities around the world, a number of approaches and technologies have demonstrated success in supporting sustainable urban transportation that exploit a broad range of models moving away from strict private ownership to sharing and leasing.

A transportation system that integrates public and self-powered transportation, information and communication technology, and transportation electrification, as shown in Fig. 12.4, could provide essential speed, convenience, cost-effectiveness, and reliability while reducing energy use, limiting fossil fuel burning and improving health. Greater use of public and self-powered transport can also make a significant impact on reducing traffic congestion. Megacities such as Tokyo, Seoul, and London have excellent public transportation systems that are quick, reliable and cost-effective, encouraging high ridership. These cities have a combination of trains, buses, sidewalks and bike lanes that help residents transport themselves where they want to go in an accessible and convenient manner.

Advances in information control technology (ICT) offer great opportunities to encourage a shift toward greater use of mass transport or vehicle-sharing schemes and away from private ownership. Reservation, payment, and tracking of public transportation with ICT, utilizing smartphones and mobile access to the Internet have been a new application that is being adopted in many cities. Having knowledge of schedules, routes, and real-time status updates for traffic and accidents will make the use of public transportation much more efficient and convenient. Increased convenience helps increase ridership, thus amplifying the benefits associated with the public transport model of sustainable urban transport.

12.5.4 Superconductors for Dense Urban Requirements

The stresses on existing electricity distribution and supply infrastructure will be exacerbated by the growth of the electrification of transportation, and the information and communication technology expansion to meet broadband applications. The existing transmission and distribution system is ageing and its replacement along traditional technologies will not be adequate to meet the needs of a growing urban population and a much higher level of demand for electricity services. Conventional infrastructure for existing transmission lines such as poles, towers and cross-arms are limited in their ability to support the weight of the extra wires required to increase capacity. The electricity supply infrastructure will need to be expanded by some magnitude if electricity becomes a primary source of power for transportation in addition to the demand requirements of a dense urban population for high-quality energy.

Superconductors offer an opportunity to dramatically increase both the capacity and efficiency of power transmission. They achieve this by allowing much more current to pass through much narrower wires and this feature would be a premium in a highly dense urban environment with severe geographic limitations. Super cables, or high- temperature superconducting cables, that would transmit extraordinarily high electricity current nearly resistance-free through superconductivity are capable of delivering the energy for the urban population in emerging megacities.

Just one superconducting cable could replace more than ten copper cables, cutting weight by over 95 % and eliminating heating loss. Superconductive wiring carries about ten times as much power as the same volume of conventional copper wiring. Although some of that power is lost and liquid nitrogen must be used to keep the superconducting cables cool, such cables are still more efficient than copper wiring, which loses 7–10 % of the power it carries as heat. Superconductors may also possess promising attributes related to reliability and quality, due to the characteristics of smart, self-healing power control. Superconductivity offers fast limiting of fault current, avoiding damage to grid and equipment and power interruptions. Demonstration projects currently under development in South Korea indicate the potential for a more efficient and robust Smart Grids [4, 63, 64].

12.5.5 Overcoming Range Anxiety Through Technical and Behavioral Innovation

To facilitate a greater shift to electric cars, recharging stations at central locations and at all major shopping centers are vital to reduce consumer range anxiety. The electric vehicle battery significantly increases the capital cost of a vehicle, due to the advanced materials and technologies required. The limited energy capacity of the battery results in the ‘range anxiety’ phenomenon for drivers who fear they will become stranded during their commute. Charging infrastructure may help mitigate

Fig. 12.5 Solar charging stations of different scales of electric vehicles (Created by the Waterloo Institute for Sustainable Energy [4])

some fears but requires significant investment and also may not be compatible with frequent usage such as car sharing. Fast charging infrastructure faces integration issues as the local grid may not be able to support this feature. Plug-in hybrid options or alternative fuel options are the likely suitable stopgap measures. Charging stations utilizing distributed energy resources for generation can also play a role in reducing stress on the electricity grid, as shown in the Fig. 12.5.

Also, access to transit lanes by electric cars during peak driving times and discounts for free parking in the central business districts (adjacent to recharging stations) will further encourage the adoption of electric vehicles in the shorter term. Further improvements in the energy density of lithium ion and lithium air batteries (expected to continue to be the dominant technology for electric cars in the short term) will help to remove range anxiety and lower capital costs; while improved cycle life management of batteries themselves will reduce replacement and operating costs.

Other than technology R&D, there are also innovative financing and business models that can be used to address some of the challenges of electric vehicle adoption. Some auto-dealers have decided to lease the car batteries to consumers, deferring the initial up-front capital costs associated with ownership. An unconventional business model is to decouple the battery from the vehicle and generates revenue from the distance travelled. This would include provision of a supply of batteries and a network of swap stations where depleted batteries can be swapped for fresh ones. Such a model has the potential to lower the capital costs to consumers, address range anxiety, and limit the location of necessary grid upgrades [4].

12.6 Conclusion

The need for a global energy system transition is clear, and the provision of reliable and affordable energy supply is not a trivial proposition. Moreover, the interactions among energy and other domains of water, climate change, socioeconomic development, health, and poverty are so pronounced that no country can ignore them. Communities, regions and nations must consider credible scientific and technological principles as they craft policies and portfolios that balance sustainable growth, economic reality and external relationships.

We recommend a tiered approach to energy sustainability that begins at the community level, and involves broad participation and engagement of stakeholders to elicit system interactions and metrics. Through structured, collaborative approaches, communities can develop portfolios that optimize satisfaction of diverse needs and priorities. In order to best respond to this enhanced understanding, designers must employ informed and multi-pronged approaches that orchestrate generation, conversion, distribution, and storage of energy.

Ultimately, consumers must learn to use energy in ways that optimize the overall utility – manifesting “energy-informed” behaviors. This cultural transformation will be extensive, but the revolution in popular information applications – personal computers, Internet and smart phones – offers a useful example. Developing more useful and efficient energy capabilities will go hand-in-hand with increasing technician and end- user sophistication, with the ultimate goal of increasing sustainability and resilience across global communities.

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Chapter 13
The Army Net Zero Waste Program and Its Implications for Energy

A Comparison of Waste Diversion to Landfilling and Waste to Energy

V.F. Medina, M. Wynter, S. Waisner, S. Cosper, and G. Rodriguez

Abstract Net Zero Waste is one of three Net Zero Goals (the other two being energy and water) that the U.S. Army has implemented for various test installations that it operates. The Net Zero Waste program focuses on diversion of the wastes, which means that it seeks to reduce wastes first, then focuses on finding useful repurposing and recycling of materials currently managed as wastes. The ultimate goal of the Net Zero Waste program is to achieve a complete elimination of wastes managed by landfilling, although it is more likely that the end result will have a small amount that will have to be managed in this manner. This contrasts with current practice, which largely promotes landfilling wastes. Equations were derived and presented that allow for the calculation of net energy savings (or possible losses in some cases) by applying the Net Zero hierarchy to wastes currently managed by landfilling. Reviewing the range of wastes commonly found in municipal wastes indicates that most can be repurposed, reused, recycled or composted in some form or another. Another management option would focus on promoting waste to energy, and these are discussed in the document. A waste to energy focus maybe a very effective approach for forward operating bases, which are temporary bases used by the Army (and other services) for expeditionary operations.

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13.1 The Army Net Zero Waste Program

The Army Net Zero program is a new initiative designed to make Army installations more efficient in terms of energy usage, water and wastewater, and solid waste [1]. The Assistant Secretary of the Army for Installations, Energy and Environment has issued guiding definitions for the Net Zero waste concept, which can be summarized as follows:

- Goal of no wastes going to landfill
- Emphasize waste diversion (reduction, reuse, recycling, and composting) as opposed to waste to energy (WTE)
- Alter the supply chain to favor incoming materials with low waste volume and toxicity
- Includes municipal solid waste (MSW) and non-hazardous construction and demolition (C&D) debris. Does not include hazardous wastes or remediation, although the spirit of Net Zero is certainly expected to impact these activities as well.

13.1.1 Pilot Installations

The Net Zero policy indicates that five installations demonstrate the Net Zero Waste by the year 2020. After an application process, where several installations voluntarily applied, the following six installations were selected to be Net Zero Waste pilot facilities: Fort Detrick, MD; Fort Hood, TX; Fort Hunter Liggett, CA; Fort Polk, LA; Joint Base Lewis-McChord, WA, and the U.S. Army Garrison, Grafenwoehr, Germany. In addition, Ft. Bliss, TX and Ft. Carson, CO agreed to be integration installations, combining the Net Zero goals of Energy, Water and Waste.

13.1.2 Net Zero Hierarchy

Figure 13.1 depicts the Net Zero strategy towards waste. It is an inverted triangle, with the upper part representing the pre-net zero wastes being landfilled and the bottom point indicating the goal for no landfilled waste. From top to bottom are means to reduce landfilled waste, the upper part being preferred and ideally applied to the greatest amount of materials currently handled as waste. The first approach is to eliminate or reduce waste before it is generated, by methods such as careful inventory control for perishable materials, replacement of disposable materials with materials that can be reused, or the use of long lasting materials that need to be replaced far more infrequently. Changing materials or practices can sometimes eliminate or reduce waste generation.

Fig. 13.1 The Net Zero hierarchy logo

If the waste material cannot be completely eliminated, then the next desirable approach is repurpose the material, which is to find a constructive use for the material in its current state. For example, used tires could be repurposed as a shock absorbent at a dock. The next hierarchy is recycling and composting. In these, the material is collected and processed to allow for its reuse. For example, aluminum containers can be reprocessed into other aluminum products or even back into cans, but original container itself is completely reprocessed.

Only if repurposing and recycling/composting are not feasible (feasibility can include economic aspects) is when waste to energy may be applied. The least desirable approach is landfilling of the wastes, it is hoped that by the end of the Net Zero process the quantity landfilled will be miniscule. At the sides of the inverted triangle are the terms waste, energy and water, which are the three components of the army Net Zero program. These interplay with each other. For the purpose of this chapter, we will focus on the interaction of waste with energy.

13.1.3 Solid Wastes at Military Installations

The U.S. Environmental Protection Agency (USEPA) has conducted national assessments of Municipal Solid Waste (MSW) in the United States [2]. According to this assessment the majority of the MSW composition is organic forms, encompassing over 80 % of the composition (Fig. 13.2). Studies of military bases by Concurrent Technologies Corporation indicate similar trends for military installations. It is interesting to see that most of the constituents, if separated, could be recycled, composted or similarly treated for nutrient recovery, or burned for energy. It is probably reasonable to expect that MSW generation at military bases would be similar, as they have analogous sectors to a city: residential, office, industrial and institutional.

Medina and Waisner [3] conducted a study of solid and hazardous waste generation at military installations, focusing on Joint Base Lewis-McChord (JBLM) (WA) and the Picatinny Arsenal (NJ). Because the study focused on all solid wastes,

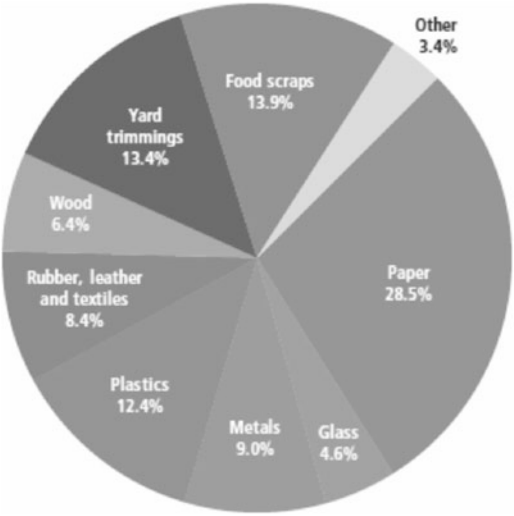

Fig. 13.2 Typical composition of municipal solid waste [2]

the findings were greatly affected by large building and demolition projects and on soil remediation projects. However, a critical issue in waste generation was determined to be fluctuations in populations at these installations. For examples, JBLM had population variations ranging from 25,494 to 51,132 between fiscal year (FY) 2003 and FY2008 (the US Federal FY is from 1 October to 30 September). The population variations were related to preparing units for large deployments during Operations Enduring Freedom and Iraqi Freedom. Concurrent Technologies Corporation (CTC) conducted a series of waste audits for 6 of the 8 Net Zero Waste installations ([4] for an example). Detailed audits were conducted for Ft. Hood and Ft. Hunter-Liggett. Their findings indicated that most wastes produced at military installations are potentially divertible. However, the studies indentified a waste category called Consumer Contaminated Wastes, or CCW. These are materials that are rendered unrecyclable by the nature of their use. This includes paper towels used in handwashing, paper and plastic food wrappings and containers, soiled tissue paper, etc. These materials could make up to about 30 % of the MSW streams studied.

Residential areas at military installations are generally operated by a contractor via the residential communities' initiative (RCI) program. As such, they are excluded from the Net Zero program. However, it is desired that significant waste reductions would be obtained in these areas as well. Residential areas are likely to be similar to national averages in waste generation. One key difference between military housing and the average civilian neighborhood is the higher rate of turnover due to relocation at military residential area. When a residence is vacated, a large amount of waste is typically generated as residents will desire to dispose unwanted clothes, electronics, furniture, household items, food, etc. Managing these departures will be critical in reducing wastes in these areas.

13.2 Diversion and Energy

The Army Net Zero approach emphasizes resource recovery. Resource recovery is obtained through a process call diversion, in which materials that have been typically handled as waste are looked upon as potential resources to be not wasted in the first place, repurposed, recycled, or composted. Current waste management is a landfilling focused approach, which emphasizes rapid removal of waste products. To understand how Net Zero will affect energy, let's explore each form of diversion and compare it mathematically to landfilling.

13.2.1 How Eliminating Wastes Affect Energy

Studies have demonstrated that there are three main ways of effectively reduce waste. First, better inventory control can result in significant waste reductions. For example, careful studies of dining patterns may be used to reduce food ordered and prepared for meals at dining hall facilities, reducing wastes. This form of waste reduction has very little energy expenditure. Energy savings come from reduced wastes to be picked up and from less material landfilled. Mathematically net energy saved (NES) over a given period of time can be described as:

$$\mathrm{NES} = \mathrm{M_r}\ (\mathrm{K_P} + \mathrm{K_T D} + \mathrm{K_D}) \tag{13.1}$$

where $\mathrm{M_r}$ is the total mass of waste reduced over a given period of time (t), $\mathrm{K_p}$ a coefficient relating energy related to waste pick up to $\mathrm{M_r}$, $\mathrm{K_T}$ is a coefficient relating energy to distance the waste is transported (D) and $\mathrm{M_r}$ and $\mathrm{K_D}$ is coefficient that relates energy used in disposal to $\mathrm{M_r}$. This equation suggests that reduction of waste due to better inventory control is a "can't lose" proposition in term of saving energy due to waste management as there are no negative inputs.

A second method involves substituting longer lasting materials that need to be disposed of less frequently. For example, replacing light bulbs with long lasting ones reduce waste. Once again, the Mr results in an energy savings. However, in most cases, these new materials require more energy (and cost) to produce. At the same time, the more durable materials can be purchased less frequently, resulting in some energy savings. This modifies the energy balance to:

$$\mathrm{NES} = \mathrm{M_r}\ (\mathrm{K_P} + \mathrm{K_T D} + \mathrm{K_D}) + (\mathrm{N_E} - \mathrm{N_R})(\mathrm{ME_E} + \mathrm{TE_E}) - \mathrm{N_R}(\mathrm{ME_R} - \mathrm{ME_E}) \tag{13.2}$$

where $\mathrm{N_E}$ is the number of existing units needed for the time period considered, $\mathrm{N_R}$ is the number of replacement units, $\mathrm{ME_E}$ is the manufacturing energy of the existing units and $\mathrm{C_R}$ is the manufacturing energy of the replacement units, and $\mathrm{TE_E}$ is the transportation energy for the existing units. This example only focuses on the waste management costs, in the case of light bulbs, most long lasting bulbs also offer substantial energy use reductions over a given time period. In looking over the equation, it indicates that there are two areas of energy savings, one from reduced waste mass managed, and the second from production and transportation of the existing units, which must be purchased and shipped in larger numbers. However, since most longer-lasting products require more energy to produce, the total energy savings is reduced by this factor.

A third scenario involves replacement of a waste material with a new material that can be reused with some reprocessing. An example is replacing disposable food service materials with washable ones. The energy balance becomes:

$$\begin{aligned}\mathrm{NES} = \mathrm{M_r}\ (\mathrm{K_P} + \mathrm{K_T D} + \mathrm{K_D} - \mathrm{K_{RPR}}) + (\mathrm{N_E} - \mathrm{N_R})(\mathrm{ME_E} + \mathrm{TE_E}) \\ - \mathrm{N_R}(\mathrm{ME_R} - \mathrm{ME_E}) \qquad (13.3)\end{aligned}$$

where $\mathrm{K_{RPR}}$ is a coefficient relating the additional energy use related to reprocessing the material. The situation is similar to the material substitution example presented in Eq. 13.2, but differs in that there are reprocessing costs that must also be factored in. It is not inconceivable that the reprocessing costs could be greater than the combined savings of the waste disposal.

In viewing these equations, it can be clear that as minimization becomes more complex, the energy benefits can be greater. Or, they may decrease or even be eliminated.

13.2.2 How Repurposing, Recycling, and Composting Affects Energy

As discussed above, repurposing, recycling, and composting are different means to divert waste, but each have a similarity – they all result in the development of a usable product that, ideally, is produced with less energy than from other materials. Because of their similarities, we will refer to these as RRC. Basically, the same equation can be used to estimate the NES from RRC activities:

$$\mathrm{NES} = \mathrm{M_{RRC}}\ (\mathrm{K_T D} + \mathrm{K_D} - \Delta\mathrm{K_p}) + \mathrm{N_{NRRC}}(\mathrm{E_N} - \mathrm{E_{RRC}}) \qquad (13.4)$$

where $\mathrm{M_{RRC}}$ is the mass of repurposed, recycled, or composted material, $\Delta\mathrm{K_P}$ is a coefficient relating the difference of energy required for pickup of RRC materials. In some cases, $\Delta\mathrm{K_p}$ may be zero, but in other cases, there may be an addition energy cost due to the need for separate pickups, additional handling, etc. $\mathrm{N_{NRRC}}$ is the number of new products (or mass of compost) generated from RRC. Energy savings result from the difference of producing the unit ($\mathrm{E_N}$) new versus from repurposing ($\mathrm{E_{RRC}}$). With RRC, there is no energy required for disposal, but there may be some energy costs associated with collection or separation of the material.

13.3 Diversion for Specific Waste Streams

As mentioned earlier, diversion is achieved when the waste is either not generated in the first place, or when the potential waste is recycled or re-used. As a result, the material never actually becomes a waste. Separation is a critical part of waste diversion. Separation is probably most efficiently conducted at the point of generation. However, post collection separation is also feasible.

13.3.1 Metal

For metals, diversion in waste streams begins with the reduction of metallic items. Perhaps the largest source of metals in MSW is from single use metallic beverages containers. Encouraging households to use larger (typically plastic) containers or reusable drink containers could reduce the generation. Fountain drink loyalty programs with reusable cups could also reduce generation of this source.

Most metals found in MSW can be recovered and recycled [5]. Aluminum, which is widely used in drink containers, is the most commonly recycled metal. Similarly, metallic cans can also be recovered and recycled. Ferrous metals can usually be easily recycled as well. The economics of recycling can change quickly over time, particularly for aluminum. Sometimes recycled metal is competitive or even less expensive, but sometimes producing metal from ore is less costly. Subsidizing recycling efforts to account for these variations may make sense, since the costs from the environmental advantages are frequently not included in economic analyses.

13.3.2 Glass

Glass is another readily recyclable material [6]. Glass comes in three main forms: containers for beverages, food stuffs, and flat glass. Flat glass is primarily used in windows in houses and cars, picture frames, and mirrors, and glasses associated with high value technical and consumer products. Glass bottles can be cleaned and reused. Bottle reuse is commonly used throughout the world, but is no longer widespread in the U.S as glass has been superseded by plastic as a preferred drink container. Glass can also be ground and reused as a feedstock for new glass production. Ground glass can also be used as a sand substitute in sand boxes. Rounded glass pieces can be incorporated in concrete or plaster to achieve decorative effects.

13.3.3 Cardboard

Cardboard is generally used as a packaging material. Overpackaging often results in excessive use of cardboard and other packaging materials. An easy way to reduce cardboard waste is to work with vendors to reduce the amount of packing materials when shipping and delivering items.

Many cardboard boxes can be reused for packing, shipping, storage, etc. The key to their reuse is to keep the boxes dry and limit damage to them. Cardboard can also be sent to paper recycling facilities for use as a raw material in paper mills [7]. Cardboard could also be composted, acting as a bulking agent and carbon source.

13.3.4 Paper

A major source of paper use is from printing of electronic information. A simple means of reducing paper use from this is to set printer defaults to two sided printing and to encourage the use of this format. Another means to reduce paper use is to encourage the use of electronic readers to read articles and documents in-stead of printing paper copies.

Paper can also be recycled – it can be reprocessed and used as a raw material in paper mills. However, a given paper source has a limited recycling life, as the paper fibers wear out after each use. Even so, paper is one of the most widely recycled constituents in MSW, with about 60 % of paper is estimated to be recycled [7]. Some paper waste is likely to be CCW (such as paper towels from handwashing, and paper plates and napkins from food service), which makes recycling difficult if not impossible. Composting could be a good choice for addressing these challenging waste streams.

The Army frequently uses pulverizing to destroy sensitive documents. Pulverized paper is a challenge from a recycling standpoint, as it is generally not suitable for paper recycling because of the damage to fibers. Furthermore, its small size makes it difficult burn in a waste to energy incinerator, as the small pieces of paper can become entrained in the flue gas, however, systems with existing particulate control could use this material as fuel. Pulverized paper could be composted or it could be added directly to soil as an amendment (D. Gebhart, Personal Communication, Soil Scientist, U.S. Army Construction Engineering Laboratory).

13.3.5 Plastics

Plastics have become the preferred container material for beverages and food in the United States. Consequently, these materials make up a large fraction of MSW. There are great opportunities for reducing plastic materials in wastes. Large quantities of plastic bottle wastes come from the use of single use water bottles. Much of this use is due to the usually mistaken belief that bottled water is safer to drink than tap water. In reality, tap water quality in the US is more regulated and monitored than most bottled water. Educational programs can help address this mistaken belief. Tap water filters can address any concerns about particulates in water pipes, or taste. Another issue is convenience. By providing convenient fill up sources, the use of reusable containers can be promoted. Another major source of plastics is shopping bags. People can be encouraged to use reusable bags by vendors charging a token amount for the plastic bag.

Nonetheless, plastics are such a useful material; they will remain in the waste stream. Once again, there are opportunities for diversion, if these materials are cleaned and separated. Technology has been developed to wash, disinfect and reuse plastic bottles. It is not clear if this will become publically acceptable, but could be viable in some cases. In addition, many plastics, depending on their chemistry can be also recycled. Polyester based plastic containers and bags can be drawn into fibers, which can be used to make clothes, bottles, and other plastic products [8, 9]. Thermochemical treatments, such as gasification and pyrolysis, can be used to recover hydrocarbon chemicals from bottles and bags, which can be used as raw materials for new plastic production [9]. Plastics are excellent materials for waste to energy recovery, particularly if composed of non-chlorinated sources.

13.3.6 Rubber/Leather/Textiles

Rubber, leather, and textiles are organic materials that are highly resistant to degradation. Probably the largest source of rubber is used tires. Since these are usually changed at a service center, they are not commonly disposed as MSW. However, recycling opportunities abound for used tires, such as retreading the tires for further use, use as noise barriers, artificial reefs, fill, landfill cap material, insulation, sport and playground surfaces, industrial applications (such as non slip floormats), industrial powders, and shredding as a berm material for small arms firing ranges [10]. Rubber is a good material for waste to energy production as well.

Textiles are primary in the form of clothing, bedding, and draperies. In many cases, unwanted items are still functionally usable and can be reused [8]. Consignment shops and charities will often find new users for these materials. These materials can also be cut up for other uses, such as art projects and quilting. Textiles can also be recycled or recovered by fiber recycling industries, although these can be complex processes [8]. Grinding fibers also yield products for beneficial reuse, such as insulation products. Dry textiles can be incinerated for energy recovery. Like textiles, most leather products (clothes, furniture, belts) can be re-used. Leathers are particularly resistant to degradation and wear, and can be reconditioned in some cases.

Fig. 13.3 Static pile composting of vegetative and other solid wastes at Joint Base Lewis-McChord, WA

13.3.7 Vegetation/Yard Waste

Beneficial reuse is feasible if these wastes are separated prior to disposal. Composting is a great approach to beneficially reuse these materials as a nutrient rich soil amendment [11–18] (Fig. 13.3). Large woody debris can be used for building, erosion control [19, 20], playground equipment, wood chips for soil stabilization, and wood for fire places. Vegetation can also be grounded and used as a feed stock for paper mills, this approach was used to recycle large amounts of vegetative debris after Hurricane Katrina [21]. Dried, finely ground woody debris can be added to coal as a fuel source.

13.3.8 Food Waste

Food waste is perhaps the most problematic of the major waste constituents found in MSW. Spoilage creates offensive odors and health risks that must be managed. Because food wastes are wet, they are not amenable to incineration, although they can be dried, often by using excess heat from a combustion source. Food wastes may be concentrated, or mixed with paper and plastic service items.

The first step would be to reduce food wastes. For families, this involves better planning so that the appropriate amount of food is prepared and used per meal. For institutional meal service, studies can be conducted to assess excess food during meals, and develop better planning to reduce waste. Keeping actual food waste separate from other wastes could limit the amount of wastes in this category.

Once food waste is generated, diversion is difficult. Food could be composted or treated in an anaerobic digester to recover nutrients and generate energy [13, 22–30]. Worm composting, or vermi-composting is not common in the United States, but the science is well developed and this approach has been extensively used internationally [31–34]. Dehydration is a developing approach in which the treated food can be used for animal feed or as a soil amendment. In some cases, food could be used as a raw material for biofuel generation. If food is mixed with other waste, such as paper or plastic service items, a CCW results, and diversion options for this material are greatly reduced.

13.3.9 Household Hazardous Waste (HHHW)

The Resource Conservation and Recovery Act (RCRA) defines hazardous waste from a regulatory standpoint. In the definition, household wastes are exempted. However, hazardous chemicals and materials in household waste can be very problematic [35]. Household hazardous waste (HHHW) is non-regulatory term used to describe unwanted household chemicals, such as cleaning chemicals, paints, automotive chemicals, etc., which would be considered hazardous wastes if they were in an industrial or commercial setting. Presence of these materials in MSW can greatly complicate resource recovery, making Net Zero more difficult.

Diversion is the key to eliminating these items in MSW. Many waste management organization have implemented zero tolerance policies for HHHW. To do this, alternatives are needed to give customers outlets to safely get rid of unwanted HHHW. Periodic turn in days can be valuable for this purpose. Collected materials in good condition could be sent to an exchange, where they can be offered at a low price or free of charge to other potential users. Other materials can be sent to recyclers. In some cases, some of the materials may need to be safely disposed.

13.3.10 Electronic Waste (E-Waste) and Batteries

Electronic wastes, or E-wastes, are disposed electronic goods. With the rapid development of electronic technology, the disposal of old goods when new ones are obtained is increasing substantially. Studies have shown that metals in E-waste can be leached over time into landfill environments [36]. Fortunately, there are opportunities for diversion to reduce the need for disposal [20, 37]. Many unwanted electronic products are still in good working order and could be resold at used electronic stores or given away to charities and schools. E-waste recyclers accept a wide range of electronic items to recover batteries, electronic boards, and valuable metals.

Batteries are specialty wastes that could be considered as HHHW, but are also found in E-waste. With the development and increased use of mobile electronic technologies, battery usage is increasing [38]. Batteries contain metals and acids that can become environmental contaminants if leached. Like HHHW, batteries mixed with MSW can complicate resource recovery.

Once again, separation and diversion are important. Zero tolerance battery disposal in MSW should be adopted, along with sufficient alternative turn in sites to discourage illicit disposal. Since many electronic items are disposed in a useful state, batteries can be recovered and reused. In some cases, batteries can be reconditioned and reused. For many other batteries, useful metals (particularly lead) and constituents can be extracted for reuse [38]. If needed, batteries can be disposed of in an environmentally safe manner.

13.4 Alternatives to the Net Zero Approach

Of course there are alternatives to a Net Zero waste approach. Two alternatives are a landfilling focused approach (as is currently used in most cases) and an approach focused on maximizing waste to energy (WTE).

13.4.1 Landfilling Approach

Current waste management in the United States is still focused on landfilling the bulk of wastes. There have been great strides in waste reduction and instituting recycling. However, landfilling still remains the primary means of managing wastes that are inevitably generated. Landfilling materials is a wasteful process that removes the waste materials from beneficial use by mankind. However, we must keep in mind that landfilling has persisted as a waste management strategy because, in many ways, it is effective. It is relatively fast and removes waste materials from contact with humans, reducing the threat of disease. It can be applied to a wide range of materials. A landfilling centric approach does not preclude minimization, reuse, or recycling, but only under conditions that are most favorable.

Landfilling is not considered a resource recovery or WTE approach. However, it has been found that biological reactions in the wastes can produce gases (Fig. 13.4). If uncontrolled, these gases can be hazard, spreading foul orders and causing potential combustion hazards in basements. However, if recovered, these gases can be a resource, as they contain methane – a potentially useful fuel source. The gas usually requires processing to remove offensive elements (like hydrogen sulfide, which is foul smelling, potentially toxic at very high concentrations, and can contribute to acid precipitation) and to concentrate the methane to commercially useful concentrations.

Some landfills have been designed, or retrofitted, to enhance methane gas production [39]. Typically, this process involves allowing limited water penetration into the landfill to stimulate more biological activity. Obviously, this process must

Fig. 13.4 Flare system for landfill gas burning at Joint Base Lewis-McChord

be well controlled to prevent unwanted leachate migration. However, by recycling leachate (with some treatment to adjust pH and remove toxic metals), active microorganisms can be returned to the landfill to further stimulate gas production. Some bioactive landfill management plans choose to limit certain wastes to reduce production of unwanted constituents in the gas.

Over the past decade, natural gas, which is also primarily composed of methane, has greatly increased in use in the United States. In fact, new technologies and approaches, which have allowed natural gas to be recovered from previously inaccessible formations, have created so much new production and new potential that there is thought that the U.S. could become energy independent by 2030 [40]. This is both a positive and a negative for biologically produced methane, such as produced in landfills. A positive is that gas utilizing engines and other gas exploiting technologies are more widespread than ever before. The negative is that fossil sources of natural gas are becoming increasing less expensive, which may make biological production non-competitive from a cost standpoint.

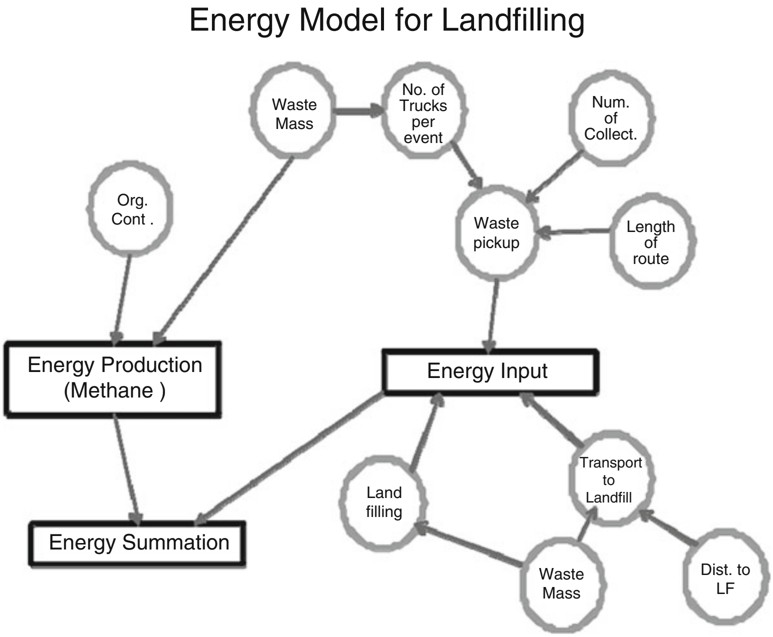

Fig. 13.5 Graphical energy model for landfilling wastes (*Org. Cont.* organic content, *LF* landfill)

Figure 13.5 is a conceptual energy model for landfilling MSWs generated at an Army installation. The key energy inputs come from collection and transportation of the wastes, and energy needed to conduct landfill operations. Energy output comes from energy generated from the wastes themselves, in this case from recovered landfill gas. Essentially, all other waste management approaches have a similar energy configuration. All require energy pickup and transportation, all require a certain amount of operating energy, and all generate energy that can be recovered.

13.4.2 Waste to Energy

Another approach that can be compared would focus on maximizing waste to energy. Once again, waste minimization, reuse, and recycling could be included, but the main focus would be to collect appropriate organic wastes for energy production. In fact, for these specific wastes, minimization may not be applied and there may even be pressure to maximize production of those specific materials.

Waste to energy focuses primarily on the organic portions of the waste stream, which, as discussed earlier, make up about 80 % of the typical waste stream in the United States. Organic material can be roughly divided into two types, wet and dry. Wet materials include food and wet vegetative material. Dry materials include dry

Table 13.1 Landfilling versus WTE [41]

	Electric power generated from 1 ton of MSW (kWh)
Typical waste to energy	470–930
Landfill gas to energy	41–84

paper, plastics, rubber, etc. Table 13.1 indicates that WTE approaches can produce about 10 times more energy per unit waste compared to gases produced in landfills. Energy production in WTE is rapid, whereas methane production from landfills can take years.

WTE can be divided into two types: thermal and biological. Thermal processes focus on higher temperatures to directly convert the wastes to energy, or to create chemical changes to generate liquid or gaseous fuels. Biological WTE relies on anaerobic respiration to generate combustible gases [42, 43]. Thermal and biological processes tend to be complimentary, in that thermal approaches work best on dry materials and high energy materials like plastics and rubber, while biological approaches work well with wet materials.

Three primary thermal methods are incineration, gasification, and pyrolysis. Table 13.2 summarizes these methods and their operations. Incineration burns the wastes to produce heat, which is used to generate electricity. Gasification focuses on the production of gaseous fuels and pyrolysis focuses on liquid fuel production. Of these methods, incineration has far more applications for full scale energy production, while applications of pyrolysis and gasification have been typically more experimental in nature [44].

Fuels (liquid and gaseous) produced by WTE have positive and negative aspects. On the positive side, a fuel can be stored and transported and used when and where it is needed. The problem is that many WTE systems produce fuels of inferior quality and that some of these fuels can contain impurities that may result in undesirable air pollution consequences. Some thermal systems that focus on a narrow range of inputs with high energy value, such as plastics or rubber, can produce high quality fuels. However, even these present problems, because they are nor certified and cannot be used in military vehicles or even in most generators. This problem can possibly be solved with changes of Army policies, but would require additional testing to insure quality, which would increase the cost of the fuel. This most likely limits WTE to solid waste incineration at this time.

A key issue about WTE incineration is that it requires a large portion of material to create an economically viable enterprise. Such quantities are probably only capable by the largest of the Army installations, and even this is debatable. The installation would likely have to partner with local communities to create a commercially effective WTE facility. Such a facility would probably have to be located off site of the installation, since receiving wastes from outside the installation is generally not allowed.

Waste reduction, repurposing, recycling and composting of wastes that are not suitable for the WTE would be appropriate in a WTE focused management strategy.

Table 13.2 Comparison of combustion, gasification, and pyrolysis [45]

	Combustion	Gasification	Pyrolysis
Aim of the process	To maximize waste conversion to high temperature flue gases, mainly CO_2 and H_2O	To maximize waste conversion to high heating value fuel gases, mainly, CO, H_2, and CH_4	To maximize thermal decomposition of solid waste to gases and condensed phases
Operating conditions			
Reaction environment	Oxidizing environment, excess stoichiometric oxygen	Reducing, low oxygen	Zero oxygen
Reactant gas	Air	Usually air, could be oxygen enriched, or steam	None
Temperature	850–1,200 °C	500–1,500 °C, depending on specific process	500–800 °C
Pressure	Atmospheric	Atmospheric	Slight positive
Process output			
Produced gases	CO_2, H_2O	CO, H_2, CO_2, H_2O, CH_4	CO, H_2, CH_4, and other hydrocarbons
Pollutants/unwanted byproducts	SO_2, NOX, HCl, PCDD/F, particulates	H_2S, HCl, NH_3, HCN, tar, particulates	H_2S, HCl, NH_3, HCN, tar, particulates

However, reducing organic wastes appropriate for the technology chosen would not be advantageous. In fact, the need for organic materials to cost-effectively run a WTE facility may create an environment where wasteful use of resources occurs.

One environment where a waste to energy focus approach could make sense is a Forward Operating Base, which is a temporary base created to support an expeditionary operation. Diversion opportunities may be minimal, at least in the initial portions of an operation when relationships with the local populace are not well established, and landfilling can create security hazards. Furthermore, even modest energy recovery would be beneficial, as it would allow for fewer fuel shipments, which are vulnerable to hostile attack. Figure 13.6 is a schematic depicting a waste to energy focused scheme developed for forward operating bases (FOBs) during expeditionary operations. The schematic indicates that a wide range of wastes could be potentially harnessed for energy production, particularly if both thermal and biological methods are used. Some recycling can also be included, particularly for metals. Organic wastes not suitable for WTE would likely be landfilled, but presumably in relatively small quantities.

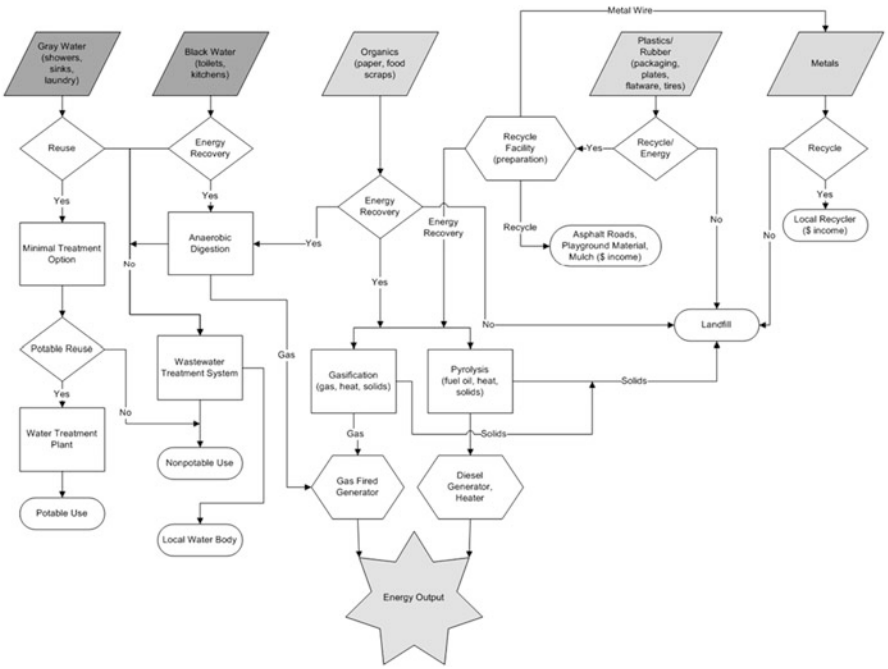

Fig. 13.6 A waste to energy focused waste management schematic developed for forward operating bases

In summary, a WTE energy approach focuses on maximizing energy produced from waste products. In contrast the Net Zero approach seeks to conserve resources and as such, its benefit is energy savings. Both WTE and landfilling are viable waste management approaches. However, Net Zero serves the goals of the Army in that conserving resources is a strategically sound decision.

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Chapter 14
Off-Grid Energy Access

Jatin Nathwani and Zhewen Chen

Abstract One critical aspect of the global transition to a low-carbon energy system is the provision of an adequate level of energy services to a large and growing proportion of humanity. The energy poor, living primarily off any electrical grid, offer a unique opportunity and new markets for a modular concept for energy access. New technologies, especially those making use of renewable sources of energy, will be key ingredients in insuring long-term sustainability, the quality of life of communities and mission success of military installations. This chapter examines the realities and challenges facing remote, off-grid communities and location, and introduces a modular design concept – Smart Micro-Grid within Smart Energy Network – that leverages technologies, such as small hydroelectric technology and thin-film solar, to capture distributed renewable energy resources.

14.1 Introduction

One of the biggest challenges of our time is the problem of a transition of the global energy system to one with a lower carbon footprint. Several key constraints will determine the outcomes: the forecast growth in global energy demand in the coming decades; the uneven distribution of population growth; the continued rise in greenhouse gas emissions from fossil-based energy consumption; and the consequential deterioration of the global environment coupled with stress on the climate system. Replacement for the existing carbon-based energy infrastructure will occur for long time frames, anywhere from 50 to 70 years and this will need to be synchronized with growing demand, the daunting challenges of energy poverty and the need to limit or reduce carbon emissions.

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One critical aspect of the challenge is the provision of an adequate level of energy services to the billions of energy poor worldwide. A large and growing proportion of humanity has either no access or limited access to modern energy services. Some 2.8 billion people lack access to clean and reliable fuel sources for cooking and heating. Of these, approximately 1.5 billion live without a reliable supply of electricity [2]. The world's energy poor, living primarily in rural areas, distant from the existing energy infrastructure, offers a unique opportunity to reshape the energy system that is more reliant on local distributed renewable energy resources at a cost lower than or comparable to the build-out of the traditional distribution and transmission system. The pervasive effects of energy poverty on the health status, education and quality of life are well known. Breaking the cycle of energy poverty not only creates the potential for economic development and employment, it also creates new markets for energy services not dependent on fossil fuel supply. For those with no access to electricity, the first few hundred watts can power life-changing tasks – from turning on lights for reading and working at night to refrigerating vaccines – with which they can begin to bootstrap development.

