Spring 2019

Military applications of geological engineering

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MILITARY APPLICATIONS OF GEOLOGICAL ENGINEERING

by

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A DISSERTATION

Presented to the Faculty of the Graduate School of the

MISSOURI UNIVERSITY OF SCIENCE AND TECHNOLOGY

In Partial Fulfillment of the Requirements for the Degree

DOCTOR OF PHILOSOPHY

in

GEOLOGICAL ENGINEERING

2019

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PUBLICATION DISSERTATION OPTION

This dissertation consists of the following two articles, formatted in the style used by the Missouri University of Science and Technology:

Paper I: Pages 47-58 has been published in *2019 State and Future of GEOINT*.

Paper II: Pages 59-69 has been published in *2019 State and Future of GEOINT*.

Paper III: Pages 70-80 has been published in *The Engineer Bulletin*.

Paper IV: Pages 81-110 has been accepted by *The Military Engineer.*

Paper V: Pages 111-122 has been accepted by *The Military Engineer*.

Paper VI. Pages 123-131 has been invited by *Army Engineer*

Paper VII: Pages 132-136 has been accepted by *The Military Engineer*.

ABSTRACT

This work examines the premise that military engineering and geological engineering are intellectually paired and overlapped in practice to a significant extent. Geological engineering is an established, albeit young, academic discipline that enjoys wide industry and civil demand and is supported by many professional organizations. In contrast, military engineering is an ancient, empirically derived training or "OJT" program with practice-based trade-associations that has narrow government-only utility. The premise is formed by decades-long observation of U. S. Army military engineer officers completing a Master of Science degree in geological engineering as a complement to their practice-based training in military engineering at the "Captains Career Course" of the U.S. Army Engineer School.

Almost everywhere has some existing data on the local geology for civil purposes, yet these are ignored, not accessible or not translated to military purposes. A description of the intersection between military and geological engineering is followed by comparison the practice of the geological and military engineer. Research and intellectual development is projected to fill current gaps in military considerations by geological engineers. Finally, steps to share these concepts and convince military engineers to adopt and extend the geological underpinnings of their profession are outlined. This work serves both a personal and professional interest. Previous personal work at the intersection of military scholarship and engineering underlie this premise.

ACKNOWLEDGMENTS

I am deeply indebted to the counsel of Dr. Norbert Maerz who has long extended himself personally to practitioners of military engineering. His practical knowledge of geological engineering operations allowed for a clear comparison with military practicalities.

Dr. Henry Wiebe brought the discipline of engineering management to bear for the education of young U. S. Army engineer officers. Dr. Neil Anderson has guided many military engineers into the utility of geophysical methods for military operations and opened pathways for them to earn advanced degrees in geological engineering. Dr. J. David Rogers lifted the military practice of understanding history to practical levels for engineers highlighting the approaches used within military engineering to solve intense practical issues under even extreme environmental circumstances. Dr. Jeffery Cawlfield demonstrated patient tolerance in shaping the study curriculum and early coaching of many Army officers in conversion to warrior-scholars.

Having studied many military and engineering authors over the years, one that pushed consideration of the vital and strategic role of engineering was Colonel James Collins in his *Military Geography for Professionals and the Public*. His work helped me focus on the fundamental relationship between the geosciences and military/national purposes. Engineering aspects he described recognize that the military can manipulate the earth to strategic and tactical advantage.

Finally, I thank my adored wife Clara-Marie whose ‘Show Me’ approach pushed me forward academically.

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NOMENCLATURE

ACRONYM	Description
ACE	The American Council on Education
AEA	Army Engineer Association
AI	Artificial Intelligence
ANN	Artificial Neural Network
AOC	Area of Concentration for military officers
ASCE	American Society of Civil Engineers
B-hut	Barracks Hut
C2	Command, Conrol
CASCOM	United States Army Combined Arms Support Command
CCAF	Community College of the Air Force
CCM	Certified Construction Manager
CIC	Cambridge Innovation Center
CA/T	Central Artery and Tunnel
CBITEC	Contingency Basing Integration and Technology Evaluation Center
CBR	California Bearing Ratio
CENTCOM	US Central Command
COOL	Credentialing Opportutnities Online
CRO	Contingency Response Operation
DAAB	Deployable Aerobic Aqueous Bioreactor
dBBR	Deployable Baffled Bio Reactor

DOD MOU	Department of Defense Memorandum of Understanding
DOL GTCM	Department of Labor Geospatial Technology Competency Model
EBK	Essential Body of Knowledge
ERDC	USACE Engineer Research and Development Center
FLIR	Forward Looking Infrared Radar
GEO-INT (GEOINT)	Geospatial Intelligence
GIS	Geographic Information System
GI & S	Geographic Information and Services
GPR	Ground Penetrating Radar
GPS	Global Position System
HHS	Department of Health and Human Services
ICBM	Intercontinental Ballistic Missle
IED	Improvised Explosive Device
IEEE	Intitute of Electric and Electronic Engineers
JST	Joint Services Transcript
KAMA	King Abdulaziz Military Academy
KD	Key Development jobs for military officers
KKMC	King Khalid Military City
LIDAR (LiDAR)	Light Detection and Ranging Sstem
MCOO	Modified Combined Obstacle Overlay
ML	Machine Learning
MS	Master of Science
NGA	National Geospatil Intelligence Agency

PDB	CASCOM Planning Data Branch
PFAS	Per- and Polyfluoroalkyl Substances
PME	Professional Military Education
PMP	Project Management Professional
PVC	Poly Vinyl Chloride
NATO	North American Treay Organization
R&D	Research and Development
RO	Reverse Osmosis
QC	Quality Control
SAME	Society of American Military Engineers
SI	Speciality Indicator
SLAWG	St Louis Area Working Group of the USGIF
SNEP	Saudi Naval Expansion Program
TME	The Military Engineer
UAV	Unmanned Aerial Vehicle
USACE	US Army Corps of Engineers
USGIF	United States Geospatial Intelligence Foundation
USGS	United States Geological Survey
UXO	Unexploded Ordinance
WW1 (WW I)	World War One
WW2 (WW II)	World War Two

1. INTRODUCTION

A campaign to show that geological engineering is a fundamental aspect of military engineering is presented with articles for the military engineer periodicals. These works set an example that geological aspects of military applications should be examined and researched by senior military engineers both for the practical aspects of large 'civil' works such as water control, transportation and environmental adaption as well as for strategic or campaign, also known as grand tactics, considerations of engineering in geopolitics and warfighting. Geological engineering is penultimately a practical application of geology affecting location, design, construction, operation and even maintenance of earth-structure interactions. As a structures-centric discipline, it has not applied strongly to far ranging, rapidly moving and constantly adapting military operations. Yet history has many instances where military purposes and geological engineering intersected – Roman road building, Panama Canal, ports and harbors, airfields. In some aspects, it seems that geological engineering left a structural footprint geospatially fixing military capabilities in place and time.

Although warfare significantly preceded the development of geology as a science, geological aspects assisted the development of civilization with caves and other geological formations as early, yet crude, fortifications. Rocks, notably flints, were adopted by our young species as tools and weapons. That gives credence to the notion that military engineering preceded all other disciplines of engineering by a significant margin. Earth structures for protection from enemy and flood were built as essentially military concerns often motivated by liberally mixing in the supernatural and religious.

Even the term ‘civil’ engineering was adopted to distinguish the application of engineered works from military purposes to largely commercial ones.

Early on after the birth of geology as a science, the discipline was brought to bear on military matters with the earliest publications on ‘military geology’ matching the time when geology advisors were called into service for military commanders. The engineering separation between military and civil purposes was perhaps more imaginary than fact. As examples William Seibert came from the Army to the Panama Canal and Leif Sverdrup from civil engineer to the Pacific Theater and then back again. With technical developments, the intersection is also clear. California Bearing Ration (CBR) was adopted by civil practice and Robert Letourneau brought heavy equipment to the Army.

