Introduction

Scientific Bonanzas

Infrastructures as Places of Knowledge Production

Eike-Christian Heine and Martin Meiske

Infrastructures are more than just technical artifacts or networks; "they are not things, but bundles of relationships."[1] This characteristic makes them treasure troves for historical studies about conflict and cooperation between human actors and the material world they inhabited and transformed. Politicians, planners, engineers, workers, local inhabitants, activists, farmers, and fishers not only compromised and quarreled with one another; they also cut trees, dug up the earth, inaugurated a piece of infrastructure, used, repaired, or even abandoned it. For historians, infrastructures thus open up good places for research. Here we can study the complex interactions of people with both the natural world—including flora and fauna, hydrology, or geological features—and the technologically made second nature, which has encompassed more and more aspects of modern history.

The main argument of this volume is that negotiation, promotion, and critique of the intersecting social, technical, and environmental dimensions of infrastructures have driven and intensified the production of knowledge since the late nineteenth century.[2] In the shadow of infrastructural assemblages, a growing variety of actors produced and mobilized knowledge in quantity and increasingly diverse forms. To characterize these relations of infrastructure and knowledge, we propose to speak of "scientific bonanzas." In the language of mining, a *bonanza* is a place where two mother lodes of precious metal meet, a situation of great opportunities in which enormous profits are made. While

the promises of Klondike resulted in wealth for some, a gold rush rarely came without disappointment and suffering for others. In our time, mining often continues to disrupt communities and destroy the local environment. While these intersections produce wealth and opportunity, they generally create distress and misfortune as well. Such ambivalence characterizes the junction of the two fundamental strands of modern history—infrastructure and knowledge—in our collection of essays.

From the beginning, we understood "scientific bonanzas" not with the precise English meaning of "(natural) scientific." Instead, we comprehend them as "scientifique" or "wissenschaftliche" bonanzas, encompassing all forms of academic knowledge. While such scientific knowledge undoubtedly gained growing importance beginning in the nineteenth century[3] and plays the most prominent role in our book, some of the case studies collected here urge us to consider other forms of knowledge.[4] These include the experiences of operators and users that shaped the evolution of infrastructures. The know-how of artisans and workers was what allowed—and still allows—their realization and functioning. Wear and tear and unexpected defects demand permanent repair and maintenance, while unforeseen environmental impacts call for explanation and mitigation.[5] Protesters have left their mark on the planning and realization (or not-realization) of infrastructures since the formation of the ecological movement in the 1970s. They have also established institutions for monitoring environmental impacts and producing critical knowledge.[6] So as not to reproduce affirmative narratives of progress—of which the growth of knowledge and the improvement of infrastructures were cornerstones—any inquiry of scientific bonanzas needs to ask: For which actors can we speak of a "bonanza"? For which can we not? For what purpose was the newly produced knowledge mobilized? We do not tell of the victory march of science and technology. We tell stories of ambivalent change.

Infrastructures as Cornerstones of Modern and Contemporary History

The growth of technical infrastructures in extent and importance is among the distinct aspects of modern history. They form a "second nature" through which modern men and women move naturally. However, access is not universal. It is often a function of class, race, or geographical location.[7] If infrastructures work, they are primarily unseen systems of supply and disposal. How much everyday lives depend on their functioning we can see and feel during disruptions, breakdowns, and catastrophes. With the advent of the second industrial revolution, the networks of railroads, steamships, and telegraphs continued to grow into a global system while new systems were rapidly being introduced. Public transport, telephone, gas, electricity, waterworks, and waste disposal formed what

Mikael Hård and Thomas Misa call an "urban machinery." These infrastructures had "profound interdependencies . . . with the multiple levels of urban life—*everyday-practical, institutional*, and *discursive*."[8] William Cronon made similar observations. He diagnosed a "merging of first and second nature" in the nineteenth century. In the wake of this change, the harvesting of resources on a worldwide scale and the transformation of landscapes through the introduction of marketable crops can be observed.[9]

Infrastructures were also highly symbolic and thus political. The transatlantic cables of the 1850s and 1860s or the Parisian metro at the 1900 World's Fair were emblems of progress and modernity. The completion of the US American transcontinental railroad in 1869, the Gotthard Tunnel in 1882, and the Kiel Canal in 1895 signified national power and unity. The Trans-Siberian railway and the Panama and Suez Canals represented early European and US American "phantasies, plans, and practices" of expanding imperial ambition as well as a means of making the empires economically and politically viable.[10] Beginning in the 1950s, infrastructure—the term now also encompassing hospitals, schools, and other "social infrastructures"—was generally considered the foundation of human development.[11] In expanding its scope and signifying a fundamental basis of modern life, the term had come a long way since the 1870s, when French engineers introduced it to denote the groundwork of a railroad.