New technologies, especially those making use of renewable sources of energy, will be key ingredients in providing access to electricity to those distant from the existing grid. Long-term sustainability is key to the quality of life of communities and mission success of installations, and the desire to reduce overall carbon footprint brings us to a choice of technology options that are essentially based on renewables. Some options include innovative solar, wind, geothermal, combined heat and power (CHP), bio-energy, and small hydroelectric technologies, where feasible. In addition, small-scale nuclear energy (e.g., small modular reactors) provides flexible and cost effective energy to areas that may be lacking in renewable resources.

This chapter examines a technological evolution – Smart Micro-Grids within Smart Energy Networks, and within it, thin-film solar technology as an illustrative example of distributed generation – one that hold the promise of delivering basic energy services to rural, remote communities and has good potential for mobile or temporary military installations that are off-grid.

14.2 Energy Access for Remote Communities and Locations

In the past, the policy for rural electrification has met with mixed success but all too often it has been an unfruitful experience. Two critical factors have contributed to the sad state of affairs.

Focus on centralized electrification projects as the primary solution has not always been appropriate to remote and rural settings because the costs of extending centralized grid services to those communities are too high for local economies. Centralized models are not often sensitive to – nor do they capture – the unique characteristics and needs of rural and remote populations. Traditional grid infrastructures are optimized for cost and reliability of operation that caters to high level of energy demand from industrial, commercial and residential customers congregated

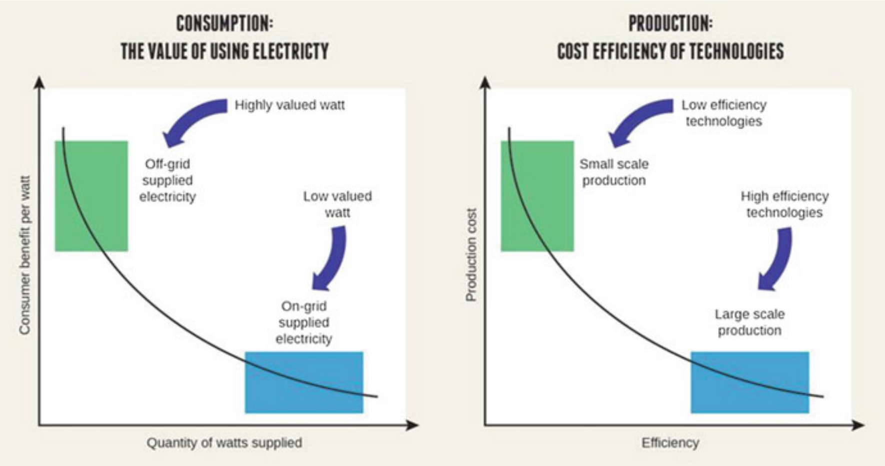


Fig. 14.1 Consumption and production: value and cost of electricity [6]

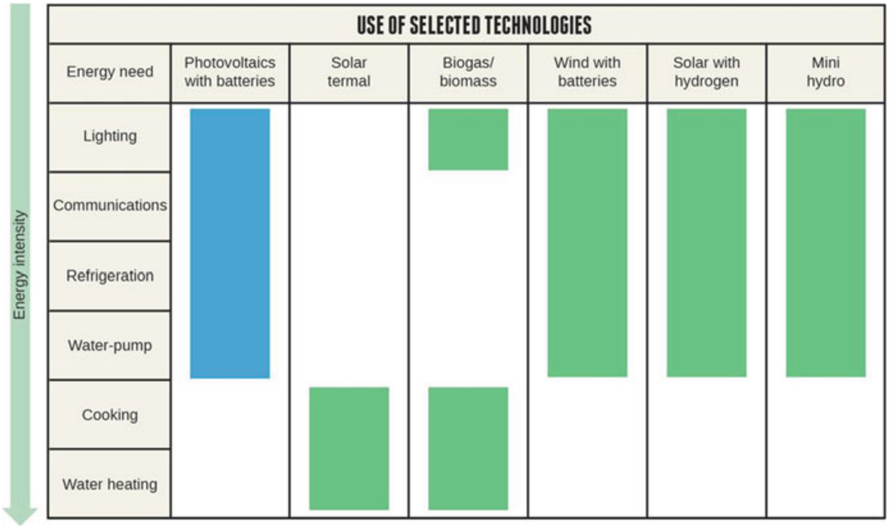
in large urban or sub-urban centers. They become unaffordable for distant, dispersed communities with low level of demand; they also ignore the endowment of diverse local renewable resources that can be utilized for low-carbon generation.

On the other hand, there existed an economic misperception that on-grid supplied electricity through high-efficiency technologies produced on a large-scale offers the best-valued watt and consumer benefit. It is predicated on the assumption that a low-valued watt readily equates a best-valued watt. In reality, a level of energy service at different price points has a different value to the end consumer depending on their situation. Figure 14.1 below illustrates this point:

In many rural and remotes contexts, off-grid supplied electricity generated by low-efficiency technologies on a small-scale can provide sufficient consumer benefit and therefore the best-valued watt, even though they are highly-valued from a production cost standpoint. Recognizing this idea will allow innovations to flourish and create conditions for energy poverty eradication.

14.3 The Essential Nature of Challenge in Delivering Off-Grid Electricity

The above economic rationale reveals the essential nature of challenge of off-grid electrification both technologically and economically: firstly, how to capture and utilize local renewable energy resources, the size, quality and availability of which will vary widely depending on location and geography; secondly, how to integrate them into systems that respond to varying levels and types of local demand and are easy to install, operate and maintain; finally, how can such a scheme achieve widespread implementation from a financing and policy perspective.



USE OF SELECTED TECHNOLOGIES

Energy need	Photovoltaics with batteries	Solar termal	Biogas/ biomass	Wind with batteries	Solar with hydrogen	Mini hydro
Lighting	🟦		🟩	🟩	🟩	🟩
Communications	🟦			🟩	🟩	🟩
Refrigeration	🟦			🟩	🟩	🟩
Water-pump	🟦			🟩	🟩	🟩
Cooking		🟩	🟩			
Water heating		🟩	🟩			

Fig. 14.2 The increasing energy intensity of energy demand for various tasks, and technologies that match requirements [6]

The requirements for the provision of off-grid electricity access will vary depending on circumstances. Whether it is a temporary forward military base or a fixed remote facility or a distant community subject to extreme weather conditions, the scope and scale of the technology solutions to be implemented must be optimized for cost and reliability.

There is matchmaking to be made in energy needs between the energy intensity of demand types and the use of selected renewables generation technologies. The basic human needs at 100 kW/person should cover lighting, communications (of basic mobile devices), small refrigeration, water-pump, cooking and water heating. Each of these tasks requires energy intensity at a certain level that cannot be uniformly met reliably, flexibly and efficiently by any one renewable energy source. For example, photovoltaic technologies coupled with batteries are suitable for lighting, recharging mobile devices and perhaps small refrigeration needs, but they are unsuitable for cooking and heating purposes. Solar thermal on the contrary, serve opposite energy intensity requirements, as Fig. 14.2 illustrate below:

It goes without saying that the endowment base of local resources can also vary simply because of a shift in geography. So can the sizes of communities and levels of aggregate energy demand thereof. The confluence of these factors presents challenges in terms of system integration in an intelligent, efficient, and cost-effective manner. Figure 14.3 below illustrates this point:

The social and economic development outlook unique to each community also raises concerns regarding capacity build-up to finance, own, install, operate, and maintain critical infrastructure.

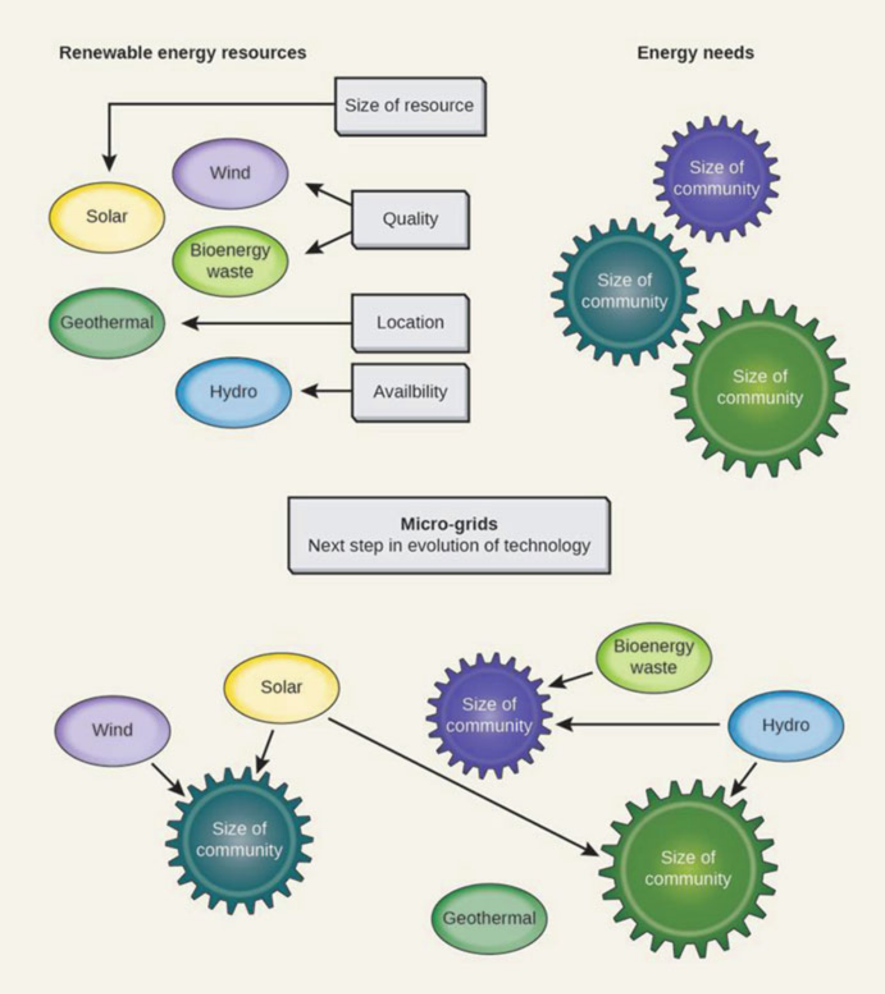


Fig. 14.3 Challenges of renewable resource integration [6]

The essential nature of challenge begs the question: is there a next step in the evolution of energy technology that has the potential of addressing those challenges?

14.4 A Modular Concept for Energy Access

In contrast to centralized approaches, a modular system paradigm can provide sensible solutions to off-grid contexts. More specifically, the challenges can be resolved by modular system designs that range anywhere from 5 kW to 10 MW

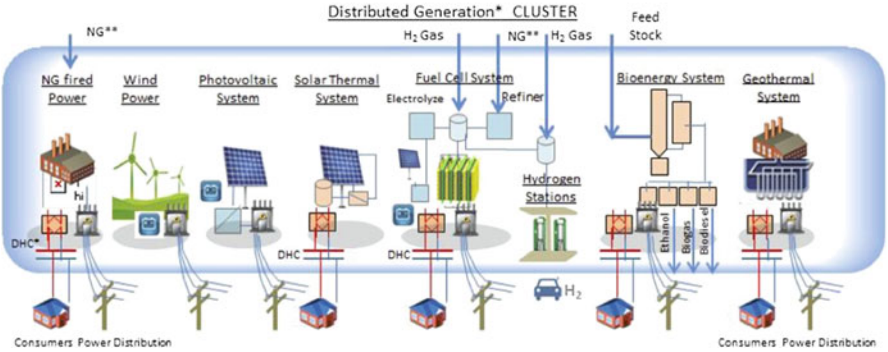


Fig. 14.4 Distributed generation cluster [1]

and are simple to install and maintain, tailored to community needs, and operated intelligently and effectively through optimized delivery systems. Such designs would use local renewable energy resources for generation. Solar photovoltaics, micro-hydro power plants, wind turbines, biomass, small conventional generators and storage offer credible potential technological solutions to utilize distributed energy resources. Such self-sustaining designs that embrace an integrated model of electrification are often called Smart Micro-Grids (SMG) [6].

14.4.1 Conceptual Model of a Smart Energy Network

A smart energy network can be modeled as a cluster consisting of facilities designed to produce electricity from multiple sources of energy. When integrated with the existing power or gas networks, a cluster of distributed generation is as shown in Fig. 14.4. A conceptual model of a comprehensive smart energy network is shown in Fig. 14.5 to illustrate different scenarios and scales that are classified by a number of clusters. For off-grid access, the comp onents of the clusters shown in Fig. 14.4 comprise the functioning elements of a distributed generation network.

A summary of the technology state of art for distributed generation is shown in the table below:

14.4.2 Smart Micro-Grids Within Smart Energy Network

The most fundamental concept of a micro-grid can be understood as an integrated system that utilizes an aggregate of small loads and distributed generation resources (both high-frequency AC and DC systems), operates as a single system (in parallel

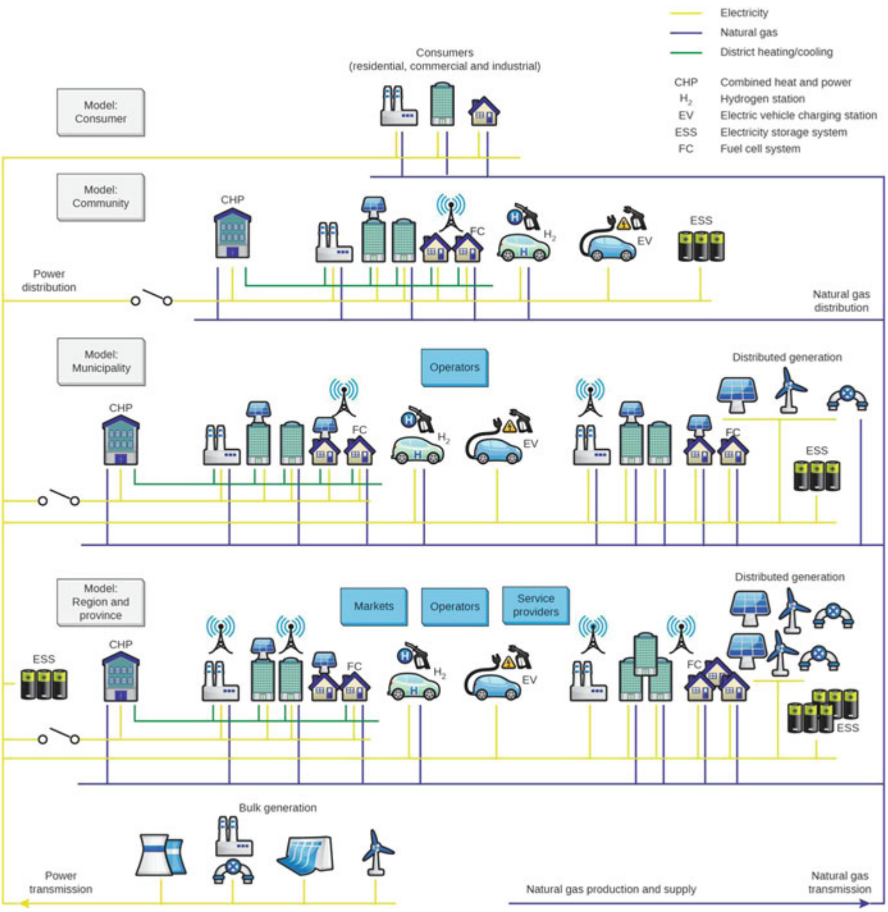


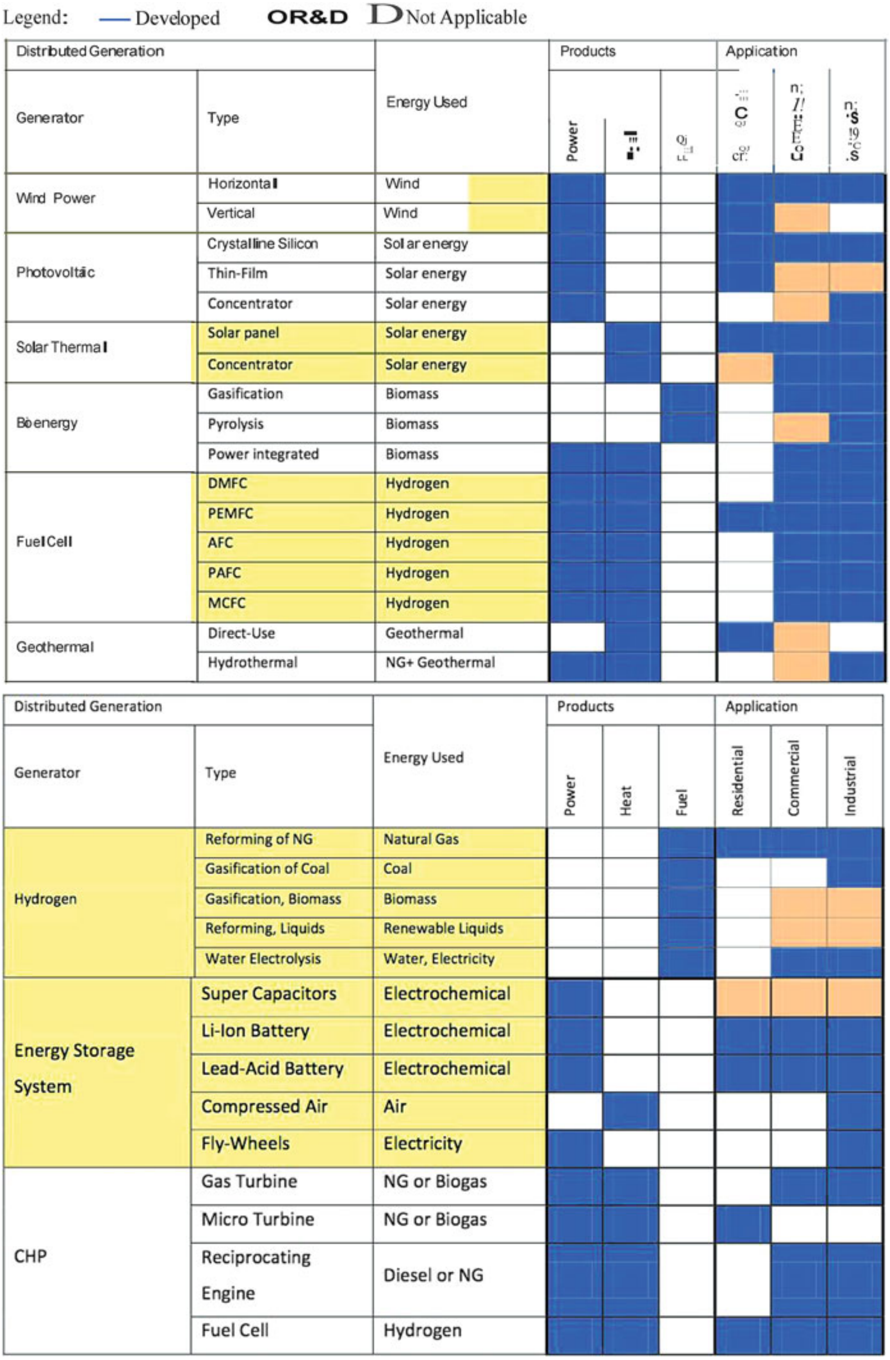
Fig. 14.5 How the Smart Energy Network will work. Created by the Waterloo Institute of Sustainable Energy (WISE) [1, 6]

to or in isolation of traditional power utility grid), and is able to provide sufficient and continuous energy to a significant portion of the demand internal to the system itself.

A grid architecture that can operate in isolation from traditional centralized models is not a new concept. There already exist many micro-grids in rural regions around the world, but they lack the level of embedded intelligence that would enable efficiency maximization, information monitoring and control, and subsequently cost minimization, and are therefore ‘dumb’ grids.

Recent advances in electrical engineering and communication technologies, including power electronics, internet-based communications, advanced nanosensors, wireless power distribution, distributed photovoltaics and storage, and zero

Summary of technology state of art for distributed generation [1]



Legend: 🟦 Developed 🟧 R&D ⬜ Not Applicable

Distributed Generation		Energy Used	Products			Application		
Generator	Type		Power	Heat	Fuel	Residential	Commercial	Industrial
Wind Power	Horizontal	Wind	🟦	⬜	⬜	🟦	🟦	🟦
	Vertical	Wind	🟦	⬜	⬜	🟦	🟧	⬜
Photovoltaic	Crystalline Silicon	Solar energy	🟦	⬜	⬜	🟦	🟦	🟦
	Thin-Film	Solar energy	🟦	⬜	⬜	🟦	🟧	🟧
	Concentrator	Solar energy	🟦	⬜	⬜	⬜	🟧	🟦
Solar Thermal	Solar panel	Solar energy	⬜	🟦	⬜	🟦	🟦	🟦
	Concentrator	Solar energy	⬜	🟦	⬜	🟧	🟦	🟦
Bioenergy	Gasification	Biomass	⬜	⬜	🟦	⬜	🟦	🟦
	Pyrolysis	Biomass	⬜	⬜	🟦	⬜	🟧	🟦
	Power integrated	Biomass	🟦	🟦	⬜	⬜	🟦	🟦
Fuel Cell	DMFC	Hydrogen	🟦	🟦	⬜	⬜	🟦	🟦
	PEMFC	Hydrogen	🟦	🟦	⬜	🟦	🟦	🟦
	AFC	Hydrogen	🟦	🟦	⬜	⬜	🟦	🟦
	PAFC	Hydrogen	🟦	🟦	⬜	⬜	🟦	🟦
	MCFC	Hydrogen	🟦	🟦	⬜	⬜	🟦	🟦
Geothermal	Direct-Use	Geothermal	⬜	🟦	⬜	🟦	🟧	⬜
	Hydrothermal	NG+ Geothermal	🟦	🟦	⬜	⬜	🟧	🟦

Distributed Generation		Energy Used	Products			Application		
Generator	Type		Power	Heat	Fuel	Residential	Commercial	Industrial
Hydrogen	Reforming of NG	Natural Gas	⬜	⬜	🟦	🟦	🟦	🟦
	Gasification of Coal	Coal	⬜	⬜	🟦	⬜	⬜	🟦
	Gasification, Biomass	Biomass	⬜	⬜	🟦	⬜	🟧	🟧
	Reforming, Liquids	Renewable Liquids	⬜	⬜	🟦	⬜	🟧	🟧
	Water Electrolysis	Water, Electricity	⬜	⬜	🟦	⬜	🟦	🟦
Energy Storage System	Super Capacitors	Electrochemical	🟦	⬜	⬜	🟧	🟧	🟧
	Li-Ion Battery	Electrochemical	🟦	⬜	⬜	🟦	🟦	🟦
	Lead-Acid Battery	Electrochemical	🟦	⬜	⬜	🟦	🟦	🟦
	Compressed Air	Air	⬜	🟦	⬜	⬜	⬜	🟦
	Fly-Wheels	Electricity	🟦	⬜	⬜	⬜	⬜	🟦
CHP	Gas Turbine	NG or Biogas	🟦	🟦	⬜	⬜	🟦	🟦
	Micro Turbine	NG or Biogas	🟦	🟦	⬜	🟦	⬜	⬜
	Reciprocating Engine	Diesel or NG	🟦	🟦	⬜	⬜	🟦	🟦
	Fuel Cell	Hydrogen	🟦	🟦	⬜	🟦	🟦	🟦

*Combine (1) & (2) into one graph

energy building systems and so forth [7], have enabled novel characteristics and ‘intelligent’ components in micro-grid designs. A schematic framework of how these components operate is shown in Fig. 14.6 below.

Some of the features SMG architectures can offer include increased reliability, carbon reduction, sensible service differentiation, ancillary support to traditional grid, and enhanced security.

All in all, SMGs thus form a new ecosystem of grid technological solutions, as illustrated in Fig. 14.7 below.

14.4.3 Cost Comparisons

Smart Micro-Grids hold great promise in enabling affordable energy access for all. There are, however, a few constraints in the way of engineering this vision. From a technical standpoint, SMG performance has not equaled promise, partly due to the relative high generation cost of distributed energy resources, i.e. fuel cells, microturbines, and photovoltaics and so on, as illustrated in the figure below. Within a spectrum of distributed generation technologies compatible for SMG integration, there are still technical challenges to be solved (primarily through the coupling with storage solutions) in terms of ameliorating the intermittency and variability issues that plague renewable resources such as wind and solar.

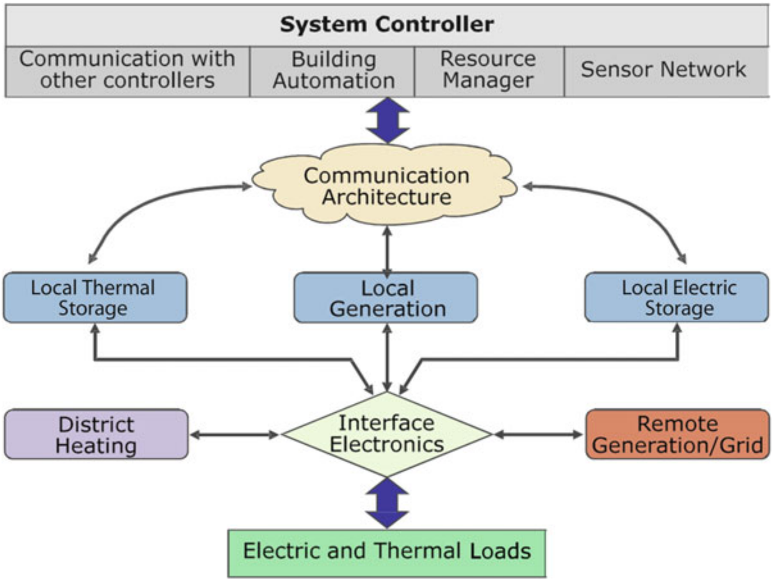


Fig. 14.6 Schematics of distributed micro-grid power systems [7]

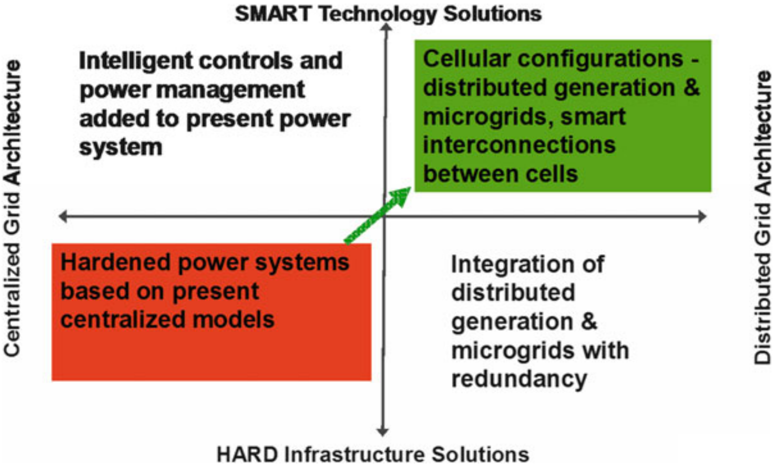


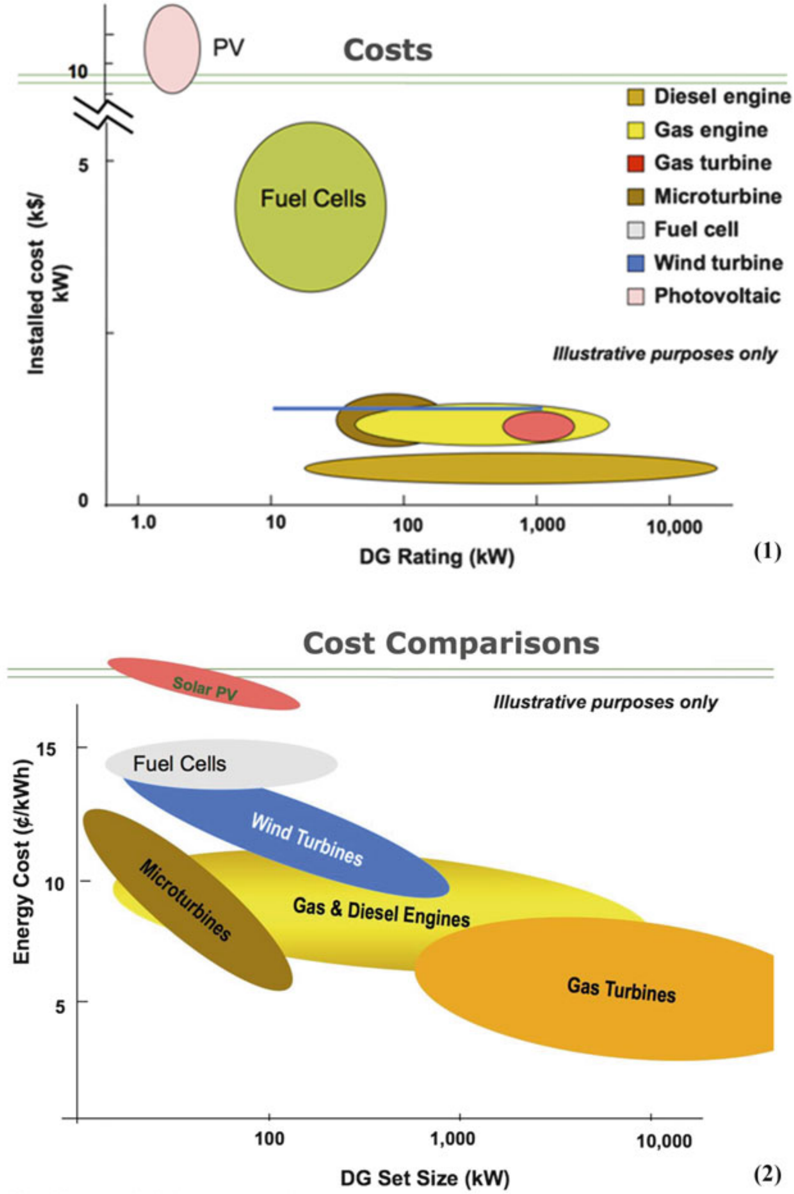
Fig. 14.7 A conceptual framework of evolution in grid technologies [7]

Another aspect of technical challenges has to do with bringing the general SMG ecosystem to a "plug-and-play" or "delivery on a crate" status. It means on-demand fabrication of each SMG unit and the robustness of deployment in terms of installation, configuration, and maintenance, all of which are vital for SMGs to achieve mass-market appeal (Fig. 14.8).

Accelerated research and development programs in various domains, as well as demonstrations during the 'trial and error' part of the process, can advance the evolution of SMG technology and its constituent technical components. Due to the complexity and multiplicity of the required technologies, these programs are likely taking place in developed settings and can thus be incentivized through policy and market initiatives. In addition, engineering mass-market appeal in remote and rural regions where SMG systems can deliver the best-valued and life-changing watts can draw lessons from some of the successful socio-entrepreneurship transpiring in the underdeveloped and developing world.

The complexity and multiplicity of required technologies implies that SMG technologies would be nurtured mostly in developed settings where knowledge knowhow and technical expertise are more intensely populated. How much scientific, technical, regulatory and financial energy the developed world put into accelerating SMG technologies has direct consequences in bringing sensible modular designs to an aforementioned "plug-and-play" status.

The integration of the modular concept represents a future in which traditional utilities would face unprecedented challenges and changes. Swapping centralized fossil-based power plants with clean baseloads (advanced nuclear and deep geothermal for instances), complemented by distributed generation is a retooling process that require massive financial commitments. Regulatory and incentive structures are needed to induce willingness in traditional utilities to invest in the SMG ecosystem. Potential mechanisms can include feed-in tariffs, carbon pricing, tax



*Combine (1) & (2) into one graph

Fig. 14.8 Cost perspectives of distributed generation [4, 5]

exemptions and alternatives for accelerated depreciation on capital expenditure and so forth. Eliminating utility restrictions on SMGs, imposing fundamentally higher distribution reliability standards are also regulatory instruments worthy of consideration.

Moreover, business models on which traditional power utilities operate will need to change in response to a ‘smart’ future. It includes several critical features including the management of intelligent energy delivery and information network, time-of-use pricing and monitoring programs, elimination of regulated fees that hamper reinvestment in decarbonized technologies and so on.

14.5 Thin-Film Solar for Personal Power

Smart Micro-grids, as a modular approach, recognizes that many regions with energy-poor individuals are endowed with renewable sources of energy such as sunlight, wind, biomass or waterways for generating hydroelectricity. New technologies that make use of those resources for generation will be a key ingredient and constituent part of the modular concept enabled by SMGs.

As an illustrative example, portable but durable solar power, based on thin-film solar technologies (for example, Organic Photovoltaics) hold enormous promise to provide a basic level of energy service for personal power.

Compared to burning kerosene at US$1 per week, the savings inherent in using solar energy over the medium term – even where the solar technologies deployed are initially more costly than in those used in a first-world setting – makes a great deal of sense. To help unleash the economic productivity of those with very low incomes, provision of even a basic level of energy services could well be the tipping point for a range of positive economic, social and cultural developments, helping to prime the pump for radical leaps in education, health and economic productivity [6].

There are a plethora of photovoltaic technologies in development. These technologies form an ecosystem that extends from silicon-based photovoltaics to thin films and emerging next-generation nanotechnology concepts. These various solar technologies can, in turn, be viewed as a part of a larger energy ecosystem with the potential to be integrated within SMGs, alongside other local renewable resources that complement and enhance the level of energy access to those who have very little. The schematic below (Fig. 14.9) shows the scope and range of materials used for thin film solar cells that include: amorphous silicon, copper indium gallium diselenide (CIGS), cadmium telluride (CdTe), organic thin films and dye-sensitised integrated photovoltaic.

Among the different photovoltaic technologies in development, a variety of thin-film approaches offer advantages including cheap deposition technology, low material consumption, low material costs, low energy payback and capital investment, and low balance of system cost.

Organic Photovoltaics are a rapidly emerging solar technology with improving cell efficiency (currently more than 8 %), encouraging initial lifetime (more than 5,000 h unencapsulated), and potential for roll-to-roll manufacturing processes.

The great strength of Organic Photovoltaics lies in the diversity of materials that can be designed and synthesized for the absorber, acceptor and interfaces. Research to further improve efficiency and lifespan is currently underway to

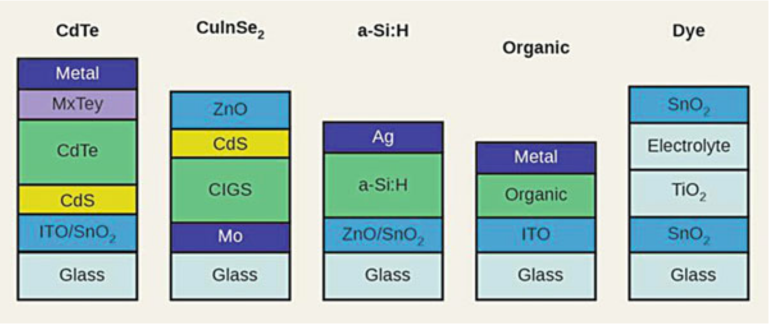


Fig. 14.9 The range of materials for thin-film solar cells [3, 6]

enhance understanding of the fundamentals of device operation, including charge-separation processes, device physics and interfacial effects that will allow design of more efficient and stable devices. For example, the National Renewable Energy Laboratory (NREL) in the U.S. is developing Organic Photovoltaic devices that include advances in transparent conducting oxide (TCO) materials, and the means to deposit and process materials and fabricate devices under ambient temperature and pressure conditions.[1]

Within the array of distributed energy technologies in development, Organic (also known as plastic) Photovoltaics are an option with great potential to address energy poverty. They have the potential to become one of the lowest-cost thin-film alternatives to the currently dominant silicon photovoltaic technology, due to their potential for low-cost, high-speed processing.

Organic Photovoltaics also have several characteristics that offer potential advantages for addressing off-grid energy needs. Their plastic nature makes them easy to transport, use and install (as shown in Fig. 14.10 below). They are light and can be installed into or onto irregular surfaces due to their extreme flexibility. They can be installed in a piece of cloth, rolled up and carried to the installation point, and laid across a roof. Installation requires no specialist equipment or skills.

In addition, these photovoltaic cells can be printed with a modified inkjet printer, allowing production facilities to be located anywhere. The technology is therefore very conducive to the creation of a new branch of small-scale, local producers of photovoltaic cells. Organic Photovoltaics require none of the expensive, heavy housing of current silicon solar panels. It is expected that once this technology reaches maturity – expected within 4–6 years – it will cost a fraction of even the cheapest silicon based cells.

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[1] See U.S. National Renewable Energy Laboratory (NREL): http://www.nrel.gov/pv/advanced_concepts.html.

Fig. 14.10 Application of flexible solar panels [6]

There are several technical hurdles to be overcome before Organic Photovoltaic technology can be used to help address the global challenge of energy poverty – meeting energy needs affordably through a non-carbon source of energy. For photovoltaic technology in general, current module efficiency is low; breakthrough research in materials and device technology is necessary for practical realisation of high-performance devices.

Conversion efficiencies of commercial photovoltaic cells are in the 15–20 % range. It should also be noted that, due to material-specific and thermodynamic constraints, today's commercial silicon solar cells have a theoretical maximum efficiency of about 30 %. Similar hurdles remain for Organic Photovoltaics. The product life of Organic Photovoltaic cells remains under 10 years, which is still substantially shorter than currently available alternatives. Additionally, the Organic Photovoltaics currently in production are only about 5–6 % efficient, although 8 % efficiency has been attained in the laboratory. In comparison, current silicon cells have reached 25 % efficiency.[2]

For grid-scale application, breakthrough changes in performance, reduced material cost and increased stability are required before existing commercial photovoltaic technologies can reach cost parity with the conventional grid. However, the situation is very different in remote and rural settings, where the focus is on the provision of the first few watts to those currently lacking any access to electricity. Marketed in this niche application, photovoltaics in general – and Organic Photovoltaics in particular – can be commercially viable. When combined with advanced battery systems, even existing Organic Photovoltaic technologies available today would allow the remotest of locations to deliver, install and use their own power systems.

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[2] According to the U.S. National Renewable Energy Laboratory (NREL) numbers published in October 2010: http://en.wikipedia.org/wiki/File:PVeff(rev100921).jpg.

14.6 Concluding Remarks

In the context of military applications, access to affordable energy is a critical requirement for mission success. Exploiting the potential for existing renewable resources also serves the dual purpose of improving access to affordable energy for remote communities with little access to electricity or reasonable quality energy services.

The convergence of strategic goals to foster development of smart grids and energy networks with component technologies that can support mobile and stationary applications is fortuitous. Reducing cost and improving reliability and access creates new markets. Reliable access to electricity will remain vital to the sustainable development of remote communities and the success of missions. Smart Micro-grids, emerging solar technologies and other renewables-based, self-sustaining energy options have the potential to break the cycle of energy poverty, by evolving the energy economy away from fossil fuels.

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Part IV
Infrastructure and Integration

Chapter 15
Integrated Perspectives on Sustainable Infrastructures for Cities and Military Installations

M. Merad, T.J. Wilbanks, L. Halfaoui, A. Marcomini, C.ST. John, and A. Tkachuk

Abstract Central to all cities, communities, and military installations is the sustainability of infrastructures. Because infrastructures are intensely interconnected and interdependent, their sustainability is rooted in "systems of systems," subject to cascading impacts as disruptions of one infrastructure spread to other infrastructures. As a result, assuring sustainable infrastructures requires an integrated perspective, recognizing not only connections between infrastructures but also connections between their sustainability and a wide range of threats and other driving forces, including but not limited to climate change. In most cases, such an integrated approach calls for broadening organizational practices to make them more participative, as well as strengthening the base of knowledge and technologies related to cross-sectoral infrastructure resilience.

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15.1 Introduction

Central to all cities, communities, and military installations is the sustainability of infrastructures. By infrastructure, we mean “systems of structures”, with physical, organizational and societal inter-connections, which deliver services that enable cities and installations to perform their functions. Without reliable, safe and resilient infrastructures to deliver shelter, food, comfort, convenience, mobility, productivity, security, and other services, no community of any size is sustainable.

One of the most dramatic examples in the past century has been post World War II in Berlin. In June 1948, the Soviet Union blocked access by the sectors of Berlin under allied control (“West Berlin”), 100 miles inside the Soviet zone, to imports of any resources from surrounding areas. The response was an airlift to provide food, fuel, and other essential resources by air. For a city with a civilian population of about 2.5 million, that meant flying in up to 4,700 t of commodities each day, involving more than 200,000 flights in 1 year. Infrastructures matter to sustainability and survival.

More recently, the Northeast US/Canada blackout of 2003 was the second most widespread blackout in history, after the 1999 Southern Brazil blackout. More than 10 million people in Ontario and 45 million people in eight U.S. states were impacted, and significant impacts on infrastructures such as power generation, water supply, rail and air transportations, communication, and industry were among the consequences.

A variety of other experience over the past several decades has shown vividly how urban/community infrastructures are both vulnerable and can in some cases resilient to a wide variety of types of possible disruptions, from terrorist actions (e.g., 9/11) to extreme weather events (e.g., Hurricane Katrina 2005), economic collapses (e.g., the US financial and some industrial sectors in 2008), social conflict and violence (e.g., recent years in some countries in the Middle East), pandemics (e.g., pandemic Influenza in 2005), and other threats to stability.

This chapter proposes an integrated approach to sustainable community infrastructures that recognizes and incorporates linkages between individual infrastructures that can either enhance or threaten sustainability under conditions of stress or threat. It indicates why infrastructures and their interdependencies are considered a challenge to the sustainability of cities and military installations, and explains why an integrated approach is likely to be not only useful but in fact essential for responding to this challenge. It closes by suggesting actions that should be considered in order to improve the resilience of interconnected infrastructures in order to assure the sustainability of cities and military installations.