Technical aspects of military engineering continued to grow over the last two centuries with specific military engineer formations and capabilities included as organic pieces of military forces in nearly all modern armies, navies and air forces. Those capabilities allow forces to handle and work with the ground – earth working equipment, bridging, and mapping and range in discipline from geotechnical to geospatial. Infrastructure development for military logistics is an easy to trace development; many are now documented historical tour stops with fortifications along coasts and borders. The Maginot Line is a notable example; it is a protective earth and concrete structure on France’s eastern border that is much more than a geotechnical masterpiece. Today it is a metaphor for expensive remedies and a false sense of geographic security based on outdated technology and tactical ideas. Nevertheless, Maginot is also a worthy child of military experience and strategic planning; it was never directly challenged only bypassed.

Somewhere along the way, perhaps during the exhausting build up in the Cold War, military engineering faded back from technical development and become an art of tactical practitioners and less than an academic topic. Military engineering has lost its intellectual standing despite some technological developments from within the military notably Rhino Tank, Rome Plow, Forward Looking InfraRed (FLIR) and Ground Penetrating Radar (GPR) for mine detection.

The writing campaign for geological engineering as a study area for military engineers is primarily to argue that an ‘army’ of experienced and capable engineers can be ‘enlisted’ into the intellectual study, advancement and application of geological engineering to national purposes.

2. MILITARY ENGINEERING INTERSECTIONS WITH GEOLOGICAL ENGINEERING

2.1. LINEAGE OF MILITARY ENGINEERING AND THE ADOPTION OF GEOLOGY AS A SCIENCE

Warfare is more ancient than human records as is the art of manipulating the earth to the tactical or strategic advantage of a military force. Today that is called Military Engineering. Introducing his article on “Military Engineering Geology” the prolific British military historian, Ted Rose, began with “Military engineering is arguably as old as civil engineering, for some of the oldest major cities are defensive in their site and construction. Modern military engineers recognize their antecedents in the ancient armies of Greece and Rome; in Britain, the Corps of Royal Engineers, established in 1716 as a small unit of professional skilled officers but expanded to some 14,000 regular officers and soldiers at the present day, maintains a tradition of military construction practiced by the King’s Engineers of the Middle Ages” (T. Rose 1980). Archeological earthworks have been attributed to defensive works, agricultural drainage and ceremonial-social platforms. Scholars interpret these earth scars using an array of ever-modernizing technologies to assign man’s intended functional purposes to the enduring geological evidence. Conscription of mass labor for such projects was necessary and organized along military styles by public authorities to achieve the desired functionality of the design. Even if the purpose was civil, such as drainage, the process of construction was inherently military. Therefore, most structures can be safely included as products of military engineering.

In the run up to WWI, U. S. Army engineer Captain C. W. Otwell addressed civilian engineers in Philadelphia with these words:

> "Military Engineering sprang up with strife, and strife began when Adam made his transgression and received the curse of the Almighty, to earn his bread by the sweat of his brow. He was compelled to fortify himself against the cold by the growing of wool, against the wild beasts of the field by the rearing of walls, and against the burning sun and falling rain by the building of roofs. All this seemed naturally enough, but when selfishness sprang up and brother sought the life of brother, minds were stirred to devise methods of defense. Cain built around his city, Enoch, on the Mount of Libau, a wall which was the beginning of fortification. The walls of Babylon, of Jerusalem, Tyre, Troy and Carthage were but the development of this idea of the necessity of protection. A study of history will show that that nation ruled which made the best use of engineering devices, not only for defense but for aggression" (Otwell 1911).

Geology as a science is a more modern approach. Certainly, builders and soldiers were intimately familiar with the ground, stone quarries, hydrology and trafficability. Their knowledge was based on empirical results: this worked and that did not. This stone endured that one did not. Muddy roads made slow and tiring passage. Therefore, engineering was founded on practical approaches. Despite earlier insights from the likes of Theophratus, Pliny the Elder, and Nicolas Steno, James Hutton's *Theory of the Earth* published in 1785 can be described as the breakout point for the adoption of modern geology. The predictive design and stability of tunnels with long stand-up times, bridges and roads with sturdy foundations and the building of infrastructure onto softer and wetter soils evolved intensely from that time.

When the practice of building geological structures and the science of design first met in recorded history is not settled. History does record the first formal inclusion of geological study in military ranks with Napoleon Bonaparte's establishment of *Ecole Polytechnique* in 1794 and the U. S. Military Academy at West Point in 1802. Military engineers and geologists went to Egypt together with the French in 1798 and to Mexico with General Zachery Taylor leading American forces in 1845 (Barbour 1917).

2.2. THE STUDY OF MILITARY ENGINEERING AS AN ACADEMIC DISCIPLINE VERSUS EMPIRICAL PRACTICE

Colonel Sylvanus Thayer was charged with the duties of establishing the curriculum for West Point and as a point of historical trivia; he went to France to secure the necessary texts of instruction as noted by Stephen Ambrose in *Duty, Honor, Country: A History of West Point*. Hence, we can trace the beginning of academic study for preparing Army engineer officers to France's first engineering college, *Ecole Polytechnique,* which served as the national military academy and began seeing students coincidently with general society's adoption of geology as a science. Early texts show the practical approaches taken in such instruction (Vogdes 1884). Published literature marks widespread application of military engineering and geology on European battlefields in World War I. Instruction and recruiting approaches of the time indicate that not only military engineers, but also civil builders relied more on proven techniques and known properties from tables rather than calculated design. Education for many engineers was by practical experience rather than classroom discipline (Black 1916).

In subsequent years, thought has been given by military educators to the military engineering curriculum aspects of geological knowledge and their application to overall military forces. Writing about the relationship between military geology and geopolitics for the 2015 International Conference on Military Technologies, Petr Beyr noted that modern command and control concepts require the integration of geology into decision making but leaves flexibility to national armies on most of the implementing details. Use of an embedded staff geologist or outside experts and inclusion of specific subtopic expertise are to be decided by contributing NATO allies against a standard to meet all CRO (Crisis Response Operations) requirements. Beyr argued that the primacy of understanding the NATO concept of operations requires combat engineers, as a subspecialty of military engineers, must be educated and charged with this integration. Such integration will never be satisfactorily accomplished by external consultation. Beyr lists specific curriculum topics to be included as soil mechanics, geology, gravity studies, precipitation, running and stagnant water, glaciers and biogenetic processes of the regolith. He draws upon precedents during WWII when external commissioned geologists supported advancing troops over the Western European and Pacific theaters (Beyr 2015).

Even today, much of the training curriculum at the U. S. Army Engineer School covering military engineering is structured as facts, doctrine, processes and other prescriptive approaches that can be commonly accomplished by soldiers of all stripes and components. It is a subject of study, but one of lesser academic quality than tactics or communication.

The literature also showed that an academic quality increased at the time of WWII credited to both the importation of experts like the USGS Military Geology Units and by the appearance of research papers pushing beyond the regimented practices (Guth 1998, Terman 1998). The Cold War accelerated technological achievement in the West for military purpose. Geological engineering itself learned much over the century with great military-led projects such as the Panama Canal (Rogers 2014), Cheyenne Mountain (Karafantis 2017) and nuclear testing (United States Geological Survey Military Geology Branch 1966).

A combination of study and research increased academic quality and expanded the body of knowledge for military geological engineering. Practitioners and scientists both pushed effectiveness, application and understanding of geological factors forward to meet military needs. It has been simplified by the keen observer Edward Rose that research and practice were accomplished by two distinct populations most easily described as soldiers and scientists (Edward P F Rose 2014). Beyr and this paper argue that further progress can be achieved by merging these two groups (Beyr 2015).

2.3. GEOLOGICAL GAPS IN MILITARY ENGINEERING

Military engineering is enhanced by geological engineering practices whether from application of external expertise or by education of military engineers themselves. Arguably, both external experts and military engineer insiders have more to learn on a list of applications. Specific areas that seem ripe for better understanding and protocols start most notably with hydrology applied to combat operations, civil relief and sustainable infrastructure. Better understanding is also needed of mobility across inhospitable terrain and under severe conditions. More is to be learned of deeply buried facilities for protection as well as countering subterranean threats. Sharpening of techniques to “know the earth”, as the mission is described by the National Geospatial-Intelligence Agency, can be accomplished using artificial intelligence, machine learning and big data handling. An immediate need is learn how to better share geological and geographic information, mapping and terrain products. Military experience indicates a lack of understanding about ground and subsurface hazards such as mineralized aggregate and trafficability in karst terrain.