Historians have researched various other aspects of infrastructures. They have explored its relations to technological development, environmental change, consumer culture, European integration, or political power in general.[12] We share the conviction that infrastructures have to be understood as cornerstones of modern and contemporary history. The topic that is missing from the debate, however, is knowledge. Our proposal to understand infrastructures as places of knowledge production is structured as follows: First, we propose a differentiation of the knowledge production that takes place alongside infrastructures. On the one hand, infrastructures can offer once-in-a-lifetime opportunities for scientists; on the other hand, the constant planning, promotion, operation, and maintenance of infrastructures calls for perpetual regimes or institutions. After arguing that knowledge along infrastructure was produced both by chance and in more permanent institutions, we set out to show that it is necessary to understand the *relation* of infrastructures to the "classical" places in which historians analyze the production of scientific knowledge, namely, the laboratory and the field. Indeed, researchers themselves have not understood infrastructures as places that shaped academic self-perception and professional identity as profoundly as the border between the lab and the field. Yet, for engineers, land planners, sociologists, and many other academic professions, the border never was as

important as it was, for example, within biology. Accordingly, we argue that the history of the (natural) sciences needs contextualization within the formation and rise of a much broader scope of academic knowledge. Infrastructures are ideal places for such an undertaking, as they were formative for the relations between technology, knowledge, nature, and society, and thus for modern and contemporary history. Finally, we propose a framework for the historicization of scientific bonanzas and identify three phases that span from the late nineteenth century until contemporary history.

Once-in-a-Lifetime Opportunities

The construction of infrastructures has repeatedly unearthed opportunities to explore objects and regions, which otherwise would have stayed beyond the reach of research. One of the rare historical studies that analyzes such a historical situation is Jeremy Vetter's book about field studies. His study is located in the US American West, mainly during the second half of the nineteenth century. Research "during the railroad era was produced through intertwined environmental and technological systems," he notes.[13] Similarly, infrastructures repeatedly provided prospects for scientific observations over brief periods. A prominent example is the construction of sea canals. The Panama Canal and Kiel Canal have resulted in deep cuts through the upper lithosphere that have given scientists a chance to observe a section of the earth's interior at their leisure. Another example is archaeology; today, most professional archaeologists are probably occupied with hurriedly securing and documenting sites to clear the way for dredgers and construction crews. Little wonder that some researchers understood infrastructures as "once-in-a-lifetime opportunities." A group of geologists identified the Panama Canal as an "extraordinary opportunity" for research when they first arrived in 1911 to accompany construction.[14] Things did not always go so well. During the construction of the Kiel Canal, a Swedish paleontologist had observed a rich collection of glacier flora. In hindsight, he complained that the works had not been halted for proper investigations: "Millions of leaf-remains, after being kept here for millennia, are now completely lost."[15]

The ambiguity of the intersection of infrastructure and knowledge is very obvious at places where the opportunities that infrastructures provided fundamentally altered or even destroyed the objects that were made accessible in the first place. The examples are manifold, and some are collected in this volume. Paul Sutter shows how the Panama Canal not only made a region accessible for researchers from the life sciences but also profoundly altered the flora and fauna of that place. The chance to study the rainforests of Panama was transformed into the opportunity—and in hindsight, maybe also into an obligation—to

witness the vast scope in which the technologies of modernity transformed nature. Valentina Roxo describes in her study how the growth of the Siberian oil industry was a bonanza for ethnographers in the Soviet Union, who discovered that they were not helping with the transformation of nomadic tribes into shining examples of communism. Instead, they recorded and mourned the loss of indigenous environmental knowledge and the destruction of once-proud cultures. Christian Kehrt shows how during the Cold War, research in the extreme environment of the poles relied on technological infrastructures and how—at the same time—these infrastructures threatened the environment, which was not only hazardous to the life of the researchers but also fundamentally fragile.

Infrastructures have also offered less ephemeral, much more solid, and lasting opportunities. As mentioned above, they often became icons of the nation, the welfare state, or an economically bright future. Emerging disciplines could harvest this symbolic resource and use it to secure public attention, social and political capital, and ultimately funding.[16] Infrastructures created spaces where knowledge was produced beyond already established disciplines. Martin Meiske discusses such an example in his paper when he traces the origins of engineering geology. A geologist employed at the Kiel Canal construction site in 1899 wrote about the potential of popularization for the young discipline: "A better time to arouse geological interest in the country than now may . . . not have been here before and might not come back soon."[17]