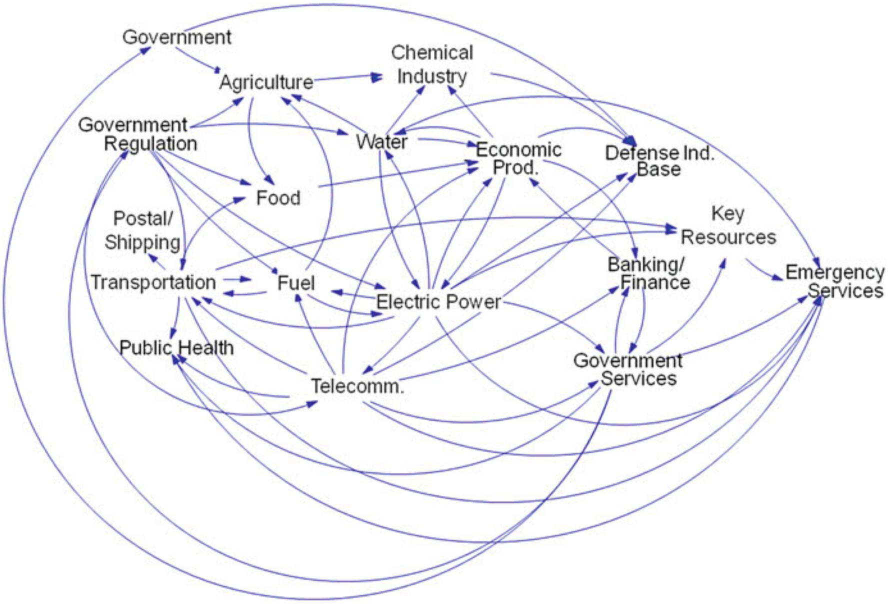

Fig. 15.1 Interconnection between infrastructures

15.2 Integrated Approaches to Sustainable Community Infrastructures

15.2.1 Sustainable Community Infrastructures as "Systems of Systems"

More than half a century of experience and research have shown that infrastructure sustainability cannot be understood by considering each infrastructure individually. Infrastructures are so intensely interconnected and interdependent that their sustainability is rooted in "systems of systems," subject to cascading impacts as disruptions of one infrastructure spread to other infrastructures through networks of interconnections. Such cascading impacts can result in unexpected but very serious effects on communication, water, and public health infrastructure sectors, at least in the short term (e.g., [1, 2]: see Fig. 15.1). These interconnections, for instance between energy and communication, are the reason that integrated perspectives are needed when sustainable infrastructures are being assessed for cities and military installations.

Examples of the reality of infrastructures as interconnected systems of systems abound in real life. Especially vivid cases include (1) a Baltimore, Maryland, freight train derailment in July 2001, which started a chemical fire that continued for more than 5 days. By the end of the first day, a water main ruptured, flooding streets in the downtown area for 5 days. Fire and water effects damaged an electric power cable, leaving 1,200 buildings without electricity. The accident also destroyed a communication system fiber-optic cable passing through the tunnel, slowing Internet service in the Northeast; and train, bus, and boat transportation were also disrupted (http://www.fra.dot.gov/downloads/RRDev/brn1.pdf): pp. 2 18; (2) The US Northeast (and neighboring Canada) electricity blackout in August 2003, which shut down water treatment plants and pumping stations, interrupted air travel as computing and communication systems lost power and caused regional oil refineries to shut down because of a loss of control systems [1, 2]; (3) an extreme heat wave in France in August 2003, which resulted in a tragic cascade of health effects, in considerable part because of organizational failures within a rigidly compartmentalized sanitary system; and (4) an ammonium nitrate explosion in Toulouse, France, in September 2001 that caused extensive deaths, injuries, and stress-related reactions [3].

15.2.2 Viewing Sustainable Community Infrastructures in an Integrated Way

The concept of "infrastructure" embraces a variety of kinds of systems and structures and their interrelationships that aims at providing services. Infrastructures can be physical (e.g., railways, pipelines, . . .) or organizational (e.g.,. health, civil protection, emergency preparedness and response, ...), public or private. These infrastructures can be associated with social perspectives such communication, interaction, and problem-solving, including such realities as social capital and social networking.

For this assessment, however, the emphasis is on physical built infrastructures. Such infrastructures include urban buildings and spaces, energy systems, transportation systems, water systems, wastewater and drainage systems, communication systems, health-care systems, industrial structures, and other products of human design and construction that are intended to deliver services in support of human quality of life. Of course, it can be difficult to distinguish, in the governance and the management of such categories of infrastructures, between technical, human or organizational factors. In fact, infrastructures are "complex socio-technical systems" (see [4, 5]).

15.2.2.1 Considering Sustainability as an Issue

Sustainable development is becoming a salient challenge at every scale, from global to local, as governments, private sector institutions, and other decision-making groups are urged to incorporate a wide variety of environmental, economic, and social dimensions in their strategies for both the near and the longer terms, in order to assure that social and environmental well-being and business continuity can be sustained.

Sustainable development is an appealing concept (see [6]), but it remains unclear and complex to define and to apply in daily activities. Although global and national discourses have helped to establish a number of commonly held principles, the concept itself remains elusive and contested; and in practice many authorities interpret in ways that serve other agendas [7, 8]. For these reasons we suggest the following definition: a managed system is consistent with the concept of sustainable development if it "is able to identify, analyze and assess the risks (both positives and negatives) taken and induced by its functioning, the exercise of its activity in its sphere of influence, within short, medium and long terms and is able to define effective and efficient measures/alternatives to improve its resilience". This definition communicates the difficulty and complexity of resolving the wide range of issues associated with sustainable development. For instance:

- The risks that must be considered include environmental, social and economic consideration ones. One must identify both the risks that are taken (stakes and opportunities) and the risk induced (damages) by the system.
- For sustainability, an organization must be able to identify all the shareholders and the stakeholders (or "actors") in its sphere of influence. These actors are diverse, can be internal and/or external to the organization, can represent a physical or a moral entities, and can have a direct or indirect influences on the system (functioning and missions/activities).
- An organization must deal with different trade-offs in order to consider different kinds of short, medium and long terms balances to be fulfilled, e.g., between near-term economic gains and long-term social acceptance.

By sustainability, we also mean the ability of a system to maintain a service (for what the system was designed to provide) during its full life cycle, considering a wide range of possible driving forces and threats over that extended period. More specifically for infrastructures, sustainability means a capacity to continue the provision of services as conditions change and threats to performance appear (see Fig. 15.2). Indeed, sustainability is a "trajectory", not a state [9], because socioeconomic, political, environmental, and technological change are inevitable over time; and a sustainable system moves through these changes without significant lasting disruptions in functions. Such an infrastructure assures resilience by recognizing its vulnerabilities, identifying and assessing hazards and risks and taking actions to reduce those vulnerabilities, reduce as low as reasonably achievable the risks and being prepared to respond to threats and disruptions, and being prepared to recover over a longer period so that the infrastructure is better able to provide services than before [10].

In summary, the sustainability of managed systems means that risk analysis and risk management are practiced in an iterative manner, monitoring emerging variations and changes in driving forces and refining its responses through a continuing process of learning about both threats and experience with responses [11].

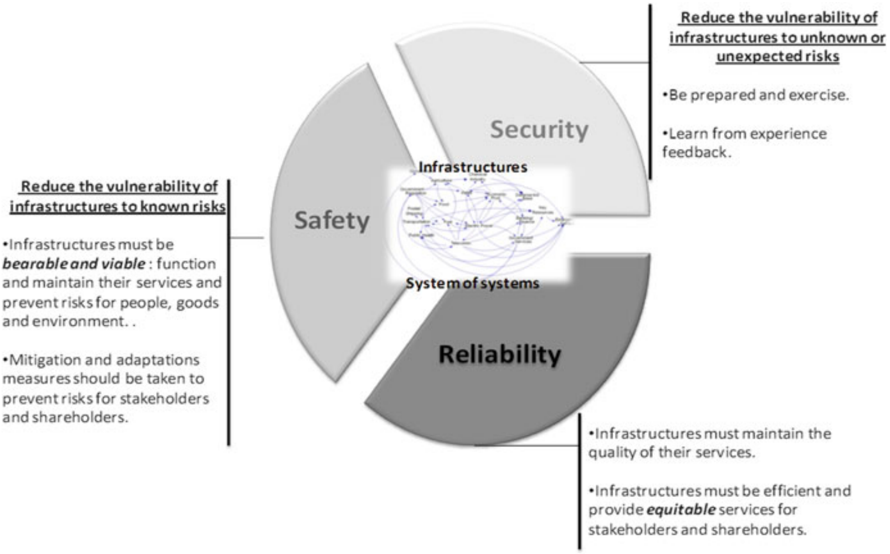

Fig. 15.2 Sustainability of infrastructures

15.2.2.2 Infrastructure Interconnections and Interdependencies as an Issue

The intrinsic interconnectedness and interdependencies among individual infrastructure (see Fig. 15.1) mean that sustainability depends fundamentally on “viewing infrastructures as an integrated system”, where non-sustainability of any important part undermines the sustainability of the entire ensemble (Fig. 15.2). In considering such vulnerabilities in an integrated way, an approach being used widely in the United States, developed during the past decade in the aftermath of the 9–11 disaster [1, 2], views infrastructure interdependencies as a complex system of systems problem, composed of individual infrastructures that are each defined by a number of components (Fig. 15.3). These components of individual infrastructure sectors are linked with components of other infrastructure sectors in ways that can be identified; Fig. 15.4 depicts these linkages via what the modeling community calls a “sandwich diagram.”

In this way, interconnections can be modeled as pathways between interconnected components of infrastructure layers; Fig. 15.5 illustrates these interconnections, which in infrastructure interdependency models number in the hundreds.

Being able to trace these interdependencies makes it possible to answer questions in particular instances; for example, suppose that a severe weather event or other kind of disruptions causes electric power supplies to be interrupted. One effect would be that traffic lights would go dark. As a result, traffic congestion would increase, then highway vehicle emissions would increase, then respiratory distress in the area would increase, then demands for public health care services would increase, etc.

Agriculture & Food
Banking & Finance
Chemical
Commercial Facilities
Dams
Defense Industrial Base
Emergency Services
Energy
Government Facilities
Manufacturing
Nuclear Reactors, Materials & Waste
Information Technology
National Monuments & Icons
Postal & Shipping
Public Health & Healthcare
Telecommunications
Transportation
Water

5. ENERGY	
5.1	**ELECTRICITY**
5.1.1	Electricity Generation
5.1.1.1	Hydroelectric Generation
5.1.1.1.1	*Hydroelectric Dams*
5.1.1.1.2	*Pumped Storage Facilities*
5.1.1.1.3	*Run-of-River Generators*
5.1.1.2	Fossil Fuel Electric Power Generation
5.1.1.2.1	*Coal-fired Generators*
5.1.1.2.2	*Natural-gas-fired Generators*
5.1.1.2.3	*Oil-fired Generators*
5.1.1.3	Nuclear Electric Power Generation
5.1.1.3.1	*Light Water Reactor Power Plants*
5.1.1.3.2	*Other Reactor Power Plants*
5.1.1.4	Other Electric Power Generation
5.1.2	Electricity Transmission
5.1.2.1	Transmission Lines
5.1.2.2	Transmission Substations
5.1.2.3	DC Converter Stations
5.1.2.4	Generation Dispatch and Transmission Control Center
5.1.3	Electricity Distribution
5.1.3.1	Distribution Lines
5.1.3.2	Distribution Substations
5.1.3.3	Distribution Control and Dispatch Centers
5.1.4	Electricity Markets
5.1.4.1	Generation Markets
5.1.4.2	Transmission Markets
5.1.5	Other Electricity Facilities
5.2	**PETROLEUM**
5.2.1	Crude Oil Supply
5.2.1.1	On-shore Wells
5.2.1.2	Off-shore Wells
5.2.1.3	Crude Oil Production from Other Sources
5.2.1.4	Gas-Oil Separation Plants

*Defined in the NIPP**

*National Infrastructure Protection Plan

Fig. 15.3 Interdependencies: a complex system-of-systems problem [1]

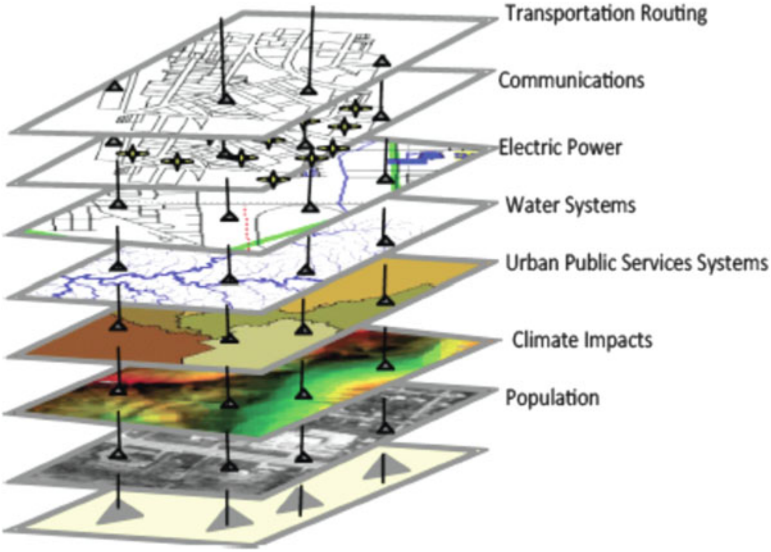

Fig. 15.4 An interdependent system of systems approach [1]

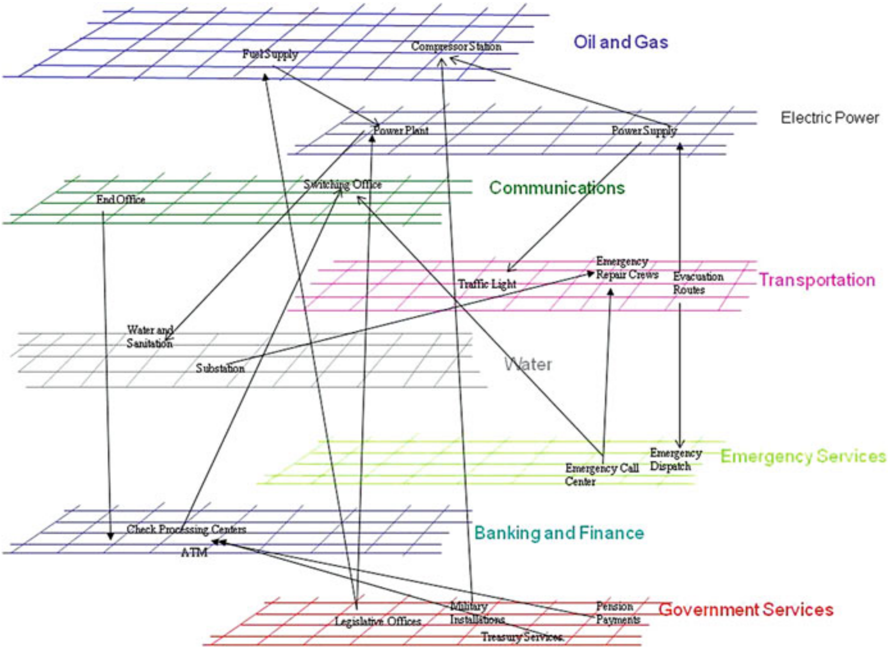

Fig. 15.5 Infrastructure systems can be modeled as interconnected infrastructure layers [1]

15.2.2.3 Military Installations as a Special Case of Sustainable Communities Dependent on Integrated Infrastructures

Like other kinds of communities, military installations are vulnerable to impacts on interconnected infrastructures, especially if the governance and the management of the associated infrastructures are divided between military and non-military authorities. As one example, naval port facilities can be affected by coastal storms that disrupt electricity supplies provided by the regional civil society (see Box 15.1: Issues for Infrastructures to Assure the Sustainability of Military Installations).

Box 15.1 Issues for Infrastructures to Assure the Sustainability of Military Installations

As a particular kind of small (or not so small) community, a military installation is subject to threats to infrastructure that affect its sustainability from climate-related (and other potentially disruptive) events and trends, regardless whether a substantial percentage of the personnel live on the base. Such

(continued)

Box 15.1 (continued)

effects relate to both structures and operations of military installations. For example, structures depend fundamentally on energy, transportation, water, communication, and other supportive infrastructures, often largely external to the installation as larger regional infrastructures. Operations depend on flows of commodities, from fuel to food; on supportive transportation infrastructures; on communication infrastructures that connect on-facility operations with larger military agendas; etc. And, as a general rule, installation funding that must be allocated to supportive infrastructures is not available for the main missions of the installation; therefore, infrastructure efficiency is important as well as infrastructure resilience.

Examples of threats to infrastructures that support military installations range from climate-related extreme weather events (coastal or land-based storms) that can disrupt transportation and electricity infrastructure services to national energy security issues that can put pressure on supplies of transportation fuels for military installation operations.

Military installations may differ from other communities in a country or region in several ways: (1) they may have access to other public-sector funding sources to supplement regional infrastructures in order to assure sustainability, e.g.., to provide backup systems for potentially vulnerable infrastructures (such as electricity); in other words, where security issues are important, military installations tend to be less cost-constrained; (2) their decision-making processes are more direct and top-down, often able to respond to challenges more quickly – but also, in some cases, risk-averse about departing from familiar experience and precedents; and (3) the consequences of failure may be more serious in terms of national security; therefore relatively low-probability contingencies can be considered seriously if the consequences are very serious. In addition, military installations are linked with their host regions by the fact that military units are often asked to help a civilian population in responding to an extreme event (and often also by the fact that most of their personnel live beyond the boundary of the installation).

As one example, the U.S. Department of Defense (DoD) currently manages 28.4 million acres of land and owns 202,178 buildings. These real property assets are located in geographically diverse regions of the world where climactic conditions and the availability of resources can vary considerably. Taking into account this sizeable footprint, the DoD has published several strategic guidance documents that address sustainability, including the 2010 Quadrennial Defense Review (QDR) and the 2011 Strategic Sustainability Performance Plan (SSPP).

The QDR states that: "DoD will need to adjust to the impacts of climate change on our facilities and military capabilities . . . DoD's operational readiness hinges on continued access to land, air, and sea training and test space." The QDR notes that the Department will continue to develop the environmental stewardship it already conducts at hundreds of installations to meet resource efficiency and sustainability goals.

In 2009 President Obama signed Executive Order 13514, “Federal Leadership in Environment, Energy, and Economic Performance.” This directive establishes an integrated strategy towards sustainability and prescribes increases in energy efficiency, reduction in greenhouse gas emissions, conservation and protection of water resources, fostering markets for sustainable technologies, and specifications for high performance buildings in sustainable locations. The Executive Order requires federal agencies to develop annual Strategic Sustainability Performance Plans (SSPP) that prioritize actions based on lifecycle return on investment.

The Department of Defense outlines its vision for sustainability and maintenance of built infrastructure as an organizing paradigm in the 2011 SSPP: “To maintain the ability to operate into the future without decline, either in the mission or in the natural and manufactured systems to support it. Sustainability is a critical enabler in the performance of mission. DoD must plan for and act in a sustainable manner now in order to build an enduring future.

The SSP identifies four key areas that form priorities for the Department: (1) Energy and Reliance on Fossil Fuels; (2) Chemical and Environmental Concern; (3) Water Resource Management; and (4) Readiness in the Face of Climate Change. The SSPP recognizes that “The design of facilities, and the evaluation and prioritization of activities, should consider environmental and societal factors in addition to mission, financial and regulatory considerations.” In incorporating sustainability into investment decisions, the Department is focusing on sustainable acquisition of future capabilities and addressing maintenance backlogs in facilities.

More specifically, the U.S. Navy’s sustainability efforts are integrated throughout its energy, environmental, and climate change adaptation efforts and there is an increasing focus on the resiliency of infrastructure systems. A 2011 report by the Naval Studies Board (part of the National Research Council) states that “Global sea-level rise has significant potential to affect many naval coastal installations. These installations are enduring facilities, predominately in the coastal zone, that have been built to last for decades” [12].

The potentially vulnerability of Navy’s infrastructure to climate change presents challenges and opportunities. Challenges include the possible need to relocate mission critical facilities impacted by greater frequency and duration of flooding related to sea level rise; to adapt or retrofit current infrastructure including the re-siting of critical infrastructure such as buried power lines or computer servers; to account for vulnerabilities of specialized assets such as aircraft and runways; and the loss of usable land area on vulnerable installations due to flooding, erosion, and other processes.

The Naval Studies Board report cites several specific impacts to built and natural infrastructure that may occur, including effects on piers, utilities like electrical substations and communications nodes, and freshwater aquifers that are vulnerable to saltwater intrusion with rising sea levels. Most current infrastructure was designed and built to respond to historic variation in climate patterns, which does not take into account the likelihood for future changes in climate variability. The availability of regionally-specific data for integration into installation planning is sparse, but many efforts, such as the National Climate Assessment in the U.S., are beginning to provide managers with the information needed to better understand projected changes to climate patterns on a localized scale.

Military installations are often dependent upon surrounding communities to meet their water, energy, and transportation needs. This dependence encourages the military to foster sound working relationships with neighboring communities and to work toward collectively reducing risk due to shared vulnerabilities. Programs such as the DoD's Joint Land Use process and Navy's Community Liaison Planning Officer program have garnered success engaging local communities on land use issues and are useful templates to foster cooperation on shared approaches to infrastructure issues. Additionally, the DoD REPI (Readiness and Environment Protection Initiative) enables the military to work with willing partners who help provide cost-sharing land conservation solutions to limit incompatible uses around key test and training areas. It is one of the Navy's key land use programs that addresses sustaining military readiness at a long-term regional scale. The Navy can use REPI in the future at installations as the physical environment changes and necessitates changes in use of space.

Despite the challenges to infrastructure adaptation, opportunities also exist for the Navy to recapitalize aging infrastructure in the face of changing conditions. The Navy recognizes these challenges and opportunities and uses a science-based approach to identify coastal installations most vulnerable to climate change. The Navy plans to begin assessing methods to incorporate climate projections into the Navy installation planning process. For example, the real property of Naval Base Norfolk is comprised of 13 million square feet of space and valued at more than $4.2B, much of which could be at risk from increasing sea level rise, storm surge, and more frequent storms. The base already has a long-term approach of demolition of old infrastructure and consolidation into buildings that are more energy-efficient and compliant with regulatory requirements [13, 14]. Incorporation of climate trends into infrastructure management will also improve the resiliency of the Navy infrastructure and bases as a whole.

15.2.2.4 Particular Concerns About Climate Change Vulnerabilities and Impacts

Climate change is one of many concerns for the vulnerability of integrated infrastructures, especially when it may mean increased exposure to severe weather events. As a factor In infrastructure performance and sustainability, it is surveyed in ORNL, 2012 [15]. In general, that report finds that, at least in the United States, extreme weather events associated with climate change will increase disruptions of infrastructure services in some locations at some times, and a series of less extreme weather events associated with climate change, occurring in rapid succession, or severe weather events associated with other disruptive events may have similar effects. Disruptions of services in one infrastructure will almost always result in disruptions in one or more other infrastructures, especially in urban systems, triggering serious cross-sectoral cascading infrastructure system failures in some locations, at least for short periods of time. These risks are greater for infrastructures that are located in areas exposed to extreme weather events and/or located at or near particularly climate-sensitive environmental features, such as coastlines, rivers, storm tracks, and vegetation in arid areas; and they are greater for infrastructures that are already stressed by age and/or by demand levels that exceed what they were designed to deliver. In particular, and this is almost certainly true of most infrastructures in most regions of the world, these risks are significantly greater if climate change is substantial rather than moderate.

Regarding urban systems in particular, the report finds that urban systems are vulnerable to extreme weather events that will become more intense, frequent, and/or longer-lasting with climate change. They are vulnerable to climate change impacts on regional infrastructures on which they depend. Urban systems and services will be affected by disruptions in relatively distant locations due to linkages through national infrastructure networks and the national economy. Cascading system failures related to infrastructure interdependencies will increase threats to health and local economies in urban areas, especially in locations vulnerable to extreme weather events. In particular, such effects will be especially problematic for parts of the population that are more vulnerable because of limited coping capacities.

15.2.3 Implications of Interconnected Infrastructures for Community Sustainability

As indicated in the introduction above, one consistent finding from both research and practice is that particular infrastructure failures tend to cascade through system interdependencies, leading to much more extensive interruptions of infrastructure services in an urban area [1, 2]. For example, considering climate-related extreme weather events as a case in point, impacts from disrupted infrastructures occur almost annually from extreme weather events [16]. In 2011, for instance, Hurricane Irene, the September San Diego Blackout, and flooding in the Upper Midwest illustrated both the cascading of disruptions through infrastructures and cascades reaching far from the original damage zone in ways that are difficult to predict because of the complex connections of built infrastructures [17]. Climate impacts are likely to increase flooding, wind damage and increased demand for services in areas currently unequipped to handle the new challenges [18]. Extreme weather events such as hurricanes create direct and cascading impacts within the key infrastructure sectors [18] such as:

- Energy (electric power, natural gas) [19].
- Water/wastewater (including sewage and sanitation).
- Water distribution.

- Telecommunications (wireline, wireless, internet) [20].
- Public health (hospitals, urgent care, nursing homes) [21].
- Transportation (ports. road, rail, air including pipelines).

Climate impacts that present specific, identifiable risks to these six sectors of energy and other infrastructures include increases in precipitation, changes in wind (both damaging and as an emerging source of electricity), increased frequency of storms, and higher temperatures ([18, 22]).

Each of these sectors is interdependent with the others because disruptions within one networked infrastructure will cascade into other infrastructures, which may in turn cause further disruptions in a third infrastructure [23]. This coupling can provide both a source of resilience and a source of additional vulnerabilities beyond those discovered by examining each infrastructure independently [17].

During the ORNL [1, 2], assessment, examples were found of potential impacts of climate change for infrastructures and their linkages along with evidence that the trend for interdependencies is increasing. For example, if weather and climate extremes associated with climate change exceed the designed resistance of a structure, or if resistance has degraded through time, then increased vulnerabilities result. As urban infrastructures evolve to higher degrees of interconnected complexity, the likelihood of large-scale cascading outages are likely to increase as risks to infrastructures increase [23]. This outcome in turn leads to higher levels of vulnerability and consequence within urban infrastructures [24]. This effect is due in part to temporal and spatial interdependencies that are inadvertently created in an attempt to service changing populations using constrained resources [25].

For example, reliance upon and integration of sophisticated information technologies and digital control systems places public health, communications, and transportation sectors at increased risk from loss of electric power and in turn power availability increasingly depends on undisrupted communication networks [26], while information technologies are critically important for infrastructure service restoration and recovery. Traffic control is more reliant on communication technology that is dependent on power availability that in turn relies on undisrupted fuel deliveries (13). Power outages can cascade through direct damage to the power grid as well as disruptions to control communications, fuel sources, and workers unable to get to work stations [23]. Public health and wastewater management tolerate only few hours of power disruption before direct sewage spills are released into public waterways [27]. Refineries in blackout areas cannot fulfill deliveries to pipelines with impacts to transportation hubs throughout the served region. Fuel deliveries to hospital generators must be restored within 1–2 days to maintain hospital and other lifeline utilities. Loss of power to water distribution systems reduces pipeline pressure allowing infiltration of contaminated sources [27]. Each networked infrastructure in turn is highly dependent on computerized Supervisory Control and Data Acquisition Systems (SCADA) that depend on an undisrupted data and information networks [26, 28].

As illustrated by the examples of the 2011 San Diego Blackout, the 2003 Northeast Blackout, [29], and Hurricane Irene [21], the greatest losses may be distant from the infrastructure where damages started. For example, Hurricane Katrina disrupted oil terminal operations in South Louisiana, not because of direct damage to port facilities, but because workers could not reach work locations through surface transportation routes and could not be housed locally because of disruption to potable water, housing, and food shipments [30].

In a study of a hypothetical major hurricane event in Miami in 2030 [1, 2], interdependent infrastructure cascades occur when failures of components within one infrastructure trigger failures in other, interconnected infrastructures [23]. These cascading failures can be either caused or aggravated by regional convergence (which refers to collective business decisions concentrating important infrastructure in small geographic areas or corridors) [18]. Regional convergence is likely to place more infrastructure assets at or near climate-sensitive environmental features that are particularly sensitive to water availability, water quality, and direct damage from floods, wind and precipitation [31], suggesting that some separation might be a risk management strategy for the future.

15.2.4 Challenges in Assuring Sustainable Community Infrastructures

Institutions responsible for assuring a sustainable flow of infrastructures face a number of serious challenges, often leading either to public sector management or public sector sharing of risks with private sector managers. Challenges (beside potentials for cascading failures) include the fact that citizens view many of the services not as commodities but as entitlements, because they are so important to the quality of life. Maintaining the services is confronted by a wide variety of contexts and stresses, some of which are different from the conditions the infrastructures were designed to handle. In fact, in many cities and regions infrastructures are aging and declining in their ability to perform while demands increase; and a need for improvements is becoming increasingly urgent. But improvements often face significant constraints: they are typically large in size, long in expected lifetimes, and high in capital costs. A profound challenge is that it is vitally important to be able to associate sustainability improvements in community infrastructures with benefits/payoffs, given high expectations, high costs, and high visibility, but infrastructure services are often difficult to value – and the value is usually variable across different components of the community [1, 2].

15.2.5 Threats to the Sustainability of Infrastructures

These challenges are daunting enough, but the sustainability of infrastructures faces further threats as well. Threats include a possible convergence of a number of types of disruptive events: for example, severe weather events, economic weaknesses, a pandemic health event, and weak local leadership. Determinants of resilience to such threats have been a recent topic of study (e.g., [10]). In general, they tend to include a combination of a social dynamic that supports effective collective problem-solving in the face of threats or disruptions, access to resources (financial, managerial, critical commodities), and mechanisms for cost-sharing.

In many parts of the world, there is a sense of impending crisis for community infrastructures that are neither resilient nor sustainable:

(a) Cities, communities, and military installations highly vulnerable to episodic disruptions of their services (related to climate change and other forces), as major events cascade through interconnected and interdependent infrastructures.
(b) Disruptions more likely when individual infrastructures and integrated cross-sectoral infrastructures are not resilient now, because of age, outmoded design, and/or poor physical condition.
(c) Most knowledge and frameworks for management and action for infrastructures focused on individual infrastructures rather than on integrated strategy development and resilience improvement – whose job is integrated strategy development?

15.3 Contributions of an Integrated Perspective to Identifying, Reducing, and Responding to these Potential Threats

In what ways does an integrated perspective make a difference in responding to threats to infrastructure sustainability?

15.3.1 Issues in Cross- Sectoral Resilience/Sustainability Strategies for Infrastructures

Integrated infrastructure sustainability raises a set of issues. Some issues are of substance (the what), some that are regulatory (the how), some that are analytical (what do we need to know and how do we learn more), and some that are related to the front end of a sustainability enhancement trajectory (science and technology to expand the range of options) or to the back end of the trajectory (user interfaces). All these issues are discussed below.

15.3.1.1 Substantive Issues

In many cities worldwide, improving infrastructure sustainability faces daunting challenges. Built infrastructures tend to be very large physical structures, requiring very large capital investments, remaining in place for periods of many decades. In many cities, existing infrastructures installed decades ago are now aging, needing repair or replacement, and having to cope with levels and types of demands for services that are beyond what they were designed for. Many observers of issues for multi-hazard resilience and adaptation to environmental changes suggest that built infrastructures are among the least adaptable of all the systems important to urban areas and communities.

Examples of critical issues include the following:

1. The adaptability (or lack thereof) of physical infrastructures, given uncertainties about future conditions and threats. For instance, what are potentials for designing flexibility and adaptability into new/emerging infrastructures?
2. Limited financial resources for investment in large infrastructures. What are options in times of limited public sector funding prospects? To what degree might unfortunate infrastructure disaster events represent "policy windows" for infrastructure improvement, if strategies have been developed in advance?
3. A lack of understanding of cross-sectoral infrastructure interdependencies, including limited knowledge bases about linkages and interrelationships because communities of both research and practice are so often focused on individual infrastructures.
4. Critical weaknesses in existing infrastructures in assuring resilience/sustainability in coming decades, including infrastructures that are aging and/or were designed with lower or different demands in mind.
5. A compartmentalization of responsibility for infrastructure assessment and enhancement, impeding integrated strategy development and action. For instance, who is responsible for cross-sectoral integration (aside, to some degree, from place-based integration in urban areas)?

15.3.1.2 Regulatory Framework

Public infrastructures (and some private infrastructures that serve public needs) are subject to regulatory oversight to protect the public interest. Countries and regions may differ in their approaches to infrastructure regulation, e.g., safety standards, reporting requirements, and performance standards. Approaches may include laws, government agency oversight (or management), and engineering standards, including different practices in coordinating between jurisdictions. In an increasing number of cases, issues are emerging about whether current policies, standards, and regulations encourage or discourage sustainability (e.g., engineering codes and standards.

15.3.1.3 Analytical Issues

Analytical issues are focused on the adequacy of existing data and tools for informing infrastructure strategies and decisions. They include:

1. A lack of indicators/measures of infrastructure resilience and sustainability, so that levels of resilience can be determined, comparisons can be made, and progress can be evaluated.
2. A lack of data regarding infrastructure weaknesses in advance of incidents or failures), based on sustainable observational platforms, along with approaches for identifying especially critical weaknesses.
3. Significant difficulties in assessing institutional coping capacity as a key element of resilience.
4. A lack of clarity about the meaning of adaptability vs. resilience vs. sustainability, especially for operational rather than theoretical purposes.

15.3.1.4 Science and Technology Issues

Science and technology issues focus on strengthening the science and technology base for infrastructure resilience enhancement, e.g., developing more resilient materials (possibly self-healing materials?). Other issues include developing appropriate resilience measures/indicators, resilience monitoring technologies, and infrastructure response control technologies [32].

15.3.1.5 User Interface Issues

Neither infrastructure science nor infrastructure analysis is likely to enhance sustainability unless it is linked effectively with users of that knowledge in developing and managing infrastructures in an integrated way, both to prevent threats to infrastructures and to control infrastructures as they address changes in driving forces and threats to sustained performance.

15.3.2 Framing Discussions of the Value of an Integrated Approach to Infrastructure Sustainability

The value of an integrated approach is relative to how one thinks about sustainability and who it is for. The sustainable integration of infrastructure is in fact both “actor dependent” and “aims dependent”. Indeed, contextual and time frames of reference shape the way sustainability is defined. Each actor (individual, firm, city, country) will have its own vision of sustainability depending on its projection of historical experiences, its expectation about how the future can be, and the methods that it use to turn expectations into fuller visions (e.g. futurology/projection/narrative construction). Perceptions of sustainability are subject to changes through time, depending on evolving experience and social dynamics (see, for example, the Algerian experience in Sect. 15.2.5). Moreover, they combine the variety of human, organizational and technical aspects that define the integrated infrastructure system.

In principle, any effort to assess the value of an integrated approach should rooted in a set of indicators that describing "system of systems" characteristics and interactions, context characteristics that include social and cultural values, and both normal conditions and surprise (e.g., disaster) conditions of the system (e.g. resilience, risks, vulnerabilities, mitigation, adaptation).

In the end, the value of an integrated approach depends on its contributions to sustaining infrastructure services [1, 2]. This means that it is necessary to consider who are the stakeholders and consumers served by the infrastructures and the sustainability of those services as contexts, conditions, and driving forces change. In effect, public infrastructures are common properties for which perceptions of value depend on a variety of needs of actors with different types of responsibilities (e.g., financial, engineering, job performance, convenience for well-being) and different level of obligations (from individual services to institutional roles). These stakeholders tend to be involved in public-private sector partnerships, formal or virtual, to frame and take care of infrastructures. It remains difficult to characterize how possible differences between needs and values are or should be resolved in know in framing sustainable integrated infrastructures.

15.3.3 Analytical Instruments to Deal with Sustainability

Because, as indicated above, infrastructures and sustainability issues are almost infinitely complex, analytical challenges are daunting. In many cases, rather than treating such challenges as purely technical issues, it has proven helpful – even essential – to apply participative approaches, i.e., approaches that involve participation by infrastructure user and stakeholders [33]. A considerable base of experience and assessment exists to document the benefits of participative approaches to participative management and governance (e.g., [34]), extending to most forms of infrastructure and their place-based integration. One important lesson has been to avoid "one size fits all" approaches that are insensitive to differences between systems, threats, and social/institutional contexts.

Fundamental to integration, of course, is linkages between infrastructures, locations, social agendas, and events (see Sect. 15.2). For instance, most built infrastructures have finite life or mission cycles, from creation through improvement to replacement. This cycle can be affected by events ranging from extreme environmental disruptions to military action; but change is inevitable, modifications in one infrastructure tending to change conditions in others. Connectivity is a double-faced issue that can produce surprises, adding to the analytical challenge. Indeed, the more the infrastructures are connected, the more the system is coordinated; but at the same time the more the systems are connected, the greater are risks that disruptions in one part of the system of systems will pose risks for other parts of the system.

There are many kinds of software tools that can be used for achieving sustainability, including those developed to support cognitive analysis; decision analysis; risk analysis, risk communication; education; and other management processes [35]. These tools enable sound process design, development, and maintenance of sustainable systems. For example, cognitive analysis tools are used to structure a problem, including identifying alternatives, criteria, factors, values, preferences, etc. Decision analysis tools are used to translate found items into courses of action that leads to sustainable systems. Risk analysis tools are used to obtain information about risks associated with possible courses of actions. Risk communication tools are used to design focused strategies and messages for engaging stakeholders in communication about risks and decisions. Education tools are used to teach people how to avoid or mitigate risks. Management tools are used to implement decisions. This process can be iterative analyzing, updating, and making decisions in changing conditions.

Such tools can help dealing with multi- disciplinary, multi-actor, multi-scale, and multi-issue complexities. However, there is a need to know the limits of these tools as well as their capabilities. In particular, how can they be used in an integrated way – e.g., how might strengths of one set of tools compensate for weaknesses of another? Fig. 15.6 suggests a methodology to map these tools according to the nature of data, the aim of the tool, the nature of the tool, the context for which it was developed, the intended users of the analysis, the expected beneficiaries of good decisions, and such issues as the treatment of uncertainty.

15.3.4 Is Sustainable Governance and Management of Infrastructures the Answer? some Organizational Perspectives

As one can see, thinking about the sustainability of infrastructure systems for cities or military installations invites an in-depth change in the way systems are managed and governed. Sustainability is embedded in an ethic of functioning and operating that needs a strong involvement at political and at strategic levels before undertaking concrete practical actions. This model of sustainability can reach equilibrium between economic, environmental, and social issues only by: (a) looking at systems in an integrated way, (b) using a participative model of governance in order to assure sustainable practices, and (c) employing appropriate and robust tools to assist in arriving at effective strategies.

It is important to note that environmental and social issues are often represented weakly in infrastructure strategy development, sometime only considered as aspects of achieving economic objectives. Due to the fact that these two sets of issues are often both critically important and largely overlooked, vulnerable cities, installations, and organizations are well-advised (a) to rethink how they are used in assessing and

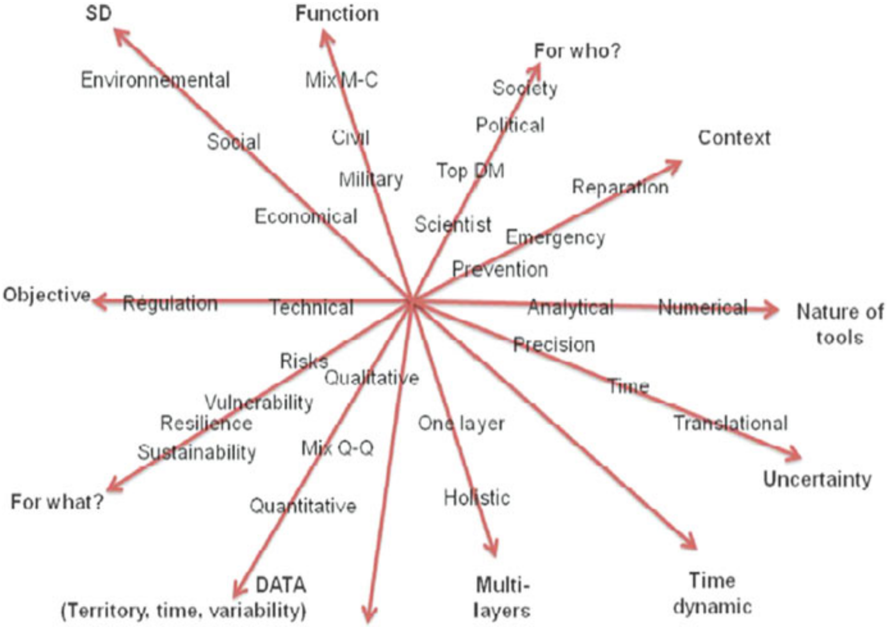

Fig. 15.6 Mapping tools to deal with complexity issues of integrated infrastructures

managing risks that oversimplified actions can undermine economic sustainability and (b) to consider that for continuity in changing markets and a need to innovate to be sustainable, organizations must be prepared to think and act differently.

Within this general context, organizations are systems in a constant and continuous interaction with surrounding social, economic, and environmental eco-systems. Organizations need always to be prepared to make decisions, to take risks (e.g., proposing a new service), and at the same time to define policies for risk prevention and/or management. In the classic model of organizational behavior, risks are identified, studied, and prevented in a fragmented way; and risk integration is reserved for the top level of management. In effect, however, for an organization the integration of sustainability within a risk management process is likely to require the framing of debate areas within and outside the organization about the larger effects of risk prevention measures (are they bearable? will they contribute to assuring positive working conditions? are they equitable?), placed in the context of the relevance and appropriateness for sustainability of the risk prevention approaches that are used (especially: is the general system for risk prevention sustainable?). The fact is that, for an organization, the sustainability of a system of systems is not only the sum of the sustainability of the subsystems (e.g., functions of the organization). It involves the sustainability of the ensemble as well, interacting with a changing landscape of driving factors, often calling for the use of coherent and robust tools to diagnose issues, analyze options, and take decisions that are simple enough to be operable and understandable but fully cognizant of the complexity of the organizational context.

A critical part of this is the way an organization thinks about its management (or "governance") as a sustainable institution. How does it:

1. Identify the values represented by the organization and how they are reflected in both strategic and operational actions;
2. View the appropriate decision processes to be used to achieve sustainability (e.g., the right mix of top-down, deliberative, and participative processes), considering the range of institutional needs and constraints;
3. Determine the policies and practices that guide its functions and effectively manage its risks.

In an organizational context, the term "governance" refers to a number of aspects of management: the structures for decision-making (e.g., board of directors, executive hierarchy), the procedures for decision-making; and approaches that balance top-down bureaucratic, administrative decision-making system by also incorporating participative involvement of organizational staff and other stakeholders.