2.3.1. Water. Already identified as a national grand challenge, human access to water will be a geopolitical driver for the 21st century with military action acting as one of several arbiters. Exploration of how to handle water resources within contingency operations areas including assets available and costs of surface and groundwater conflicts are research problems for further study. Environmental considerations and climate change are projected to cause societal and military competitions over the hydrology and access to water supply. The sustainability of cities, countries, agriculture and military installations are entwined and not all the answers will come from policy of legal dicing of supplies. Military engineers have much to study on this topic.

2.3.2. Movement of Forces. Military engineers are tasked to assure the mobility of armed forces and freedom to maneuver. In the Civil War, this meant pontoon bridging, while in WWI it was overcoming mud, shell holes and trenches. In WWII, it meant airfield construction. In Vietnam, it meant clearing forests for landing pads and fields of fire for artillery and base camps. Korea called for finding tunnels, while Gulf conflicts called for supply flow management. The Global War on Terror required extensive and repeated route clearing operations. Geological engineering holds answers to predicting risks and remedies for military engineers.

2.3.3. Deeply Buried and Hardened Facilities. Immense firepower is countered by one of three tactics: get out of the way, strike first or seek shelter. Combining these tactics is the wisest choice. With mobility already covered and striking first a strategic, moral and national issue, the military engineer is charged to create the shelter as the remaining choice. Even the densified armor of a battle tank has proven to be a second choice to the age-old solution of "digging in". The art and science of creating such subterranean refuge has advanced little since the Cold War or even WWI (Barton et al. 2005).

2.3.4. Geospatial-Intelligence. The technology that is changing military engineering the most today is location science empowered by Global Positioning Systems (GPS). It is also known as Geospatial-Intelligence (GEOINT). It has pervaded most of the civilized world as a technology that was transferred from military to civil use. The military engineer has largely lost the role of surveying and mapping in favor of data and visual scientists. This has become a mega-industry pushing advances in artificial intelligence, machine learning, and collection of large data sets with temporal information. However, there are places where remote sensing and highly powered data engines cannot reach. In these places, it is the military engineer, along with his geological companions, that have a nearly solitary role. Geophysics, with its many approaches, is the science of choice for investigating the world beneath: beneath the waves, beneath the soil, and even beneath the roof. A great deal of work is being done in the field of terrestrial Light Detection and Ranging (LIDAR), seismic studies, tomography, and borehole investigation with even more effort being put forth to create intelligence readily understandable by non-experts and is displayed in a timely way to the public.

2.3.5. Geo-Hazards. An entire class of risks is naturally present in landscapes or caused by human interference. The military engineer works with the geological engineer to assess the seismic risk and mitigate effects of the shifting earth. The geological tools to find water and buried metal used the military and geological engineers are the same. However, differences in the data processing and analysis, and the applications are still being discovered.

2.4. NOTABLE FAILURES DUE TO POOR UNDERSTANDING OF GEOLOGICAL ENGINEERING IN MILITARY SETTINGS

Military engineers have not always had the right skills or advice in geological matters. Several examples illustrate this point starting in the American Civil War and extending to current operations.

2.4.1. Vicksburg Bypass 1863. Ulysses S. Grant's strategies for the Vicksburg campaign initially included five actions called the Bayou Operations of January–March 1863 by which he attempted to bypass the city. The Williams Canal across the De Soto Peninsula was excavated to allow river traffic to bypass the Confederate guns but was improperly engineered for the hydrographic conditions of the Mississippi River. A rapid river rise broke the head dam filling up the dug portion with sediment. Two steam-driven dipper dredges were called in but the Confederate artillery fire from the bluffs made that action untenable. Better geological engineering could have precluded fighting in the eventual Siege of Vicksburg (Hogan 1992).

2.4.2. Battle of the Crater 1864. The Siege of Petersburg finally brought about the surrender of the Confederate Army of the Potomac at Appomattox Courthouse after some ill-informed geological decisions were made at the Battle of the Crater. A clever Union engineer convinced General Grant to tunnel and undermine the stalemate of trenches with explosives. This stalemate was a precursor to the practice that stalled the troops of WWI after extensive maneuvering. Two geologically poor decisions were made, one by each side and both by discounting the effectiveness of the plan. The Confederate General Robert E. Lee visited the site and disregarded the risk completely. Meanwhile the U. S. Army Commanding General U. S. Grant and his subordinate generals, Meade and Burnside, determined that the value of the tunneling was to keep the men busy and did not provide the leadership, logistics or attention to ensure a success. When the plan actually worked and a large crater was blown, breaching the Confederate trenches, the Union troops didn't take advantage and instead crowded into the 30m deep crater bowl where they were killed by Confederates shooting down into them (Wolfe 2012).

2.4.3. Maginot Line 1939. Maginot is an unfortunate case of an excellent piece of engineering that was bypassed by the *Wehrmacht*. It was considered so impenetrable that the attacking Germans determined it was worth the risk of incurring a wider war by invading instead through neutral Belgium to avoid the Maginot Line, or as it was nicknamed "Fortress France". The military works making up this massive fortification are generally considered an engineering marvel that made great use of the geological setting and geographic position (Kaufmann, Kaufmann, and Idzikowski 2005). But the military engineering overwhelmed the national war plan and led to the entire country of France being captured (Britannica 2012).

2.4.4. Dieppe Raid 1942. Anxious to keep the Western Front on par with Soviet success in the Eastern Front, 5000 Canadians, 1000 British and 500 U.S. Rangers assaulted a French coastal town across five beaches. Very poor terrain intelligence at the Red and White beaches proved to be a very costly mistake, particularly for the Canadian troops. The troops could not clear the beach obstacles and were assaulted by heavy machine gun fire from well-positioned, dug-in emplacements on the overlooking cliff faces. Tanks were unable to traverse the shingled beach while other tanks drowned, never making in onshore. Better GEO-INT and mobility work by military engineers may have spared some of the lives lost even though too many other poor military and political decisions were involved to make this gamble pay off (Edmondson and Edmondson 2004).

2.4.5. Bar-Lev Line 1973. Israel had captured the Sinai Peninsula and meant to keep it by fortifying the eastern side of the Suez Canal. The Bar-Lev live was long, lightly manned, and made of rudimentary but robust construction giving Israeli troops field of fire control over the Suez. However, this did not work; Egypt's military engineers used float bridging to bring water pumps that effectively washed away the Bar-Lev Line sand embankments and even damaged portions of the line that had clay backfill. Credit is due to the Egyptian military engineers and their geological approach (AP 2018).

2.4.6. New Orleans' Levee Breach – 2005. The U.S. Army Corps of Engineers has been heavily criticized for its design of the levee walls that failed during Hurricane Katrina. Major criticisms pointed at overestimated the soil strength where the I wall supports were embedded and overestimating the factor of safety which should have been reduce by the presence of water-filled voids. The Corps' civil works division was responsible for the design. Few soldiers serve in this division and the professional engineering establishment is comprised of government civilians. However, this is still a military failure in that it goes to the heart of the argument that the uniformed military engineer who supervised the civilian workforce must be able to look deep into the geological assumptions (Seed et al. 2008).

2.4.7. Semmes Lake Dam 2015. This little-known failure is highlighted as a case of a military installation working to sustain its infrastructure but not understanding the impacts of geological decisions. Semmes Lake at Fort Jackson South Caroline has an earth dam with a concrete spillway. Full reports of the failure have yet to be shared publicly by the Corps but at least two elements have been released. One was the decision to purposefully raise the lake's water height by partially blocking the emergency spillway and the second was to neglect the routine maintenance on the emergency equipment (Fretwell 2018).