Johann Fülscher, the technical director of the construction of the Kiel Canal, later joined the ministry of public works in Berlin. He received at least a dozen medals from different German orders, clearly indicating the growing prestige of engineers in imperial Germany since the end of the nineteenth century.[18] As a discipline, engineering itself—at least to a certain extent—can be understood only through the close interaction with the nation, for which infrastructures were among the most visible symbols. In eighteenth-century France, infrastructures such as *allées*, canals, mines, and fortifications developed hand in hand with the state-sponsored institutionalization of knowledge.[19] In the United States, the construction site of the Erie Canal in the early nineteenth century produced vast amounts of practical knowledge and was also one of the seeds for the establishment of American civil engineering.[20] When the canal engineer Johann Fülscher became part of the Berlin ministry in 1906, it had not yet been ten years that students could earn their doctorate in civil engineering. Engineers had become "new national elites" of nation-states—and the construction of infrastructures had been vital during that process—that understood and used infrastructures as a political tool to produce knowledge and execute power over territories and people.[21]

Monitoring Natural and Social Environments

The corresponding large-scale landscape transformation plans of modernizing states resulted in the foundation of research institutes and administrative bodies that employed whole generations of students of emerging disciplines, like civil engineering, spatial planning, or melioration. For them, infrastructures became lifelong job opportunities in long-lasting institutions. Timm Schönfelder presents in his chapter a corresponding example from the Soviet Union. In the Kuban region, gigantic irrigation proposals of state planners met insufficient technologies on site. Institutions had sprung up that included those of concerned melioration experts who first predicted and then helplessly observed soil degradation. They voiced concern within the limits of the authoritarian state but failed to receive a response, as other interests ranked higher. This example reminds us that there are no shortcuts between knowledge production and political action. With high capital investment, symbolic implications, and many actors and interests involved, the stakes for planning, construction, and operation of infrastructures are high. Infrastructures tended to develop, in the words of Thomas P. Hughes, a "technological momentum.[22] This momentum gives historians the chance to observe boundary work among various actors from multiple disciplines.

One crucial reason why infrastructures tend to institutionalize know-how and knowledge production is that they "corrode, rust and crack; they are sabotaged and destroyed, they break down and they acquire accretions." Accordingly, the geographer Andrew Barry observes: "Infrastructure requires monitoring, repair and periodic updating."[23] In his essay "Rethinking Repair," Steven J. Jackson has similarly expressed his "deep wonder and appreciation for the ongoing activities by which stability (such as it is) is maintained, the subtle arts of repair by which rich and robust lives are sustained against the weight of centrifugal odds, and how sociotechnical forms and infrastructures, large and small, get not only broken but restored, one not-so-metaphoric brick at a time."[24] As permanent close monitoring is essential, the continuous presence of experts was necessary. It often led to permanent in situ positions, expert commissions, or even to the foundation of research stations.

A related example that is concerned with neither the natural sciences nor engineering is presented by Roy Kozlovsky and Neta Feniger. Their chapter focuses on the development and popularization of historical knowledge in the context of preserving historical sites from destruction by infrastructure and the subsequent political turbulent implementation of heritage laws. Accordingly, we argue that the spreading of institutions was often initiated by infrastructures and regularly resulted in perpetuating institutions. A majority of these were directed

at the stabilization of technological infrastructures in their socioenvirotechnical context.

Infrastructures not only spawned the institutions necessary for their maintenance but also encouraged the foundation of other permanent research institutions. Sutter presents one example collected in this volume, mentioned already above. When the Panama Canal was under construction, an extensive biological survey of the canal zone was conducted. Over time, research was perpetuated, and the field station on Barro Colorado Island that even today monitors the transformation of the Isthmian environment developed into one of the world's most important institutions for tropical ecological research—the Smithsonian Tropical Research Institute. More generally, anthropogenic intersections of geomorphological formations and the alteration or even destruction of regional natural equilibria by big infrastructure projects caused long-lasting adaption processes of society and nature.

Contextualizing infrastructures as places of knowledge production complicates existing spatial and temporal narratives. A classical topos of modernity is the experience of acceleration. When the first long railway tunnel through the Alps opened in 1871 at the Mont-Cenis between Savoy and Piedmont, and others, like the Gotthard Tunnel, were planned to be built soon, an Austrian newspaper emphasized that from now on "there are no Alps anymore."[25] In combination with the recently opened Suez Canal, travel from Great Britain to India was cut by several days through this newly opened transalpine railway line. Infrastructures have been at the center of this modern acceleration narrative.[26] For example, the cultural historian Wolfgang Schivelbusch argued that the ubiquity of railroad travel created a feeling of "abolition of space and time" among the contemporaries of the nineteenth century.[27] The contributions in our volume, however, paint a more nuanced picture that recognizes that "technology harbours manifold temporal dimensions."[28] Accordingly, we understand infrastructures as places where different spatial and temporal ideas flow together because they "not only extend spatially, but they are also enduring, as well as shifting and mutating over time," as Barry has noted.[29]