For organizations, "good governance" does not mean a normative system of governance for all categories of organizations. It is clear that different organizations have different management structures, different missions and objectives, and different histories and cultures. It can be suggested, however, that "good governance" is consistent with a set of seven basic values and great principles that are summarized in ISO 26,000: accountability, transparency, ethical behaviors, respect for stakeholders interests, respect for the rule of law, respect for international norms of behaviors and respect for human rights. In this sense, even if it is difficult to define in an absolute way what is meant by "governance" and "good governance", it is possible to say that for sustainability it is important to involve a range of stakeholders and actors in a process of fixing and defining "a common and shared vision of what is a good governance" [8]. More specifically, good governance is "a governance model of the organization that helps to conciliate, at short, middle and long terms, the economic, social, and environmental stakes and opportunities with and with respect to stakeholders/actors concerns and expectations".

As indicated above, such a complex process benefits from tools to inform both organizational practices and decisions. It tends to presuppose the identification and definition of a set of indicators, perhaps grouped together in a dashboard, and the elaboration of an accepted and legitimated diagnosis, evaluation, and assessment methodology [8]. But any use of indicators needs to remember that they are means to organizational ends (e.g., monitoring performance and progress, assessing and managing risks), not an end in themselves (implying the quantification of governance).

15.3.5 The Algerian Experience of Integration

Algeria does not enjoy the luxury of contemplating sustainable development without needing to overcome security problems, societal conflicts, and other obstacles to harmonious, participative development.

Algeria is today developing an approach to sustainable development that includes criteria for sustainability, integration, and active participation of civil society. New modes of intervention reserve a special place for people involved in development projects so that they are involved in all phases of design, installation and project implementation. This is a truly new approach to help guide development projects so that they are shaped by the beneficiaries in order to establish a viable partnership with government.

In this approach, different time scales, geographic scales, and decisions are identified to include all scales of development activities and investment and to respond to local, regional and national needs. Development institutions for major sectors (water, agriculture, energy, health, jobs, infrastructure, etc.) have been strengthened and are more active and effective in the field.

In Algeria, sustainable development aims to establish a new style of governance, a new approach to progress, and a new policy that require changing the traditionally problematic structures in the management of development projects. This is expected to lead to principles that require:

- A strategic vision for the future,
- An ability to benefit from the experiences of others, by a technological, regulatory, commercial interactions and collaborations.
- A democratization of socio-economic tradeoffs at a local level,
- A strong will to implement participative decisions by public authorities.

For Algeria, sustainable development is an approach that goes beyond conventional notions of economy, social enterprise, and/or responsibility. In this deeply complex country, sustainable development is differentiated by the nesting of elements related to history, culture, physical environment, the mode of appropriation of space, and individual and collective perspectives. As one example of a fundamental obstacle, Algeria suffers from an inability to mobilize investors, although its Human Development Index (HDI) is almost equivalent to that of Tunisia.

Achievements to assure synergies among economic, social and environmental goals, rural and urban, face multiple constraints: difficulty in reconciling environment and development, lack of coordination between different stakeholders, lack of measures and means for monitoring, control and enforcement. Integration requires substantial intervention by government in land use planning at different scales and especially at the national level in order to limit disparities, placing heavy demands on the quality of governance and relations between those who govern and those who are governed.

Central questions include: Are public awareness of and the government communication about sustainable development enough? Are there enough channels of information flow about the national approach to planning in the context of sustainable development? Are there participative discussions of issues of sustainable development (e.g., in the press, forums, social networks)?

Finding answers is complicated by the fact that there are no performance indicators established for evaluating the results of these processes. For instance, what is the appropriate territorial entity for integrative development? Should it be focused on a city and its suburbs? Algeria believes that this practice, often followed in industrialized countries, is inappropriate in developing countries such as Algeria. It believes that the structure of its cities is not comparable to Western cities. After independence (1962), urban areas were "ruralized," and it was not until the 1990s that its cities have began evolving toward more "modern" forms. At the same time, there are often considerable differences between a national vision of sustainable development and views of local authorities, and it is not clear how to resolve such differences.

Moreover, there are questions about the place of Algeria in global sustainability, in terms of responsibilities in both directions. For example, Algeria is projected to lose thousands of hectares of arable land to desertification due to rising temperatures with climate change. Since the early 1970s, Algeria has developed a green barrier, by planting millions of trees on a strip of 10–15 km wide with a length of 1,500 km between the southern and northern parts of its country to halt the advance of the desert to the Mediterranean coast. This action has some positive impacts on global climate change and its effects. In such a case, is the achievement of a "green dam" the responsibility of a country or the international community? As global phenomena desertification, land degradation, and drought cannot be integrated at a national or sub-national scale; as a result, in some connections integration and sustainability must converge at a global scale.

15.4 Possible Actions to Improve Integrated Infrastructure Resilience as a Key Component of Sustainable Cities, Communities, and Military Installations

Given the enormous challenges and complexities of both infrastructure integration and urban/community sustainability, how do leaders and stakeholders move toward truly sustainable systems of infrastructures? The starting point is to develop, through broad community participation, a vision of a better future. That vision can be pursued in a variety of ways, often combining aspects of all the major alternatives; but these tools are embedded in a continuing process that can start with actions now that lead a community in the right direction.

15.4.1 A Vision of a Better Future

Given the lifetimes of major components of urban/community infrastructures, along with processes of social and technological change, it is reasonable to try to think in terms of how a community would like its system of infrastructures to be in fifty years. For instance, a vision might include the following elements:

1. Each infrastructure system structurally sound, embedded in a process of continuing maintenance and revitalization as components age, uses evolve, and technologies change; associated with sensor-based monitoring systems to provide information about system resilience and warnings of system weaknesses; and supported by a viable long-term funding model to enable continuing improvements.
2. Linkages among the infrastructures well-understood and monitored, with institutional responsibilities for system integration clearly defined and related to user needs for infrastructure services.
3. Effective structures in place for a continuing process of vulnerability assessment, vulnerability reduction, and preparedness to respond to and recover from threats and disruptions.
4. Contingency planning for the possibility that, under some combinations of circumstances, sustainability could require major transformative changes in infrastructures rather than a succession of incremental changes [36].

15.4.2 Approaches for Pursuing Infrastructure Resilience for Community Sustainability

Alternative tools, mechanisms, and processes for achieving such a vision include three major categories described in sections above:

1. Participatory governance approaches. A very important step is to catalyze continuing community assessments of infrastructure sustainability goals, challenges, and strategies, with broad-based participation by stakeholders to assure awareness of the issues and support for the strategies [36]. Such assessments should include attention to a range of possible threats to sustainability, the development of structures for monitoring infrastructure resilience over time, and contingency planning for potential disruptions and other types of crises.
2. Analytical approaches and tools. Such a continuing assessment process needs to be supported by analytical tools for characterizing risks, analyzing alternative responses and strategies, and considering linkages within the infrastructure system of systems – all supported by data collection and management systems and by technical support by appropriate centers of expertise.
3. Policy and regulatory approaches. Infrastructure sustainability strategies will only lead to increased resilience if they are “main-streamed” into the policy and

regulatory settings that determine rules and standards for infrastructure development and operation. For example, it can be useful to enlist the assistance of professional engineering associations in revisiting engineering codes, standards, and certification structures to assure that they are sensitive to sustainability threats, are informed by the best available knowledge about effective responses to those threats, and promote flexibility as a strategy for coping with an uncertain future.

15.4.3 Considering Agendas for Action

In considering agendas for action, nations, cities, and military installations would be well-advised to consider at least two sets of actions [36, 37]:

1. Initiating and sustaining participative processes for integrated infrastructure system vulnerability assessments and contingency planning (see above).
2. Strengthening the base of infrastructure sustainability knowledge and technologies through research, both to strengthen decision support (e.g., credible indicators) and to enlarge the menu of technology options (e.g., materials, sensors). Research needs and priorities include [1, 2, 32]:
   (a) Developing appropriate indicators of infrastructure resilience and monitoring systems to measure levels and trends.
   (b) Adding analytical capacities, e.g.: to identify and understand linkages among infrastructures, trace supply-chain linkages, identify and understand threats to infrastructure resilience, anticipate possible tipping points/thresholds associated with abrupt changes, understand scale dependencies (e.g., isolated vs. widespread, slow vs. fast changes), and enhance risk-based framing, scoping, and analysis capabilities, especially given uncertainties that surround large investments for long-term structures.
   (c) Enlarging the menu of physical/structural options for resilience improvement, e.g.: more resilient materials, more reliable and affordable sensors, and more robust and appropriate control systems.

15.5 Summary

Sustainable infrastructures for cities and military installations depend fundamentally on the use of an integrated "system of systems" perspective, embedded in interactions with a wide range of institutions and stakeholder interests. The challenges are considerable for many countries, regions, cities, installations, and infrastructures, related to a wide variety of possible threats – including but not limited to climate change. In many cases, these challenges are intensified by current infrastructures that are aging and/or operating under demands for which they were not designed, limitations on the availability of public-sector funding for large-scale infrastructure revitalization, and different perspectives within societies and between organizations about infrastructure goals and strategies. As a result, the sustainability of infrastructures in many cities and for at least some military installations is in serious question at this time, and the need for serious attention to this issue is becoming ever more urgent.

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Chapter 16
Natural Hazard Risk Assessment and Management Methodologies Review: Europe

G.T. Cirella, E. Semenzin, A. Critto, and A. Marcomini

Abstract In the last decade, Europe-wide natural hazards have accounted for large numbers of the most serious causes of mortality; this death toll accompanies several billions of euros in damages. These facts support the need to reduce natural hazard impacts on the European territory in which, by in large, are going to augment in the future primarily due to climatic change and inappropriate land use management. In this context risk assessment and management through appropriate prevention and protection measures play fundamental roles in redefining natural hazard occurrences, risk areas prone to these events and reducing future phenomena at all levels. To better integrate the contextual role of risk assessment and management a descriptive state of the art based on scientific publications reviewed from 2000 to present is broken down into two domain types: hydro-meteorological and geophysical hazard events. A comparative examination draws potential viewpoints on choice of methodology which largely depends on the considered area and addressed target. Focus is put on analysing the prevention, protection and preparedness principle in which can define conclusive technical development; based on the results, some conclusions are drawn to support further developments at the knowledge-base level.

16.1 Introduction

In the last decade natural hazards have been one of the most serious causes of unintentional death Europe-wide, triggering billions of euros in damages. It has been estimated that floods alone produced over 700 fatalities and at least half a million persons have been evacuated since 1998; more than 25 billion euros of

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economic losses and invaluable socio-economic potential future losses have affected much of Central Europe, especially countries that interlink with the large rivers of the Danube, Elbe and Rhine [10]. Climatic alteration and inappropriate land use management continue to augment this impact which further underlines the need to reduce consequential effects [13]. It is evident the need to support the reduction of natural hazard impacts on the European territory interrelates with risk assessment and management as fundamental steps in defining risk prone areas and reducing potential impacts regardless of the authority in charge or stakeholder awareness. Through appropriate prevention and protection measures natural hazard impacts can reduce the threat to economic assets, society and environment.

A state of the art review of natural hazard risk assessment and management methodologies reveals that this knowledge-base is growing at an alarming rate; the specifics of this review will focus mainly on water-related hazard risk, since it undoubtedly is the most unsafe phenomena affecting Europe. The European Union (EU) published the Floods Directive [17], which aims to establish a common approach for flood risk management, and a set of reports and guidelines, in order to provide a common framework on disaster prevention and to delineate the current European environmental state.

16.2 Natural Hazards: Brief

Natural hazards can be divided into two main domain types: (1) hydro-meteorological hazards (i.e. floods, storms, water scarcity, extreme temperature events and forest fires) and (2) geophysical hazards (i.e. landslides, avalanches, earthquakes and volcanic eruptions). This European centric briefing extends as a case study for the continent at large; main natural impacts are divided according to the affected hazard zone (Table 16.1) [13] and are the basis for a geographical definition of natural hazard occurrences and risk areas prone to the event under consideration. In light of better understanding European dimensional components, it should be stated that the methods and concepts are not necessarily European centric specific; the scientific publications reviewed from 2000 to present outline the state of the art of the discipline and configure an evolving viewpoint which technically could be labelled as a developmental progression. To better set the tone for Europe as a whole, the topic brief will consider climatic change and issues of governance.

16.2.1 Climatic Change

An interlude to climatic change relates to the number, frequency and magnitude of events. A statistical viewpoint shows background and support for the development and necessity of developing assessment and management methodologies. The

Table 16.1 Continental Europe: main affected natural hazard zones [13]

Arctic	Decreasing in Arctic sea-ice coverage and higher risk of biodiversity loss
Northern (boreal region)	Less snow, lake and river ice cover, increasing river flows northward movement of species, higher risk of damages by winter storms
North western	Increasing in winter precipitation, increasing in river flow, higher risk of coastal flooding
Mountain areas	Increasing in temperature, decreasing in glacier and permafrost mass, higher risk of rock falls, higher soil erosion risk, higher risk of species extinction
Central and eastern	Higher extreme temperature, decreasing in summer precipitation, increasing in winter floods, higher water temperature, increasing in forest fires
Coastal and regional seas	Sea-level rising, higher sea surface temperatures, northward movement of species, higher risk for fish stocks
Mediterranean	Decreasing in annual precipitation, decreasing in annual river flow, increasing in forest fires, increasing in water demand for agriculture, higher risk for desertification, more deaths by heat waves, higher risk of biodiversity loss

consequences of climatic change will directly or indirectly affect all economic and social sectors, regions and citizens and is particularly prone to affect some European locations like the Mediterranean or arctic zone. Since the 1980s river and coastal floods, droughts, water scarcity and loss of biodiversity result as major natural impacts that support the climate change phenomena; the influence of these phenomena is affecting not only the ecological context, but also economic, political, social and medical sectors [13].

Natural hazards between 1998 and 2009 caused an increasing in the number of human fatalities per year mostly due to floods, heat waves and earthquakes which occurred mostly in Central and southern Europe. Differently, the economic losses from natural hazards tended to be higher in central-northern Europe, probably reflecting differences in the accumulation of infrastructure, wealth and living standard. The economic context of climatic change has especially influenced: (1) decreasing availability in arable land due to droughts, water scarcity and floods causing massive losses in crop output; (2) forest fires causing many infrastructural damages (besides a reduction in wood production); (3) decreasing thermal power and hydropower causing augmentation in energy demand; and (4) attractiveness of Mediterranean resources have been reduced causing losses in tourism and recreation-based activities [13]. In addition to these cause and effect impacts, it can be emphasised that climatic change can affect human health by way of changes in food and water quantity and quality, livelihood, temperature and mortality via disease rate and mismanagement of infrastructure and resources [13].

In order to limit the impact of climatic change, the EU has been moving toward an adaptation strategy that consists of an "adjustment of natural or human systems to actual or expected climate change [impacts] or its effects in order to moderate harm or exploit beneficial opportunities" [13]. This reflects three different adaptation responses or solutions: grey measures (technology oriented), green measures (eco-friendly based) and soft measures (political ratification). Climate change adaptation strategy is closely related to the concept of disaster risk reduction (DRR) which aims at reducing future impacts of natural and technical hazards. Adaptation options have a different implementation pending geography and, more specifically, locality: coastal zone management is primarily based on buildings and strengthening natural flood defences; metropolitan zone management is oriented on securing the functionally of essential infrastructure for energy provision, water supply, wastewater treatment, transport and health services.

16.2.2 European Governance

In order to reduce natural hazard impacts on the European territory, the EU Floods Directive now requires Member States (MS) to assess if all water courses and coast lines are at risk from flooding, to map the flood extent and asset the humans risk in these areas and undertake adequate and coordinated measures to reduce such risk [13]. The Floods Directive is complementary to the EU Water Framework Directive [16] in which policy must suitably reflect qualitative and quantitative status of all MS water bodies by 2015. The EU developed a set of guidelines to support these regulations by implementing risk assessment and mapping processes [15] and by developing a community framework on disaster prevention [13]. These guidelines aim at reducing the national gaps on risk assessment methodologies and to further develop a national risk management procedure by the close of 2011. It should be underlined that all MS must make available to the Commission relevant information on natural hazards risk in order to develop sound, future European governance [15]. In particular, guidelines focus on the reduction of three different types of natural hazards impacts: (1) human impacts referring to the number of affected people (i.e. permanently displaced, injured and deaths), (2) economic and environmental impacts referring to total costs (i.e. healthcare, emergency services, property damage, cultural heritage, environmental restoration and other associated costs between environment and economy), and (3) political and social impacts referring to public outrage or social psychological impact (i.e. public order and safety and political implications). The objective of the Council is to minimise these impacts by trying to reduce their potential negative consequences and improving local preparedness [14].

EU guidelines for national risk assessment and mapping enlist the development of gradually coherent and consistent risk assessment methodology and terminology via each MS. It provides risk management instruments for authorities, policy-makers, and public or private stakeholders. The development of a knowledge-base for disaster prevention policy can contribute to raising public awareness for better disaster prevention measures [15]. The three basic steps of the risk assessment process, defined for each MS, is (1) risk identification, (2) risk analysis and (3) risk evaluation; these steps generalise a primary outline for developing an EU-wide standard and principal background for national policies aligning with Commission

Table 16.2 EU set of relevant initiatives for natural hazards disaster prevention [15]

	Initiative
Step 1	Ensure that DRR is a national and local priority with a strong institutional basis for implementation
Step 2	Identify, assess, and monitor disaster risks (especially enhancing the early warning systems)
Step 3	Use knowledge, innovation, and education to build a culture of safety and resilience at all levels
Step 4	Reduce the risk factors by developing appropriate risk management measures
Step 5	Strengthen disaster preparedness for effective response at all levels

intentions. The Commission presented at the end of 2010 a set of relevant initiatives for natural hazards disaster prevention (Table 16.2) [15].

These initiatives must complement MS action and adopted and implemented plans; the Community framework on disaster prevention is focused on an understanding that the link between natural hazards and climatic change, in order to develop specific disaster management programs of prevention and on supporting MS' early warning systems, is raising public awareness and educating the populace at a cultural level [14, 33].

16.3 Risk Assessment and Management Methodologies: Review

Based on scientific publications, prevalent risk assessment and management methodologies are reviewed from 2000 to present and categorised into two hazard event groups: hydro-meteorological and geophysical. These two main groups address the impacts and risk and analyse criteria based on varying assumptions (Table 16.3).

Table 16.3 is designed with the conceptual framework expressed in each risk assessment or management method – specifically risk, hazard, vulnerability and exposure concepts and their application to the specific natural hazard under examination. The objective of the research describes the main steps of the application via the analytical approach adopted and the target group(s). The input data utilised are exposed and defined, distinguishing them based on the step of the method in which they operate. Conclusively, critical comparisons of the analysed risk assessment and management methodologies are presented in order to highlight main differences and common points and to identify gaps for future development and research.

16.3.1 Hydro-Meteorological Hazards

Hydro-meteorological hazards comprise primarily of floods, storms, water scarcity, extreme temperature events and forest fires. Within Europe water-related hazards

Table 16.3 Structure of the criteria used with definition: method review

Criteria	Definition
Objective	Purpose of the research
Analytical approach (A) and targets (T)	Specifies the kind of analysis employed in the method
Stakeholders and experts involvement	Indicates whether their role is utilised in the method and, if so, how
Geospatial scale	Classified as *local* if the pilot area covers a municipality (e.g. Paris); *regional* if the pilot area covers a wider territory (e.g. Île-de-France); *national* if the pilot area considers an entire state (e.g. France); or *supranational*, if the area involves two or more states (e.g. Europe) – specific case study is reported
Temporal scale	Specifies and quantifies the temporal forecast considered in the study; if considered, but the timeframe is not specified, the term used is not specified; if there are no specific forecast, the term used is not applicable
Model (M), input (I) and output (O)	Reports the applied tools and models and describes the input data used in the analytical approach and how the method's results are presented – extended detailing of the final output of every step of the method
Strengths (S) and weaknesses (W)	Highlights strong points and limitations of the method

encompass several natural phenomena and a large number of physical modifications such as dams, weirs, sluices, straightening, canalisation and disconnection of floodplains [12]. Furthermore, the water availability and the population density are unevenly distributed – except in some northern and sparsely populated countries that possess abundant resources. Where water scarcity occurs, particularly in southern Europe, it is confronted with a crucial combination of a severe lack of and high demand for water. Different water uses, such as storage of water for hydropower, navigation or flood protection, caused many hydro-morphological and ecological impacts, including: changes in hydrological regime, disruptions in the river continuum and soil erosions which change biological communities and cause biodiversity loss [12].

Flood events are undoubtedly the most relevant in Europe, causing intense flooding over the last few decades, especially between 2003 and 2008, in which much loss of life, displacement and heavy economic loss occurred. The most affected countries include the United Kingdom, Hungary, Romania, Turkey, Czech Republic and most Balkan states [11]; nonetheless it should be pointed out that regular annual floods provide water resources for domestic supply, irrigation and industrial use. An important benefit to such events is the linkage maintained via biological diversity in what is known as flood plain ecology. The increasing number of Europe-wide flood events in the previous last few decades suggests that the increase in population and development in exposed areas are the main factors [11]. Storm events, which are natural phenomena closely related to floods characterised by strong winds in combination with heavy precipitation have the second highest number of human fatalities from natural hazards after floods, heat waves and earthquakes –especially in Germany, UK, France, Spain, Italy and Sweden [11]. In the last decade, their frequency and magnitude have locally increased during recent decades due to atmospheric and climatic change [11].

Drought is also a key hydro-meteorological hazard that affects Europe primarily in the summer – principally the southern half of the continent; during this period each year an area that extends from Portugal and Spain to the Czech Republic and Bulgaria is most affected by varying levels of water scarcity. An example of this scarcity was in Barcelona, Spain in 2008 in which the city suffered its worst drought recorded in 60 years [11]. Moreover, major impacts from drought events affect human health and the economy at large – especially in south Eastern Europe where the duration of drought events continue to get longer. It has to be emphasised that this phenomenon is greatly amplified by human activities; this imbalance has been linked to abstraction and availability in which relayed effects are often related to agriculture, industrial use and tourism [11]. In addition, most drought-like natural hazards circumvent extreme high-temperature events, such as hot or warm spells, which are projected across Europe to become more frequent, more intense and much longer in years to come. The most affected countries to date are Romania, France and Germany, followed by the Mediterranean and Balkan areas [11]; however, low temperature extremes, such as cold spells, are a very dangerous natural hazard during winter periods, above all in northern countries.

Hydro-meteorological natural hazards also take into account forest fires which are an essential disturbance for the regeneration of certain tree species and ecosystem dynamics. Fire events are closely related to the extreme high-temperature events which mostly affect Europe in the summer months; about 70,000 fires per year occur throughout Europe, mostly in the Mediterranean area accounting for approximately 70 % in total. The most affected countries were Portugal in 2003 and Greece in 2007 [11]; however, it has to be emphasised that over the 95 % of fires are caused by humans, either deliberately, by negligence or accident. The major damages caused by forest fires are the loss of human life, but also the economic context is very relevant.

16.3.1.1 Hydro-Meteorological Hazards Methodologies

A methods review of the predominant hydro-meteorological hazards is presented in Table 16.4 and is broken down using the criteria described from Table 16.3. Within the reviewed papers, a varying definition of risk is provided; authors define risk using different parameters and assumptions. Some key variances include Forte et al. [18] which links the hazard factor to the vulnerability factor using a scalar quantity approach. In this case the hazard is considered as a combination of the intensity and frequency, while vulnerability is defined as a combination of rainfall intensity and regional distribution of socio-economic elements at risk. The final risk is represented by a risk index, which include the number of total people affected and the economic damage to the surrounding buildings. Likewise,

Table 16.4 Hydro-meteorological hazards method review

Author(s)	Objective	Analytical approach (A) and targets (T)	Stakeholders and experts involvement	Geospatial scale	Temporal scale	Model (M), input (I) and output (O)	Strengths (S) and weaknesses (W)
Vis et al. [38]	Develop a resilience strategy for flood risk management	**A**: flood damage assessment based of five steps **T**: urban areas (building and infrastructures), agricultural areas(crops)	Hydrologists, engineers, geographers, and economists, assign scores to criteria in a matrix	*National* – Netherlands	N/A	**M**: SOBEK-River model (Delft Hydraulics and RIZA, 1996), Delft-FLS model [37], Standard Damage Module [40], GIS **I**: criteria results from flood damage assessment steps **O**: GIS modeling results of assessment	**S**: involvement of stakeholders in assigning scores **W**: social criteria is specifically looked at
Forte et al. [18]	Assess flood risk	**A**: spatial, mathematical **T**: buildings and infrastructure (indirectly people)	Not involved	*Regional* – Salento (Italy)	N/A	**M**: GIS **I**: framework inputs **O**: assessment findings and potential policy implementation	**S**: new sustainable approach **W**: difficult to utilize if not replicated and used in a consistent manner; timeframe covered by the stakeholders' dialogue is too long, compared to the urgency of implementing the proposed strategies

Lavery et al. [26]	Manage the flood risk in the Thames Estuary	**A**: spatial, management based **T**: property, houses and people	Decision makers: define best management measure supported by a decision-testing tool	*Local* –River Thames Estuary (London, England)	Long-term prevision (100 years)	**M**: GIS **I**: framework inputs **O**: assessment findings and potential policy implementation	**S**: new sustainable approach **W**: difficult to utilize if not replicated and used in a consistent manner; timeframe covered by the stakeholders' dialogue is too long, compared to the urgency of implementing the proposed strategies
Schmidt-Thomé et al. [35]	Revise economic flood risk maps	**A**: spatial, mathematical **T**: potential economic damage, potential exposure of people	Not involved	*Supranational* – Europe	N/A	**M**: N/A **I**: number of floods, economic data, social data **O**: hazard map, vulnerability degree, risk map	**S**: the risk is assessed at European level **W**: used of only an economic perspective
Kenyon [22]	Manage flood risk in Scotland	**A**: multicriteria approach, composed by six steps **T**: Buildings, infrastructure and population	Citizens, which indentify the criteria, score the options and assign the weights	*Local* – Inverurie, Callender and Alloa (Scotland)	N/A	**M**: N/A **I**: scoring and weightings **O**: assessment results and potential policy implementation	**S**: method actively involves public **W**: citizens have to be briefly educated on all flood risk management options

(continued)

Table 16.4 (continued)

Author(s)	Objective	Analytical approach (A) and targets (T)	Stakeholders and experts involvement	Geospatial scale	Temporal scale	Model (M), input (I) and output (O)	Strengths (S) and weaknesses (W)
Forster et al. [19]	Assess flood risk for a rural detention area	**A**: spatial, mathematical **T**: agricultural production	Not involved	*Local* –Elbe river (Torgau, Wittemberg, Germany)	Annual prevision	**M**: N/A **I**: empirical data, number and frequency of floods, economic data **O**: expected damage expressed by graphs (histograms)	**S**: detailed economic damage estimation for every type of crop **W**: risk is assessed only as economic damage of agriculture
Meyer et al. [28]	Assess flood risk	**A**: multicriteria, disjunctive MAUT weighting **T**: expected damage expressed by graphs (histograms)	Decision makers: assigning threshold values and weights	*Regional* – Grimma (Germany)	Long-term prevision (200 years)	**M**: expected damage expressed by graphs (histograms) **I**: expected damage expressed by graphs (histograms) **O**: risk maps (for single criteria), multicriteria risk maps	**S**: risk is assessed in the economic, environmental and social dimension **W**: laborious method
Brundl et al. [6]	Apply the risk concept in risk management	**A**: mathematical, multicriteria **T**: buildings, infrastructure people and single individual	Not involved	*Regional* – Davos (Switzerland)	Long-term prevision (30 100, 300 years)	**M**: EconoMe (BAFU, 2009) **I**: topographic map, historic chronicles, field data **O**: individual and societal risk index	**S**: method allows to assess both the societal and the individual risk **W**: stakeholders are not involved

Kubal et al. [24]	Assess urban flood risk	**A**: multicritera, weighting **T**: buildings and infrastructure environment, population	Decision makers: assigning threshold values and weights	*Regional* – Leipzig (Germany)	Long-term prevision (100 years)	**M**: GIS, FloodCalc Urban [28] **I**: public social, economic and environmental data **O**: damage maps, risk maps (for single criteria), multicriteria risk maps	**S**: risk is assessed in economic, environmental and social dimension **W**: laborious and highly technical method
Merz et al. [27]	Manage flood risk in a changing world	**A**: five levels of response to change in flood risk management **T**: people, industries, buildings and natural environment	Organizations, institutions, societies and population involved in the open risk dialogue with decision-makers (fifth level)	N/A	N/A	**M**: N/A **I**: decision making **O**: assessment results and potential policy implementation, management based findings	**S**: considers the responses to future flood risk management changes **W**: method has not been tested through a case study application
Bosom et al. [5]	Assess coastal vulnerability	**A**: probabilistic approach **T**: coastal environment	Decision makers: involved in establishing the acceptable return time period of analysis	*Regional* – six Catalan beaches (Spain)	N/A	**M**: GIS **I**: physical data, geographic data **O**: hazard graphs (probability distribution curves), vulnerability maps	**S**: method is applicable to all beaches and involves active participation from stakeholders **W**: complicated mathematical functions

Schmidt-Thomé et al. [35] consider risk as the combination of hazard intensity and economic vulnerability; hazard intensity is explained as the effect of a natural hazard (i.e. flooding) and it is dependent on the average number of flood events that occurred in a specific area; the vulnerability concept is considered as an economic value expressed by the regional Gross Domestic Product (GDP) per capita (in euro) and by the population density – weighted equally. Brundl et al. [6] give an analogous and significantly different definition of risk, distinguishing between societal and individual risk; the first type of risk depends on the total expected loss of lives in a hazard area (i.e. expected damage) and on the frequency of a considered scenario. The total societal risk is indicated as the sum of the societal risk of each scenario. The second type of risk is individual, which is expressed by the probability for the single individual to die during a hazardous event, considering factors as exposure and mortality rate of persons. It should be noted that the total individual risk is calculated in the same way as the total societal risk and that in both cases, the risk is expressed by the probability of a group of persons or individual exposed to a natural hazard and by the mortality rate of that specific scenario.

Table 16.4 chronological describes some of the main analytical approaches adopted and shows a brief breakdown of each method; the methodologies that comprise hydro-meteorological hazards are somewhat variable in design and output but generally are oriented around a flood-based outline. A point of interest of the methods is reviewed. Among all methodologies, Vis et al.'s [38] approach is based on a previous risk assessment methodology; more precisely, it is a damage assessment methodology which involves five main steps that focus on selection of representative flood waves and a breach development scenario. This procedural method allows the determination of economic expected damage from flooding which is one of the criteria utilised to choose the best risk management measures. This method is based on a resilience strategy which implies "living with floods" instead of "fighting with floods".

Forte et al. [18] proposed a methodology that consists preliminarily in the identification of hazard areas using susceptibility maps which is followed by a detailed study of geo-environmental factors and flood causes. In a mathematical approach on flood hazard assessment the determination of frequency and rainfall intensity is examined and then combined into a matrix. Vulnerability assessment is based on a combination of hazard data with spatial distribution of elements at risk, which is calculated a damage degree (divided into nine vulnerability classes). The final flood risk is determined by defining mathematically a flood risk index by combining the hazard classes and the vulnerability classes.

Another flood risk management measure, defined as the Thames Gateway project, is proposed by Lavery et al. [26]; it is aimed at replacing future existing long-term tidal defences systems by testing their robustness and sustainability to which climate change scenarios are considered. The decision makers in this method decide the implementation of flood risk management measures based on the knowledge of socio-economic, environmental and physical and engineered factors. The idea is to constantly inform stakeholders of the process, namely, a "strategy envelope" in which an interim suggestion based on the current understanding of the estuary is put forth. This tool describes future trends at the economic, social and environmental level and attracts an approach of educating public opinion with an improved ideology of risk perception.

Schmidt-Thomé et al. [35] present a methodology based on a spatial approach for the calculation of a vulnerability degree, using GDP per capita and population density data. This method then converts the number of flood events in flood hazard intensity classes using input data as the average numbers of floods in the projected target area. The final risk is calculated by integrating the vulnerability degree with five flood hazard intensity classes via a matrix in order to define nine risk classes.

Another study based out of Scotland is by Kenyon [22] in which seven different types of flood management measures are proposed; these measures overlook flood walls and embankments that require buying and demolishing buildings in flood risk areas with the intention of regeneration of plants and trees; reduction of drainage on some agricultural lands (to create wetlands); and inspection, maintenance and monitoring of watercourses to provide flood warnings and sustainable urban drainage systems (SUDS). The SUDS approach is based on a scoring and weighting notion and formulates assessment results and potential policy implementations.

In the study conducted by Forster et al. [19] the approach uses a different spatial and mathematical approach to assess monthly and annual expected flood damage in a rural detention area. The probability of flooding is determined separately from the flood frequency analysis; a sensitivity analysis is used in order to evaluate the relative importance of different factors such as shared agricultural land use, market price of crops and flood return period(s). Forster et al. [19] empirical and field data illustrate the market value of agricultural production (in euro), the damage impact on targets (per month) and the relative damage cost (as a percentage); statistically, they define the risk by the monthly and annual expected flood damage.

Meyer et al. [28] work within a Geographic Information System (GIS) based multicriteria flood risk assessment methodology in which three risk dimensions are present: environmental, social and economic. This method expresses the expected damage of each dimension in an evaluation procedure calculated for different flood probability; that is, erosion potential, accumulation potential and inundation of oligotrophic biotopes (environmental dimension); annual average affected population and probability of hot spots to be affected (social dimension); and annual average damage (economic dimension). The annual average damage is derived from the sum of all expected damage from each dimension and utilised via two different approaches of multicriteria risk: (1) disjunctive approach, where the decision makers have to define a threshold level for each criterion (e.g. if a value is in excess, then the area considered is a risk area); and (2) the Multi Attribute Utility Theory (MAUT) weighting approach, where the criteria values (derived from the evaluation procedure) are normalised between 0 and 1. The weighted value for each criterion is calculated and the overall risk value is obtained by summing all the weighted value of each criterion. The results are analysed in a sensitivity analysis in order to eliminate uncertainty in the risk value.

In Switzerland, Brundl et al. [6] adopt a methodology based on three fundamental steps of risk, developed via the Swiss RIKO guidelines [29] and published within the *Interpraevent* research society, they overlook: (1) mathematical risk analysis, which in turn includes four analyses: hazard, exposure, consequence and risk calculation; (2) multicriteria evaluation of risk, which compares risk analysis results with predefined goals (i.e. the probability of death should not be higher of 1 % of the lowest risk); and (3) planning and evaluation of mitigation measures, based on a multicriteria approach which evaluates the cost-effectiveness of measures using a risk-cost diagram. Brundl et al. [6] consider topographic and geological maps, supported by aerial and satellite images and historical chronicles; three intensity maps are produced which forecast the flood hazard without the application of measures after 30, 100 and 300 years.

Kubal et al. [24] define risk using an evaluation procedure that standardises risk values between 0 and 1, then calculates them into a function of different preselect scenarios (i.e. EQUAL, ECON, SOCIAL, ECOL, SPOTS, COHORTS, ECON extreme and ECOL extreme) in the weighting approach. These scenarios are the sum of the different weights of each criterion, expressed in a percentage. For example, the EQUAL scenario represents an equal division of the weights (the sum is 100 %): economic 33.3 %, social 33.3 % and ecological 33.3 %. Another example is the SOCIAL scenario, where the social weight represents the 60 % and the economic and environmental weights the 20 % each. In this method the decision makers cover a central role and outputs calculate aggregated flood risk maps based on the standardised risk values from lowest to highest.

A shift from flood protection to flood management is the focus of Merz et al.'s [27] research in which three strategies are proposed: (1) managing of all floods and not only flood events of a given severity, (2) risk-informed decision making in which transparent and accessible estimation of flood risk is used to choose the correct risk response; and (3) integrated systems approach where risk reduction is replaced in order to reduce the effect of flooding (e.g. via warning systems, emergency measures or spatial planning regulation). Merz et al. [27] develop their risk management methodology to cope with current and near future environmental change – posed mostly by concerns with climate variation and change. It is underlined, sea level rise and increasing floods in both number and magnitude are key to better understanding long-term provisional strategies required to upgrade and modify recorded data and decision assessments.

The method proposed by Bosom et al. [5] assesses coastal vulnerability and not coastal risk; it begins with a hazard assessment, that is, hazard is defined as the potential coastal damages (caused by a storm), characterised by two main natural phenomena: erosion and inundation. Then, vulnerability is defined as the potential of a coastal system to be harmed by the impact of a storm and quantification compares the magnitude of the impact with the adaptation capacity of the system – defined by the physical characteristics of the beach to cope. This methodology is based on a probabilistic approach defined by the probabilities of occurrence of induced hazards along a coastline; the estimated and then compared spatial distribution of the expected magnitude of the impact (vulnerability) is examined in order to identify the potential most endangered areas.

16.3.2 Geophysical Hazards

Geophysical hazards include landslides, avalanches, earthquakes and volcanic eruptions; landslide events account for some of the most relevant hazards Europe-wide. They include two main characteristics: (1) material involved (rock, earth) and (2) type of movement (falls, topples, slides, spreads, flows). Landslides are closely connected with hydro-meteorological hazards, as storms can be often linked as a main cause. Landslides are a major threat to human life, property, buildings, infrastructure and natural environments – especially in mountainous and hilly regions. Countries located in the Scandinavian peninsula, in the Alpine region and in southern parts of Europe are most prone to these hazard events. One of the most affected regions in Italy was Friuli Venezia Giulia, in 2003, when more than 1,100 landslides caused over 364 million euros in damages [11]. Furthermore, climatic change is expected to increase the mean temperature and to alter precipitation patterns in Europe in the near future, causing an increase in overall landslide events.

Avalanches are another type of geophysical hazard that is related to varying hydro-meteorological hazards. Heavy precipitations, intense snowfalls and strong winds can be cause and effect events for avalanches to occur; the occurrence of large avalanches is not governed by general climatic trends but rather by shorten weather events. The last catastrophic winter in Europe with a large number of fatalities was in 1998–1999 where Austria, France, Switzerland, Italy and Germany fell victim to these event occurrences [11]. Generally avalanches are natural events that mostly occur without causing damage or even being noticed. Atmospherically, climate change is having a more pronounced effect; most of all at altitudes below 1,000 m, due to a reduction of snow coverage, has forced previously non-avalanche prone areas to consider this type of new threat.

Differently, earthquakes and volcanic eruptions are geophysical hazards that are not related to any other natural hazard and they are also totally independent from human activity. From 2003 to 2009, 15 great earthquakes occurred in the 30 European Economic Area Member States and one of the most damaging was in L'Aquila, Italy in 2009, causing 332 victims. Similarly, tsunami-based hazards are also earthquake-related and pose a serious threat to coast lines and communities. Major volcanic hazards are situated in Iceland and in southern Europe, specifically Italy and Greece (e.g. Vesuvio, Etna and Santorini) [11]. It should be cited that due to the massive movements of gas, dust and land volcanic eruptions often completely immobilise an affected area. About 20 countries closed their airspace (a condition known as ATC Zero) and affected hundreds of thousands of travellers throughout Europe when Mount Eyjafjallajökull, Iceland started volcanic eruptions during 2010 – ash covered large areas of northern Europe making atmospheric conditions hazy, dark.

16.3.2.1 Geophysical Hazards Methodologies

The basis of geophysical hazards is consistent with standardised risk assessment and management approaches and allows for consistency and comparative evaluation across the cited two domains. The reviewed geophysical hazards methods depict key prevailing papers and provide a chronological look at the direction and ideological change within the scientific field (Table 16.5). Within the reviewed papers, a differing level of risk is defined using various checks and hypotheses. The notion of risk plays an important role in decoding the analytical approach and reasoning behind the development of a method; a noteworthy example of this is Dai et al. [9] in which risk is a measure of the probability and severity of an adverse effect to health, property or the environment – expressing risk by the product of probability and vulnerability. In this case, hazard is described as the probability of occurrence of a given magnitude of the event, while vulnerability considers the level of potential damage, or degree of loss, of a given element.

Key reviewed geophysical hazards methodologies in Table 16.5 are illustrated chronologically; the review methods include key works within the sub-disciplines of landslide, avalanche, earthquake and volcanic eruption events. Identical to the structure of hydro-meteorological hazards methodologies, geophysical hazards methodologies are broken down at par with criteria explanation from Table 16.3. Geophysical hazards methods are to some extent variable in structure, nonetheless landslide events dominate the outlined literature and as a result have foreseen a miniature evolutionary development from alluvial science to long-term management course of action.

Among reviewed methods, Dai et al. [9] outlines a classic approach to assessing landslide risk of people and property using a mathematical approach; risk is calculated via probability of an annual landslide event, spatial and temporal impact (determined during the hazard assessment) and vulnerability. Respectively the general idea is a representation of a base-framework on hazard and vulnerability assessment in which hazard assessment is determined by combining the probability of landslide with the runout behaviour. The latter involves the delimitation of the endangered areas with three specific methods: empirical modelling, analytical modelling and numerical simulations. Dai et al. [9] expand by calculating the probability of a landslide event using three different approaches: heuristic (which involve experts to estimate the preparatory variables), deterministic (which is based on slope stability analysis) and statistical and probabilistic (which incorporate the application of the statistical determination of past variables that have led to landslides). The subsequent vulnerability assessment involves "the understanding of the interaction between a given landslide and the affected elements" [9]. In conclusion, the results are subsequently integrated with the hazard assessment outputs in order to produce landslide risk results.