2.4.8. Birds Point-New Madrid Floodway and Yazoo Pumps Project. US Army Corps of Engineers is also under significant criticism for several long-proposed projects along the Mississippi River. The Birds Point-New Madrid floodway was designed to prevent flooding above a certain elevation on the Mississippi River levees near the confluence of the Mississippi and Ohio rivers. It was thought that the emergency spillway would be activated about once per decade. Completed in 1932 it was in place for the 1937 flood and the emergency elevation has been raised since such that in the 1973, 75 and 79 floods it was threatened but not activated. From that time on and including the 1983 and record-setting 2001 floods the controversy has been on the purchase of flood plain lands, the adjudication of operating rules and various legal redresses sought in courts. (Engineers 2017) That experience has shaped subsequent projects such as the proposed Yazoo Pumps Project Area. The project is a structural approach to draining interior waters that would make an impoundment of the Yazoo Backwater Area. That area historically functioned as a natural flood-water storage area for the Mississippi and Yazoo rivers but is now isolated by a levee system. Once again the contrroversy comes from the land use, legal ramifications and economic and environmental costs that correlate with legal activity. The criticism of either projects engineering design is minimal and rather the controversy stems more from the Corps unrestricted calculation of the cost and benefits of the projects. (Fish and Wildlife Service 1985)

3. CONTRASTING THE MILITARY AND GEOLOGICAL ENGINEER

3.1. DUTIES AND CAREER PROGRESSION

Military engineering is a broad term related to responsibilities assigned and conducted. Typically, a uniformed solider, sailor, Marine or airman is charged with engineering responsibilities as part of an assigned and trained specialty. Alternatively a civilian inside or outside of government is contracted to work on military projects that include engineering. In many aspects, service in the field of geological engineering is similar in that a range of skill, training and experience is present in those working on geological projects. Narrowing this range to military engineers and geological engineers restricts the population to those with enough academic background to allow for the comprehension of the specialized instructions, practices and protocols of engineering. Those assigned as military engineers carry with them an expectation of continual learning and increasing responsibility over a career. Both the military and the geological engineer start their careers with the awarding of a bachelor's degree and a first job. The military engineer is trained exclusively in military studies to handle a broad range of problems, to use temporary and indigenous sources, and to provide immediate solutions. Typically, the military engineer is assigned to a military organization and starts with junior leadership positions that require a combination of technical, managerial and tactical skills. This early "breaking in period" is typically three to four years long and covers a range of projects that have some interdisciplinary nature. The geological engineer is more likely to join a specialized team focused on a specific geologic project or a narrow set of tasks repeated in similar projects. The time in this junior learning status varies dramatically from weeks to years. At midcareer, both the military and geological engineer have generally moved up to increased responsibilities and are a frequently under the tutelage of mentor. Each may have conducted advanced learning at the graduate level or in specialized credentials, and each has at least been encouraged to acquire a professional engineer license. Table 2.1 illustrates the career progression of the typical military and geological engineer.

Table 2.1 Comparison of Career progression

	Military Engineer	Geological Engineer
Early Career	First 0-4 years of a career. Assigned to junior leader positions in military units. Command responsibility for 10 to 40 people and equipment equivalent to a small business. May design small projects and execute such work with his organic assets.	First several jobs working for a company. Usually a member of a team with a repeating set of technical duties. Unlikely to design but may do QC work and sampling. Subject to on-the-job training.
Midcareer	5-20 years of service in a variety of assignments covering staff work, planning and additional commands of 100 and 1000 people. Equivalent to running a mid-sized and large company. Mentors and develops others to include professional engineers.	Undefined period of time. Frequently moves to an increasing level of responsibility in one or more firms. May consult or manage larger and more complex geological projects. Starts to manage people and define operating procedures and may lead commercial entities.
Late-Career	20-35 years of service. Responsibilities over geographic areas or widely dispersed forces. Technical work is more in programmatic and coordination with civil or other federal authorities. Advisor on technical and operational approaches to large problems.	Undefined period of time. Responsible for business operations and people development. May approve design and work of other engineers. May lead corporate alliances and create large teams.

They differ at the midcareer stage in how they make engineering trade-offs. For the geological engineer, the trade-offs are between the technical necessities, time, risk, and cost. These differences are from accrued institutional values. For the military engineer, the trade-off is between tactical efficiency and logistics or, if assigned to public works, between the social license to operate and getting the job finished. Finally, in their late career, each has grown in responsibility and prudence with a few exceptional members climbing fast up the organizational ladder.

The following descriptions of the two engineering professions come from the Army's official pamphlet on career development and industry guidance offered to high school students. These two descriptions echo the differences between the two parallel professions.

The Army describes the unique knowledge and skills of an Engineer officer as well grounded in engineer doctrine and able to serve as problem solvers. They are to be warriors first and serve ground force commanders and technical specialist second. Engineer officers are required to update their education and professional certifications continuously because of the technical nature of their work. Licensing as a Professional Engineer and obtaining a master's degree in engineering is highly encouraged as is obtaining relevant professional certification such as Project Management Professional, Project Engineer or Geographic Information Systems Professional. They gain competency through a sequence of "professional military education" courses, experience gained in operational assignments, and continuous self-development (Army 2014).

In contrast, the EducatingEngineers.com site describes geological engineers as broadly combining geology, civil engineering, mining, and geography to apply earth sciences to human problems. Specialty areas suggest the enormous width of the field and include geotechnical site studies, rock and soil slope stability, environmental studies, planning for construction sites, groundwater studies, hazard investigations, and finding fossil fuel and mineral deposits. Their careers consist of service as specialist consultants for engineering or environmental firms and staff of highway departments, environmental protection agencies, forest services and hydro operations. A geological engineer holds Bachelor of Science degree, generally in geological engineering, with significant laboratory work. Advanced degrees are needed to pursue careers as environmental, petroleum and mining geologists and post-graduate degrees open opportunities for higher salaries, research and teaching (Geological Engineer Careers 2017).

3.2. EDUCATION AND PROFESSIONAL ASSOCIATION

For the geological engineer the common United States associations are the Association of Environmental and Engineering Geologists (AEG) , and the American Society of Civil Engineers (ASCE) Geo-Institute. Other countries have national organizations of similar names. The associations provide, to the subscribers at least, the mechanisms of continuing education and constant updating. Graduate education remains an option for personal development but not a mandate for continuance in the profession.

The military engineer with the Society of American Military Engineers (SAME) is matched by a professional society with a breadth that covers all possible military engineering duties. SAME suffers, as a consequent of that wide range, a degree of shallowness in technical depth in comparison to other professional engineering societies. Military engineers often rely on traditional engineering societies from civil society such as Institute of Electrical and Electronic Engineers (IEEE) and the American Society of Civil Engineers (ASCE) to serve their technical depth needs. This practical approach of having two, or more, professional engineering societies reinforces an internal dichotomy of what they are as engineers, for example civil, electrical, or geological, versus what they do as engineers, such as military works, combat engineering, and geospatial analysis. Table 2.2 compares the typical education pathways of the military engineer and the geological engineer.

Table 2.2 Associations and Education

	Military Engineer	Geological Engineer
Early Career	Professional Military Education at 'basic' and 'advanced' training. Likely to join military associations but not engineering associations.	On-the-job training and credentialing for specific equipment or protocols related to duties. Carry over membership to geological associations from college and accrue some continuing education from such associations.
Midcareer	Advanced degree from a university to earn a master proving intellectual competence. Additional professional military education is required at 'staff colleges' but has no engineering content. Generally, becomes a member of SAME and may seek professional engineer license.	Personal development based on ambitions, time and resources available. May expand professional association involvement to additional specialties. Significant mobility between companies within the industry is common.
Late-Career	Continued professional military education relating to working with public authorities. Continued with SAME in leadership and conference speaking roles.	Takes ownership or high personal stakes in the company success. Spends time in business development and development of people. Leverages professional associations for these tasks.