In other words, infrastructures not only *compress* but also almost necessarily widen and deepen the time and space of their historical analysis. In this volume, Eike-Christian Heine argues along similar lines that infrastructures and spatial planning did more than foster the physical and symbolic control of large territories. Nazism ideologically linked German motorways with the claim of reconciling a deep past and a faraway future. While archaeological findings along the construction sites were interpreted as proof of a millennia-old racial Germanic homogeneity and continuity, the motorways themselves became

symbols of technological progress and the chiliastic claim of the self-proclaimed Thousand-Year Reich. Martin Meiske shows in his essay that one of the main findings of geological research along the Panama Canal was indeed an expansion of spatial and temporal horizons. The analysis of the recurring immense landslides showed that their origins were horizontally and vertically much more far-reaching than engineers had been anticipating. It became clear that they would have to be monitored "indefinitely." Infrastructures can serve as a lens to uncover the historical evolution of the deepening of this entanglement between humans and the earth that the widely debated concept of the Anthropocene proposes.[30]

Placing Infrastructures in the Laboratory-Field Dichotomy

If infrastructures are indeed—as we claim in this book—cornerstones of modern and contemporary history, and if they are places characterized by an intensifying knowledge production since the late nineteenth century, is there anything specific about them? Or, more precisely, how do they relate to the spaces typically associated with knowledge production in modern history, namely the laboratory and the field?

Research in laboratories is often considered the "quintessential mode" of modern knowledge production.[31] Two characteristics of laboratories are generally identified. One defines the lab as "a distinction between an uncontrolled outside and a controlled inside"[32] and concerns the alleged "placelessness" of the knowledge produced here. This "significantly epistemological" consideration[33] does not necessarily contest that laboratories are tied to specific places and have a variety of material, social, and political connections to their historical surroundings.[34] Instead, this notion refers to the character of the knowledge produced, which is considered to be not specific to a particular place but universally applicable.[35] The second widely shared characteristic stresses its historical role. It refers to the laboratory as an educational space in which generations of modern men (and less frequently and much less visibly, women) were instructed in the virtues of the middle classes, the nation-state, and a bourgeois knowledge economy.[36]

Historians of science have studied the rise of laboratory research since the eighteenth century in its relation to field studies. Epistemologically, field sciences were initially considered to have produced knowledge about specific regions, like their flora, fauna, or geology. Through processes of "scaling up," field scientists have extended the territorial scale of their research so that it can include spaces "such as oceans and polar regions."[37] Of central importance is the notion that lab and field studies are in many disciplines interrelated to a point where an isolated understanding of one of the two is misleading.[38] For one example, archaeological, ethnographical, geological, or biological fieldwork is linked to institutions that

organize expeditions and later analyze, order, and conserve collected specimens. Laboratories, museums, universities, or similar "venues of experimental epistemology"[39] were prerequisites for field studies to produce meaningful knowledge and vice versa. Additionally, to such predominantly epistemological consideration, the relation between lab and field has been crucial in the historical development of professional identities and the shaping and stabilizing of academic disciplines.[40] Also, field research practices are tied intimately to both the origin of the researchers and the historical situation on the field.

Historical research has often been concerned with the question of how the significant themes of modernity defined field studies. Examples come from Europe, where ecological knowledge was tied to studying regional environments and developing political identities. The imperial context is central to all expeditions and long-term research projects in what Europeans thought of as the colonial realm.[41] Only a few field science historians have discussed the role of infrastructures in detail. Infrastructures so far are mainly introduced along the way as innovations in transportation or supply. Rarely have they been in the center of analysis. While we have seen fruitful approaches to merging environmental history with field science studies, amalgamations with infrastructure studies and the history of technology are still rare.[42] Vetter's work on the role of railroads in the American West, introduced above, is one of the notable exceptions. Our book takes a perspective similar to Vetter's, yet with a view on different infrastructures in various environments. We seek to identify characteristic relations between infrastructure and knowledge in modern history. Placing infrastructures in the lab-field dichotomy—if not as a third place, then at least as a hybrid site of knowledge production—needs a well-weighted historical analysis at the intersection of the history of science, technology, and the environment.[43]

How do infrastructures fit into this complex historical and epistemological debate? Studies about the laboratory, the field, and the border between the two rarely take the knowledge of engineers into account. Here lies our first argument, why infrastructures are places of knowledge production and need to be researched: they allow or maybe even urge us to study the formation of technical knowledge. The late nineteenth and the twentieth century saw the rise of engineers into the ranks of national elites. Accordingly, engineering needs to be understood alongside the (natural) sciences, and infrastructures offer ideal places for studying the concurrent processes in detail. Also, on-site work and a hands-on approach have shaped the professional identity of many engineers.[44] Thus, infrastructures are—in many ways comparable to the laboratory—educational places for engineering students, schools for growing into the engineering habitus, and the application of economically viable instrumental knowledge.