Using a geomorphological approach, the methodology presented by Cardinali et al. [7] aims at assessing landslide risk for structures, infrastructures and population; it combines a data analysis of site-specific and historical information. Based on observed changes in the distribution and pattern of landslides they infer the possible

Table 16.5 Geophysical hazards method review

Author(s)	Objective	Analytical approach (A) and targets (T)	Stakeholders and experts involvement	Geospatial scale	Temporal scale	Model (M), input (I) and output (O)	Strengths (S) and weaknesses (W)
Dai et al. [9]	Assess and manage landslide risk	**A:** mathematical, spatial, heuristic, deterministic, statistic and probabilistic; cost-benefit analysis with a direct involvement of decisions makers in the selection of the best management measures **T**: property and people	Expert opinion in heuristic approach and in assigning vulnerability factor; decision-makers choose the best management measure	*Regional*- Hong Kong	N/A	**M**: GIS, frequency-number of fatalities curves, synthetic aperture radar interferometry (InSAR) [23, 31] **I**: historic data, physical data, field data, geographical data **O**: hazard data, vulnerability matrix, risk map	**S**: method involves many factors and approaches; allows to compare many different measures **W**: laborious due to the involvement of many different approaches; the definition of tolerability in the acceptance option does not involve directly the population
Cardinali et al. [7]	Assess landslide risk	**A**: multi-temporal, mathematical, spatial **T**: structures, infrastructures, population	Geomorphologic expert judgment on interpretation of aerial photographs	*Local* – Umbria (Rotecastello, Italy)	N/A	**M**: GIS **I**: historic data, topographic maps, field data, physical data **O**: hazard index, hazard maps, vulnerability table, risk map	**S**: applicable to all landslide events **W**: requires a lot of historical data

(continued)

Table 16.5 (continued)

Author(s)	Objective	Analytical approach (A) and targets (T)	Stakeholders and experts involvement	Geospatial scale	Temporal scale	Model (M), input (I) and output (O)	Strengths (S) and weaknesses (W)
Lateltin et al. [25]	Manage landslide risk in Switzerland	**A**: mathematical (using a matrix); based on protection goals and previous hazard assessment and definition of protection requirements, the prevention and protection measures are planned **T**: structures, infrastructures, population	Commission formed by political authorities, administrative officers, scientists and public to analyse each critical situation and each change in local risk management plan	*Local* – sorenberg; *national* - Switzerland	N/A	**M**: N/A **I**: landslide intensity, landslide frequency, probability data, geographic data **O**: hazard maps, damage table	**S**: approach allows for the hazard assessment of all kind of landslide; applicable to all the whole Swiss territory **W**: method does not involve social criteria; definition of safety goals does not involve stakeholders
Keiler et al. [21]	Assess avalanche risk	**A**: multi-temporal, mathematical **T**: buildings	N/A	*Regional* – Gaultur (Austria)	N/A	**M**: SAMOS [32], ELBA+[39] **I**: historic data, economic data **O**: risk graphs (line chart)	**S**: uses three different risk scenarios **W**: method does not make any future risk prevision

Garcin et al. [20]	Assess tsunami hazard and risk in coastal areas	**A**: spatial, mathematical **T**: population and buildings	N/A	*Local* – Beruwala to Weligama (Sri Lanka)	Long-term prevision (2100)	**M**: GIS, ARMAGEDOM (Sendan et al. 2003) **I**: physical data, GIS and geographic data damage function **O**: hazard maps, exposure maps, risk scenarios	**S**: method allows to assess the hazard and risk both for tsunami and sea level rise phenomena (monsoon); allows for long-term urban development **W**: stakeholders are not involved
Arattano et al. (2008)	Manage the risk of alluvian fan	**A**: 4 step assessment; improvement of civil protection intervention strategy **T**: buildings, infrastructures, population	Autorità di bacino del fiume Po (Po river basin authority) risk assessment; civil protection risk management	*Local* – Villar Pellice (Italy)	N/A	**M**: 4 step intervention strategy **I**: stakeholder involvement **O**: hazard maps, exposure maps, risk scenatios	**S**: method provides many practical solutions **W**: developed only for civil protection and not for other local authorities
Strunz et al. [36]	Assess tsunami risk	**A**: multi-scenario, spatial **T**: people	N/A	*Local* – pilot area; *national*- Indonesia	N/A	**M**: GIS, TsunAWI [3], DSS [30] **I**: geographical data, statistical data, physical data, social data **O**: hazard map, exposure map, evacuation map, risk map	**S**: tsunami risk is assessed at national and local scale **W**: method required a large number of data and relating datasets

(continued)

Table 16.5 (continued)

Author(s)	Objective	Analytical approach (A) and targets (T)	Stakeholders and experts involvement	Geospatial scale	Temporal scale	Model (M), input (I) and output (O)	Strengths (S) and weaknesses (W)
Alberico et al. [1]	Assess volcanic risk	**A**: spatial, mathematical **T**: buildings, infrastructure (indirectly people)	N/A	*Local* – Napoli (Italy)	N/A	**M**: GIS, HAZMAP [8] **I**: physical data, geographical data, topographic maps, economic data, social data **O**: hazard map, exposure map, risk map	**S**: method involves physical, economic and spatial dimension **W**: over-estimation of risk, due to the unavailability of vulnerability based assessment

change in slope, probable short-term types of failure and expected frequency of occurrence. The proposed method involves an inventory map and identification and mapping of elements at risk; using a spatial approach the inferred relationship between the intensity and type of expected landslide, and the likely damage that the landslide will cause, an evaluation of landslides risk is obtained via a hazard index.

Lateltin et al. [25] propose another ground breaking method based in both Switzerland and at the local municipality of Sorensen, Switzerland. The assessment of landslide hazards, respectively, expand Cardinali et al.'s [7] research by using a more complex approach based on the combination of landslide intensity with probability occurrence. Using a cross-reference matrix based on hazard levels, hazard maps are developed and factor the assessment of landslide hazard levels as a probability of occurrence which is defined using four different classes: high, medium, low and very low, according to return times of the landslide event of 1–30, 30–100, 100–300 and > 300 years, respectively.

Avalanche risk assessment methodology presented by Keiler et al. [21] is another ground breaking approach; it utilises different risk scenarios to calculate avalanche tracks, using a multi-temporal approach quantified between the timeframe 1950–2000. It should be emphasised that this method aims at describing past risk scenarios without making any future risk forecast or any risk classification. Avalanche risk is expressed as the potential monetary loss of building values and vulnerability of buildings is understood as a degree of loss to a given element within the affected area. Four classes of vulnerability are defined: general damage level, specific damage level, destruction level and detach limit. Monetary values of buildings are estimated using the building volume and average prices per cubic meter. During the pilot studies, risk scenarios are calculated and describe mitigation measures and risk-influencing factors.

Garcin et al. [20] propose a methodology based on an integrated approach aimed at assessing the hazard and risk for coasts affected by tsunami and sea level rise; the latter has a relationship cause and effect with extreme storm events, for example monsoons. The methodology involves three main steps: (1) assessment of tsunami and sea level rise hazard using GIS; (2) analyse output data from a hazard assessment without using a specific numerical model in order to define a less generic spatial distribution of elements exposed; and (3) use the simulation tool ARMAGEDOM [34] in order to carry out the risk scenarios for tsunami events. The obtained results of combining the expected damage, related to natural hazards and exposure of each element at risk, emphasise explicitly the link between tsunamis and climatic change.

From the list of assayed methodologies, the most theoretical-based is Arattano et al.'s [2] approach; it does not have a final conclusive proposal that provides concrete measures to manage landslide risk via an alluvian fan. It does, however, offer a set of improvements at the civil protection intervention strategy level. That is, it puts forth practical, non-structural points which can be implemented either as part of: (1) territorial planning which is an imposed limitation in building construction or (2) civil protection intervention strategies and organisation before, during and after a catastrophic event. More precisely, with such an event an automatic early warning system and varying meteorological bulletins can forecast rainfalls to assist in preventing or minimising impending risks.

In 2011 Strunz et al. [34] proposed a tsunami risk assessment methodology based on the BBC framework by Birkmann [4]. The methodology's final target is people; it incorporates tsunami hazard assessment and vulnerability assessment. The hazard assessment is based on a multi scenario approach while the vulnerability assessment is divided via exposure estimation, which provides information about the distribution of people, and response capabilities and preparedness assessment, when considering: warning decision time, warning dissemination time, anticipated response time and evacuation time. The overall vulnerability assessment is based on the estimated time of arrival of a tsunami wave which can determine two groups of time components: (1) those depending on institutional behaviour (warning dissemination strategy) and (2) those depending on people's behaviour (evacuation strategy). The final risk is determined by spatial integration of three maps: hazard, population exposure and evacuation time. Strunz et al. [36] utilise the software entitled unstructured mesh finite element model for the computation of tsunami scenarios with inundation (TsunAWI) [3], to elaborate the tsunami inundation area, then integrate tsunami risk data into a decision support system (DSS) of early warning systems [30] – allowing assigned risk classes subsequently used to produce overall risk maps.

Another recent study conducted by Alberico et al. [1] examines volcanic risk in which four risk classes are established, from high risk to very low risk; based on the integration of hazard and exposure maps these risk classes are defined by superimposing themselves over each other and cross-referencing the combination. The outcome of the intermediate combinations is not explicitly reported; exposure input data is obtained from statistical land use data and maps, population density data and response capabilities.

16.4 Comparative Examination of Natural Hazards

A comparative examination of prevalent natural hazards risk assessment and management methodologies have been separated into two domains as a basis for breaking down natural hazards at large. Both hydro-meteorological and geophysical hazards, in a general sense, can somewhat be compared with each other as they both exist under a conceptual natural hazards umbrella; however, since each domain specifically draws upon specific methods it would be knowledgeable to focus a comparison at this level. That being said, a comparative examination draws potential viewpoints on choice of methodology which largely depends on considered area and on addressed target(s). In this sense, timeframe is very important and contrasts and similarities between methods is mostly case specific in which potential strengths and weaknesses can be identified. While method complexity may often imply a wide range of physical and social information that subsequently integrates the use of distinct tools, like TsunAWI or DSS, they regularly are based on historical developments that evolve via trial and error; tools are fostered and progressively improve via knowledge-base and scientific examination. Since natural hazards often cause varying levels of harm and destruction, readers should take into account the prevention, protection and preparedness principle in which defines conclusive technical development from a resilience viewpoint according to EU Floods Directive, Article 7. The development of these resilience-based views is where people participate, decide and plan their conurbation with the local government authorities, based on their capacities and resources under a EU backdrop; the extension of national policies within Commission guidelines plays an important part of this development.

16.4.1 Examination of Hydro-Meteorological Hazards Methods: Review

After analysing the hydro-meteorological hazards methodologies it is clear that there is more than one method that can be used to assess varying forms of flood and coastal risk. The choice of one methodology over another largely depends on the respected local and targeted subjects. In hydro-meteorological risk management the prevention, protection and preparedness principle can be examined. For instance, the prevention principle is expressed by correct land use planning, as avoiding the development of urban centres and inhabitations in flood-prone areas [27], the protection principle is highlighted by rising flood walls or river edge defences [26] and the preparedness principle is emphasised in developing a proper early warning system.

It must be emphasised that not all methods are aimed at conclusively putting forth a complete appraisal on risk; Forster et al. [19], in fact, estimate only economic expected damage and explicitly go no further, while Bosom et al. [5] stops at assessing only vulnerability. Differently, other methodologies perform a more complete risk appraisal through the integration of both hazard and vulnerability assessment [18, 35] or combine expected damage with the probability of flooding [6, 24, 28]. These methodologies present different levels of complexity and integration; for example, the method proposed by Schmidt-Thomé et al. [27] has quite a simple form of implementation since it involves three input data types (i.e. GDP, population density for vulnerability and average number of flooding for hazard) and combines the hazard and vulnerability outputs using a simple 5×5 risk matrix. On the contrary, the methodology presented by Forte et al. [18] is much more problematic in application, even though it utilises a similar conceptual framework, it requires several input data types before calculating final outputs via three different integration methods which include two different matrices. The methodology presented by Brundl et al. [6] allows for the calculation of two types of risk (social and individual) which are obtained separately using an elaborated mathematical approach involving several input data types – topographical maps and historical data. Additionally, the methods proposed by Meyer et al. [28] and Kubal et al. [24] are also quite complex; they integrate a large number of input data types into a software program made up of three risk dimensions (i.e. environmental, social and economic). The complexities depend on stakeholder involvement and decision makers; if the method is aimed at expert decision making, as in Meyer et al. [28] and Kubal et al. [24], risk is defined via threshold values and weights. The methodology proposed by Bosom et al. [5] is also rather complex as it uses a probabilistic approach which incorporates a large number of different functions in calculating overall vulnerability.

The methods presented by Kenyon [22], Lavery et al. [24], Merz et al. [27] and Vis et al. [38] also show a high level of complexity which may be limiting to laypersons as the terminology is not easy to understand. Kenyon [22] incorporates two different methods by assigning weights via two distinct mathematical functions (rank sum and rank order centroid) which combine these weights and scores from a third mathematical function (linear equation) into an integrated multicriteria evaluation. The methodology proposed by Lavery et al. [26] includes a complex framework of risk communication between stakeholders, public and decision makers while Merz et al. [27] provides a theoretical framework for risk-based adaptation. Differently, the methodology proposed by Vis et al. [38] aims solely at expert stakeholders; hence, a high level of complexity is exercised which includes three different types of mathematical models in order to assess flood damage before combining scores with strategies proposed in a Delphi method.

Inversely, if the methodology is aimed at the community level or public (or does not involve stakeholders) as in Schmidt-Thomé et al.'s [35] method, it typically is designed in a simplistic manner in order to be easily understood and explained to non-experts. As far as public participation is concerned, the methodologies developed by Meyer et al. [28] and Kubal et al. [24] obtain final risk through the involvement of stakeholders. More precisely, Meyer et al. [28] incorporates decision makers' threshold risk values into a developed multicriteria disjunctive approach and weights each criterion using a MAUT weight-based process; Kubal et al. [24] simple asks decision makers to define the weights for each scenario-based case. This is quite a significant characteristic as it relates to specific queries within European governance and current legislation relating to use of the EU Floods Directive and its implementation. Other methods obtain final risk by applying arbitrary chosen thresholds, derived from mathematical approaches – for example with the use of data normalisation.

Within the compared methods, the considered targets are very similar; Forster et al. [19] considers only agricultural production, while other authors consider buildings, infrastructure and population. This means that the presented methodologies, with the exception of Forster et al. [19], are very complete as they respectively allow for the assessment of different impacts on structures and population at large. Differently, Vis et al. [38] does not address population but only buildings and infrastructures due to its non-involvement of social criteria. It should be pointed out that methods that cover local or regional scales require much more detailed input data than national or supranational; similarly, large or regional scaled output are more detailed and accurate than national or supranational ones. For example, Schmidt-Thomé et al. [35] cover a supranational scale and consider flooding in a cross-border event and assess economic flood risk within a European study; in this scenario it would not be necessary to produce final risk maps that are extensively detailed since local risk is not taken into account. Among the applied tools GIS is the most present, Forster et al. [19] uses spatial integration of different information to perform and support a risk communication based approach by providing easy to understand outputs by way of risk maps; this communication is detailed via a cost-benefit and sensitivity analysis showing the probability of flooding.

16.4.2 Examination of Geophysical Hazard Hazards Methods: Review

The examination of geophysical hazard methodologies is very dependent on the type of natural hazard being looked at; a part from all the analysed geophysical hazard methods, Lateltin et al.'s [25] research did not comprise a complete risk assessment – it only focused on assessing hazard and damage. In most of the methods the concept of risk is similarly identified; however, Keiler et al. [21] bases its research on the interaction of hazard and vulnerability factors while Alberico et al. [1] consider only one constraint based on exposure outputs. In the landslides risk methodologies – generally – landslide risk is a combination of hazard-based factors which are expressed by physical characteristics (i.e. magnitude, velocity, intensity and frequency) and vulnerability-based dynamics are defined by way of distribution of elements at risk and their potential damage. In terms of landslide risk management measures – based on the prevention, protection and preparedness principle – the prevention principle is expressed by land use planning measures, as avoiding inhabitations or any other construction in landslide prone areas [25], the protection principle is highlighted by engineering options [9] and the preparedness principle is emphasised by developing proper early warning systems and emergency planning [2].

The complexity of the reviewed geophysical hazard methodologies indicates a varying level of intricacy; for example, Alberico et al. [1] join three different approaches in hazard assessment and a large number of physical input data. The methodology by Strunz et al. [36] entails a wide range of physical and social data types which subsequently is integrated using two distinct tools (i.e. TsunAWI and DSS). Similarly, the methodology proposed by Cardinali et al. [7] involves a wide range of input data within a large timeframe (1941–1999) to combine function-based processes within dual mathematical and spatial techniques. Likewise, in design, Arattano et al.'s [2] method is somewhat simplistic, in that it mainly addresses public and local authorities by proposing a set of improvements contra future events in the examined study area. In contrast, Dai et al.'s [9] risk assessment method is extremely complex – involving three distinct approaches in probability assessment, three different methods for predicting runout distance, a large number of physical datasets and active participation of stakeholders in its vulnerability assessment. Keiler et al.'s [21] research, less multivariate, aims at assessing past risk scenarios by way of input data as an economic value over exposed buildings and statistically combining them; furthermore, they do not provide any future risk forecast or any risk classification. Similarly, Dai et al. [9] involves stakeholders and public opinion in combination with a cost-effectiveness analysis in choosing the best management strategy. The complexity of each method is dependent above all on stakeholders and relevant decision makers; most of the presented approaches are elaborated for expert decision makers, hence a high level of complexity is used in order to accurately define risk [1, 9, 36]. Stakeholders are central to the functionality of the Dai et al. [9] and Cardinali et al. [7] methodologies, while the approach proposed by Garcin et al. [20] is stakeholder free. Garcin et al. [20] does, among all the review methods, explicitly report the link between tsunami and climatic change.

Generally, the considered targets are buildings, infrastructure and population; however, Keiler et al. [21] only considered buildings and Strunz et al. [36] population. This entails that most of the reviewed methods have a general grounding over all possible impacts from the considered natural hazard events – for example social aspects may deal with population efforts while economic may umbrella notions relating to buildings. This is especially important when dealing with landslide risk assessment as it is fundamental to understanding policy and structural relationships in direr needs before and after such events. Furthermore, all the analysed geophysical hazard risk methodologies, except for Keiler et al. [21], have final outputs as risk maps (i.e. landslide, tsunami, storms and volcano). It should be noted that among all the applied tools, GIS is the most present, exemplar of this use is Lateltin et al. [25] where performance via spatial integration of different information (e.g. environmental and social) to support an increased level of risk communication provides easy to comprehend risk maps.

16.5 Conclusion

Based on the review, the existing assessment and management methodologies for the two domains denote natural hazards under given reference to recent analysis and discussion of European reports, guidelines and scientific publications. The analysed reports and guidelines are focused above all on the link between the most relevant European natural hazards (i.e. floods, storms, landslides, seismic activity, volcanic eruptions and avalanches) and climate change; this issue is significant as it relates to the most affected geographical areas and proposes different risk assessment and management strategies and measures to reduce overall natural hazard risk [11] and mitigate climate change impacts [13]. The Commission's need for proper implementation of national scales, in reference to recently published regulations addressing natural hazards and specifically water-related hazards, concerning risk assessment and management implementation define the major impacts that MS have to address (i.e. human, environmental, social and economic). The three basic steps of risk assessment are: risk identification, risk analysis and risk evaluation – with its main initiative on community disaster prevention and resilience. One example of this initiative is the use of educational tools to help build a culture of safety and risk awareness [14]. The carried out review underlines that in recent years there has been a large production of scientific publications addressing risk assessment and management methodologies for natural hazards; this confirms a remarkable interest in the topic due to an increase in number, frequency and magnitude of natural hazards – above all in relationship to climatic change. In particular, the most threatening hazard events in Europe continue to cause a major number of fatalities and high economic loss.

In detail, risk methodologies that are characterised by hydro-meteorological hazard events address two different conceptual frameworks: integration of hazard and vulnerability and integration of the expected damage with the probability of the hazardous event. Accordingly, the considered methodologies are usually structured on three steps: hazard, vulnerability and risk, requiring the integration of different risk dimensions (i.e. social, economic and environmental) through different approaches – such as multicriteria analysis. Various levels of applicable comprehensiveness within varying spatial scales and target(s) comprise a state of the art. Likewise, the risk methodologies that overlooked geophysical hazards maintain a framework based on the integration of hazard and vulnerability, and in some cases also exposure; accordingly, the performed steps are hazard, vulnerability, exposure (when included) within a risk assessment and management method integrates various forms of information that is usually applied via matrices or a process of normalisation. Moreover, in most of the presented methodologies, a spatial approach is adopted with the implementation of GIS and supporting results for communication to end users via easy to comprehend hazard, vulnerability, exposure and risk maps.

It should be clear that risk jargon is method specific and that a glossary of definitions could pose as a solution to better integrating methodologies across schools of thought and advancement in assessment and management rationale. An analysis of the examined risk management methods, in a general sense, supports more suitable management measures (e.g. cost-effectiveness or cost-benefits analysis) and stakeholders' participation (e.g. public participation through workshops). According to the hazard of concern, they present a large number of different management solutions that reduce or prevent possible risks – both structural and non-structural. This takes into account sustainability and climate change concepts; stakeholders and experts are not always directly involved hence there are opportunities for further improvements. The need for a general and comprehensive (including environmental, social and economic) methodology, flexible to be tailored to different natural hazards and spatial scales is ideal. The analysed methodologies exemplify a sound starting point for future development in the field of risk assessment and management for natural hazards, offering room for improving both the natural science and socio-economic aspects; their integration through innovative spatial and mathematical approaches identify point of reference with adoption to structuring a genuine framework, approach and key components of what characterises successful advancement and what should be considered less important. Ideal support for further development is site specific and applicative target specific – development of better assessment and management techniques that circumvent this specificity is desirable.

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Chapter 17
Sustainable Development and Adaptation to Climate Change: A Role for Defence? The French perspectives

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Abstract Since the mid-2000s, there have been debates on the issue of whether Defence should be involved in the fight against climate change. Many reports were issued by various actors among the American defence and security community (See CNA (2007) National Security and the threat of climate change. CNA Corporation, Alexandria). The CNA Military Advisory Board has issued three other reports on the link between energy and national security), eventually leading the US and the UK to identify climate change as a security issue in their respective security doctrines (US Department of Defence (2010) Quadriennal defence review (QDR) 2010. DOD, Washington, DC); UK Cabinet Office (2008) The national security strategy of the United Kingdom: security in an interdependent world; UK Government (2010) Securing Britain in an age of uncertainty: the strategic defence and security review). There was and still remains much defiance and mistrust from traditional actors in the climate change debate towards the defence and security community. Even after the subject was discussed within the UN (UN Secretary-General's report on "Climate change and its possible security implications" (A/64/350), prepared in response to the request of member States, in UN General Assembly (UNGA) resolution 63/281

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(2009)) and the European Union (2008 Paper from the High Representative and the European Commission to the European Council on climate change and international security (S133/08)), under the broad topic of the links between climate change and international security, the path for action and the possible role of Defence is not yet agreed upon. Climate negotiations are progressing slower than ever while the negative effects of climate change are already being felt around the world.

In the meantime, the Defence community has been learning to integrate environmental constraints into its activities for some time; many initiatives are now taken at various levels (national and international) to lessen the defence-related activities' impact on the environment, including its GHG (greenhouse gases) emissions. The Defense community should identify the risks posed by climate change to global and national security and how they impact Defence planning and missions; and ensure that Defence activities contribute as little as possible to the causes of climate change. In order to be sustainable, there needs to be an integration of mitigation and adaptation.

The goal of this chapter is to illustrate that climate change is already a fundamental determinant of our future and that, as such, it cannot be ignored by defence planners. By learning from the experience of the French Defence regarding sustainable development, we are able to better define potential adaptations to climate change.

After a brief definition of the French context regarding adaptation, we will first describe the French Defence approach regarding Sustainable Development and its current evolution. We will then discuss the need for a strategic approach to climate change adaptation for Defence and how it can build on the Sustainable Development policy. Finally, we will try to draw lessons and define next steps to tackle this complex issue.

17.1 Adaptation to Climate Change: The French Context

Since the international community has failed to significantly mitigate its global GHG emissions in the last decade, we will have to face the consequences of a changing global climate sooner than we originally anticipated. Therefore, adaptation is now at the forefront of the fight against climate change, both nationally and internationally.

17.1.1 What Is Adaptation?

The Fourth Assessment Report (AR4) of the IPCC (*Intergovernmental Panel on Climate Change*) defines adaptation as "the adjustment in natural or human systems in response to actual or expected climatic *stimuli* or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation exist, e.g.

anticipatory and *reactive*, *private* and *public*, and *autonomous* and *planned*." Whereas mitigation of climate change is focused on dealing with the cause (GHG emissions), adaptation aims at coping with the consequence of climate change.

To reduce the negative impacts or increase the adaptive capacity, various types of actions or policies can be imagined, such smart urbanization policies, organizing and planning rapid response measures, changing lifestyles, etc. Anticipatory adaptation relies on strategic choices based on sound knowledge of changes to come and of the desirable outcome, whereas reactive adaptation can lead to *maladaptation*, which is a solution that is potentially worse than the problem or conflicting with other policies.[1]

In the end, adaptation is a very broad notion that covers a wide range of measures, plans and policies. Its criteria and definition depend largely on the concerned territory and its vulnerabilities. The IPCC defines vulnerability as the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, the sensitivity and adaptive capacity of that system.

Adaptation policies are highly dependent on climate change impact assessments, which help put a cost on unwanted changes, namely on inaction. Even though adaptation will be costly, it is admitted that environmental, technical and human damage will be greater without adaptation. In 2006, the Stern review, commissioned by the British Government, attempted to put a global figure on the cost of climate change: it stated that action on climate change would only cost 1–2 % of the world GDP, when inaction would cost 5–20 %.[2]

However, although climate change is by essence a global phenomenon, one must keep in mind that its impacts are felt locally. This explains why adaptation plans are fundamentally national, and that they only exist as a framework for action at a local level. In this regard, France was among the first European countries to set its own adaptation strategy and plan.

17.1.2 Adaptation in the French Context: A Framework for Local Action

In France, the fight against climate change and the prevention of climate-induced risks have been national priorities since 2001.[3] In the 2000s, France formulated its climate strategy, first with a mitigation strategy (Climate Plan – "*Plan Climat*") in 2004, then with an adaptation strategy ("*Stratégie nationale d'adaptation au*

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[1] See France's National Adaptation Plan: 1.

[2] Stern, N. (2006). "*Stern Review on The Economics of Climate Change. Executive Summary*". HM Treasury, London.

[3] Loi no 2001–153 du 19/02/01.

changement climatique") in 2006. The two approaches are meant to complement each other.

The four priorities set by the national strategy are as follows:

- Protect people and property by acting in favour of safety and public health,
- Taking social aspects into account and avoiding inequality of exposure to risk,
- Limiting costs and exploiting benefits,
- Preserving French natural heritage.

From the start, the adaptation strategy was meant to give birth to a (more concrete) adaptation plan. France's 2011–2015 adaptation plan was issued in July 2011 after a participative process. It is meant as a roadmap for sectorial adaptation. More important than the result, was the process itself. The working groups underlined the importance of research and evaluation, of making observation and information available to all, of feedback forums and experience sharing, and of including citizens in decisions and their implementation. This inclusive approach builds on the previous experience of the *Grenelle de l'environnement,as well as* a consultative process organized by the French government in 2007, and has been widely experimented. The need to integrate the field actors (citizens) in decisions is essential to achieve the expected results, especially on a local scale.

The adaptation plan had to tackle three types of uncertainty: the future climate evolution, with completely different impacts depending on a 1 °C difference in temperature, the consequences of national temperature scenarios on local scales and the adaptive capacity of future societies. Thus, adaptation policies had to be evaluated according to their degree of flexibility with respect to new information that will be gradually added.[4] In order to set concrete action, the plan had to be based on robust scenarios and data. Two scenarios were set using the IPCC scenarios and the national climate models of the CNRM-Météo-France (Centre national de recherches météorologiques) and IPSL (Institut Pierre-Simon Laplace). One scenario was optimistic and the other pessimistic. Here again, projections are far from certain, but the authors chose to underline a few "concrete consequences" that they believed would have consequences across different sectors of activities: more frequent heat waves and less very cold days (impacts on health), fewer days of snow, fewer days when heating is necessary and more days when air conditioning is necessary.

In the end, the plan is organized around sectorial action sheets with 84 actions composed of 230 measures. These range from information, norms and rules, to adapting institutions and establishing investment. Responsibility for the delivery and indicators are systematically mentioned on the action sheets. It is worth noting that uncertainty does not curb action: the plan states clearly that the first measures to be taken should be the so-called "no-regret measures" (beneficial even if there is no climate change), reversible measures, measures increasing the safety margins,

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[4] Christian de Perthuis, Stéphane Hallegatte, Franck Lecocq, *Économie de l'adaptation au changement climatique*, Conseil économique pour le développement durable, février 2010.

measures that take a long time to be implemented, and adjustable measures. It states that adaptation should be "a dynamic and reversible process". Although the word is never mentioned, these characteristics of adaptation, added to the *unsustainability* of climate change, clearly call for a stronger "sustainable development-oriented" future.

17.2 The Ministry of Defence and Sustainable Development

In the last years, the Ministry of Defence had to adapt quickly to numerous new environmental constraints, then to take ambitious commitments in the field of sustainable development. This represents an important budgetary constraint: there is more than 10 M€ investments every year in the environmental dimension of defence equipment, armament programs are "eco-proofed", and 139 M€ should be used from 2009–2014 to dismantle used equipment.[5] Moreover, the ministry has sometimes acted voluntarily by going beyond its legal obligation.

17.2.1 An Important Responsibility Regarding Sustainable Development

The Ministry of Defence owns a large estate domain preserved from urban and agricultural pressure. Thus, it has undertaken environmental actions for more than 15 years, first by creating a special fund for environmental innovations (1994), then by protecting its estate through an agreement with the Ministry of Ecology in 2003 (regarding the E.U. *Natura 2000* classification). However, the environmental policy was formulated for the first time after the *Grenelle de l'environnement*, through an action plan that has since been updated yearly.

In the meantime, the *National Sustainable Development Strategy*, first issued in 1996, was revised and new versions were regularly published (in 2003 and 2010).[6] As the Ministry of Defence ranks among the first employers and contractors of all Ministries, and was then already re-organizing its environmental policies, there was a growing conscience that the Ministry needed not only an environmental policy, but that a Sustainable Developement (SD) policy, with its economic and social pillars, was needed too. The then Minister of Defence Hervé Morin thus stated, in 2008: *"The armed forces must integrate the issues of the French society. It must be*

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[5] See http://www.defense.gouv.fr/sga/le-sga-en-action/developpement-durable/environnement/politique

[6] The French National Sustainable Development Strategy (Stratégie Nationale de Développement Durable, SNDD) can be found in English at http://www.developpement-durable.gouv.fr/National-sustainable-development,21743.

compatible with the preservation of the estate, not only throughout its core missions. The military are citizens too; caring for the environment is caring for the future of the country."

The most interesting aspect of studying how and why Sustainable Development has gained momentum within Defence is to understand how regulatory measures (laws) combined with the right policy framework have created a voluntary process. The Ministry of Defence is seen as one of the most efficient ministries regarding SD.

In 2008, the Ministry of Defence published its first SD report when there was no legal obligation to do so. It was composed of several plans of actions drawn in the wake of the *Grenelle* and before: a "Handicap" plan (2006), an "Equal opportunity" plan (2007), an "environment and sustainable tenders" (2007).

Since then, it has issued the SD report in 2009 and 2010, until it was decided that a real strategy, and not just a report, modelled on the newly updated national strategy, was needed.

17.2.2 A New Defence Sustainable Development Strategy

The voluntary reports that the Ministry has produced for 4 years were very detailed, but were mostly meant to sensitize the Defence personnel to the SD actions of the ministry. In fact, there was – and still is – a lack of perception and understanding of the ministry's role and actions in SD. It is not really a surprise, as one is familiar with the core mission of the military (conducting military operations) but not with the complex administration that makes this mission possible, which is confronted with SD issues on a daily basis.[7]

With the new *National Strategy for Sustainable Development*, it was finally decided that a substantial strategy was needed for Defence. One could also note that the British Ministry of Defence (MOD), among other defence partners, had already issued their own SD strategies at that time.[8]

The process was therefore launched in 2011. An inclusive and participative framework was set up. The goal was not to start from scratch but to base the new document on the National Strategy's "nine challenges" framework, and to include all the ministry's actions that were already taken regarding SD. Within new budgetary constraints, it was said that it would not be possible to set up new ambitious priorities. Here again, the Ministry's decision to adapt the national strategy into a Defence context was voluntary, and it was the first to do so.

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[7] Colonel Evelyne Bernard, *Le développement durable du Ministère de la défense*, collection Cahiers de l'EMS no 4, septembre 2010.

[8] See UK MOD for details: https://www.gov.uk/government/organisations/ministry-of-defence (the website is currently being remodeled).

In the end, the strategy was signed by the minister in March 2012, just before the presidential elections. It encompasses five priorities, as stated by the minister in his preamble[9]:

- Reinforce energy efficiency and master energy consumption
- Promote professional integration of the youth as a factor of social cohesion
- Favour the access of SMEs and midsized firms to procurement contracts of the Ministry of Defence
- Have all the men and women within the Ministry integrate sustainable development as a stake in their daily activities
- Preserve the environment and biodiversity on land and in the sea

One can only regret that it was not possible to set up new priorities, such as climate change. However, the process was open and inclusive for the first time since the creation of SD policies. The other new feature was the tentative link established in the strategy between two levels: the "corporate" and the "strategic". The strategy admits that pursuing sustainable development objectives leads to a better adaptation of the military to their future environment and missions:

> Our Sustainable Development Strategy is an essential step in the process of **adapting** our military capacities to tomorrow's transformed world. Indeed, some environment-related phenomena, such as climate change or the unavailability of some natural resources, especially energetic ones, will have direct and indirect consequences on international security (for instance, disorganization caused by natural disasters or disputes regarding the access to natural resources).

The Defence approach to sustainable development is dynamic: it is constantly evolving to adapt to new constraints and opportunities.

17.3 The Ministry of Defence and Adaptation to Climate Change

The Ministry of Defence is largely involved in making its activities more sustainable, in the context of France's national and international engagements. By doing this, it is taking into account long term perspectives and its own impact on the future social, economic and physical environment. In the last decade, the fight against climate change has been the main catalyst to make sustainable development a top priority for many countries.[10] The Sustainable Development Strategy includes

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[9] The strategy has been published on the Internet: http://www.defense.gouv.fr/sga/le-sga-en-action/developpement-durable/strategie-de-developpement-durable.

[10] M. Merad, N. Dechy and F. Marcel, *Sustainable Development and Climate Change Challenges. Case of a Public Organization*. In I. Linkov and T.S. Bridges (eds), Climate: Global Changes and Local Adaptation, NATO Science for Peace and Security Series C: Environmental Security. (p. 194).

objectives regarding climate change, and there is no doubt that climate change is the most serious threat to a sustainable future for all. We argue here that climate change should focus more attention from the security and Defence community as it takes us on the path to a more unsustainable, uncertain and therefore insecure future.

17.3.1 Climate Change as a Matter of Consideration for Defence

It is not climate change itself that has significant implications for defence but its various impacts and consequences. Some of the effects are global and their intensity will vary depending on regions, but the effects will be felt locally. Linking a global phenomenon that is caused by global GHG emissions to local effects and local adaptation measures is the main challenge policymakers are facing.

Although widely discussed in the last decade, the emergence of climate change as a security issue has no consensus. In the anglo-saxon Defence view in general, climate change is described as a "threat multiplier", i.e. a source of heightened tensions on already strained systems such as food, water or energy systems.[11] Other have described it as a possible cause of resource wars, or a source of massive migrations. The term "climate security" remains highly controversial in itself.

However, the real concern is "not in direct links between climate and violent conflict, but in the ability of climate change to disrupt those systems that underlie stability and human security more generally", as Chad Briggs states in *International Affairs*.[12] He also defines the security view over climate change: "a disruptive force that has the potential to make operations more costly and time-intensive, and to require further deployments as part of humanitarian assistance and disaster response (HA/DR) operations."

This security-oriented definition of climate change underlines the strategic, operational as well as corporate stakes for Defence: climate change impacts may be indirect regarding security itself, but they can be direct on Defence materials and infrastructure. The direct physical impacts range from the consequences of ocean acidification on ships, sea level rise on coastal infrastructure, or more indirectly on the availability of energy resources. No complete climate change impact assessment has been done so far for the French military.[13] It is noteworthy that in the US, the explicit designation of climate change as a threat for national security in official strategic documents (US 2010 QDR) is the primary reason for the wide implication of national security and the Pentagon on the subject. In France, however, the 2008

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[11] http://www.wiltonpark.org.uk/en/conferences/policy-programmes/climate-change-and-energy/?view=Conference&id=742796182

[12] Chad Briggs, "Climate security, risk assessment and military planning", *International Affairs* 88:5 (2012) 1049–1064.

[13] Impact assessment was among the recommandations of the 2007 CNA report (op. cit.)

White Paper on Defence and Security was very careful and only cited Climate change in its "strategic context" chapter, defining it as one of the "worrying trends of globalization" that "might have some effects on the stability of polar regions, sea-level rise, migrations and geography of diseases, out to 2025". It also stated that global warming could create major crises in the long term or aggravate poor living conditions in developing countries.[14]

17.3.2 The French Case: Options to Consider

"The risks to strategic interests and operational goals are often significant enough to be included in planning".[15]

In the French case, foresight studies such as "*Strategic Horizons*", the Ministry of Defence geostrategic report to 2030 last issued in 2012, have recognized the importance of climate change in the future strategic context.[16] Climate and environmental change in general have been seriously considered by Defence analysts for some time. In 2007, the annual foresight seminar of the Directorate for Strategic Affairs (policy division of the Ministry of Defence) was entitled "*2040, strategic stakes of an evolving climate*". Although there is no official ministerial impact assessment nor a climate strategy, several unofficial documents have been issued by various actors related to the ministry (CHEM: *Collège des Hautes Etudes Militaires,*[17] IRSEM: *Institut de Recherche Stratégique de l'Ecole Militaire*[18]), some of which are available online. All these reports bring interesting bricks to the debate and have to be considered in an inclusive approach. The (unofficial) report published by IRSEM was interesting as it divided the consequences of climate change on Defence into three categories: corporate issues, such as the GHG emissions policy (the link with SD policy), planning and operations (evolution of the missions, priorities for military engagement, need for new types of equipment), adaptation of technologies and equipment. Although it raises the issue of the operational carbon footprint, this classification fails to tackle cross-cutting issues such as energy policy (which belongs to corporate as well as operational policies).

Similarly, a parliamentary report on the impacts of climate change on security and defence was issued in February 2012. The authors write about "adapting

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[14] http://archives.livreblancdefenseetsecurite.gouv.fr/information/les_dossiers_actualites_19/livre_blanc_sur_defense_875/livre_blanc_1337/livre_blanc_1340/index.html.

[15] C. Briggs, p.1054 (op.cit.)

[16] http://www.defense.gouv.fr/english/das/strategic-thinking/defense-foresight/articles-prospective/strategic-horizons.

[17] "Les conséquences stratégiques du changement climatique": notes de synthèse du Capitaine de vaisseau Stanislas Gourlez de la Motte, du Capitaine de vaisseau Andrea Romani, et du Colonel (air) Thierry Raymond.

[18] Laboratoire de l'IRSEM no 5-2011, *Réflexion stratégique sur le changement climatique et les implications pour la défense*. http://www.defense.gouv.fr/irsem/publications/laboratoire/laboratoire.

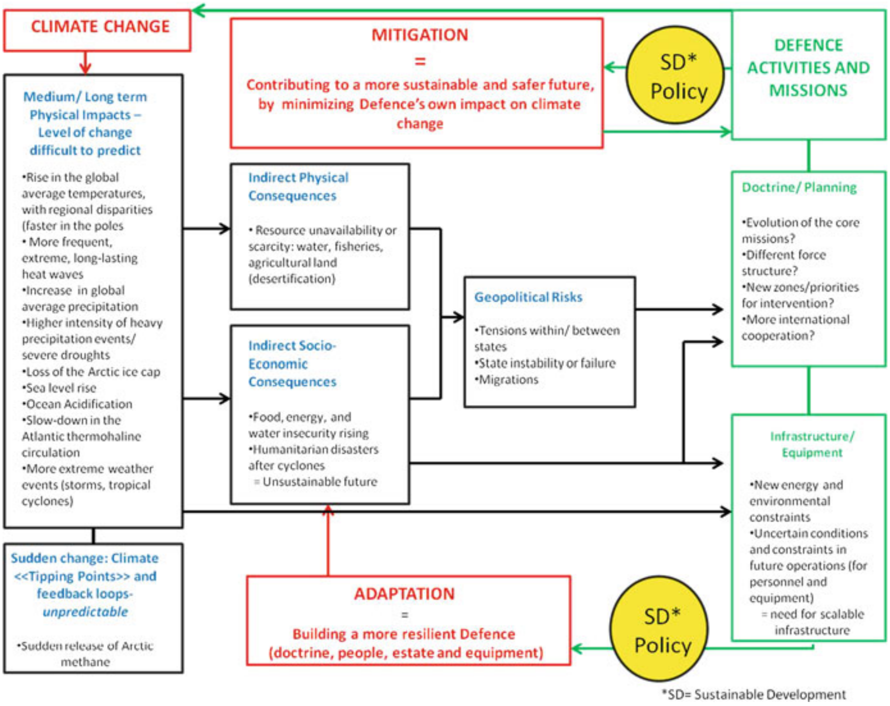

Fig. 17.1 Linking defence and climate change (Source: Compiled by the author, based on some of the aforementioned sources)

Defence functions (i.e. military tasks) to climate change". However, they mostly describe consequences but not concrete measures to take. They conclude that Defence should consider climate change more seriously (Fig. 17.1).[19]

The above table compiles the conclusions of the aforementioned reports. It shows the complexity of the issue, and is one of the possible ways to summarize it.

Most of these sources present interesting aspects of the issue, and some of them have been discussed within working groups. But their main mistake lies in the non-inclusive process they all used; neither of them was discussed widely enough and included all the needed participants. In this respect, useful lessons might be learned from other countries' experience in considering climate change as a security issue.