Other countries do not generally have a parallel to the SAME. Minor specialty groups have sprung up across international lines such as the International Association for Military Geosciences or the United States Geospatial Intelligence Foundation (USGIF) that are havens for military engineers. Continual updating of the military engineers comes from a series of formal military schooling that is mandatory. The military engineer is also expected to acquire by self-study some form of master's degree as an 'optional' mandate. The military generally supports such study and practically underwrites portions of it as a retention incentive while avoiding making an advanced degree a formal requirement.

3.3. SCOPE, SCALE AND IMPACT OF PROJECTS

Looking only at late career, when the military or geological engineer is at a career zenith, demonstrates an obvious similarity in impact. The geological engineer is going to contend just as much with large and long social impacts as the military engineer when engaged in public megaprojects.

The most senior geological engineer will be asked to tackle the most profound of geological problems. A good example is the 'Big Dig' or Central Artery/Tunnel Project in Boston, which would make an appropriate high point for any geological engineer. Listed as a megaproject, from design to completion time, this project took 11 years, and the cost was $15 billion. Describing the lessons learned to her colleagues Wendy Haynes described the scenario as "…experts in the field define a megaproject as a publicly funded infrastructure project that costs in excess of a billion dollars and requires more than a decade to plan, design, and construct. Boston's $15 billion Central Artery/Third Harbor Tunnel (CA/T) Project still hits the top of the chart for cost and complexity on the list of megaprojects undertaken in the last two decades of the twentieth century …I soon learned that the structural and civil engineering aspects of the project paled in comparison to the political and social engineering that was needed to sustain momentum toward completion" (Haynes 2008). The industry alliance that managed this project was Bechtel/Parsons-Brinckerhoff who soldiered through the many state and federal agencies', audits and critiques (Haglund 2003).

King Khalid Military City constituted the largest single construction effort in the history of the Corps of Engineers for military construction. The Corps built this mega project for the Saudi Arabian government who underwrote the cost. Initially the price was estimated at $15 billion but was later raised when compounded by additional and simultaneous construction of the King Abdulaziz Military Academy (KAMA), the Saudi Naval Expansion Program (SNEP) and other construction efforts that Army engineers managed for the Saudis over the same years. Starting with planning in 1976 the project ended in 1987 well under the estimated budget (Grathwol and Moorhus 2009). Several of the commercial alliances created a bulwark for Saudi defense and later became a cornerstone for the United States in the Gulf War and subsequent operations. Those alliances built the experience to handle the complexities of multiple contracts and construction phases with geographic dispersal common in wartime operations.

A key point in these two examples is that the military engineer and the geological engineer may be called upon to shepherd public works of enormous size, cost and benefit to public use. Two different developmental paths merge at the highest levels of responsibilities with similar scale, scope and impact.

3.4. RENDERING STRATEGIC ADVICE

A top-level task for the military engineer is providing advice to those charged with making the very important decisions. The geological engineer is unlikely to have such a burden to bear. “Policymakers, strategists and tacticians can expect unpleasant surprises whenever they overlook the fact that many geographic factors fluctuate in response to seasonal, cyclical or random change. Nuclear combat, however restrained, could instantaneously turn urban battlefields into rubble, transitions from night to day alter radio propagation characteristics and sunspots periodically cause high frequency blackouts. Viet Cong sanctuaries lost much of their utility when defoliants reduced concealment. Ice transforms unbridgeable bodies of water into arterial highways (trains have crossed bits of the Baltic Sea in wintertime), and wheels are welcome in frozen fens. Forces oriented north to south often find themselves in topographically different worlds than those facing east to west, while switches from defense to attack may cause obstacles to loom where protective barriers stood before. Streams that flood without warning can frustrate even the best-laid plans, as U.S. Army engineers in Bosnia discovered in December 1995. It took a week longer than anticipated to build a pontoon bridge over the raging Sava River, suddenly swollen by melting snow. Rising waters inundated adjacent tent cities occupied by troops waiting to cross from Croatia to Bosnia-Herzegovina. Casualties were confined to those caused by dampness coupled with bone-chilling weather, but only because the tactical situation was benign” (Collins 1998).

4. RESEARCH AND INTELLECTUAL DEVELOPMENT REQUIRED AT THE INTERSECTION OF MILITARY AND GEOLOGICAL ENGINEERING

The parallels between military and geological duties drawn so far have covered the careers, the scale of responsibility, and the impacts that the completed projects have on the public. Civil engineers can argue with justification that these parallels fit them as well. Both KKMC and the Big Dig were guided by civil engineers, in uniform and in commercial practice, and the earth works were geotechnical as much as geological for those that categorize work so finely. A quick review of the list of Corps of Engineer projects funded by the American Recovery and Reinvestment Act of 2009 shows a preference for earthwork, dams, river ways, harbor protection, dredging, hydropower, bridges, flood control, environmental restoration, levees, locks, canals and wetlands. These 'shovel ready' projects are listed by the Army Corps of Engineers - Civil Works and are publicly available. Admittedly, it's tenuous to judge by project descriptions, which involved substantial geological expertise; however, of the 354 projects on the approved list, 315 (89%) could be counted as benefitting from senior engineers with a geological engineering background (Engineers 2010).

These projects are great public works assigned to military engineers. Yet the bread and butter are projects and support given to deployed forces and other nations. These "combat" engineers create mobility for military forces, refugees or indigenous populations with transportation infrastructure and hastily created cross-country trails. Combat engineers may be seen building an airstrip, putting in assault bridging, and clearing rubble on the fly with little planning. Combat engineers provide protective structures for forces by digging in to crude positions or more erecting more elaborate barriers, walls and towers for headquarters and base camps. They build the base camps that become mini-cities and assist in environmental restoration. They find the mines and Improvised Explosives Devices (IED), clearing fields of such hazards and keeping roads open. Combat engineers update the geographical information and analysis that advises what is possible from the perspective of location science. Throughout all of these battlefield tasks, a strong undercurrent of geological engineering is present (Knowles and Wedge 1998).

Instructive is these functions are currently carried out with minor improvements slowly being adopted compared to aggressive technology insertions in other military functions. Mine detection equipment today looks remarkably similar to the mine detectors of WWII. Remote sensing, drones, and better geophysics are more experimental than standard in practice. Military engineers could become strong contributors to the research, development, testing and adoption of new technologies and approaches in these battlefield tasks if they had both the mindset and the credentials. Military engineers would contribute because of a very high, fatal, personal stake.

4.1. WATER RESOURCES

Already identified as a national grand challenge, human access to water will become a geopolitical driver for this century with military action as one of several arbiters. Water resources in contingency operations are a logistics - not engineering – responsibility (Moore 2011). However, engineers still find water sources, drill the wells and provide water infrastructure. Studies are required to improve military water operations, to estimate the assets that may be required and project the differing costs for surface or groundwater sources (Lundquist et al. 2011). A geological-trained military engineer will be better prepared to solve water supply issues in the field with practical approaches than the Army quartermaster who may see water as just one more type of supply to deliver. Geopolitically it has been shown that the potential for conflict is much higher for water insecure countries. Environmental considerations and climate change are projected to drive societal and military competitions over fresh water access (Gleick 1998). Lieutenant Colonel Robert Tucker reported based on his direct observation "Not understanding the water strategies in countries with scarce water resources can be an impediment to secure operations. This was clear in Afghanistan, where the Afghan use of the karst system seemed to baffle the commanders on the ground and planning staffs as well."

One immediate investigation to be completed is to understand fully the environmental impact of new polymers and biocides used in cooling water treatment programs. The Corps of Engineers (USACE) has not evaluated new chemicals in over ten years and Army installations may be causing long-term environmental problems slowly poisoning base operators and handlers of chemical treatments (Brugman and Hock 2004).

A military engineer is best suited to describe the hydrogeology requirements, organization, doctrine, and skills the U. S. military has needed but always handled with an *ad hoc* collection of federal agency and local government representatives (Gellasch 2012).

Polar ice is both a resource and an impediment to military and commercial transportation. Little is understood about this entire part of the world and its geological implications. Some work began in the Cold War, but has stagnated since. (Hobson 1981) Big Oil, Russia, Nordic countries and Canada especially have much they can tell us.