Our second argument is that a focus on knowledge and knowledge production is necessary because it allows the inclusion of different actors, which are central for infrastructures but have only recently been researched by the history of technology. These include failed innovations, the long persistence of infrastructures in the face of technological change, and the vital role of users, tinkerers, and maintainers. Christian Zumbrägel shows one corresponding example in which he illustrates David Edgerton's thesis of "the shock of the old."[45] He shows that water wheels are robust, easy to use, and repair, and that they, accompanied by proven technologies to regulate rivers, have formed a very persistent energy infrastructure. In some regions of Germany, they remained a vital source of industrial energy until late in the twentieth century. Zumbrägel argues that first engineers (who, especially in the twentieth century, had a tendency to favor large technical solutions and a focus on energy efficiency) and later successive historians have focused on the story of innovative technologies like turbines and iconic large dam projects. Additionally, our proposed focus of *bonanzas* allows us to compare such histories and corresponding historiographical debates in the history of technology to very similar arguments in the history of science. Here, the research practices in the laboratory and the "invisible hands" of assistants, mechanics, or engravers, or the vital role of "go-betweens" for expeditions and field research, have been emphasized.[46]

Our third argument, why infrastructures need to be considered in the ongoing debate about the history of field and laboratory, is connected with the fact that infrastructures have formed second natures in modern history. Robert Kohler and Jeremy Vetter recently published a survey of the development of studies about the field in the history of science. They show that "a widening range of disciplines" have come under historical scrutiny and include fields as diverse as natural history, geology, paleontology, anthropology, archaeology, ecology, oceanography, and climatology. The authors show that "expeditionary sciences" have "created vast infrastructures and landscapes of hybrid places that . . . are equally built and field environments." In these "border places," the mingled characteristics of the field are best studied.[47] The history of technology has likewise experienced an expansion from the analysis of technical dimensions of infrastructures to broader social and environmental processes, actors, and disciplines involved in planning, constructing, and maintaining large-scale engineering projects embedded in expanding complex socioenvironmental contexts.[48]

Yet, in the context of the historical relations between lab and field studies, infrastructures as second natures show something important: that it is not enough to just look at the (natural) sciences but that it is necessary to consider all academic disciplines. The last century saw the rise of many disciplines in

the shadow of infrastructures as assemblages of the social, technological, and environmental—for example, architecture or urban planning. This development encompasses many other fields of knowledge that analyze and model the impacts of infrastructures on cities or regions, like the social and political sciences or legal and managerial knowledge. The chapter in this book by Kozlovsky and Feniger explores the convoluted relations between historical knowledge, heritage laws, infrastructure projects, and political debates. Kozlovsky and Feniger show that the ties between infrastructures and knowledge are reciprocal: infrastructure projects funnel attention to historical sites while they, in turn, relate to changes of politically necessary knowledge. This argument about infrastructures as places where knowledge about the second nature is produced may offer the possibility to understand different forms of academic knowledge integrated into a larger historical horizon of scientific and technological modernity.

Changing Relations of Infrastructure and Knowledge

In this book, we assume that the relations between infrastructure and knowledge changed between the late nineteenth century and the beginning of the 1980s. We identify three phases characterized by structural shifts: In the large-scale infrastructure projects of high modernity,[49] scientists discovered construction sites as unique opportunities for research. This first phase of scientific bonanzas soon began to transform, when academic knowledge by and by became a constitutive part of the planning, building, and maintaining of infrastructures. We observe this second phase in liberal Western nations and their empires, but also in fascist and communist regimes. Toward the closing quarter of the twentieth century, the relation between knowledge and infrastructure changed again, when expertise was gradually produced and used to formulate and justify infrastructure projects and criticize and delegitimize them. In this third phase, very different relations between technological infrastructures and knowledge production emerged that are with us today, at least in liberal societies. It is characteristic of contemporary history that with the end of high modernity in the 1970s, "all orientation to a clear goal, a linear sequence of steps building up on the next and geared to a telos, a final end," was replaced with a more contradictory and contested outlook of the future.[50] How these conditions might fit into our understanding of contemporary history remains to be seen, especially the role of scientific bonanzas for phenomena such as the "great acceleration."[51] However, scientific bonanzas as a focus offers a necessary contribution from the histories of science, technology, and the environment to the ongoing debate about the Anthropocene. They shed light on central themes of this interdisciplinary discussion, especially on "questions about the role of techno-scientific systems of knowledge in relation to other bodies

of knowledge, the transformation of environments by human and nonhuman actors, and the breakdown of barriers between science, technology, and nature."[52]