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[19] Rapport d'information no 4415, déposé par la Commission des affaires européennes de l'Assemblée nationale, sur l'impact du changement climatique en matière de sécurité et de défense, et présenté par MM. André Schneider et Philippe Tourtelier, députés (28 février 2012).

17.3.3 What Lessons Can We Learn from Other Countries' Experience?

As we mentioned in the introduction, and is underlined in the parliamentary report, the US and UK seem to be the most active countries involved in the debate on climate security. However, they have different approaches to the issue. By its size and organization, the French ministry of Defence looks more like the UK the British MOD and as such, may draw useful lessons from British policy.

The British MOD has published a climate change strategy in 2009 and 2010. As mentioned in 2009 version, this strategy "forms a sub-strategy under the MOD Sustainable Development (SD) Strategy".[20] From the start, the link between climate change policies and SD policies is clearly stated, as well as the two sides of the problem: Defence activities' impact on Climate Change ("due to the high dependence on fossil fuels") and Climate Change impact on Defence activities, "both as a result of 'Climate Security' issues and as a result of changing environments in which equipment and personnel operate". Therefore, it tackles both mitigation and adaptation: "this Climate Change Strategy has been written to provide the single source of strategic direction necessary to enable the MOD to both mitigate and adapt to the challenges of climate change" (p. 6). The adaptation part (Sect. 17.4) finds three priorities for adapting the MOD: adapting Defence Policy Planning, adapting MOD Equipment Acquisition, adapting the MOD estate. This shows that adaptation is not limited to corporate issues such as adapting infrastructure, but encompasses policymaking too. This is best shown by Fig. 17.2 (p. 31) with a comprehensive diagram to summarize MOD Adaptation process (the following diagram is the 2010 updated version and can be found on page 12 of the 2010 Climate Change Strategy):

This figure shows the importance of defining responsibilities for delivery of the different tasks, as well as the prominence of vulnerability and risk assessment in any strategy linked to adaptation to climate change. The strategy also states that MOD "will only achieve (its) climate change vision if (it) embeds awareness of Sustainable Development issues into the heart of decision making in Defence and ensures that all MOD staff understand the importance of SD and how it links to their wider work" (p. 16 of the 2010 strategy). Sustainable development is the way to adapt to climate change.

The US DOD releases a yearly *Strategic Sustainability Performance Plan* which "lays out (the DOD's) goals and sustainability performance expectations over the next decade, establishing the path by which DoD will enhance (its) ability to achieve (its) mission, lower life cycle costs, and advance technologies and practices that further the sustainability goals of the nation".[21] It primarily concerns corporate

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[20] The strategy can usually be found on the internet. The current remodeling of the MOD website makes it inaccessible as this chapter is being written. Athough the 2009 and 2010 versions are similar in the list of their contents, the 2010 strategy has been much shortened compared to the 2009 one. For the sake of clarity, we will analyze the 2009 version.

[21] US DOD *Strategic Sustainability Performance Plan* for FY 2011.

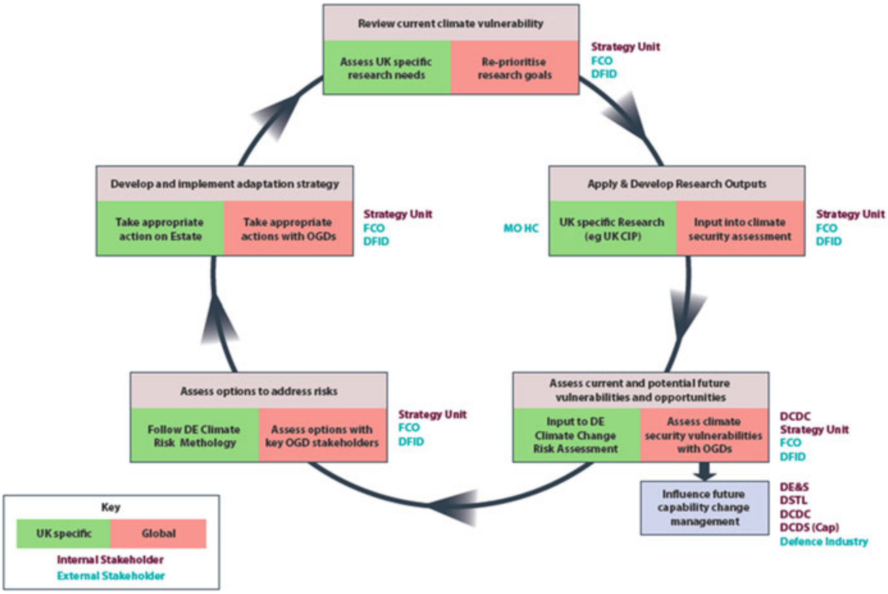

Fig. 17.2 UK MOD adaptation process (Source: UK MOD 2010 Climate Change Strategy, p. 12)

issues and energy. It is worth noting that energy security has been the main incentive for making progress towards a “greener” military. In his 2012 State of the Union address, President Obama even highlighted the role of the military in developing clean energy. As of today, the DOD does not have a climate change strategy or adaptation plan. In October 2011, the Defence Science Board, which is part of the Office of the Undersecretary of Defence for Acquisition, Technology and Logistics, issued a report on the “Trends and Implications of Climate Change for National and International Security”.[22] This report was written by an independent task force and does not represent the official views of the DOD. Nevertheless, some of its recommendations should be underlined: it insists on “the need for a strong climate information system database” that would better support decision-making, and underlines the need for a coordinated approach (“to be effective, DOD activities will need to be part of a comprehensive multi-department effort and in coordination with international efforts”).

Finally, not only have the UK and US identified climate change as a threat to national and international security, but their respective foresight reports have sometimes dedicated full chapters to climate change. This was the case for DCDC’s *Global Strategic Trends out to 2040*[23] or, recently, the US National Intelligence

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[22] http://www.acq.osd.mil/dsb/reports2000s.htm

[23] The Development Concepts and Doctrine Centre (DCDC) is a UK Ministry of Defence think-tank.

Council with its *Global Trends 2030: Alternative Worlds.*[24] This outlines foresight as one of the possible global roles of the security and defence community, i.e. the "measuring of context and coherence in an uncertain predictive area characterized by risk, ambiguity and change".[25]

It would take more than a few lines to describe accurately and extensively the British and American approaches to climate security, which is not the goal of this chapter. What we mean to show here is the process by which it was decided to tackle the issue. Directions and goals are fixed and a framework for action is set, which is very clear in the British case. To a certain extent, the process is similar to the strategies set up in France at the national level (the Sustainable Development Strategy and the Adaptation to Climate Change strategy). However, it should be noted that such strategies are only relevant within a national context, as they rest upon the definition of national interests and threats to these interests. Nonetheless, as climate change also challenges international security, there is considerable space for common action and policy and for international cooperation in the field of climate security, starting with experience sharing.

17.4 Conclusion

Climate change and its consequences have the potential to disrupt activities and systems everywhere, including in developed countries, if they are not well prepared to face them. Climate change is obviously a threat to sustainability as long as it is not factored into the preparation of the future and sustainable development policies. For the military too, the fulfilling of their mission depend on the access to resources (energy being the most important) as well as on their preparedness to the mission they are to deliver. With more uncertain conditions and a growing unpredictability, flexible adaptation seems more needed than ever. Sustainability strategies will have to integrate climate change parameters while adaptation policies will have to factor in sustainable development issues. Thus, adaptation cannot be considered in isolation, but is part of broader decision making.[26] This is in part the spirit of the French adaptation plan. It lays the foundations for the empowerment of the people at the local level, where climate change effects will be strongly felt. The military can build upon their experience regarding Sustainable Development and the progress of their partners to define a similar process for adapting to climate change.

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[24] This document identifies the food-water-energy nexus, linked with climate change, as one of the four "megatrends" that will shape the world out to 2030.

[25] https://www.gov.uk/Development-concepts-and-doctrine-centre#future-strategic-trends

[26] N. Ranger, *Adaptation as a Decision Making Under Deep Uncertainty*. In I. Linkov and T.S. Bridges (eds), Climate:, NATO Science for Peace and Security Series C: Environmental Security. (p. 119).

Appendix A: Resilience of Infrastructures and Networks in a Changing Climate: French Experiences

Impact of climate change on cities, transport and energy networks is a matter of particular interest in France since the government decided to implement a global adaptation policy (national adaptation strategy) in 2006.[27]

At the ministerial level, knowledge about impacts and adaptation to climate change is gathered by Onerc (National observatory on the impact of climate change), the French adaptation portal.[28] Onerc is also in charge of coordinating the implementation of the national adaptation policy. Thus Onerc published in 2009[29] and 2010[30] extensive analyses of sectoral impacts of climate change and adaptation options, in order to facilitate the design of the first national adaption action plan in 2011.[31] The following sections highlight some findings of these works.

A.1 The Urban Issue of Climate Change Resilience: Impact Identification and Strategic Planning in Paris

Interest in climate action is growing in French cities. In the last decades, climatic extreme events raised public awareness: heat wave in 2003, recurring summer droughts since 2000, rain and coastal floods. Moreover, since the Grenelle's laws,[32] cities beyond 50,000 inhabitants are required by law to set up a local climate action plan that combines mitigation and adaptation to climate change measures, by the end of 2012. Paris, one of the front runner French cities in climate action, has already its own "Climate Plan" and has invested in knowledge improvement to enable the update of this plan by the end of this year. The following sections highlight these current issues.

A.1.1 An Urban Heat Island Issue That Influences Health Infrastructures

Towns and cities create micro-climates, due especially to the existence of urban heat islands (UHI). UHI are urban areas where higher air temperatures are detected in comparison with temperatures observed in the rural areas that surround them.

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[27] http://www.developpement-durable.gouv.fr/The-French-National-Strategy-for.html

[28] www.onerc.gouv.fr

[29] http://www.developpement-durable.gouv.fr/ONERC-Report-to-the-Prime-Minister.html

[30] http://www.developpement-durable.gouv.fr/ONERC-Report-to-the-Prime-Minister,19649.html

[31] http://www.developpement-durable.gouv.fr/The-national-climate-change.html

[32] Grenelle laws are the achievement of a participatory environmental policies planning process started by the French government in 2007.

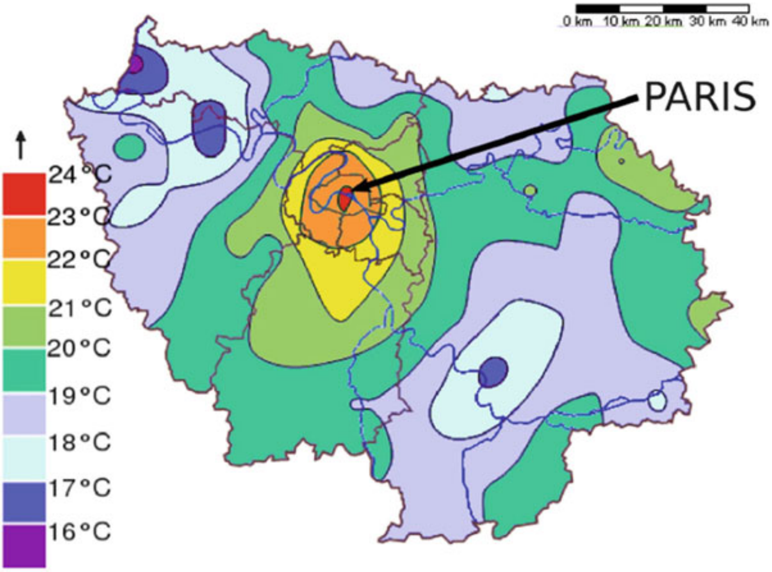

Fig. 17.3 Minimum temperature (night) in Paris and around Paris during the heat wave of 2003. We can see differences of up to 8 °C created by the urban heat island effect (Source: V. Masson, G. Pigeon, A. Lemonsu, C. Marchadier CNRM, Météo-France) (http://www.cnrm-game.fr/spip.php?rubrique134&lang=en)

According to several studies, the maximum intensity of a UHI can go from 2 °C for a town of 1,000 inhabitants up to 12°C for a city of several million inhabitants.

For example, during the heat wave in France in 2003, the temperature differences were of 8 °C between the centre of Paris and some near rural areas (Fig. 17.3). In practice, the difference in temperature between the centre of a city and rural areas depends on the architectural characteristics of the city (such as its spread, its density and the height of the buildings) and the characteristics of the rural area used as a control.

A UHI has a recurrent daily variability and its intensity is generally stronger at night. It expands progressively during the night time cooling period and is a response to a rate of cooling that is slower in the denser areas than in the periphery. In the majority of cases, the maximum attained by a UHI seems to be a few hours after the sun has set, the UHI generally diminishes rapidly after sunrise.

The intensity of the UHI diminishes as the wind rises. We note that a UHI disappears when wind speeds are over 11 m/s. When there is a moderate wind (3–6 m s-1), the temperature field is shaped like a vertical flow depending on the wind direction.

The intensity of a UHI diminishes when there is an increasing cloud cover. Clouds act by modifying the night-time radiative cooling during which a UHI is formed. The influence of seasons has been detected not only on cities in temperate climates but also in other types of climates (Mexico and Cairo for example). Nevertheless, the maximum intensity of UHIs (the difference between temperatures in town and the rural areas that surround them) is the same whatever the season.

This structural phenomenom generates adverse cumulative effects during heat-waves periods: peak temperature is increased through a retarded night cooling process. UHI and heatwaves make a dangerous cocktail for urban vulnerable persons (elderly persons and children).

That's why since 2004 an early warning system and crisis management scheme is developped in France, called "Heatwave plan". It combines information networks and investments to reduce heat impacts on vulnerable persons (cooling devices, drinking water distribution, health infrastructure improvement, hospitals networking). The plan is coordinated at the national and local level.

A.1.2 Heatwave and Transport Network Failures

In August 2003, the high temperatures created very high constraints on railway tracks (buckling) and their basement (through drying). Thus, a section of the suburban rail network has been closed during 3 week in Paris. This failure generated many direct and indirect costs at the city level and the national railway company is today investing money and time in upgrading tracks and distension seams.

High air temperature has also generated a global discomfort for travellers in Paris public transports. Today, shaded areas have been built in the parking zones.

A.1.3 Floods and Low Water Issues: Impacts on Transportation and Sewage Infrastructure

The Seine river crossing Paris played a very bad trick to Parisians in 1910, with the highest flood ever seen in Paris. Today, despite the development of many anti-flooding devices upstream and downstream, the City is very cautious with this topic because a vast part of Paris is a low lying area and if the same flood comes again, it will probably cause many infrastructure disruptions as illustrated below with the electric and subway networks (Figs. 17.4 and 17.5).

In the future climate, latest research suggests that the annual run-off of the Seine will decrease by 15 % and mainly during summer (−25 %). Nevertheless, modelling doesn't anticipate any significant change in flooding patterns. The decrease in summer flow will challenge sewage water treatment capacities.

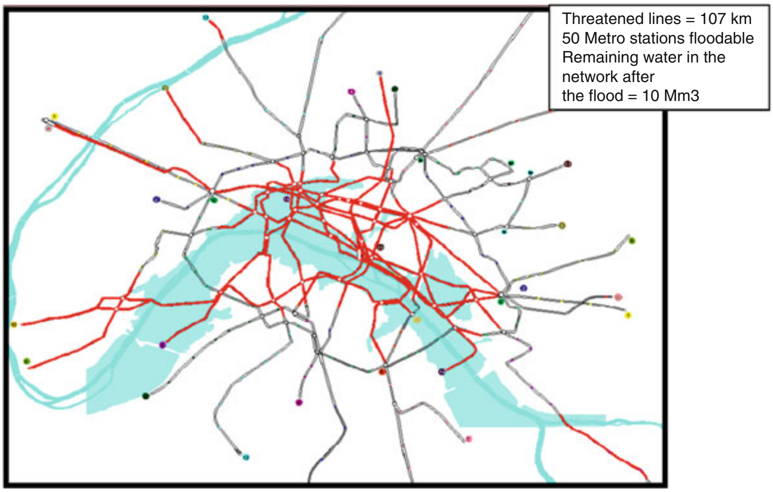

Fig. 17.4 Area of fragile electric power supply if the present protection fails to meet the threat of a flood of the height of that in 1910, or if the floods are higher (Source: *Police headquarter of Paris)*

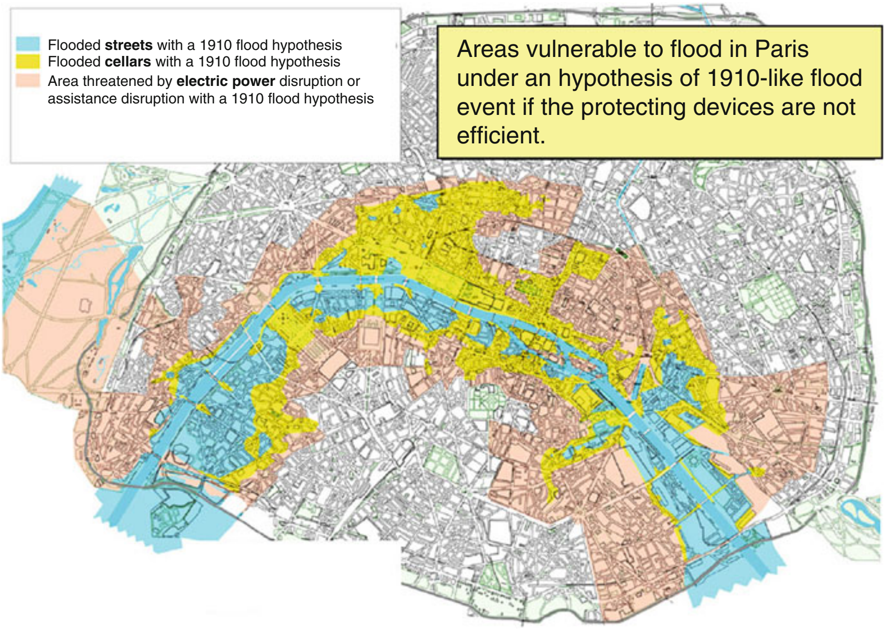

Fig. 17.5 Vulnerability of the Paris metro network if there was a repeat of the 1910 flood. The *red* lines represent the Paris Metro section affected (unaffected sections are in *grey*) (Source: Police headquarter of Paris)

Appendix B: Coastal Flooding of Infrastructures and Cities

Rising sea levels, on one hand, will have consequences in terms of material losses due to the slow submerging of the coast and on the other, potential consequences in terms of a threat to human lives from the increased risk of coastal flooding following storms.

The permanent rising of sea levels caused by climate change will lead to an increase in the geographic spread of areas submerged by storm tides and an increase in their intensity and in their frequency in areas already at risk. This effect will be at least stronger in the future since climate change could lead to acceleration in coastal erosion and will probably alter the existing natural barriers to coastal flooding.

In France, low lying areas such as the Mediterranean regions or the Vendée, Charente-Maritime, Nord-Pas-de-Calais and the Aquitaine region are the most seriously threatened.

As an illustration the following map shows the level of risk for part of the Languedoc-Roussillon region. With one meter rise in sea level (a very pessimistic scenario) the areas in red are the ones that would be directly threatened by permanent flooding; the areas in orange areas are already threatened by high tides and storms and they will see their risk increased; the areas in yellow are considered as safe today but would be at risk with an average higher sea level of over one meter. In blue are the areas that are at present urbanised and which have grown strongly in the last decades (Fig. 17.6).

In that scenario, around 100, 000 households and business will be lost at the end of the century only in that region.

We need to make clear the fact that sea defences are not generally considered to be the only adaptive solution when faced with the risk of submerged coastlines. Although they may carry out their defensive role well, they may aggravate or create problems elsewhere; the solution to the certain problems creates problems for others. In addition in some cases, the construction of defences may lead to an increase in vulnerability. This occurs when, from a false sense of security brought on by the defences, new facilities are developed in the protected areas; the risk in these areas being never zero, this can lead to even higher losses if there is a serious climate event and so, in the final analysis, increased vulnerability. It would seem more sensible to consider a policy of prevention which limits the installation of facilities and people in areas that are at risk and protect what is already there rather than consider new defences. We need to note, therefore, that physical defences (for example sea walls) will never be sufficient unless they are linked to a land use policy. In particular it is vital to avoid urbanisation and development of areas liable to flooding situated outside the defended area. From a technical point of view, if sea level rise by one meter, latest research suggests that sea wall need to be elevated by at least 1.8 m just to keep their current defence ability.

Beyond the city focus, it has been estimated that nearly 20,000 km of roads and 2,000 km of railways will be affected by a one meter rise of sea level in France. The cost associated to the damage would range up two Billion Euro only for the road infrastructure.

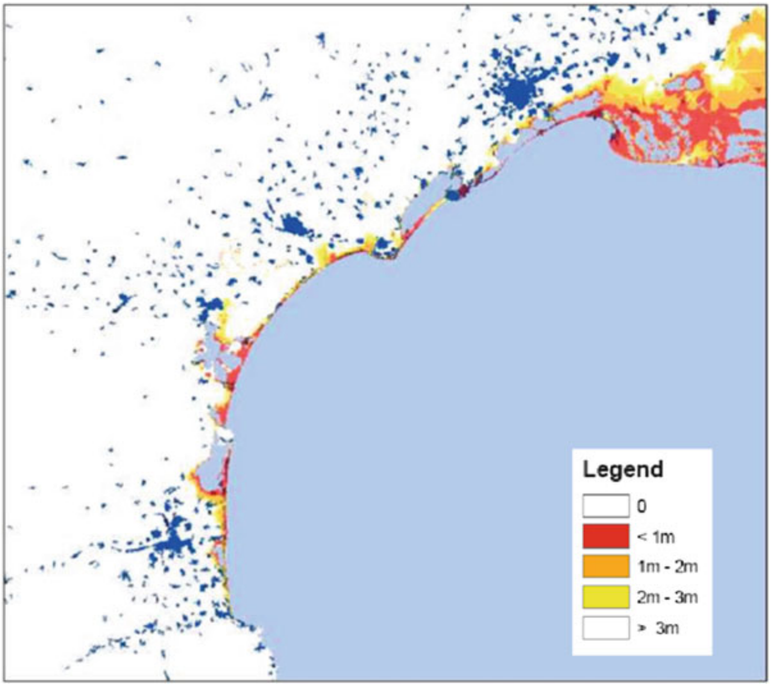

Fig. 17.6 Map of the Languedoc-Roussillon region, with urbanisation in *blue* and altitude in relation to sea level in *yellow/orange/red*. (Source: [2] (http://www.developpement-durable.gouv.fr/IMG/pdf/001-3.pdf)

B.1 Energy Infrastructure and Climate Change

B.1.1 Heatwave and Transport Network Failures

Nuclear power plants were seriously challenged during the 2003 heat wave. Technically speaking, cooling the plants was not a problem; the constraint was that suppliers had to abide by the regulation on thermal discharge (i.e. the maximum temperature authorized for water discharges in the rivers). These constraints have generated a costly burden: 5.3 TWh were lost in 2003 during the heat wave and were purchased abroad on the spot market.

Since 2004 the national electric company has invested in the adaptation of the powerplant to high temperature spells. 350 million Euro will be spent on the 2004–2019 period. At the end of 2011, around 180 million Euro have already been spent to improve cooling devices,

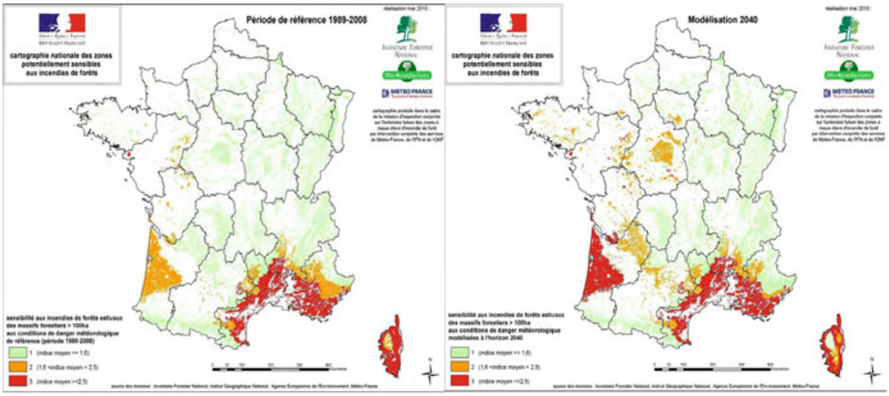

Fig. 17.7 Forest fire prone areas extension between today (*left*) and around 2040 (*right*). *Red* = highly sensitive; *orange* = sensitive (Source: Inter ministerial mission 2010) (http://portail.documentation.developpement-durable.gouv.fr/documents/cgedd/005957-01_rapport.pdf)

B.1.2 Drought, Forest Fires and Transport Network Failures

Climate modelling projects an increase of forest fire prone areas in France: in the north of the country and in altitude regions. This is an issue of major concern because forest fire disrupt directly or indirectly infrastructure and networks. For example, high voltage lines must be switched off in case of forest fire, generating blackouts downstream. Forest fires also disrupt transport networks and challenge emergency and health assistance. In France, current sensitive areas in the South of the country will become even more sensitive in a near future. And areas that are not sensitive today will become newly sensitive. To respond to these challenges, the fire management scheme is currently reviewed to gradually upgrade its efficiency (Fig. 17.7).

B.2 Next Steps

The vulnerability assessments illustrated above have been used to design the first national action plan to adapt to climate change[33] in 2011. This action plan will be implemented starting now until 2015 through several concrete actions to reduce the vulnerability of the main socio-economic sectors and to further improve knowledge of climate change impacts in France.

The UHI issue is currently studied using more detailed assumptions and approaches. Adaptation options to reduce the problems during heat waves have been recently modelled in Paris.[34] Through local adaptation planning at the regional

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[33] http://www.developpement-durable.gouv.fr/The-national-climate-change.html

[34] http://www.cnrm-game.fr/spip.php?article271&lang=en

and city levels (encouraged by Grenelle's laws), several cities are implementing actions to reduce the UHI impact (for example, Paris and Lyon through accelerated vegetization).

The Ministry in charge of transports and the national railway company are currently reviewing their construction norms to check if they need an upgrade to remain valid under a warmer climate.

Coastal vulnerability can be better assessed today since national laser cartography (LIDAR) has been performed on French coasts in the last 2 years.

The national electricity company is improving the cooling devices of their power plants and has shifted its annual upgrade programme to be better prepared in case of a summer heat wave.

More than half of the French regions have today adopted their own climate action planning policy document to be more resilient to climate change in the future.

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Chapter 18
Urban Sustainability and Poverty: Can Microfinance Make a Difference?

B. Morel, E. Linkov, and P. Morel

Abstract Microfinance is perceived as a way to provide the impoverished with access to credit, but does it provide a sustainable solution to the ever growing problem of urban poverty? Microfinance has found new visibility with the experience of the Grameen Bank in Bangladesh. The Grameen Bank is considered a model of microfinancial success leading to a Nobel Peace Prize in 2006. But microfinance has had a mix of success and failures and despite being present in every region of the world; it is poorly documented and understood. Scholars who want to get an informed understanding of the microfinance world will find themselves confronted with an abundance of anecdotal information, giving the misleading impression of a wealth of data but little in the form scientific data. For example, empowerment of women is the best documented aspect of microfinance. However important woman empowerment may be, it does not capture the totality of the impact of microfinance on poverty or on the economy. Microfinance is a unique instrument to fight poverty and the difference it has made is beyond debate, but is reliance on microfinance sustainable for developing countries?

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18.1 Introduction

For the first time, the majority of the world's population lives in urban areas. The trend of mass urbanization is occurring rapidly in all parts of the world. For developing countries, this is a mixed blessing. Urbanization is a necessary condition for growth and prosperity in modern societies, as cities are "engines of economic growth" [1]. But, the "urban age" [1] also means, among other things, the proliferation of slums. For example, It is estimated that out of "500,000 people who migrate to Delhi each year, 400,000 end up in slums" [1]. Slums raise serious challenges for sanitation, health, and poverty. They are a fast growing problem, which if not addressed aggressively will get out of control [2]. To make matters worse, these challenges affect nations which tend to have limited resources in the first place [3].

Microfinance is perceived as a way to provide the impoverished with access to credit, but does it provide a sustainable solution to the ever growing problem of urban poverty? Microfinance has found new visibility with the experience of the Grameen Bank in Bangladesh. The Grameen Bank is considered a model of microfinancial success leading to a Nobel Peace Prize in 2006. But microfinance has had a mix of success and failures and despite being present in every region of the world; it is poorly documented and understood. Scholars who want to get an informed understanding of the microfinance world will find themselves confronted with an abundance of anecdotal information, giving the misleading impression of a wealth of data but little in the form scientific data. For example, empowerment of women is the best documented aspect of microfinance. However important woman empowerment may be, it does not capture the totality of the impact of microfinance on poverty or on the economy. Microfinance is a unique instrument to fight poverty and the difference it has made is beyond debate, but is reliance on microfinance sustainable for developing countries?

The economic impact of micro credits is difficult to measure, because the total amount of money loaned is minuscule in comparison to the wealth circulating in national economies. But microfinance has no substitute. Suppressing it would do a lot of damage to societies and negatively affect the fight against poverty. The impact of microfinance is not limited to getting access to financial services for poor people, it has also inspired a new approach to business where the social impact of the business is a consideration. As some (like Dr Yunus, who contributed so much to push the idea of microfinance by creating of Grameen Bank) argue, business needs not be for profit only, it can also be for progress, i.e. its social impact matters.

In the article entitled the "Bottom of the Pyramid" [4], Pralahad and Hart argue that "the urban poor" are potentially a "resource of energetic, productive labor and potential purchasing power". However, the problem lies in how to best equip these people with the resources they need to not only have immediate improvement in lifestyle but also to have long term success. Microfinance has been propagated across the world with goals of fixing poverty, so can it be a sustainable solution for urban poverty?

18.2 Microfinance: An Overview

A superficial look at the world of microfinance reveals some common features in how microfinance is approached, but because of regional cultural, political, economic, and regulatory diversity, there is also significant variability in the form that microfinance takes and in the role it plays.

Many different approaches are being taken to apply microfinance in all parts of the world. Micro- Finances Institutions (MFI's) such as Compartamentos in Mexico ask up to 70 % annual interest on their loan. This may seem like usury, but one unavoidable complication with micro-credits is that the cost of managing loans is not proportional to the size of the loan; small loans are relatively much more costly in comparison to the size of the loan. This supported the conventional wisdom that when people live under a certain threshold of poverty, they were decoupled from the world of financial support. Lenders either have to pay a cost to lend their money or charge a high interest.

A discovery made with the Grameen experience is that small loans can generate large returns. For some borrowers, small loans are enough to allow them to start a small business lucrative enough to allow them to pay such a high interest. But with the financial reality that the for-profit MFIs must charge high interest, there are many more unsuccessful outcomes. What kind of business can transform a loan of $50 into a business generating that money in real time? Generally, successful loans involved simple business models such as small sewing shops or restaurants. If these examples were the rule, as some noticed, microcredits would be a mechanism whereby 70 % or 80 % of what richer people lend to poor people would be transferred back to the richer people.

Some characterize microfinance as a way to extract wealth from the work of the poor for the benefit of the wealthy. Each individual MFI may contribute a small sum, but when there are millions of borrowers, the total amount becomes significant. In fact many MFI's like Compartamentos in Mexico are for-profit institutions. However, this idea has its pitfalls; more often than not the borrower has difficulty to generate returns as high as 70–80 %. To avoid negative outcomes, loans are not automatic. They are accompanied by reviews and sometimes business advice. Furthermore, there are unscrupulous lenders from which other lenders have to protect the borrowers, sometimes by buying their debt. All this adds further to the cost of each loan to the lender. This is only the first layer of complication associated with micro-credits.

The idea that the universal goal of micro-credits is to fight poverty is not correct. While this may true in South Asia, in Africa, for example, it would be wrong to assume that microfinance targets poverty. The size of the loans are relatively high when compared to the average income in the country where the transaction is made and the recipients of the loans are not selected from amongst the poorest, but instead amongst people who can afford such loans. The idea of the loans is to catalyze some economic activity and so MFI's primarily invest in small businesses. In Africa, there are MFI's in most countries, but they are not distributed evenly. Ghana for example (which is a relatively economically successful country in Africa) has far more MFIs than most other African countries. Most MFIs try to create conditions for new small businesses. In a sense they complement what the World Bank (WB) does. By nature, the WB comes with relatively large investments or projects to "fight poverty" through stimulating economic development, in a top down approach. MFIs in Africa tend to operate with smaller and more focused investments, in a bottom up approach. An assumption would be that this focused approach is more cost- efficient, but there is little documented evidence to support this. In Africa, microcredit has had little to no impact on poverty in general and urban poverty, specifically. It may have an economic impact by generating some economic activity which otherwise would not occur, but the size of that effect is at best difficult to measure.

South Asia projects a different picture. South Asia (and in particular Bangladesh and India) has historically played a pioneering role in the recent new interest in micro-finance. It has seen an increase in MFI activity and has some of the best documented studies. South Asia has the largest number of MFI's but the average size of loans is small compared with regions such as Latin America, Eastern Europe and Africa. This can partially be attributed to the economic difference between these regions. Borrowers are typically the rural impoverished with individuals and sometimes local communities targeted. In the latter scenario, micro-credits are used to jumpstart a small scale local economy.

East Asia projects still a different picture. In socialist countries like Vietnam and China, the governments play a role in regulating and monitoring the activities of the privately owned MFI's and operating government run MFI's. In Vietnam, one government owned MFI controls almost 90 % of the microfinance activity. Its spectrum of loans and financial instruments is large and it tends to target a variety of communities: the rural impoverished and ethnic minorities in particular. MFIs can be construed as a policy tool for the government of Vietnam to address national problems like impoverished minorities, general poverty and "backwardness" in rural areas.

The Philippines is an interesting example in that the central government has been relatively hands-off to the microfinance industry compared to their proactive central bank: Bangko Sentral ng Pilippinas (BSP). The Philippines economy has been showing strong progress over the last few years and microfinance has surely played an important role. The Economic Intelligence Unit has ranked the Philippines as having the best microfinance regulatory environment for the last four years (2009–2012). Some examples of the strong points they indicate are a wide range of financial products offered (micro-credit, micro-insurance, etc.), computerized micro-banking, and the creation of a credit bureau known as Microfinance Data Sharing System which helps MFIs keep track of delinquent borrowers.

These ambiguities are present in Latin America, an area where there is considerable MFI activity. A majority of MFIs in the region operate for profit. MFIs tend to ask for a very high interest on their loans, even larger than what seems legitimate, resulting in MFI's in Latin America often being accused of abuse. Either the interest they charge is perceived as excessive or the financial instruments are designed in such a way that the borrowers (who tend to be poorly educated) do not understand its subtleties and do not realize that the conditions are not as fair as claimed. Despite the fact that MFI's tend to be regulated, some critics are openly asking whether it is ethical to allow MFI's to be for-profit institutions.

Microfinance is also present in Eastern Europe. The fact that it does not have the same visibility as microfinance in the rest of the world, should not hide the fact that this is also the area where the total amount loaned under the form of micro-credits is the largest in the world. The reason is that individual loans are significantly larger than is the case elsewhere, reflecting the difference of economic situation. In the case of Eastern Europe, microfinance has semblance of a provisional system helping nations which suffered 50 years of imposed communist regimes catch up to other European countries.

In some cases MFIs act as NGOs. They raise money outside of the targeted countries under the form of donations and grants which they use to support their operations. Kiva is a good example of this strategy. They accept donations from citizens of first-world countries and allow the benefactor to track the progress of their loan. They are given updates about the family they donated to and in theory, when the family repays their loan the money is added to the benefactor's "Kiva account", which they can use on a future loan.

Regulations vary between nations, and are often changing over time within a nation. In most cases, the regulations are meant to protect the borrowers. Typically, MFI's do not have the right to act as saving banks, because micro-financing is risky and MFI's can easily go bankrupt. On the other hand, savings are significantly safer in a bank than at home. However, poor people's savings are in general too small to be accepted by traditional banks causing some communities organizing themselves into groups where they put their savings together and manage them together.

18.3 A Glance at Urban Poverty

An increasing number of impoverished people is migrating to urban areas. Failing to confront urban poverty will have potentially dire consequences. According to some estimates (urban poverty, like micro- financ, is not an area with solid documented data), one third of urban residents in developing countries live in poverty. This problem is mostly a by-product of the fast urbanization in developing countries, i.e. countries which tend to have limited resources. A large percentage of the poor live in slums, and this is the root cause of many of their hardships.

The UN defines slums as urban areas lacking at least one of the following: adequate sanitation, durable housing, sufficient living space, access to safe and affordable water, and security of tenure. The consequence to living in slums is exposure to diseases, crime, and squalor [5].

There is an economic dimension: people living in slums have an income too low to allow them to live in better conditions, creating a poverty trap. This suggests that finding ways to improve their economic situation would go a long way to "solve" the problem of slums. There are many obstacles on the way of the economic integration of slum dwellers. Slum dwellers tend not to be competitive in the job market as their level of education and their skills are often low or inexistent, as slums tend to be located in unattractive areas not connected by public transportation to potential employers. Theoretically, microfinance could introduce some economic life, but it should be accompanied by measures seeking to accomplish what is apparently so difficult: improving the living conditions of those living in the slums.

Investing in education is a must, but the returns of such investments (which tend to be expensive) are only felt long term. Furthermore, for developing countries, improving education along with constructing modern infrastructure are priorities for the nation as a whole. It is difficult for any government to provide education for slum dwellers to the quality it would need to be to have a chance to be successful.

One can read in the report entitled "The Challenge of an Urban World" [1]: "In many metropolises the problems are so great and growing so rapidly that the task of achieving significant improvement in the urban fabric is truly daunting. Is there sufficient accumulated experience with successful programs that one can be confident that more resources can be effectively used?"

Looking at the speed at which urban poverty grows relative to the speed of the response, one can easily agree with the first half of the statement. The second half of the statement suggests that there may be room for hope if one can assume that there have been programs successful enough to inspire confidence that there are cost-efficient approaches to the problem. What are those success stories?

One set of measures proposed is "slum upgrading". Despite the fact that such an approach seems bound to meet insuperable difficulties, there are success stories. One example is in Indonesia (the Kampung Improvement Program) which spanned 14 years (1974–1988). Four million people distributed in several cities benefited greatly from a program targeting garbage collection, sanitation (water quality), health clinics and the like. The price tag for this effort was "between $28 and $118 per person". Therefore, the cost of the project was a few hundred million US dollars, which was paid by the World Bank. One can read this "success story" as evidence that if enough resources are invested in such projects, a difference can be made. But four million people is a small number compared to the total population needing that kind of help, which is in excess of one billion people. And the amount of money required to bring such projects to all the people in need is way beyond what the international community is prepared to invest. Similar programs are being run in other places (Nigeria, Mexico, etc . . .), yet the problem lies in the fact that in order to be sustainable these programs must produce results faster than the rate at which the poverty is growing.

Another strategy is prevention. That would mean that accommodations or basic infra-structures would have to be already built for the impoverished moving to urban areas. It does not seem that "slum prevention" has become a sizeable effort. Today the lifeline of slums is the upgrading through sanitation projects, sometimes large but mostly small projects, together with infra-structure improvements (some improvements can be made cost-efficiently if shrewdly designed).

18.4 Microfinance and Urban Poverty?

Slums are not the cause of poverty, but its consequence. In the “Bottom of the Pyramid” [4], Prahalad and Hart point to the fact that the poor living in bad conditions are potential efficient players in the economy. Given the opportunity, they could make contributions while improving their own economic conditions. The challenge is to find ways to give them economic opportunities. This is where microfinance could be beneficial. Microfinance through micro-credits is supposed to spur some economic life in communities plagued by poverty. Apart from some exceptions, most MFI activity has targeted rural poverty. It is also there that microfinance had its most notable successes. So, how can the rather heterogeneous world of micro-finance make a difference in the problem of urban poverty?

Slum communities need access to clean water, improved sanitation through latrines and sewers, better infrastructure, and educational opportunities. It is difficult to see how microfinance can play a direct role in solving these problems. Some MFIs do not limit their action to loans, with some providing support for education. These are referred to as humanitarian MFIs. They represent a subset of the large world of microfinance. This puts those MFI’s closer to the foundations which provide support for education for “underserved” communities. The real challenge with this approach to education is that the scale of those programs is dwarfed by the size of the problem they address. Their impact is at best marginal.

In other words, the impact of MFIs on the improvement of life in slums is somewhat problematic. Small loans to targeted individuals do not necessary have the potential to do much about addressing basic slum issues. MFIs are ill equipped to address problems associated with health, infrastructure, water quality, etc. The most promising contribution that MFI’s can make is providing business opportunities to slum dwellers. On that front microfinance has not been as visibly successful as with communities in rural areas. Several reasons can explain that. Most of the poverty is still in rural areas. Microfinance is still at an early stage in its learning curve, when it comes to urban poverty. Furthermore, microfinance operates at a small scale. Urban poverty needs to be addressed at a large scale. It is difficult to imagine how microfinance could scale up to that level successfully.

18.5 Can Multi-National Corporations (MNC) Make a Difference?

“The bottom of the pyramid” offers a different perspective on how to approach urban poverty [4]. The book starts with the observation that mankind can be divided in four groups building a pyramid. The top group consists of the 100 Million “richer people” (living with in excess of about $40,000 per year income), and three lower layers. The bottom layer (“Tier 4”) is made of more than half of mankind, many of whom live at less than $2 a day. In the words of the author: " According to World Bank projections, the population at the bottom of the pyramid could swell to more than six billion people over the next 40 years (that was in 2001), because the bulk of the world's population growth occurs there. Given its vast size, Tier 4 represents a multitrillion-dollar market."

The theme of the book is that the MNC's target only to the top of the pyramid, which represents a very small fraction of world population, and they should adjust their business model to target this untapped potential for economic opportunities.

At first this approach seems to take a different perspective from the ones discussed so far, potentially leading to a different system of recommendations. But to make his point the author cites the experience with Grameen Bank in Bangladesh. In other words, the recommendation seems to be for the MNC's to act as very large MFIs.