A poor understanding exists of the relationship between oases, geology and date palms in areas like Oman where the US must operate. A better understanding of these sites will benefit military operations (Luedeling and Buerkert 2008).

Deserts cover one-third of the Earth's surfaces and many battles have been fought in desert conditions. The relationships between dust, heat, cold, food and water needs investigation to help reduce the challenges to military leaders (McDonald and Bullard 2016) Arid regions challenges to the conduct of military operations come from geographic factors such as radiation balance, wind and dust. Stark and bare terrain has affected the outcome of desert campaigns even though the scientific inquiry has led to understanding desert features, biodiversity and hydrology. Military engineers are needed to transform these fundamental environmental factors to changing approaches to desert military operations. Implications for troops, equipment and tactics need to be teased out from historical and modern examples. (Gilewitch 2014).

As the U. S. Navy considers the innovation of Mobile Offshore Bases as a forward-deployable logistics facility capable of conducting flight, maintenance, supply and other military support operations a military engineer from the Army should keep pace and understand its implications to the ground operations. At a minimum, it may make a water pipeline to shore effective. (Remmers et al. 1999)

The science of hydrogeology partly owes its maturity to the needs of military forces. Synergy between geology and water supply had a turning point in WWI. Rapid drilling techniques, well screens in unconsolidated sediments, remote mapping behind enemy lines, limits to desert and semi-arid groundwater in fresh-water aquifers poorly replenished by recharge, and defining hard rock basement-type environments of islands spurred development of applied hydrogeology (Robins and Rose 2009).

Engineers should devise new approaches to generate water supply maps in preparation for military occupation (Willig and Hausler 2012). Particularly with the United States strategic ‘pivot to the Pacific’, studies are required to know where the water will be and how it will sustain heavy usage. Lodgment operations, that is establishing military beachheads and basecamps in previously unoccupied terrain – is expected, and military engineers will have to support the water needs. Historical precedents must be studied and understand (Edward P F Rose, Mather, and Willig 2002).

Drainage and fortifications is another area that will require the detailed analysis and design guidance for large entrenchments and fortifications (Salvador and Vitti 2011).

The United States introduced Agriculture Development Teams in Afghanistan from 2008 through 2014 to shift the economy of the Afghans from the poppies and drugs that underwrite militant operations to a better cash crop. Agricultural shifts are very water dependent and this topic should be thoroughly studied (Stewart 2016).

Other countries are looking to hydrogeology for how to support deployed forces. A military engineer needs to catalog and compare these approaches with U. S. efforts (Willig 2012).

4.2. MOBILITY

Physical, hydrological and geological properties strongly affect where humans can drive, walk and cross the terrain. For military forces, impediments frequently have to be overcome by mechanical action or clever planning. Cross-country mobility significantly differs for wheeled vehicles, tracked vehicles and foot traffic. U. S. Army has recently published historical case studies of mobility and countermobility operations drawn from the past 100 years in large-scale maneuver. In an included essay, "Large-Scale Combat Operations: Mobility Operations in the Future" of this work the Commanding General of the Maneuver Support Center at Fort Leonard Wood, Major General Kent Savre, opined "Emerging trends and proliferation of advanced technology will challenge current mobility capabilities" (Waitl 2018). Military engineers will continue to be challenged to provide the immense support required to move "heavy" forces, those containing armored vehicles and their logistics. Compounding developments meant to slow and disrupt organized movements are expected to evolve from high-altitude and space assets, cyber space attacks, intelligence-surveillance-reconnaissance-communications (ISR) spies and precision navigation disruptions. Assuring movement of heavy forces in rhythm with battle plans is a no excuse task for military engineers even when information warfare has confounded the command and control. Knowing the ground and describing it in unambiguous ways is significantly improved by the study and application of geological engineering aspects. Even if the GPS is down the road must be passable to move the big guns to the point of critical action.

Lighter force movement is daunting as well. Estimating the battlefields controlling geology and geotechnical constraints has improved with the long operations in the Global War on Terror. Even helicopter-carried troops are tenants of Mother Earth once they land to fight. Opposition forces who face the U. S. Army or Marines are heavily dependent on ground transportation, sometimes even very ancient modes. The recent case of the Taliban, and Osama Bin Laden, escaping mounted U. S. forces while using donkeys to carry their war supplies is an excellent example. Research into the mobility of light military forces is an area ripe for additional investigation. (Shellum and Trudnak 2005)

4.3. DEEPLY BURIED FACILITIES AND TARGETS

It has become problematic for modern weapons to reach deeply buried targets. A lot of concern exists currently over how to handle the nuclear research labs in North Korea that are buried deep under mountains (Kiersch 1998). The United States stopped researching sheltered facilities and buried command posts after the Cold War. Not only is this science not progressing but also little was documented. Coupled with the loss of the experienced builders over time the store of “know how” has significantly eroded. Geological engineering approaches from siting to construction should be investigated by the likely builders of such works, the military engineer (Zečević 2011). Many nations have suffered explosive attacks on civilian targets. As an example, long before “9-1-1”, the World Trade Center foundation was attacked by explosive devices. Military engineers working with geological engineers can help devise standards and codes for modern military facilities to withstand blasts. These same codes could be applied to civilian infrastructure whose failure could critically disrupt economic life (Zineddin 2009).

Military engineers could significantly help to re-stimulate and leverage the early works of this science. Applications included shelters from ground attack, nuclear detonations, cold and controlled storage and use of underground space for command and control headquarters (Stauffer and Vineyard 1975). Several techniques need investigating for military application: use of ground freezing to provide structural support, evaluating the societal and social and economic implications of underground space, stratigraphy and site selection, rock reinforcement in seismic and blast cycles, hard rock versus soil structures, design for hydrology and water control, boring machinery, and cost estimating (Sinha 1989, Sinha 1991)

4.4. SUBTERRANEAN WAR

Military forces have been assigned by domains of the earth. Hence, armies are land forces, navies are maritime and the sky is the dominion of air forces. Marines handle the interface between land and sea and a new space force is proposed to extend the U. S. Air Force's vertical reach. The subterranean domain has largely been unassigned and underdeveloped. Much more than merely subsurface facilities *per se* but an entire operating concept and doctrine must be invented. WWI has been nicknamed "tunnellers' war" marking the use on the Western Front of the ground to survive the 'Unholy trinity" of barbwire, machine guns and artillery (Barton et al. 2005). Minor examples exist from Civil War tunneling to the tunnel rats of Vietnam that indicate an unexplored style of warfare that needs to be considered (Traas 2010). The Cold War provided some impetus to look at underground protective structures. Researchers, many focused on the extensive works in Kansas City, recognized that the potential for manufacturing, economical cold storage and cheap vertical real estate may far outweigh the military value (Sinha 1991). Subterranean space may have advantage for the control of environmental effects or against easy intrusion to highly vulnerable assets. Geological engineers with military engineers as their partners can dig into the research to better predict the risk of joint sets within geological units, bedding slip surfaces and faults (Swift and Steedman 1972).

4.5. GEOSPATIAL INTELLIGENCE

Remote sensing, GIS, expansions of technologies in LIDAR, topographic analysis and providing of map backgrounds for command and control technologies continue to occupy military information development and investment. Collection techniques are growing rapidly with drone-based sensors, big data sciences and cooperative sharing.

Oil, gas and mineral exploration techniques are settling on a certain size, range and speed of unmanned aerial system (UAV) that is most effective for their purpose. Similar work should be done by military engineers to find the tradeoffs and the best flight parameters to meet their needs for data collection and updating of geospatial information (Barnard 2008).

Geomorphology and the technical means to portray the ground beneath the surface need to be developed. Currently GIS sensing gets to the ground level – even through vegetation – yet subsurface data, even for very shallow depths, evades technical capture. Historical examples should be studied where the land forms dictated military outcomes (Bondesan et al. 2013). This will be helpful for areas where U. S. forces are denied access (Cheng et al. 2011).