Research as a Side Product of Construction

In the age of classical modernity, infrastructures often seem to have become scientific bonanzas by chance. In this volume, the first three chapters are concerned with such chance encounters that turned into extraordinary opportunities for research. Starting in the mid-nineteenth century, large-scale projects grew substantially in quantity, scale, and scope. As they reached out further and further into new environments, limits of controlling nature were slowly uncovered. Experts, often from emerging disciplines, were called to the sites to tackle the changes and challenges when infrastructures started to transform whole regions. In the shadow of railways, tunnels, and sea canals, pioneering surveys were conducted, and collaborative research initiatives were founded. They were often somewhat temporary but laid essential foundations for institutionalizations that occurred in later phases. Innovation rarely eradicated the old in one sweep. Older forms of knowledge persisted in new amalgamations or coexistence.

In chapter 1, Paul Sutter reconstructs how the Panama Canal helped to give rise to the discipline of tropical ecology. He investigates how the construction of the canal transformed the ideology of tropicality itself. In serving the instrumental—and decidedly imperialist—goals of the US Isthmian Canal Commission, a diverse group of scientists also produced scientific knowledge that challenged and complicated those goals. Sutter analyzes the medical challenges posed by the canal's construction and the role that entomologists and other scientists played in helping to meet those challenges. He also looks at the work of agronomic and soil scientists to understand the potential productivity of the Panamanian tropics. Sutter reconstructs the emerging sense, toward the end of the construction period, that the environmental transformations caused by canal construction themselves required scientific study. The result was a biological survey of the Canal Zone that, building on the early work of entomologists and other biomedical and life scientists in Panama, led to establishing a biological field station in the Canal Zone. It subsequently evolved into the Smithsonian Tropical Research Institute in 1946.

The construction of major sea canal projects, such as the Panama Canal, also provided geologists with unique opportunities to research cross-sections of large regions and to produce detailed geological tableaus, as Martin Meiske shows in chapter 2. Meiske traces back the arrival of the first permanent resident geologist at the construction site. Here the geologist encountered civil engineers, who produced geological knowledge as well. Meiske discusses the intensifying

collaboration between the experts of the two disciplines and describes one of its consequences—the formation of engineering geology. He reconstructs how geologists and institutions like the US Geological Survey used these large-scale construction projects to initiate geological research and traces back its impacts on broader geoscientific debates, such as on Charles Darwin's evolutionary theory and Alfred Wegener's continental drift theory. In his paper, Meiske takes the power dimensions of these geoscientific bonanzas into perspective and shows how geological knowledge was mobilized to serve expansive ambitions of rising empires and big private players of an extending global economy.

Infrastructures proved to be not only places where different disciplines coexisted and formed new interdisciplinary fields of knowledge. They were also places of conflict and cooperation between traditional crafts and academic engineers, as Christian Zumbrägel shows in chapter 3. For centuries, localized knowledge and everyday practices of the experienced millwrights' craft tradition (*Mühlenbaukunst*) shaped the construction and use of small-scale watermills with their hydraulic facilities. With the advent of hydroelectricity in the late nineteenth century, new professionals entered the stage. Based on their technoscientific expertise, hydroengineers replaced the majority of local millwrights and began to dominate the scientific discourse on hydraulic engineering. Zumbrägel argues that reading hydropower history through the lens of technoscientific expertise neglects significant regional differences and obscures the local uniqueness of environmental and technical expertise, which millwrights, technicians, or operators acquired over generations. Presenting findings from different waterscapes in the hilly valleys of western Germany, he sheds light on two often unrecognized dimensions: First, he reveals how attention to the owners of small water-driven factories in their daily operations helps us concentrate on the processes of knowledge production on a local level and in interaction with a dynamic set of site-specific socioeconomic and environmental features patterns, such as legal arrangements, hydrological regimes, or physical topographies. Secondly, he highlights that localized knowledge of the experienced millwrights' craft tradition remained rooted in everyday practices of energy usage and provided a constant background to individual operations at the outset of hydroelectricity and modern engineering. Talking about infrastructures as places of knowledge production reminds us to avoid affirmative narratives of modernization. It allows us to approach the topic from opposite angles: local expertise resulting from everyday practices and the bird's-eye view of hydroengineers. Zumbrägel combines these accounts of technological change and persistence under an envirotechnical framework. He discusses the practical and local aspects of riverine and hydraulic infrastructures, which were inextricably intertwined with the unique socionatural setting of each watershed.