Having MFIs be part of MNCs instead of the smaller institutions could have its benefits. Instead of MFIs trying to make a living out of micro-credits and acting as a charity, this new kind of MFI's would become an interface between big business and the untapped economic opportunities represented by the vast number of impoverished people. Instead of operating through loans, MNCs could make vast investments, providing work and income to the poor and build a new economy.

As mentioned before, the economic impact of microfinance is difficult to detect because the overall amount of resources invested through micro credits is tiny relative to national economic activity. In the words of the author, this "billions of aspiring poor who [would] join the market economy for the first time [would provide] the companies with the resources and persistence to compete at the bottom of the world economic pyramid, the prospective rewards include growth, profits. [. . .] Furthermore, MNC investment at "the bottom of the pyramid" means lifting billions of people out of poverty and desperation, averting the social decay, political chaos, terrorism, and environmental meltdown that is certain to continue if the gap between rich and poor countries continues to widen" [4].

It seems that this route should be attractive to MNCs. But the suggestion was made a decade ago and it seems to have gained little traction since there is scant evidence that MNCs have shown interest in that kind of investment.

It is not too difficult to understand the reluctance of MNC's to become large scale MFI's. The experience with micro-credits has taught that one can underestimate the complexity of the world of poverty. Considering the cost and logistics of providing micro-credits, from the perspective of the lender, in practice each individual loan provides a small return. To have the potential to generate returns sizable enough for an MNC, a very large number of loans have to be given at any time. This level of economy of scale is unprecedented in the context of microfinance and difficult to imagine working. Furthermore, the same problems associated with urban poverty that limit the relevance of microfinance would apply to microcredits originating from MNCs.

Engaging in micro-finance is not the only way MNC's could engage the urban poor. As discussed before, they could consider another business model, following the so-called "social business model" promoted by Dr. Yunus. The idea is to make cheaper products customized to the need of the poor and more importantly, made by the poor. In this case, thanks to the MNC investment, not only are the poor employed, but they are also part of a market.

A priori, a model where business finds ways to tap into the huge market represented by the "aspiring poor", could make a real difference in the present socio-demographic world. This would follow the paradigm of business "for progress" instead of "for profit". In practice, there are major obstacles blocking the implementation of the new business paradigm mentioned above, such as the current, profitable, status quo MNCs operate in today. They use the energy of the "aspiring poor", not to develop a "social business", but as cheap labor to bolster their profit. MNCs, such as Nike have greatly increased their profits because of outsourcing unskilled labor to impoverished countries which have a much lower labor costs. As countries have developed economically, labor costs have necessarily risen. This was the case in South Korea and is currently happening in China. China used to be the hotbed of international outsourcing due to its relatively cheap labor costs, but because of China's recent economic growth Chinese companies have begun outsourcing to even cheaper countries such as Cambodia.

In other words, the sad truth is that judging by the current trends in the international market place it seems unlikely that MNCs would find in their interest to voluntarily absorb some short-term loss by investing in lifting the millions of poor people out of poverty for the long-term prospect of expanding their consumer base. MNCs often engage in smaller charity endeavors, but they are private businesses and they are not interested in solving large economic problems without large gains in return. Urban poverty is a case of market failure, i.e. governments' involvement seems necessary.

18.6 Urban Poverty: An Unsustainable Conundrum

It is not by choice that the people who migrate from rural areas to cities in search of better opportunities, often end up becoming slum dwellers. One wants to believe that many if not most of them would be quite responsive to any economic incentive. Unfortunately, the needed economic incentives are not forthcoming, and most slum dwellers have to settle for a long stay in the squalor of their environment. In the process they become part of the larger problem represented by a sector of the population not economically integrated, living in an environment lacking clean water and basic hygienic amenities, exposed to a plethora of diseases, infection and crime.

Microfinance, the only kind of activity whose stated goal is to fight poverty by providing access to financial services for the poor, can at best only marginally alleviate the problem. It cannot provide in any relevant scale the kind of investment in infrastructure and education that would be needed to make a difference. A program which spanned 14 years at a cost in several hundreds of millions of US dollars, the World Bank improved (but did not solve) the conditions of four million people in Indonesia. The size of the project was exceptional by its amount, but its impact was just a drop in the bucket. That approach should not be abandoned, but it cannot be seen as a long term solution.

Other private financial sources such as MNCs also lack incentives to direct their energy and resources to address this problem. Urban poverty is an example of market failure. Some programs have had better success then others than others in an attempt to fix urban poverty and. these programs should be emulated or improved further. But they add up to a small pile of anecdotal evidences that intelligence can breed some measure of cost-efficiency.

The solution, if there is one, will have to include governments, large scale national programs, and a lot of international support and imagination. What large companies are not interested in doing (investing in the human capital represented by the "aspiring poor"), they may find in their interests if conditions for such investments are different. For the time being it is safe to say that urban poverty is on an unsustainable path and action must be taken.

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Chapter 19
Infrastructure Modeling: Status and Applications

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Abstract Protecting the Nation's infrastructure from intentional attacks and natural disasters, including extreme weather events and climate change, is a major national security concern that has only become more critical since the terrorist attacks on September 11, 2001 (This chapter focuses on the work performed at LANL concerning the protection of the critical infrastructures of the United States (the 'Nation'); however the modeling concepts discussed here are generally applicable). Understanding potential weaknesses of infrastructure assets and how interdependencies across critical infrastructure affect their behavior is essential to predicting and mitigating single and cascading failures, as well as to planning for response and recovery and future infrastructure development. Modeling and simulation (M&S)

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is an indispensable part of characterizing this complex system of systems and anticipating its response to disruptions. With the advent of more sophisticated infrastructure M&S capabilities, the possible applications have expanded to include the security challenges faced by the U.S. military, which relies on sustainable energy resources and needs to address environmental challenges and husband its water resources. Another key area where infrastructure modeling can play a critical role is in addressing global warming concerns given changes in available technology, evolution of the energy mix toward renewable resources, and many other infrastructure-related factors.

Los Alamos National Laboratory (LANL), a U.S. Department of Energy research laboratory tasked with national and energy security concerns, is at the forefront in the development of sophisticated infrastructure M&S capabilities and provides timely analysis of natural and manmade challenges to the infrastructure. This chapter explores the use of infrastructure models by presenting a representative cross- section of the models developed at LANL and some of the analyses completed with them.

19.1 The Role of Infrastructure Modeling

The United States and, indeed all countries to some degree, rely heavily on infrastructure to generate and transmit energy, distribute water, maintain public health, support transportation, support financial transactions, and many other functions that societies rely on every day. Although modeling has been used for many years to help understand the behavior of these critical infrastructures, the development of infrastructure modeling capabilities accelerated considerably at LANL, as well as other national laboratories, universities, and elsewhere, after the terrorist attacks on the United States on September 11, 2001. A mere 6 weeks after the attacks, the USA Patriot Act passed by Congress recognized:

> This national effort requires extensive modeling and analytic capabilities for purposes of evaluating appropriate mechanisms to ensure the stability of these complex and interdependent systems, and to underpin policy recommendations, so as to achieve the continuous viability and adequate protection of the critical infrastructure of the Nation.[1]

Early on it was clear that, in addition to understanding the behavior of the individual infrastructure supporting critical functions in the society, understanding the dependencies and interdependencies of one infrastructure on other infrastructure is crucial to identifying additional vulnerabilities.[2] Infrastructure models that incorporate dynamics, dependencies, and interdependencies were quickly complemented

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[1] Section 1016 of Uniting and Strengthening America by Providing Appropriate Tools Required to Intercept and Obstruct Terrorism Act of 2001, Pub. L. No. 107–56, 115 Stat. 272.

[2] Interdependent infrastructure refers to the behavior of one infrastructure affecting one or more separate infrastructures (dependency) and the resulting behavior of the affected infrastructures feeding back and affecting the behavior of the original infrastructure.

with models of scenarios that could disrupt the behavior of infrastructure systems and affect the population that depends on them. These models also contribute to an increased understanding of the uncertainties that underlie the parameters characterizing infrastructure behavior.

These models and systems of models have been and continue to be used to prepare for and respond to manmade disruptions, such as terrorist attacks. Of equal, and often more immediate importance, are the use of these capabilities to prepare for, respond to, and recover from natural disruptions such as hurricanes, earthquakes, and pandemics, to name a few. For example, infrastructure modeling has been used many times over the last 10 years to assess potential impacts from the landfall of a hurricane, including likely areas of flooding, and lost electrical power. Stakeholders also use modeling result to assist in evacuation planning and to pre-position recovery supplies.

Other applications are emerging as well. For example, the Department of Defense (DOD) is concerned about the security challenges associated with the U.S. military's reliance on energy, particularly fossil fuels, at its installations, as well as the associated environmental impacts and water resources management.[3] This DOD focus on sustainability – the ability to operate its infrastructure into the future without significant degradation – can be greatly facilitated by applying the infrastructure modeling capabilities in use and being developed.

Another timely example for application of infrastructure modeling is in the area of global climate change research. For example, integrated assessment models (IAMs), used extensively to evaluate climate change scenarios, have historically focused on greenhouse gas emissions and their mitigation in the context of economic growth. Although current IAMs represent infrastructure, adding higher fidelity infrastructure simulation capabilities will allow a more detailed assessment of the impact of changing energy delivery technologies and energy mix as the energy infrastructure moves to more renewable sources over the next decades. Also, the research and analysis at LANL and elsewhere regarding the response of infrastructure to extreme weather events, such as hurricanes, can be readily applied to project outcomes from global climate change. Although the majority of applications in infrastructure protection have largely involved infrastructure behavior on relatively short timescales (seconds, minutes, hours, days up to several years), these models can be adapted to slowly evolving events, such as climate change, on existing and future infrastructure.

A nation's infrastructure represents a complex 'system of systems' of interacting infrastructure elements subject to a large set of possible natural and manmade events under substantial uncertainty. Modeling these interacting systems is complex. Many approaches, techniques, and methods have been developed to meet requirements for the great variety of needed applications. Although there are many approaches that could be used to describe the range of models, it is useful here to divide the models into system-level and asset-level models.

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[3] "Department of Defense Strategic Sustainability Performance Plan," Under Secretary for Defense for Acquisition, Technology and Logistics, FY 2011," July 11, 2011.

19.2 Infrastructure Model Review: System- and Asset-Level Modeling

This section discusses a broad sampling of the infrastructure models developed at LANL. This is a representative, but certainly not exhaustive, list of models for critical infrastructure protection tasks developed and in use at LANL as well as other national laboratories and universities. In any review of infrastructure models, there are many options for organizing the models by type. These options include the geographic scale of the models (urban, regional, national); the modeling techniques used (physics- based, agent-based, discrete event); and the infrastructure modeled (electric power, health care, transportation).

Component-level characterization is used to characterize the different models where the system-level models are distinguished from asset-level models. System-level models characterize the operation of an infrastructure in terms of the collective operational characteristics of all of the assets in the infrastructure system, while asset-level models characterize the behavior of each individual asset in the system. As an example, in the telecommunications infrastructure, the call behavior in a system-level representation is characterized in terms of the calls handled per unit time by the infrastructure, while an asset-level representation might track individual calls on the network. The questions analysts need to answer determine the type of component-level modeling used in an analysis, along with choices of geographic scale and modeling technique.

Table 19.1 lists a representative set of the models developed and in use at LANL. The models are listed in alphabetical order with a brief description of the model purpose provided. The table also characterizes the models in terms of their geographic scale, the model type, whether they are system- or asset-level models, and shows the geographic and timescales used by models.

Here, timescale refers to the fundamental time units that the model or simulation uses. Note that, in some cases, the table entries are not individual models but rather modeling environments where multiple models interact.

19.2.1 System-Level Infrastructure Modeling

As noted previously, system-level models represent infrastructure at a high level by characterizing the behavior of the infrastructure in terms of the behavior of all of the system's assets. This analysis does not generally represent spatial information or information about individual assets. However, the data requirements are relatively light and the models require less development and execution time than asset- level models.

Table 19.1 Representative sample of LANL infrastructure models

Model name	Purpose and use	Type of model	Geographical and timescales[a]
ActivitySim	Model of daily personal activities and travel. Used to evaluate behavior patterns and travel impacts during a crisis	Agent-based simulation population model	All geographic scales; timescales from seconds to hours or days
AGAVE (Applied Geospatial Analysis and Visualization Environment)	Integrates various data, analysis, simulation, visualization, and other software components in distributed and web-based applications. Used to aid in analyzing threats to infrastructure	Modeling and analysis environment, asset level	All scales
CIPDSS (Critical Infrastructure Protection Decision Support System)	System level model of 17 critical infrastructure and their interdependencies. Used to assess the impacts of a physical disruption on various infrastructure	Modeling and Analysis Environment, System level	Urban; minutes to hours
Complex Event Modeling & Simulation (CEMS)	Architecture to link models across and within infrastructure at various resolutions, scales, using various modeling approaches; quantifies interdependencies and cascading consequences.	Developmental architecture, can leverage asset and system level models	All scales
DamSim	Physics based flood inundation model to estimate impacts (e.g., flood risk areas) of dam and levee failure	Physics based, GIS-based, asset level	Regional; minutes to hours
Electric Power Restoration Analysis Model (RestoreSIM)	Model of infrastructure restoration after natural disasters. Used to determine the impact of network-level damage on electric power restoration	Geospatial cellular automata, asset level	Urban; hours to days
FastPOP/FastECON	Geospatial tools for high level estimates of economic impacts resulting from hazardous events such as hurricanes and floods	Geospatial	Urban, regional and national; hours to days to years
FastTrans	Road network transportation model. Used to study the implications of loss of infrastructure components in crisis management	Geospatial	Urban; minutes to hours to days

(continued)

Table 19.1 (continued)

Model name	Purpose and use	Type of model	Geographical and timescales^{a}
Fragility	Model damage to infrastructure components from several threats such as earthquakes and flooding	Physics-based geospatial, asset- level	Urban; hours to days
HCSim	Agent-based health care surge capacity model; models impacts to the health care system caused by incidents such as earthquakes and pandemics	Agent-based model, asset-level	Urban; minutes to hours to days
Infrastructure Consequence Flood Inundation Tool (ICFIT)	Physics based flood models, used to predict and characterize flood hazards following infrastructure failure	Physics based, GIS-based, asset level	Urban, regional; minutes to hours to days
Interdependency Environment for Infrastructure System Simulations (IEISS)	Framework for modeling, simulating, and analyzing multiple interdependent infrastructures. Used to study the effects of cascading failures from one infrastructure to another	Physics-based simulation of coupled networks, Asset level	Urban; minutes to hours
LogiSims	Integration of models for disaster planning and response, and for optimizing the use of available resources. Used for electric power restoration and potable water distribution for hurricane	Integrated software application suite GIS-based, asset level	All scales
SimCore	Framework used to study large-scale, high-resolution infrastructure systems at high spatial and temporal resolution	Discrete event simulation framework, asset level	Urban; minutes to hours
Water and Wastewater Infrastructure Environment	Models of the behavior of water systems (e.g., water distribution, wastewater, and water demand); estimates the impacts of water system asset failure and system resilience and response	Physics-based, GIS- based models, asset level	Urban and regional; hours to days
Water Infrastructure Simulation Environment (WISE)	Integrated framework for modeling interdependent water systems including distribution, sewer, storm water, and dams	Integration of physics based models GIS-based, asset level	Urban, regional; hours to days

[a] Timescales here refers to the fundamental time units that the model or simulation runs at; this is distinct from the timescale over which the model is allowed to evolve during the simulation that is driven by the timescale of the events that the infrastructures are responding to

System-level models are exemplified here by the Critical Infrastructure Protection Decision Support System (CIPDSS) models,[4] which afford high-level representations of all key infrastructures in a metropolitan area, along with other important features, such as population dynamics and the area's economy. The CIPDSS is a system-level risk assessment tool and analysis process that simultaneously represents all key critical infrastructure and resources in a single integrated framework. CIPDSS includes a decision-aiding process that combines multiple, nationally important objectives into measures useful for comparing strategies over a range of threat or incident likelihoods. A software tool developed for CIPDSS allows the user to build a model on the fly,[5] combining infrastructure, population, and economic models as well as choosing a scenario model to disrupt those infrastructure and populations. The tool automatically sets up key connections between the infrastructure models so they can communicate their status and affect the behavior of one another. In addition to making available models for all key infrastructures, the user can choose from scenarios involving a disease outbreak; chemical release; physical disruption, including dam break; and an airborne exposure. The system is designed to adapt if additional scenario or infrastructure models are included in the analysis.

Infrastructure and other features are represented at the system level – capacity, supply, demand, product, and information flows are relevant, rather than the state of individual assets. This level of modeling and simulation affords the simultaneous representation of all key infrastructure and their interdependencies, along with the effect of population dynamics and economics in a fast-running environment ideal for assessing a wide range of disruptions, infrastructure characteristics, planning and response, and mitigating actions and policies. Following is a brief description of a sampling of three of the available infrastructure models and one example of a scenario model.

19.2.2 CIPDSS Telecommunications Model

The information and telecommunications model handles wireline and wireless communications over public networks and the Internet, determines the availability of communications, implements network capacity limits and degradation, treats repair of the networks, including possible investments, and allows for priority use of the networks.[6]

Although facets of telecommunications are modeled at a relatively high level in this implementation (call volume and the availability of telecommunications services are modeled rather than individual calls), the phone calls and

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[4] Bush et al. [1].

[5] Bush et al. [2].

[6] O'Reilly et al. [3].

telecommunications systems are treated with the most detail as they are central to the telecommunications module and largely determine interdependencies with other infrastructure. The data network and broadcast networks are treated relatively simply, largely in terms of how they depend on telecommunications networks, the availability of power, and other infrastructure interdependencies.

The telecommunications networks are allowed to undergo degradation and repair. For voice communications, the wireless network's condition depends in part on the condition of the Public Switched Telephone Network. The condition of the two networks determines the system capacity which, when combined with the demand on the system, determines the availability of telecommunications.

Demand includes a daily variation and long-distance demand from the national model as well as possible call volume overloads due to events.[7]

The modeling team worked in partnership with domain experts at Lucent Technologies and the National Communications System (NCS) to make the models as representative as possible while keeping them relatively simple. In particular, Lucent has built a detailed model of the switching network infrastructure in large metropolitan areas and a simulation of the network traffic load under normal conditions as well as with network failures and overload traffic patterns. The output of these Lucent models is used as a guide to the desired high-level behavior of the telecom module.[8] Simple models of the NCS priority communication systems, Government Emergency Telecommunications Service (GETS) and Wireless Priority System (WPS), are included in the telecommunications module.

19.2.3 CIPDSS Water Supply and Distribution Model

The primary requirements for the metropolitan water supply and distribution model are to consume water and power supplied by the metropolitan model, treat and distribute potable water to consumers, determine water availability to customers and other infrastructure systems, estimate shortfalls to consumers due to damage, implement water rationing and emergency water supply, respect water supply and distribution limits, and track sewage flow.[9]

Conceptually, the water model tracks a balance between water supply and demand. Water supply is divided into rivers, reservoirs, groundwater, and other sources, which can be scaled based on national averages or data available for a particular metropolitan area of interest. Water supply may also be enhanced by outside sources such as water tankers and bottled water deliveries. Portions of the source water in general will be treated, while the remainder is directly available for storage and consumption. The latter process is dependent on a distribution system

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[7] LeClaire [4].

[8] Conrad et al. [5].

[9] LeClaire [6].

that may be damaged (and repaired) in some circumstances and may depend on the availability of electricity for pumping. For that portion of source water that requires treatment, the process must include functional treatment systems and electricity availability.[10]

The end-user diurnal demand profiles are estimated and used to distribute the amount of water demanded by residential, commercial, industrial, agriculture, essential services (such as public health), and other end users on a fractional scale of 0–1 over a 24-h period. These nominal end user demand profiles can be altered in several ways. For example, a policy signal from the government model that encourages water conservation could be added to the model to reduce the amount of stored water demand. Additional demand can be satisfied if investments have been made in onsite storage for firefighting or other purposes.

Sewage transport, holding, and treatment are also handled in the water model, based on the water consumption rates in the main model. Two optional extension models are also available for the water infrastructure. A water demand model estimates the effects of hoarding and latent demand. Another extension model, not used for the physical disruption scenario, models the effects of water contamination.

19.2.4 CIPDSS Infectious Disease Model

The infectious disease model is a modified susceptible-exposed-infected-recovered (SEIR) model[11] that uses an extended set of disease stages; demographic groupings; an integrated model for vaccination, antiviral prophylaxis and treatment, quarantine, and isolation; and demographic and stage-dependent behavior. As a variant on the SEIR model paradigm, this implementation represents the populations as homogeneous and well mixed, with exponentially distributed residence times in each stage. However, the use of additional stages and demographic groupings adds heterogeneity where it is useful in capturing key differences between subpopulations for disease spread and response.

The disease stages are represented generically so that the model can be used for a number of infectious agents by adjusting the input parameters appropriately. Responders are treated separately in order to model different levels of disease exposure compared to the general population and to model policies regarding access to vaccines, antivirals, and other prophylactic measures. The model is general enough to respond to a range of diseases that may originate from a terrorist event, naturally occurring pandemic, or climate change-driven disease vectors.[12]

In the model, government response in the form of quarantine and vaccination programs is initiated after recognition of the first cases in the public health system or

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[10] LeClaire et al. [7].

[11] Murray [8].

[12] Fair et al. [9].

by direct detection, if available. Once the disease is detected, appropriate mitigation measures are employed. The model represents the mitigation strategies under a variety of policy assumptions. Mitigation options include vaccines (delivered via targeted vaccination, mass vaccination, or a combination), antivirals (as prophylaxis prior to infection or treatment after infection), and isolation and quarantine. Vaccination can be biased toward particular subpopulations to model priority vaccinations of children or health care personnel. Allowances can be made for segments of the population who either refuse or cannot tolerate the vaccine as well as for a subset of the population that has some existing resistance to the disease due to previous outbreaks.

The model can handle two separate vaccines during a simulation: a pre-pandemic strain that is available early but is assumed less effective because it is not designed for the particular strain and a subsequent targeted (specifically designed for the disease strain), more effective vaccine available after a delay for production and distribution. This is a particularly relevant feature for a potential pandemic influenza outbreak that, in order to be human transmissible, will be different from the infectious agent for which current vaccines are designed.

Schools are not included in the generic infectious disease model, but school closing can be modeled by including age-group dependence for contact rates, which allows age-dependent control of the transmission and infection of school-age children.[13] The model also responds to investments in better hospital care, isolation, and antiviral treatments, which can affect fatality and recovery rates in the population. The model tracks the state of the population in terms of immunity, health status, unavailability (sick and/or in quarantine), and fatalities. Unavailability and fatalities are passed to the population and infrastructure models, where their effects can then feed back into the infection model. For example, illness and fatalities can lead to reductions in health care staff, which can raise fatality rates in the infection model due to poorer and less timely care.

19.2.5 CIPDSS Public Health Model

The metropolitan public health infrastructure model encompasses multiple aspects of the public health infrastructure. In the model, analysts can alter death rates that result from stress on the system. Scenario afflictions are entered into the model from a scenario-driver model and the health care model adjusts to the added demand. Increased death rates for both normal and scenario afflictions based on the stress that the system is experiencing can be added to the model. The flow of patients through the model dynamically changes based on available capacity and dependencies. Mortuary services, physicians' offices, clinics, emergency medical services (EMS) in the field, emergency rooms, hospital inpatients, alternative hospital beds, home

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[13] Powell et al. [10].

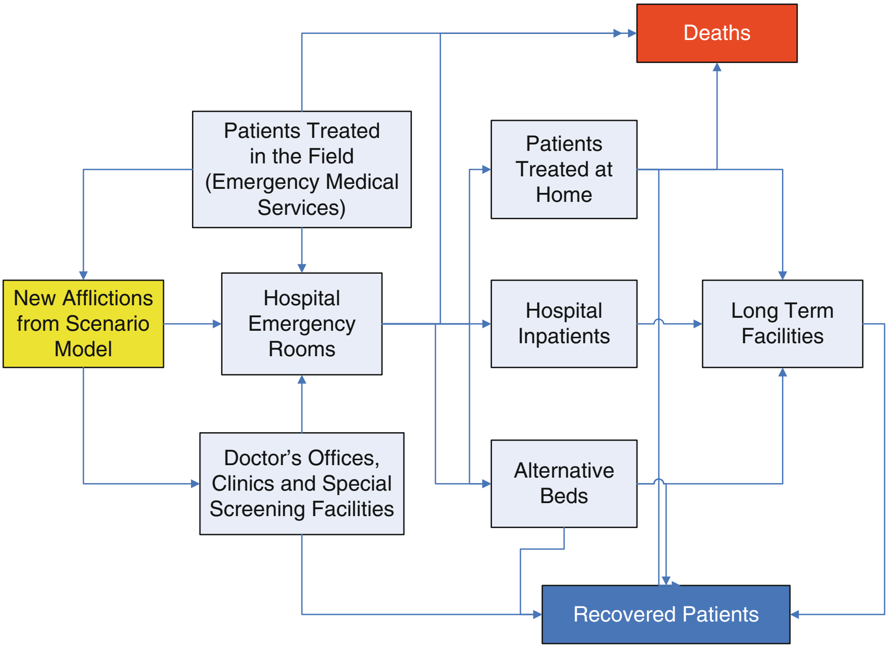

Fig. 19.1 Flow diagram of patients moving through the health care system

care, long term care, chronic patients, pharmaceuticals, and backup power are all included in the model.[14]

Patients enter the health care system at physicians' offices or from emergency treatment, either in the field by EMS or through emergency rooms. Patients then pass through other parts of the model after entering the system. Current capacity to demand ratios determine the rates of treatment, time for treatment, and the outcome of treatment. See Fig. 19.1 for a flow diagram of this process. Note that in this system level model of the healthcare infrastructure, the individual boxes in the figure represent average or total numbers (patients, deaths, emergency rooms) rather than the persons (patients) or individual assets (beds) that would be described in an asset level model.

The model separates patients into different categories based on their illness, including normal illness, illness and injury due to specific events, and worried well patients. Normal afflictions represent the average non-scenario injuries and illnesses. The model uses parameters that represent the average length of stay, mortality, and other traits that characterize normal health care operations. Illnesses and injuries related to a scenario can be parameterized to represent either a wide array of different afflictions or different severity levels for the same type of affliction.

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[14] Klare and Powell [11].

One example of this is a chemical release event that injures people at different exposure levels, each with its own specific treatment pathway and parameters that characterize outcome.[15]

Worried well patients seek treatment but they are not actually injured or sick. These patients also command health care resources and potentially clog the system. The model is general enough to be applied to disparate scenarios, including severe weather events, response to a wide range of diseases, and physical disruptions.

This model has dynamic reactions to overloading, connects different sectors of health care, and was designed by an expert in both system dynamics and health care. The model has been adapted to be a metropolitan model and is integrated with a wide variety of CIPDSS infrastructure models.

19.2.6 Asset-Level Modeling

Asset-level models assess the influence of individual assets, activities, and actors, providing a much higher fidelity picture of infrastructure behavior. In contrast to the system-level models that describe the totality of assets in terms of their average or cumulative behavior and that benefit from using the same modeling technique for all of the infrastructure models, asset-level models are purposefully designed to take best advantage of the unique character of each infrastructure.

For some infrastructures where the most important feature is the movement and activities of people, such as healthcare (patients and caregivers) or emergency services (injured, emergency service personnel, ambulances) or in tracking a disease outbreak (infected, susceptible, deceased persons), then an agent based modeling approach is often preferred. Other infrastructures can best be described as a network of interconnected assets such as electric power (power plants on a transmission network with fuel supply and repair) or telecommunications (interconnected switching stations, cellular towers). In other cases a physics based model is preferred such as when describing the circumstances of a dam break where a two or three dimensional model of the physics of water flow over terrain is the preferred approach. For some infrastructures more than one alternative modeling approach may be of interest. In many cases a geospatial description of the location of people and assets as a function of time is a key feature of the model.

This high fidelity approach results in detailed and powerful models but also complicates the process of linking the models together to represent dependencies and interdependencies because the design of each individual infrastructure model can be quite different.

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[15] LeClaire et al. [12].

19.2.7 HCSim: Health Care Simulation Tool

LANL developed the Health care Simulation (HCSim) model to assess the potential effects of a mass casualty event on the health care and public health.[16] HCSim is an agent-based, hospital response- modeling framework that focuses on gauging the impact of mass casualties on hospital resources. An agent-based model simulates a system as a collection of autonomous entities. In HCSim, the agents are patients and hospitals. The model follows the activities of individual patients, caregivers and hospitals as a function of time in contrast to a system level model that describes the total or average flow of all patients and caregivers in the healthcare system.

HCSim uses data from the American Hospital Association Annual Survey Database, Homeland Security Infrastructure Protection Gold dataset, and the Dartmouth Atlas of Health Care to populate hospital information and service areas. Analysts can use HCSim to estimate bed and treatment supply and demand (e.g., direct effects on the health care system) for a major disaster, and the potential impacts to hospitals within the region if one hospital is disrupted (e.g., cascading impacts within the health care system). HCSim also accounts for potential delays associated with transportation disruptions.

The HCSim framework consists of several sub-models (e.g., agents) including hospital facilities, EMS, and transportation. The sub-models are interdependent, i.e., information from one sub-model feeds into other parts of the HCSim model. Under a defined incident scenario, HCSim uses a triage system to categorize the severity of patient injuries/exposure/illness. These patients are then input into the EMS and dispatched to the nearest hospital based on available resources (e.g., beds). The transportation sub-model is used to estimate the distance to the various hospitals and add delays (i.e., those cause by impassable roads) based on the incident. Once a patient arrives at a hospital, it is assigned to outpatient, regular, or critical care services based on injury severity. Patients progress through a series of stages, which can last from hours (for outpatient visits) to weeks (for critical patients) before being discharged. The three sub- models can be adapted to different types of incidents. Figure 19.2 shows a schematic representation of the HCSim architecture.

LANL has used HCSim to analyze the potential direct impacts on regional hospitals under an earthquake and subsequent tsunami scenario and also to examine an anthrax release scenario. HCSim captured realistic intricacies and interrelationships within the health care system for both scenarios. For example, understanding transportation delays can help inform planning activities to facilitate and expedite treatment of patients. Similarly, understanding capacity queues for hospitals and EMS can help anticipate resource and medical personnel shortages.

Emergency response planners at all levels of government and in the private sector can use HCSim analysis results to assess and plan for health care consequences that could result from a disaster or pandemic. HCSim can provide rapid turnaround analytical results, generally within 40 min for an initial crisis and 2 h for an ongoing

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[16] Ambrosiano et al. [13].

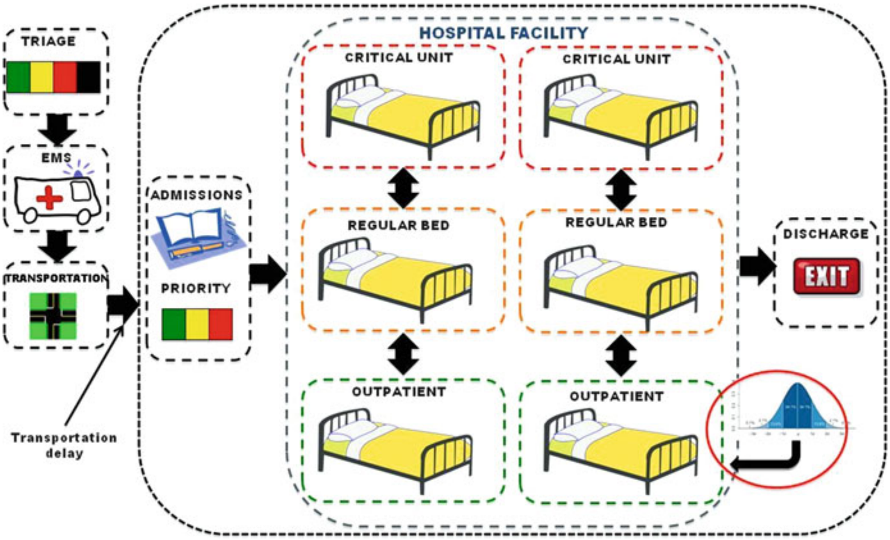

Fig. 19.2 Hospital facility sub-model with EMS and transportation modules. The *arrows* that connect the boxed groups represent movement of patients from one box to an adjacent one

crisis; however, detailed analyses may require more time. Analyses that require a series of scenarios for a previously defined incident may be provided within 2 weeks. A novel incident that has not been previously analyzed (e.g., an Ebola outbreak) will take about 2 months to complete. An incident that has not been previously studied will require some research and understanding of the hazard of interest and the development of disease/injury progression for the different scenarios. Longer-term studies can provide on the shelf references that can be used for preplanning and during a disaster.

The health care and public health infrastructure consists of many different components and depends on other infrastructure systems to function, including transportation for movement of patients and supplies during a disaster. LANL is integrating a wide range of medical facilities (e.g., improvised care facilities), explicit personnel requirements, medical supply chains, and disease transmission dynamics within medical facilities into HCSim to provide more comprehensive assessment of extreme events on the health care infrastructure.

19.2.8 ActivitySim: Human Behavior Modeling

ActivitySim is an agent-based model that generates a synthetic, statistically accurate population to represent people living in the United States.[17] The building blocks of

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[17] Galli et al. [14].

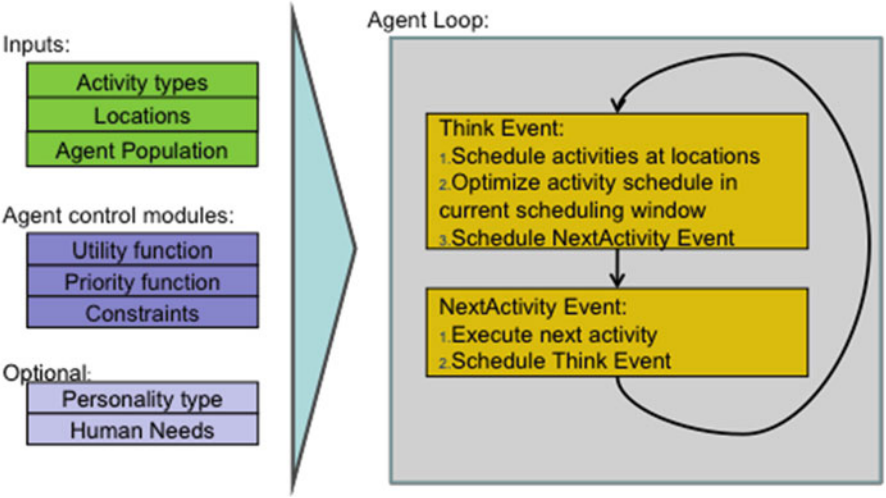

Fig. 19.3 ActivitySim building blocks

ActivitySim are illustrated in Fig. 19.3. In ActivitySim, each person is represented as an agent that plans its daily activities such as work, shopping, entertainment, etc., based on optimizing a utility function. ActivitySim's output is the activities that an agent performs including location and time of those activities. Each agent in ActivitySim plans its future schedule and execution of the next activity through a planning algorithm controlled by utility functions, priority functions, and other constraints. Optionally, personality types can be taken into account to generate different behavior, particularly in emergency scenarios.

The capability to model human behavior can also be manifested as demand for services, including infrastructure services. For example, in a climate change scenario, expected changes in water and electricity consumption as a result of behavioral changes can be modeled.

19.2.9 RestroreSIM: Electric Power Restoration Analysis Model

LANL uses its RestoreSIM electric restoration analysis model to assess the impact of network-level damage on electric power restoration. RestoreSIM analyzes crew work rates and substation priorities, critical path activities, and time to restore. The model utilizes a cellular automata approach built on geospatial representations of electric substation service areas.

Using national–scale data coverage, RestoreSIM simulates electric utility work management practices for a variety of natural and manmade events. Service areas are initially modeled as contiguous polygons at "normal" status. During a damage event, service areas progress from “outaged” to “partially restored” to “fully restored.” The model incorporates constraints, such as priority scheduling of field crews, availability of spares, line switching and generator black-start options, travel time across damaged areas, and the extent of debris. RestoreSIM provides a variety of outputs such as charts of aggregate event (time to restoration); geospatial restoration sequences; tabular lists of critical facility impacts, and work crew assignments.

RestoreSIM has been routinely applied to a variety of real and hypothetical damage events. For example, the model was used to estimate electric restoration sequences for six hypothetical hurricane tracks affecting eastern and Gulf Coast cities. Analysts used RestoreSIM to identify key response options, such as Federal Emergency Management Agency pre-positioning of emergency electric generators, likely critical paths for emergency services, and long-term customer impacts due to extended electric outages. The model has also been used to estimate impacts resulting from a hypothetical cross-border electric outage event between Texas and Mexico, quantifying the amount of customer demand outaged and of substations potentially disrupted, as well as the time to restore power.

LANL has recently adapted the RestoreSIM capability for network restoration and expansion planning to water distribution networks. LANL is developing a suite of models to describe, simulate, and analyze water infrastructure, such as water distributions, supply, and waste. This capability will also be applied to flood events, such as severe rainfall, dam/levee failure, surge, and flood. This suite includes the ICFIT.

Infrastructure Consequence Flood Inundation Tool, the Water and Wastewater Infrastructure models and the Water Infrastructure Simulation Environment (WISE), an integrated software framework for analyzing interdependent water infrastructure.

19.2.10 Water and Wastewater Infrastructure Simulation Environment (WISE)

LANL developed the WISE suite of models and simulation capabilities for water and wastewater distribution systems. Based on open-source software (e.g., EPANET and SWMM, developed by the U.S. Environmental Protection Agency), LANL uses WISE to perform large-scale, high-resolution network analyses quickly. These models evaluate potential water system disruptions and identify system-critical components to determine system resilience and response. They are integrated with geospatial consequence tools and metrics.[18] By performing many simulations over a range of conditions, analysts can evaluate the relative importance of system-critical components using system performance (e.g., pressure drop, percent demand delivered) and evaluate potential economic disruptions and cascading impacts to other infrastructure based on metrics such as population within an estimated outage area.

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[18] McPherson and Burian [15].

ICFIT1D is a complete 1D open-channel network solver fully integrated within a geographic information system environment and also includes a suite of data preprocessing/model building tools to aide in fast- response analysis. ICFIT uses SWMM as the backbone to resolve flow rate and depths in a 1D network. The Army Corp of Engineer's HEC-RAS model has been also used to simulate 1D flow and may be used interchangeably with SWMM, depending on event type and scenario requirements. ICFIT1D is generally applicable when the flow of water is considered one-dimensional, such as in non-overflowing rivers or storm sewer networks.

ICFIT2D is a complete 2D free-surface hydraulic model based on the shallow water equations. This model, developed by LANL, is applicable to multi-dimensional overland flow. It utilizes commodity high-performance computational techniques, including shared-memory parallel computing and graphic processing unit computing, to overcome computational intensity limitations.

Both models have been extensively used in events of national and global importance to determine the spatio-temporal flood risk areas for many types of events, including dam and levee failure analyses, hurricane and tsunami storm surge, and rainfall and snowmelt events. Examples of previous LANL analyses include:

- Evaluated the impact of riverine flooding during the Mississippi River and Midwest flooding 2008, 2010, and 2011 to determine flood risk areas and assess socio-economic and health care impacts, as well as impacts to other infrastructure.
- Determined areas at risk of tsunami flooding within the United States after the 2010 Chile and 2011 Japan earthquakes. LANL used wave amplitude projections from NOAA to initiate a high- resolution coastal simulation of the Hawaiian Islands. Analysts used flood characteristics to assess critical infrastructure impacts.
- Provided flood risk areas for more than 50 high-hazard dams throughout the United States.
- Developed input parameters for health care simulation modeling to assess the impact of patient surge on hospitals in the Green River Valley, Washington, during a flood.

19.3 Fragility

In the nascent aftermath of an event, federal, state, and local governments and first responders must begin to mobilize a response and make decisions long before the impacts of an event are adequately described by on-scene measurements or first-hand accounts. Decision makers need to quickly know what to expect without a significant investment of labor or time and also be able to realistically characterize the impacts of potential hazard scenarios before an event to ensure that planning and training exercises are informed and realistic.

The fragility tool automates the infrastructure impact assessment process for a variety of hazards, performs the assessment rapidly for even very large events, and enforces a single defensible paradigm for impact assessment across multiple critical infrastructure systems.

The tool's graphical user interface and underlying architecture allows users to wire together graphical widgets to quickly and flexibly define the analyses. These widgets may pull hazards from local files or external web-services, pre- or post-process hazard and/or infrastructure data, analyze results, output the assessment in various file types, or send it to an awaiting Web service. With this approach, users can switch quickly from the assessment of one hazard to another. The application automatically down selects to the set of infrastructure components in the hazard area and determines which set of infrastructure fragility curves to use.

The underlying software development framework provides a flexible, extensible environment for incorporating new and emerging hazard types and their associated infrastructure fragilities by adding new widgets. Developers specify the format of the hazard data and populate the associated fragility database with an appropriate set of fragility curves to add a new hazard assessment capability. These fragility curves provide the hazard-specific information necessary to determine the likelihood of damage to a particular type of infrastructure component given the magnitude of the hazard at that component's location. The fragility curves for each hazard/infrastructure combination are held on the same database server as the infrastructure data.

Fragility can perform the impact assessment for an event encompassing 100,000 mile^2 and tens of thousands of infrastructure components (pulled from national databases containing hundreds of thousands of components) in a few tens of seconds on a laptop. Nationwide, critical infrastructure data and fragility curves are held in an independent, commercial-grade relational database.

19.4 Dependency and Interdependency

Choices made and actions taken for the protection of the Nation's critical infrastructure must be based on a thorough assessment of risks, appropriately accounting for the likelihood of threat, vulnerabilities, and uncertain consequences due to terrorist activities, natural disasters, and accidents. To represent complex interactions between critical infrastructures; understand their interdependencies; and allow necessary integration with scenario, population, and economic models, individual models are combined. This type of model coupling is essential to representing the interplay between the event represented by the scenario model, the population's response, and the outcomes and uncertainties within the interdependent infrastructure. There are integrated modeling approaches available for the system-level and asset-level modeling but the data required, model connection methods, execution time, capability for tracking uncertainty,and the cross-section of model types that can currently be linked is quite distinct for the two methods.