Exploitation of imagery and relating it to the surface conditions, geology, infrastructure, transportation and communications links, and other land use leads to sound analysis and advice for commanders and policy makers. Few are better positioned to insert geoscience into geopolitics than the military engineer can. Additional development of techniques to use for extracting information for existing collections of imagery is coupled with a need to upgrade to the next generation of cameras and sensors (Critchley 1982). For the geological engineer this also helps with the practical use of determining the digability of land as well as searching underground for voids, graves, and water (Donnelly and Harrison 2013).

The relationship between public health, medical research and geoinformatics has been suggested but not well researched. The land is suspected to have implications on health such as the Yellow Fever swamps of Central America that became a severe impediment to the building of the Panama Canal. Native reasoning suggests health may be based on the underlying mineralogy and water quality. As examples, chemical compositions underground, and radiological conditions are checked in the United States by certified inspectors and treatment remedies are suggested or imposed depending on the authorities of local regulators. Hard water is reduced by adding sodium that has health tradeoffs and risks. Pyrite in the aquitard may mean rust stains on and ammonia in the water may have been caused by fertilizer applications. Silica, sulfur and total dissolved solids (TDS) can be measured and countered. There are even some beneficial occurrences such as the natural fluoride in water strengthening tooth enamel. Geologically informed military engineers are a part of the research collaboration that should investigate this further (Hartmann 2015).

Terrain analysis has long been a military engineer's duty and yet modern techniques have driven this into the hands of a few specialized and secretive intelligence specialists. The military engineer must work to be done to recapture a traditional role as "master of terrain" and ensure terrain understanding is immediately available to the commanders at deployed sites. The remote site analysis site can contribute but never substitute for the face-to-face frankness of tactical discussion and nose-to-ground sense of the land. The use of artificial intelligence and machine learning with mobile operations needs to complement similar work being conducted to empower fixed analysis sites (E P F Rose and Clatworthy 2008).

The Defense Threat Reduction Agency is creating country-scale geology templates for rapid estimates of geology and geotechnical properties. Work can be done by geological military engineers on lithological units, formation specific physical and engineering properties, soil depth, extent of weathered rock and underlying fresh bedrock that will make such templates useful for tactical commanders. Data will always be lacking or sparse and so on-site engineering judgement must be applied to estimate the *in situ* engineering properties of native materials within a country (Shellum and Trudnak 2005).

Training and education of the geo-intelligence workforce is in rapid change due to both expansion of the workforce and adoption of new techniques from data sciences. Military engineers who work with well-trained but partially education soldiers constantly can describe the androgological approaches to creating and sustaining this workforce's expertise (Thomas et al. 2019).

4.6. GEO HAZARDS

Military operations during combat and peace are an overlay on the earth's surface modified by existing civil infrastructure. As much as a general would love to choose where to fight, rarely does that general have complete discretion in selection and must fight on native land, sea and atmospheric conditions. With victory, or mission accomplishment, an overriding goal, all commanders work to preserve their forces and protect non-combatants. Classically this force protection and shielding of civilians and civil infrastructure is addressed by managing combat risk. A military history survey shows that geohazards planning is rudimentary and may have detrimental effects on military operations. As an example, consider the flooding of the Sava River valley in the winter of 1996 while American combat engineers constructed a float bridge in Bosnia. "We had some battles with Mother Nature and the Sava River but we overcame the challenge," said Captain Gene Snyman, commander of the 535th Combat Support Element, which helped build the bridge.

An immediate research project is to catalog geohazards for military operations, describe a doctrine for assessing and mitigating risk, define tools and techniques for analyzing risk, and outline the potential for using geohazards in offensive capabilities (Hutchinson et al. 2008).

Geohazards are a threat to biodiversity and are applicable to military training lands where expended ordnance leaves a chemical and mineral legacy. GIS-based spatial decision-support tools need to be refined to produce an assessment of relative risks for use in conservation planning over the sometimes spacious training lands (Andersen, Thompson, and Boykin 2004).

Remote sensing techniques can be applied to development of the “MCOO” (Modified Combined Obstacle Overlay) prepared by engineers to show the maneuver commanders the better passageways through an enemy obstacle belt. Research could be done by military engineers on the techniques and additional modalities of sensors and information rendering (E P F Rose, Clatworthy, and Nathanail 2006).

A repeated task, for military engineers is to find the burial sites for victims of war. Sometimes it is from a genocide or other military crime and sometimes-such geoforensics are required to find casualties. Technology and procedural improvements need the experience and practical senses of the military engineer to make better the tools and techniques to locate lost and concealed bodies (Pringle, Jamie K; Cassella, John P; Jervis, John R; Williams, Anna; Cross, Peter; Cassidy 2015).

Geohazards are a safety factor for our own troops and a good example came up in the Iraq operations when mineralized gravel was bought and used for the development of motor pool operations. The serpentine dust and long-term health problems would have been ruled out by the U. S. Army safety program if caught and understood. More work needs to be done to protect U. S. forces from inadvertent hazards of natural materials even during combat operations (Jennings 2007).

Almost everywhere has some existing data on the local geology for civil purposes, yet these are ignored, not accessible or not translated to the purposes of military geology. As geological hazards terms differ by language and by region some effort is required to convert expressions from civil geology to military geology (Liu et al. 2016).

The United States has spent a lot of research money on the effort to find, categorize and deal with unexploded ordnance (UXO) and expended munitions. Research is required to get a satisfactory and safe approach for surveys at active defense facilities and formerly used defense sites. The case is much worse for munitions used in active combat zones where mines and improvised explosive devices are deliberately hidden. Geophysical techniques need military engineer experimenting and researching to address this enduring hazard (Miller et al. 2011). The remediation efforts to mitigate the potential environmental and public health hazards posed by old munitions and explosives typically incorporate electromagnetic induction or magnetometer surveys to identify potential MEC hazards located throughout cleanup sites and these lead to many "false positives". The expense of digging up magnetic field anomalies that in fact are harmless objects calles to effort to improve sensor technologies. Better classification of non-hazardous "junk" not only saves expense but increases the confidence and long-term warib=ness of military engineers tasked to do field investigations. Geological engineers and miliutary engineers can work together on sensor positioning, signal-to-noise ratio, data sampling rates and classification algorithms (Miller, Zelt, and Lutes 2013).

The Army has little understanding of the hazards to underground facilities due to joint sets, bedding planes and fault lines. Risk is less well understood when the facilities might be treated to repeated shocks due to bombing and assault. Attention is required to develop the science of vulnerability assessments (Swift and Steedman 1972).

4.7. ENVIRONMENTAL SECURITY, SOCIAL GEOGRAPHY, AND HUMAN TERRAIN

U. S. Army created and experimented with human terrain teams during the operations in Iraq and Afghanistan. These teams were designed and used to operate in the confused indigenous population where local citizens can be simultaneously neutral, enemies and allies. The concept of human terrain was created on the good results the Army had had in analyzing and interpolating the effects of terrain on their operations. The new construct extended the idea that location and movement describe people, which in turn, is relatable to civilian and military capabilities. Human terrain teams can predict and, perhaps, partially control civilian personnel and resources' effect on military missions (Stewart 2016). This rudimentary concept needs extensive investigation by practical-minded military engineers.

Military geography and terrain analysis are the root disciplines of military engineering. These roots must be updated with the new concerns from the growing field of social geography and coupled to environmental security. A major portion of the Corps of Engineers civil works as funded by the Congress is environmental work and includes significant amounts of engineering geology. The Corps sees itself as the nation's environmental engineer and working with the Environmental Protection Agency, the National Forest Service manages the largest federal environmental portfolio restoring degraded ecosystems, creating sustainable facilities, regulating waterways including permitting, managing natural resources and cleaning up contaminated sites from past military activities. Moralism and social justice are likely to challenge the 'green ethics' adopted by the Corps using the pulpit enjoyed and funded by environmentalists. Brownfields, decommissioned nuclear plants, estuaries, and formerly used defense plants all have geological implications that will be handled by military engineers (Beyr 2015).