Knowledge Production as a Formative Element of Infrastructure Projects

Toward the middle of the twentieth century, knowledge and expertise became of ever-growing importance for infrastructures. Many academic disciplines further strengthened and institutionalized their contribution to asserting and stabilizing large-scale projects. Four chapters in this volume analyze how knowledge became an essential and permanent part of the planning, construction, and management of infrastructures in fascist Europe and the Soviet Union. The Tennessee Valley Authority would be one corresponding example from the United States. Beginning in the 1930s, the government institution not only built up one of the world's largest engineering geology teams, it also developed divisions of chemical engineering, agricultural relations, and forestry relations that employed scientists from different disciplines.[53] As the wide-reaching impacts of large-scale engineering projects became visible, infrastructure planning developed more and more into a form of "integrated" or "organic" regional planning.[54] During this phase, infrastructures became more permanent scientific bonanzas than before. The chapters in this volume also show that there were no seamless translations from knowledge into practice. Nor do they absolve infrastructure and expertise from their political implications.

In chapter 4, Benjamin Brendel describes how, between 1920 and 1970, the construction sites of dams became important places for a global caste of engineers to exchange theoretical and practical knowledge. He also explores how a scientific character of dam building was displayed. As a result of such a scientific bonanza, dams became "successful machines." This notion is being questioned today by an antidam movement in the United States. However, by and large, it still thrives in other world regions that are trying to catch up in a dynamic global economy. Serious accidents involving high death tolls accompanied the development of these constructions around 1900. Such catastrophic consequences and the construction of dams all over the globe triggered the "scientification" and "professionalization" of dam building. By including the exchange between Francoist Spain and the United States and the interaction between Soviet and US engineers, Brendel shows that the distribution of dam-building knowledge was not only connected to one bloc during the Cold War. Through engineers' visits to dam sites, ideas were exchanged, and the image of dams as safe and successful buildings consistently reestablished. Laboratories were established on the construction sites. Here, dam builders experimented with materials and conducted shape tests on models. The results became a substantial part of the construction. The intersection of computer modeling and engineering science that evolved in the second half of the twentieth century further complicated the convoluted relations of lab and field in infrastructure construction.

Archaeological finds are still today made on building projects. During the Third Reich, the intersection of motorways construction and prehistoric archaeology was particularly productive, as Eike-Christian Heine shows in chapter 5. Here, the junction of infrastructure and knowledge constituted an "ideological bonanza" for Nazism. While *Autobahnen* were publicized as the symbol for the regime's stance toward mass motorization and modernity, meticulously documented and preserved archaeological findings became part of the Fascist propaganda about the millennia-old history of superior Germanic people. Heine's analysis of *Autobahnen* and archaeology during Nazism contributes to the "scientific bonanza" concept by pointing out that knowledge is a valuable analytical category but certainly not one that should be used affirmatively.

In chapter 6, Valentina Roxo tells the story of Soviet ethnologists whom Moscow sent out to support the construction of the West Siberian petroleum industry in the tundra. In this region, the state wished to claim the lands of the indigenous nomadic tribes of Khanty, Mansi, and Nenets for a giant industrial complex. Alongside engineers, geophysicists, and petrogeologists, the project sent ethnographers to study the potential of the local inhabitants to be transformed into sedentarized "proper Soviet citizens" capable of serving the petroleum infrastructure. West Siberian petroleum infrastructure as a place of economic activity for their subjects provided Soviet ethnographers of the 1960s with empirical evidence to challenge the absolute superiority of Soviet culture. These researchers criticized Moscow's sedentarization strategy, advocating the application of indigenous knowledge of how to work and live in the harsh West Siberian climate. Their scholarship on the inefficiency of Sovietization in the Tyumen North illuminated its Russocentric and unjust foundations, and even contradicted mainstream Soviet postulates. Thus, Roxo shows that working near the newly constructed sites of oil production turned out to be a scientific bonanza for the progressive school of Soviet ethnography.

Timm Schönfelder takes us to the Kuban River region in the North Caucasus in chapter 7. The area ranks among Russia's agriculturally most important areas, yet it is prone to disaster, as human-induced soil degradation threatens its sustainable productivity. Schönfelder's story begins in the mid-1930s, when Soviet experts started planning for the region's water supply and irrigation systems, promising triple crop production. Projects like this gave rise to a new class of engineers within the Soviet system: the meliorators. For them, the ever-expanding area under artificial irrigation proved to be a gold mine and a true scientific bonanza. To critically minded pedologists, on the other hand, the ensuing problems came as no surprise: long before the development of the irrigation system began, they had strongly advised the installation of drainage systems to

avoid waterlogging, which is known to cause salinization in the highly fertile black soil. The logic of quantity over quality in construction prevailed until the end of the Soviet Union, as the meliorators proposed the megalomaniacal "Project of the Century," the redirection of the North Russian and Siberian Rivers, to supply the Volga and the Kuban as well as the dying Aral Sea in Central Asia with ever more irrigation water. Schönfelder's chapter focuses on the intersection of hydroinfrastructures and the production of knowledge about irrigation and shows how the inner workings of the Soviet system hindered the implementation of critical scientific findings. He retraces the deepening rift between skeptical pedologists and pragmatically resolute engineers who were all hard-pressed to present simple solutions to the nation's problems with agricultural productivity.