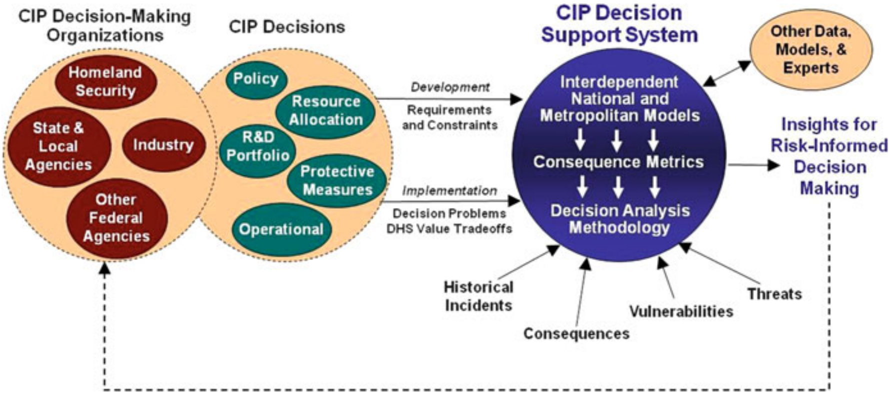

Fig. 19.4 Critical infrastructure protection decision support system

19.5 CIPDSS Modularity and Model Integration

CIPDSS models the primary interdependencies that link key critical infrastructure and resources together and calculates the impacts that cascade into this interdependent infrastructure and into the national economy. The CIPDSS project has conducted analysis on disruption of telecommunication services, a smallpox outbreak, pandemic influenza, H1N1 pandemic outbreak, industrial chemical accidents,[19] physical disruptions, cyber, insider, and natural disaster scenarios.[20]

The outputs of the consequence models are captured in a consequence database from which consequence metrics are convolved with decision-maker risk profiles and value tradeoffs. Multi-attribute utility functions are used to compare alternative infrastructure protection strategies and help build consensus among stakeholders.[21]

The consequence models simulate the dynamics of individual infrastructure and couple separate infrastructure through interdependencies. For example, to repair damage to the electric power grid requires transport to repair sites and delivery of parts, fuel for repair vehicles, telecom for problem diagnosis and coordination of repairs, and the availability of labor. The repair itself involves diagnosis, ordering parts, dispatching crews, and performing repairs. The electric power grid responds to the initial damage and to the completion of repairs with changes in its operating capacity. A flow chart of the CIPDSS system is shown in Fig. 19.4.

This decision model translates simulated fatalities, illnesses and injuries, economic costs, lost public confidence, and national security impacts into a single measure of merit for each mitigation measure, operational tactic, or policy option

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[19] Powell et al. [16].

[20] Powell et al. [17].

[21] Berscheid et al. [18].

considered by a decision maker. As new information becomes available and the view of the intelligence community evolves with respect to the near- and long-term capabilities and intentions of U.S. adversaries, a preferred course of action that minimizes overall risk can be selected from a growing set of threat case studies. In the realm of climate change, the evolution of threat information is analogous to the evolution of our understanding of the implications of climate change for infrastructure and populations.

A custom-built model linker called the "Conductor" is used to assemble a unified multi-system infrastructure model from individual files, each containing a single sector model. The linker identifies "shadow variables" present in models with dependencies on other sectors and resolves the references when the models are combined. This allows for the development and testing of models at the sector level, with analyses run at the multi-sector level using any combination of infrastructure systems as the questions being asked dictate.[22]

CIPDSS has demonstrated capability in estimating interdependent consequences from variants of several national planning scenarios, and has been used to assess alternative mitigation measures related to infectious diseases, hazardous chemical releases, disruptions in telecommunication, communicable animal diseases, physical destruction of critical assets leading to the loss of key resources, and natural disasters.[23]

The CIPDSS models are fast running and handle a wide range of infrastructure, behavior, and disruptions, making it an ideal foundation for developing simulators for a variety of applications. For example, the CIPDSS team has developed the Learning Environment Simulator (see Fig. 19.5), designed to engage decision makers at the grass-roots level (local/city/state) to deepen their understanding of an evolving crisis, enhance intuition, and allow them to test their own strategies for events before they occur.[24]

19.5.1 IEISS

The Interdependency Environment for Infrastructure Simulation Systems (IEISS) tool is a flexible and extendable modeling and simulation software environment designed to assist individuals in analyzing and understanding infrastructure interdependencies.[25] This integrated tool set allows users to simulate the behavior of physical infrastructure at the asset level (such as electric power, natural gas, telecommunications, etc.), and study the effects of cascading failures from one

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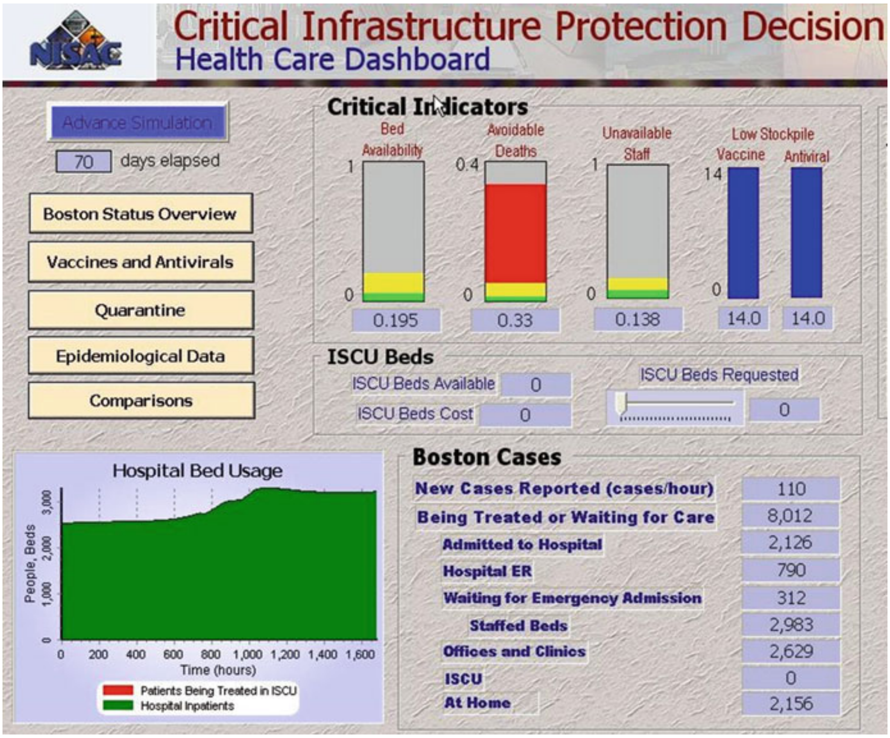
[22] LeClaire et al. [19].

[23] Powell et al. [20].

[24] LeClaire et al. [21].

[25] Unal [22].



70 days elapsed

Bed Availability	Avoidable Deaths	Unavailable Staff	Vaccine	Antiviral
0.195	0.33	0.138	14.0	14.0

ISCU Beds Available 0

ISCU Beds Cost 0

ISCU Beds Requested 0

New Cases Reported (cases/hour)	110
Being Treated or Waiting for Care	8,012
Admitted to Hospital	2,126
Hospital ER	790
Waiting for Emergency Admission	312
Staffed Beds	2,983
Offices and Clinics	2,629
ISCU	0
At Home	2,156

Fig. 19.5 Sample screen from the CIPDSS simulator

infrastructure to another. This simulation is used to study the complex, nonlinear, and emergent behaviors exemplified by complex systems.

The IEISS analysis tool models infrastructure networks (mostly energy transmission network systems, such as electric power systems and natural gas pipelines as shown in Fig. 19.6) and simulates their physical behavior, including the interdependencies between systems (such as when the energy supplied by one system is used to operate components of another system). Each physical, logical, or functional entity in the model has a variety of attributes and behaviors that mimic its real-world counterpart. IEISS is a flexible software framework available for the modeling, simulation, and analysis of interdependencies among critical energy infrastructure, allowing analysts to identify and deeply understand the implications of infrastructure interdependencies for normal operations as well as for disruptions, and providing analysts an unprecedented capability to assess, from an interdependencies perspective, the technical, economic, and national security implications.

IEISS utilizes a system-of-systems approach to provide a seamless and unified view of infrastructure. The IEISS contingency screening algorithms allow automated batch-mode searching for important initiating contingencies, i.e., loss of

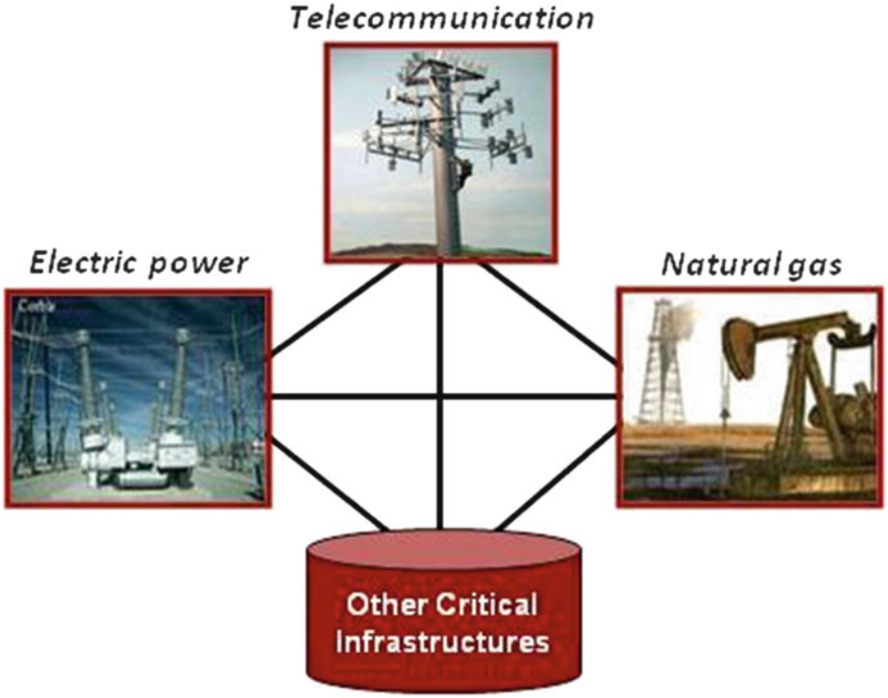


Fig. 19.6 IEISS links energy, telecommunications, and other infrastructure

system components. The algorithms are useful for studying robustness, criticality, and vulnerability in interdependent infrastructure and can be used for dynamic asset prioritization rankings.

The IEISS analysis tool has become a general, operational platform used to study energy interdependencies.[26] IEISS has been used to examine dependencies between electricity, natural gas, and petroleum fuels with respect to a hypothetical natural gas pipeline break. Analysts can accurately identify critical components and vulnerabilities in coupled infrastructure systems, assess how future investments in the systems might affect quality of service, evaluate the effect of policies, and aid in decision-making during crises. Additionally, IEISS is a research tool for investigating fundamental issues related to real- life, nonlinear, coupled, complex networks. The simulations can be used to visualize the interconnectivity between different systems, predict the outcome of incidents affecting the networks, measure the effects of disruptions in service, assess system robustness under varied future plans and forecasts, and identify components critical for the operation of the systems.[27]

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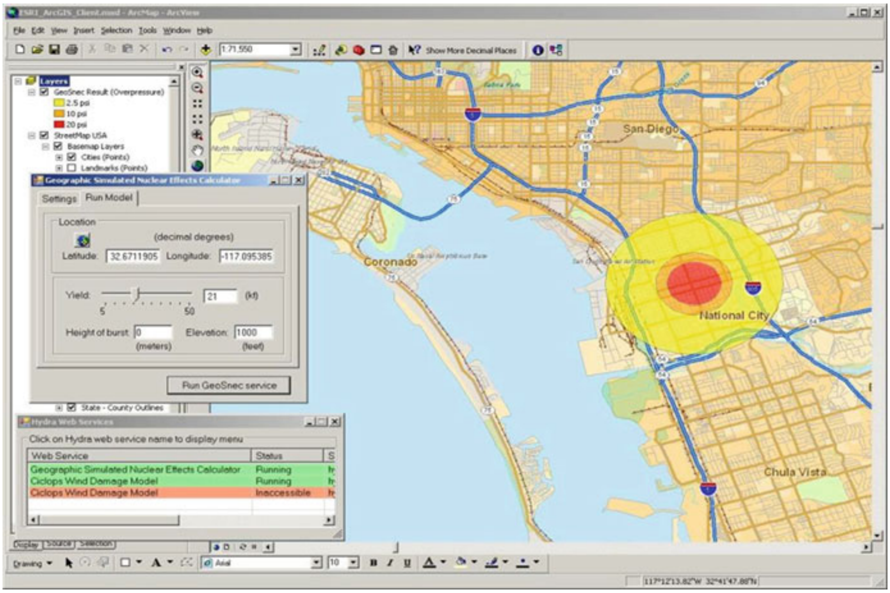
[26] Bent et al. [23].

[27] Bush et al. [24].



Latitude: 32.6711905 Longitude: -117.095385

Yield: 21 (kt)

Height of burst: 0 (meters) Elevation: 1000 (feet)

Web Service	Status
Geographic Simulated Nuclear Effects Calculator	Running
Ciclops Wind Damage Model	Running
Ciclops Wind Damage Model	Inaccessible

Fig. 19.7 ARCGIS application within AGAVE

19.5.2 Applied Geospatial Visualization Environment

The Applied Geospatial Analysis and Visualization Environment (AGAVE) is a Web-based, quick analysis tool for assessing potential impacts to infrastructure. The tool can quickly simulate incidents and analyze estimated impacts to gain a high-level understanding of the potential consequences of a situation in terms of affected population, infrastructure damage, and economic disruption. Providing infrastructure simulation software and data as reusable services enables custom applications that integrate many capabilities that were previously only available as stand-alone applications. AGAVE allows multiple applications to share information back and forth, facilitating interdependency analysis across multiple simulation packages. The AGAVE architecture provides a technique for integrating various data, analysis, simulation, visualization, and other software components in distributed and Web-based applications to aid in analyzing natural and manmade threats to U.S. infrastructure and possible responses. Providing infrastructure simulation software and data as reusable services enables the user to create custom applications that integrate many capabilities that were previously only available as stand-alone applications. AGAVE allows multiple applications to share information back and forth, facilitating interdependency analysis across multiple simulation packages. An example using an ARCGIS application with AGAVE services is shown in Fig. 19.7.

19.6 Uncertainty Quantification

Computer simulations often focus on producing the single best possible prediction, but vulnerability assessments and capital investment decisions often hinge on the full range and likelihood of possible outcomes, especially the occurrence of rare extreme events, rather than on a single prediction. This is the domain of *uncertainty quantification* (UQ), which encompasses a broad range of statistical techniques to produce probabilistic predictions that account for input and data uncertainties. UQ has direct application to critical infrastructure modeling and climate change.

Uncertainties contributing to model predictions include *parameter uncertainty*, *scenario* or *forcing uncertainty*, and *structural uncertainty*. Parameter uncertainty arises when the numerical values of settings within the model are unknown. Scenario or forcing uncertainty refers to exogenous processes or ‘driver data’ that determine model output but are not part of the model dynamics, such as initial and boundary conditions, meteorological data or forecasts, and socioeconomic variables and projections.

19.6.1 Sensitivity Analysis

Sensitivity analysis examines the sensitivity of the model response outputs to uncertainties in model inputs. It is used to determine which input uncertainties are most influential to model predictions and which inputs have negligible effect. This informs decision makers about which uncertainties are most important to characterize and reduce to achieve desired outcomes. *Local sensitivity analysis* examines the response of the model to small perturbations of inputs, and is typically a linearized, derivative-based approach. *Global sensitivity analysis* is an ensemble approach that quantifies the response of the model over a wide range or probability distribution of inputs, and is most useful for highly nonlinear systems. *Factor mapping* is an inverse technique used to determine the regions of input space that are responsible for an output behavior of interest. *Scenario discovery* is a clustering or classification technique that categorizes combinations of input settings that are predictive of specific types of outcomes. They are used, for example, in vulnerability assessments to identify combinations of inputs that may drive the system to failure modes, unstable dynamics, or other high-risk behavior.

19.6.2 Uncertainty Propogation

Uncertainty propagation quantifies how input uncertainties influence output or prediction uncertainties. A typical approach assumes probability distributions over the space of inputs, which are determined by measurement uncertainties, elicited from expert judgment, or assumed hypothetically. The input distribution is then sampled randomly (Monte Carlo simulation) or according to some efficient statistical design (e.g., stratified Latin hypercubes). The ensemble of model outputs in this sample approximates the propagated uncertainty in model predictions. Models or model subcomponents can be chained together to propagate overall uncertainties, treating the distribution of outputs from one model as the distribution of inputs to another. When experts disagree on the form of the input distributions and data are unavailable to determine them, a *prior sensitivity analysis* can be conducted to examine the sensitivity of the output distribution to choices of hypothetical input distributions.

19.7 Decision Making Under Uncertainty

Decision makers take a range of qualitative and quantitative approaches to representing uncertainty. Some may prefer to work with simple upper and lower bounds for outcomes, which, in a probabilistic framework, depend on the decision maker's risk tolerance. Others prefer to work with the prediction variance or higher order moments of the outcome distribution, while some prefer using the entire probability distribution.

Decision-making approaches under uncertainty similarly vary widely. Many decision problems involve a diverse group of stakeholders with differing value judgments, embedded within a socio-political context, in the presence of *deep uncertainty* (where experts do not agree on the level of uncertainty present). These problems are often better served with a qualitative decision approach, usually informed by sensitivity analysis than formalized calibration approaches, where different stakeholders can evaluate policy outcomes against their own judgments of uncertainty. This leads to a group of methods known as *robust decision making* (RDM), which lean heavily on scenario discovery and other methods to summarize key controls on the system outcomes in terms of a few transparent variables. The goal of RDM methods is to identify classes of risk mitigation policies that perform well over wide ranges of possible outcomes without committing too strongly to a particular characterization of uncertainty.

A competing, more formal approach favored in some economic and engineering settings is *cost-benefit analysis*, which is often formulated in terms of *expected utility maximization* (EUM). EUM is an optimization procedure based on a utility function that quantifies the value of a policy (benefits minus costs, possibly discounted over time) given a potential state of the world. An optimization algorithm finds the policy with greatest expected utility, averaging over uncertainties in the current and future system state. Recognizing that individuals may be averse to risk and ambiguity, modified approaches to EUM attempt to find an optimal policy subject to precautionary constraints, such as keeping the probability of some particularly undesirable outcome below a specified tolerance. Such approaches are known as *chance-constrained optimization*. When EUM is used in the presence of deep uncertainty, a prior sensitivity analysis should be constructed with respect to different expert assessments of uncertainty, bringing EUM closer to the robust decision-making approaches.

Sequential decision making occurs when policies can be revised over time in light of new information. Passive decision making is based on the current state of the system, without attempts at forecasting outcomes. Anticipatory decision making attempts to predict the future behavior of the system, but bases all decisions on the current level of uncertainty. Adaptive decision making, or decision making with learning, bases decisions not only on the current level of uncertainty, but on expected future reductions in uncertainty due to anticipated future data. Endogenous learning is adaptive decision making where what is learned in the future depends on decisions made in earlier time periods. Many sequential decision- making methods exist; in the EUM context, one approach is dynamic programming algorithms.

19.8 Example: UQ Infrastructure Modeling Application–Pandemic Influenza

Influenza pandemics occur relatively infrequently, with consequences ranging from mild to extreme. The challenge in predicting and planning for future pandemic events is rooted in the uncertainty of pandemic consequences.[28] To quantify the potential range of consequences of future pandemics, analysts applied well-established methods in uncertainty analysis. In modeling disease progression, model outcomes are determined by the inputs; the range of simulated outcomes is based on the range of inputs. The goal is to quantify the uncertainty of pandemic consequences conditioned on intervention strategies using probabilistic measures. The distribution of outcomes describes both the magnitude and relative likelihood of possible pandemic consequences. Due to a lack of consensus on the relative effectiveness of interventions and the attendant risks of unintended consequences, decision makers need to know the important driving parameters of a situation, as well as the range of potential consequences. A simulation- based uncertainty analysis uses repeated evaluations of a model with different combinations of key model parameters sampled from specified probability distributions to estimate not only the range of potential outcomes but the induced probability distribution of those outcomes, i.e., uncertainty propagation.

The assumed distributions of inputs were selected through subject matter expertise, policy maker review, and peer-reviewed publications. They provided a reasonable basis for evaluating breadth of outcome uncertainty via sampling from the assumed input distributions. LANL also identified key model parameters through sensitivity analysis, which determines how the outcomes vary with changes in the values of model parameters and preferentially focuses on inputs that measurably drive the greatest variation in outcomes. In the uncertainty analysis, the model inputs are limited to those parameters identified in sensitivity analysis as leading to the most variation in the outcomes, i.e., the important parameters.

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[28] Fair et al. [25].

The sensitivity and uncertainty analysis employed statistical experimental design methods to sample pandemic characteristics to simulate in order to obtain information that addressed the questions of interest, including evaluating statistical quantities and correlation in an efficient manner. The goal of the experimental design was to improve the understanding of the relationship between important inputs that drive variation in a pandemic and responses of interest, as well as to propagate the induced parametric uncertainty in the pandemic response due to assumed variability in the important inputs.

Orthogonal-array-based Latin hypercube sampling (LHS) is in common use for computer experiments. LHS, an improvement to random sampling, samples input parameters based on stratification of specified marginal distributions of the parameters.[29] This approach to designing and conducting a simulation experiment provides data that support both uncertainty analysis and sensitivity analysis. For the pandemic influenza sensitivity study, the experimental design was an orthogonal array-based LHS plan (strength three, allowing evaluation of main effects with reduced bias from two factor interactions), using 80 runs for each of the 24 mitigation scenarios and varying 40 input variables based on their input distributions for a total of 1,920 runs. The 24 mitigation scenarios were made up of six distinct vaccination strategies using different combinations of secondary strategies of social distancing (SD) and antiviral usage (AV). A sample result in the form of a box plot indicating the range of results for illnesses obtained in all of the runs is shown in Fig. 19.8.

For each combination of social distancing and antiviral usage (for example, noSDnoAV refers to the absence of social distancing and antiviral usage), results are shown for all six vaccination strategies. Each box plot indicates the range of results between the 25th and 75th percentiles by the extent of the gray bar. The median result is indicated by the black circle within each bar. The result is a convenient method to display the range of uncertainty obtained using a range of mitigation strategies and the set of variables treated as uncertain in the analysis. In this case, it is clear that the use of both social distancing and antiviral usage is most effective and that vaccination strategy 4 appears to be of most utility. However, other analyses in the study also showed that this strategy, particularly as it involves social distancing, can have significant economic impacts as workplace and school attendance patterns are disrupted.

19.9 The Future: Complex Events and Climate Change

Although a great deal of work has been completed at LANL and at other national laboratories and universities to address the many challenges associated with critical infrastructure modeling, there are still significant opportunities for improving the

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[29] McKay et al. [26].

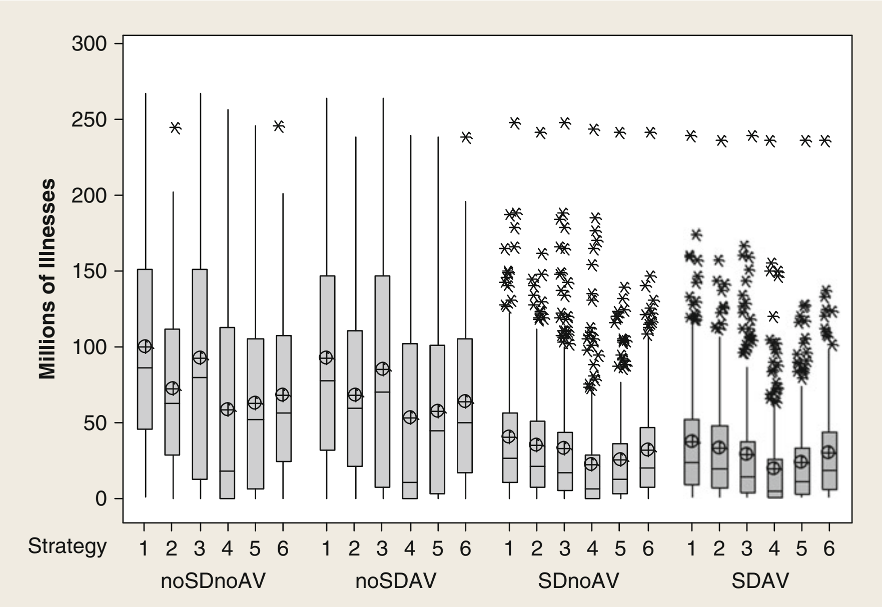

Fig. 19.8 Box plot with median, 25th percentile, 75th percentile, minimum and maximum values

models, modeling environments, and analysis processes and for applying these models to readily leverage the investments already made. There are promising new avenues for and further global climate change research.

19.9.1 Complex Event Modeling and Simulation (CEMS) Project

The Complex Event Modeling and Simulation (CEMS) project represents the next logical step in the evolution of critical infrastructure protection modeling tools and analysis development.[30] In recent years, LANL and other national laboratories have developed tools, provided analyses, and supported exercises involving single disruptions to the nation's critical infrastructure due to manmade and natural disasters. This work has generally focused on disruption events with infrastructure impacts and interdependencies at either a low level of detail over a broad set of infrastructures or a high level of detail for a few infrastructures.[31]

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[30] LeClaire et al. [27].

[31] LeClaire et al. [28].

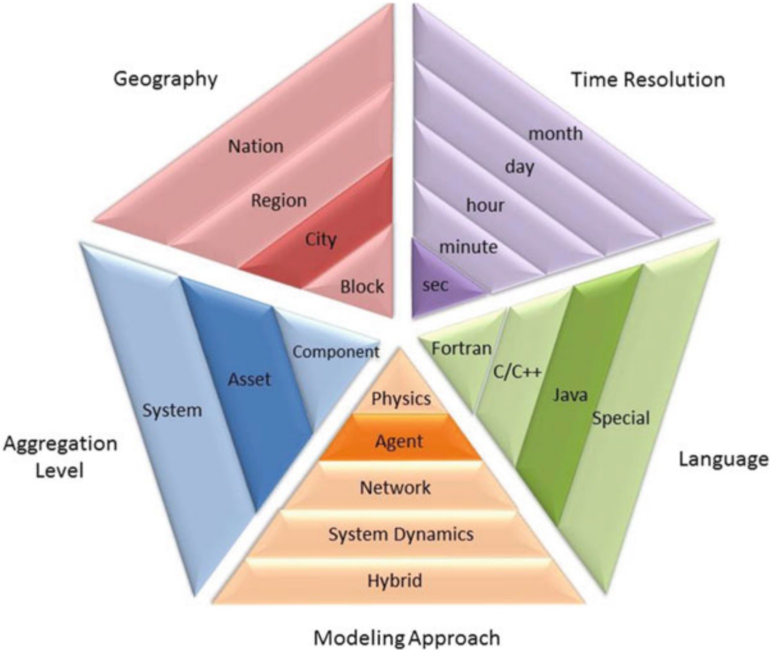

Fig. 19.9 Pictorial representation of the range of possible model attributes

However, comprehensive tools do not yet exist to handle complex disruptions that may result from multiple natural disasters, terrorist exploitation of a natural disaster, or simultaneous terrorist attacks against many infrastructures at multiple locations. Such circumstances may lead to complex and exaggerated disruptions due to a cascade of failures through many interdependent infrastructures in environments filled with uncertainty regarding infrastructure and population response.

A wide range of modeling approaches and languages are currently being used (generally tailored to the infrastructure, disruption and/or question being addressed). This fact and the proliferation of models in general, is a particular challenge if the models are to allow complex, interdependent relationships. This is illustrated in a notional representation of the range of attributes a given model may have, illustrated in Fig. 19.9. These attributes are generally chosen based on the particular infrastructure or disruption being modeled, available expertise, and other factors, often without regard to how they may be connected to other models and analysis tools. The attributes are divided into five categories in the figure – modeling approach, aggregation level, geography, time resolution, and model language–with a range of attributes possible in each category. The figure also illustrates that any particular infrastructure or other model will have its own combination of attributes, as illustrated in the figure by the darkened areas of each attribute. Thus, in the example of the figure, the model would be an agent-based model written in Java, using asset- level representations of infrastructure behavior capable of modeling activity throughout an urban area with a time resolution of seconds.[32]

Developing and using interoperable software architecture would address these variations in modeling methods and application, interdependency challenges, and the other elements requiring further attention. Using such an architecture, the developer, technology, data, language, and modeling approach of individual models (whether they are models of infrastructure, disruptions, population, economy, geography, etc.) can be divorced from one another and yet communicate together to form an integrated solution.[33] This affords flexible options for representing dependency, interdependency, and uncertainty and allows the incorporation of new or replacement models as capabilities and requirements change. Interoperability can leverage the work of the entire community of M&S practitioners and encourage the use of modeling approaches and languages that are most appropriate for addressing the unique aspects of the individual infrastructure or disruption. Interoperability can also reduce the time and cost associated with developing new solutions.

Seamlessly connecting one model to other models that may have very different sets of attributes is one of the challenges of achieving practical interoperability. This connection is a major goal of the CEMS development.[34]

The concept of the interoperability of technology can be very broadly defined as the ability of diverse systems and organizations to work together. This concept has been used in business and government for years. One notable example of this broader definition is the need to achieve interoperable communications among first responders, where the goal is to have the various communication technologies developed separately and used in various communities, government agencies, and first responder organizations to work together seamlessly in a crisis.[35] This is the same general concept of interoperability relevant for M&S, in that the goal is to have separate models with differing technology and pedigree work together seamlessly.

19.10 Global Climate Change Research

The research described here in infrastructure modeling and analysis could be applied to global climate change research to enhance IAMs and other models to project the onset and magnitude of sea rise, precipitation (flooding), temperature rise, and other subsequent energy-economic effects of climate change. This research could also be used to assess the impacts on all infrastructures once the effects of sea rise, increased severe weather activities, global temperature rise, and other effects occur.

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[32] LeClaire [29].

[33] LeClaire and Bent [30].

[34] LeClaire [31].

[35] Jenkins [32].

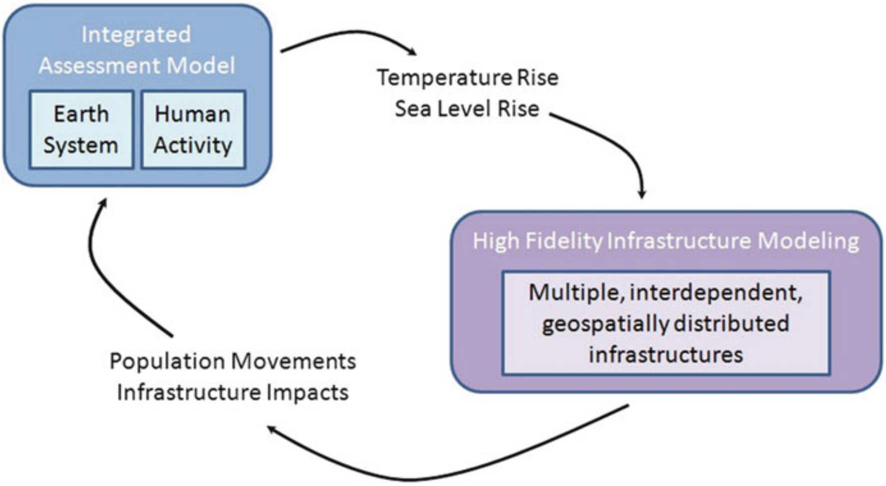

Fig. 19.10 Potential synergy between IAMs and infrastructure models

A notional diagram depicting how IAMs and infrastructure models could interact is shown in Fig. 19.10. The IAMs Earth system and human impacts to that system are modeled at a high level; they do not represent infrastructure or other systems at the asset level or contain any geospatial information, but they can project likely climate change impacts over extended time periods. In many cases, LANL's infrastructure models model individual infrastructure behavior with geospatial fidelity and their interactions with other infrastructure and populations under uncertainty. This provides information, for example, about what particular infrastructure assets may be affected by sea level rise, and which areas of a region will suffer significantly from increase average temperatures. This provides a high-fidelity picture of impacts to infrastructure, population, and economy that can be fed back into the IAM to improve its assessments of future outcomes.

19.10.1 Climate Change Influence from Infrastructure and Its Evolution

Analysts use IAMs to assess the onset of global climate change and the magnitude of its effects over time. Adding advanced infrastructure simulation capabilities allows an assessment of changing energy delivery technologies and energy mix as the energy infrastructure moves to more renewable sources over the next decades. It will also further assessments of dependent and interdependent relationships with many other infrastructures, such as transportation, public health, emergency services, and water. Changes in technology, energy mix, energy transmission, water usage, and other infrastructure-related factors will affect greenhouse gas emissions and other drivers of global warming. The experience with modeling interdependent infrastructure will also be of great value in global warming scenarios, where it will be critical to understand the interplay between, for example, the energy, water, and public health infrastructures.

19.11 Climate Change Impacts on Infrastructure

Once the effects of global climate change are in evidence, research and analysis into the response of infrastructure to extreme weather events can be readily applied to project outcomes from global climate change. These effects on infrastructure are potentially wide ranging and severe, and could involve many infrastructure elements simultaneously. Sea level and temperature rise and severe storm activity can displace and increase the burden on and demand for natural gas, electricity, dams, fuels, and other energy infrastructure. Infrastructure elements and populations may need to relocate, which could lead to energy interruptions and stresses on the transportation infrastructure as its components (roads, water, and rail) are interrupted and traffic demand shifts geographically. The water infrastructure can be impacted by increased demand from the energy infrastructure. Interruptions may very well extend into the public health, emergency services, and banking and finance. Even the assets, operations, and sustainability of national defense could be susceptible to these effects.

All of these potential effects take place under significant uncertainty with regard to the magnitude of the climate change effects and how those changes will displace and interrupt the operation of these interdependent infrastructure elements. Work in recent years at LANL on interruptions to dam operations and the physical disruption of water systems[36] has shown that considering uncertainty when assessing the impacts of disruptions on physical infrastructure is critical.

The long-term demographic shifts and changes in functioning infrastructure expected as a result of climate change are analogous to those experienced in the short-term response to a hurricane (population relocation and infrastructure losses). There has been some research in the area of the impact of climate change on infrastructure, including a recent study[37] that indicates the potential severe impacts of the effects of global climate change on these interdependent critical infrastructure and the important role that existing research on infrastructure behavior can play in protecting infrastructure.

LANL has provided numerous studies in recent years that exemplify the application of infrastructure models to extreme weather events. For example, a June 2010 study examined the infrastructure impacts of inundation events in the San Francisco Bay area, including several different levels (0-, 50- and 100-cm) of sea level rise based on mean sea level (msl) and a 100-year flooding event (on top

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[36] Water System Physical Disruption [33].

[37] US Department of Energy [34].

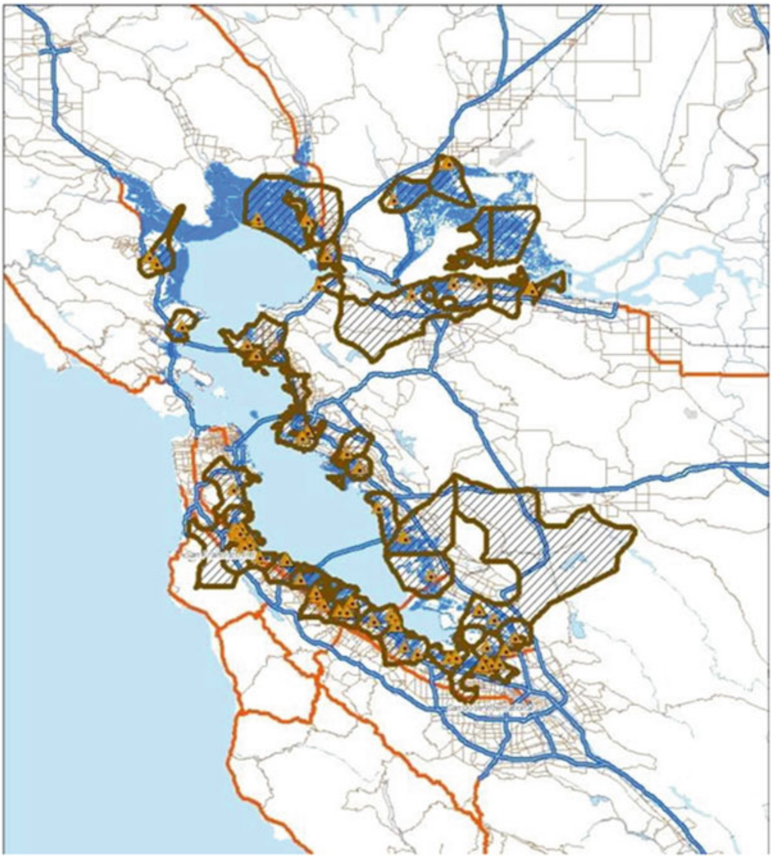

Fig. 19.11 EP Outage and inundation areas in the San Francisco Bay area

of the sea level rise). The analysis examined the impacts to the electric power infrastructure, including the outage area and any cascading impacts, using the IEISS tool. Population and economic impacts were also examined.

An example of the results is shown in Fig. 19.11, where the electric power outage and inundation areas are shown for a sea rise level of 100 cm. In the figure the brown hashed shapes are electric power outage areas and the blue shapes are areas of flood inundation. At msl, 20 electric substations are affected, largely on the southwest side of the bay. In contrast, for the 100-year flooding event shown in the figure, 128 substations are affected: the affects remain concentrated on the southwest side of the bay.

Los Alamos, in partnership with Sandia National Laboratory, has provided analysis of hurricane events both prior to landfall and post event.[38] An illustrative

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[38] Fernandez et al. [35].

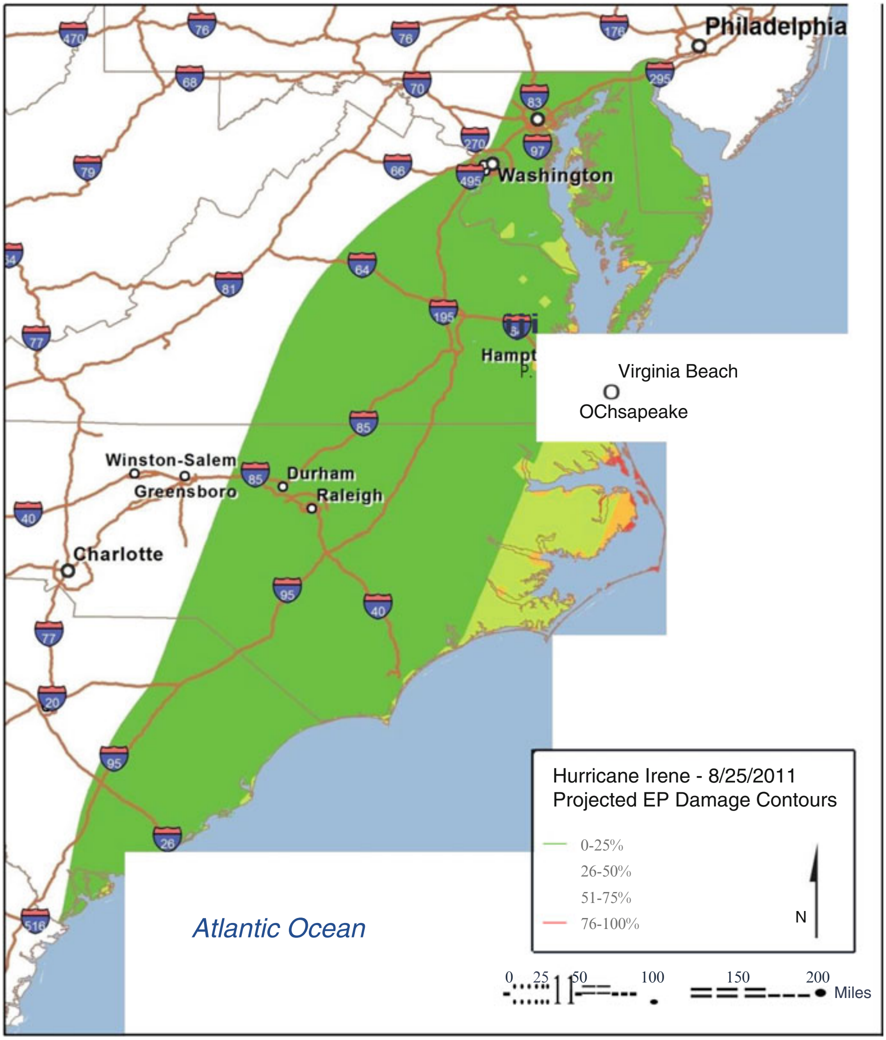

Fig. 19.12 EP damage contours predicted for Hurricane Irene (2011)

example is the work delivered a few days prior to landfall of Hurricane Irene as it moved toward the coast of North Carolina and Virginia in August 2011. The potential impacts from this hurricane on critical infrastructure were modeled for several key sectors located in the assumed storm track. Analysts used the National Hurricane Center's hurricane advisories as the basis for projected hurricane track and intensity. The most important issues were those faced after most major hurricanes: the rescue and treatment of people injured and stranded by the storm, distribution of basic services to the population (safe drinking water, food and shelter), restoration of normal infrastructure services and rebuilding structures.

Major issues include the evacuation of population living in the surge zone, power outages, and the impacts of power outage, storm surge, and debris on the functioning of local emergency services, road transportation, air transportation, water supply, wastewater treatment, and communications.

Estimates for electric power system damage were calculated based upon wind speeds, as well as estimates of damage to aboveground substations and transmission/distribution poles that occurred in historic storms. The results were then used to project the areas likely to experience power disruptions, along with the duration of the potential power outages.

Hurricane damage to the electric power system is usually due to wind (impacting low-voltage electric distribution components, and to a lesser degree transmission towers/lines) or water (assets that are flooded). Figure 19.12 illustrates estimated electric power outages anticipated for Hurricane Irene. Four outage zones are shown with the percentage of customers projected to be without power indicated by color codes. For example, yellow indicates that 25–50 % of the customers are projected to be without power in that region.

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