Knowledge as Delegitimization of Infrastructure Projects

With the environmental age,[55] knowledge changed its relation to infrastructure once more: it became a tool that also allowed for delegitimizing infrastructures. A practice of counterexpertise developed that challenged established ways of assessing the impact of infrastructures.[56] Such developments seem especially formative in democratic and pluralistic societies, in which projects have been shaped in their design, or even prevented, by protests. In contrast, even if critical knowledge was produced in more autocratic regimes, it could not unfold as dynamic, and sometimes not at all. But case-to-case differentiation is vital in this perspective, as the growing literature shows, which complicates monolithic assumptions like the long-dominating "ecocide" thesis for the Soviet Union.[57]

In chapter 8, Vincent Lagendijk offers a conceptual approach to understanding how protest and knowledge shaped and continue to shape Europe's infrastructures from the postwar period up until today. He proposes to understand protests as part of system building and as scientific bonanzas in two distinct ways. On the one hand, he takes an analytical point of view. He urges seeing protest as an integral part of system building, not as its disruption. Understanding public participation in the coshaping of infrastructure like this allows for a better and more constructive understanding of infrastructures in society. His second point is concerned with a historical perspective. He sees such historical protests as a bonanza, because forms of local and regional knowledge—together with the understanding of the technical experts—are forged in the smithy of protest. The possible destruction or disruption of old land- and cityscapes often leads to a rediscovery and reappreciation of local culture. At the same time, Lagendijk argues for seeing protesters as system builders who redirect, reshape, and reconfigure the original system design. His chapter builds

upon several conceptual notions. For one, his chapter uses parts of Thomas Hughes's large technological systems (LTS) framework, most notably the idea of sociotechnical systems and the notion of system building. Lagendijk combines this with Sheila Jasanoff's concept of civic epistemology, which seeks to give credit to the agency of citizens in responding to science and technology to overcome the gap between top-down and bottom-up system building in LTS approaches.[58]

In chapter 9, Neta Feniger and Roy Kozlovsky examine specific moments in the history of the construction of the Ayalon Crosstown Expressway in Tel Aviv since the 1960s. They draw on the conceptual tools developed in actor network theory and on the notion of the detour by Albena Yaneva. Yaneva concentrates on the moments in which a course of action becomes unstable and reaches an impasse, and a new arrangement of forces and practices comes into being. With these methodological tools, Feniger and Kozlovsky show the detours, infrastructure, and knowledge formed in the encounter with three obstacles: a derelict building, an ancient tree, and a substandard bridge. Each case not only had its specific intersection of objects, subjects, and discourses but also was an opportunity for the production of knowledge through the transnational transfer of technical know-how. These detours uncover an ambivalent and, at times, comic relation between the complexities of a city and the much more straightforward infrastructural rationality.

With the rise of the ecological age in the 1970s and the 1980s, polar science was challenged by environmental knowledge about the consequences of human activity in extreme environments, as Christian Kehrt shows in the final chapter. The "conquest of the poles" during the Cold War required robust technology and global logistics. Modern infrastructures of air transport were of particular importance to supply research teams and stations over long distances and more extended periods. Kehrt takes a closer look at French polar technologies and asks why the perception of these vital infrastructures changed over the course of the 1980s. Kehrt argues that there is an environmental turning point in polar exploration. While there was no protest against high modern approaches to the poles from the 1950s to the 1970s, the 1980s brought change. Ornithologists and marine biologists started to research and assessed environmental impacts, degradations, and damage of polar infrastructure. Together with Greenpeace activists, these experts publicly acted against the French construction project of a major concrete landing strip in Terre Adélie. Penguins, other birds, and the fragility of Antarctica's nature suddenly came into play. These new actors ended the major construction project that turned into a white elephant. This failed French infrastructure project indicates a major shift in the perception

of the polar regions. It clearly shows that the idea of bonanzas depends on the perception and interests of the actors involved. While polar exploration and the construction of air transport facilities and research stations was meant to help conquer and control hostile environments, this close interrelation between science and technology was delegitimized in the early 1980s.