4.8. UNEXPLODED ORDNANCE

A continuing and perplexing word challenge is the location and rendering safe left behind military munitions. Techniques of geophysics are particularly applicable to investigation as are remote sensing and data capture. Several ideas are ready for determined research by a military engineer to survey the current approaches, training and research efforts and outline complimentary strategies for render safe and force protection.

Airborne systems for mapping unexploded ordnance (UXO) and other shallow metals have been developed. Refinement, improvement and testing of the technologies are required in relevant operating conditions. In particular magnetic and electromagnetic approaches need field testing (Doll et al. 2008).

Classification and discrimination methodologies for buried munitions need to be coupled with improved sensor technologies leveraging physics-based analysis. Both the clutter problem and the false alarm rate remain problematic (Miller et al. 2011).

Mine hunting equipment suffers degraded performance, a dangerous aspect, with improper sensor positioning, low signal-to-noise ratio, or insufficient data sampling. To overcome this intensive training and simulators ae employed. Nevertheless, human factors, such as early fatigue and fear, have suggested the use of unmanned systems as a substitute for the dull and dangerous approach of manned systems. All these need significantly more attention by researchers with a personal stake in the results (Miller, Zelt, and Lutes 2013).

4.9. PROJECT MANAGEMENT AND DELIVERY OF MILITARY GEOLOGICAL PROJECTS

Engineering management has taken center stage in project delivery, risk management and cost control. It has been adopted nearly universally and is a controlling discipline for the projects conducted by military engineers. In contrast, the mining industry has researched the management of projects, risks and control suitable for unique operating conditions and risk (Freitas et al. 2017). Damage assessment studies by Chinese military engineers have applicability to the management of geotechncial projects. Project management of geological work does not strongly account for vulnerability of the geological setting. Large but unexpected grouting tasks, failure patterns of anchored tunnels subjected to explosive and seismic loads and slope stability effects on military underground engineering are areas that need some attention (Wang and Zhang 2011).

Modeling and simulation to estimate extensive grading control, drilling and characterising unknown soil properties by geostatistical methods will help military engineers plan for work in denied areas (Carpentier, Gamache, and Dimitrakopoulos 2016). U. S. forces have occupied lands and tried to dig in for protection or improve infrastructure as part of pease operations without reasonable estimations of the constrcution risks. Extending the work of the mining engineer researchers to apply to military projects with large geotechnical and geological risk is worthy of additional work.

5. PROMULGATION TO CONVINCE MILITARY ENGINEERS TO STUDY, RESEARCH AND DEVELOP THE GEOLOGICAL UNDERPINNINGS OF THEIR CRAFT

Military engineering as a practical science has few academic programs that specifically support it. Instead it is recognized that a broad array of classic civilian engineering disciplines provide a sufficient background to qualify for entry into the sub-profession of military engineering. West Point, long the source of military engineers, ended the military engineering Bachelor of Science program applied to all cadets in 1981. By 2001 all cadets had to specify a major with the assumption that the military needs an array of officers with broad liberal educations (Keith 2010). Very few universities offer a degree specifically in military engineering except Birchaum International University and Pakistan's Military College of Engineering.

Military engineering is taught as non-credit skills and knowledge – based curriculum by military services. U. S. Army Engineer School at Fort Leonard Wood, the Marine Corps Engineer School at Camp Lejeune, the Navy's Civil Engineer Corps Officer School Port Hueneme and the Civil Engineer School at the U. S. Air Force Institute of Technology Wright-Patterson Air Base serve this purpose. The Navy and Air Force programs are essentially civil engineering and generally continue to develop their engineer officers at civilian universities. The Army and Marine Corps programs primarily focus on combat engineering, which covers the duties of the early career.

Military engineers get their broadening in graduate studies and many have been led to seek degrees in engineering management or civil engineering as most applicable to their future duties in civil-public works and senior leadership positions. Both are important aspects of military engineering and worthy of study and research. Neglected to date has been the applicability of geological engineering to the military engineers' careers. Mounting a case to bring geological engineering into some balance with the other disciplines has already progressed with the Geological Engineering Program at Missouri University of Science and Technology allowing access to its Master of Sciences program for military engineers at the Captains' Career Course.

The follow on steps to this start are to provide a continuance of professional and academic development for these officers. A marked program to deepen that experience by including more research opportunities over the topics outline in Section 3 and opening of the pathway for serving military engineers to seek a Doctor of Engineering (DE) or Philosophy (PhD) in Geological Engineering is recommended.

The military engineer, not the military, chooses the course of study to pursue and indeed even chooses whether to study or not. An effort can be made to inform the choices and convince the military engineer that geological engineering is an appropriate academic pathway strongly related to the craft. An argument could be forwarded that a doctorate in geological engineering is a logical endpoint for studies on military engineering. The hypothesis depends on two key points. First is that the breadth and applicability of geological engineering to military problems is very broad, broader even than either civil engineering or engineering management. Second is geological engineering has more flexibility and hence leaves room for innovation, refinement and shaping of the discipline by the military engineer.

5.1. READINGS

Military engineers are reluctant readers by nature (Roberts 2002). They are served by an official publication, *The Engineer Bulletin*, and by several unofficial ones, *The Military Engineer*, *The Army Engineer*, *Navy Civil Engineer* and *Air Force Civil Engineer* in the United States They are coached to read by publications of the U. S. Army Engineer Commandant's reading list and the Chief of Engineers' "Bookshelf".

As a supplement to the Commandant's reading list and Bookshelf, an annotated bibliography of military geology and geological engineering writings and research has been submitted for publication in *The Military Engineer,* a periodical of the Society of American Military Engineers. The bibliography is presented as a useful reference for those engaged in study of the profession or development of future capabilities. The articles included cover the major mission areas of assured mobility, geospatial-intelligence, base camps, installation resilience and force protection. Other categories include resource development, civil infrastructure restoration or improvement, disaster recovery, engineer talent development and historical precedencies. This bibliography is included in Section 6.

Key words covered in the 100 article in the bibliography are:

- Military engineering
- Military geology
- Geospatial-intelligence
- Infrastructure recovery
- Cross-country mobility
- Assured mobility

- Base camps
- Installations sustainability
- Installation resilience
- Nation building
- Combat engineering
- LIDAR
- Deeply buried construction
- Geophysical methods

5.2. WRITINGS AND PUBLICATIONS

A series of publications covering aspects of the intersection between military engineering and the military applications of geological engineering have been prepared and submitted for publication. Each is covered in Section 6 and stand as early milestones in an extended campaign of writings by this author and others to follow. Journal articles should focus on traditional engineering lanes such as ASCE's *International Journal of Geomechanics*, *Journal of Geotechnical and Geoenvironmental Engineering*, *Leadership and Management in Engineering*, *Engineering Geology* and *The Military Engineer*. Journals articles in military practice and doctrine have influential homes in *Military Review*, *Naval War College Review*, *Strategic Studies Quarterly* and *Parameters*. Practical periodicals that reach rank and file of military engineers are *Army Engineer*, *Engineer: The Professional Bulletin of the Army Engineer*, *Navy Civil Engineer* and *Air Force Civil Engineer*. Each should be included in an enduring campaign to extend the academic and research acumen of the force.

5.3. DISCOURSES AND PRESENTATIONS

Although publications appeal to many and represent indelible records of contributions, oral presentations are frequently more compelling and reach a broader audience. This author has had the privilege to speak frequently to Army Engineers. Formal recorded presentations occurred in the 2018 graduate research poster presentation organized by the Office of Graduate Affairs and at the 2019 GSA South-Central/North-Central/Rocky Mountain Joint Section Meeting.

In balance, real persuasion comes from this authors experience in working within the Army for 30 years, the Corps of Engineers for 26 and subsequently with the university research enterprises for 16 years. Two years of intense learning and application of geospatial engineering to Army operations included the preliminary ground studies for Gulf War 2 at Fort Leonard Wood and at U. S. Central Command (CENTCOM) headquarters.

The acceptance and growth of geological engineering as a selected program of study by the military engineers in the captains' career courses at Fort Leonard Wood is significantly greater than the selection of its predecessor, Master of Science in geology. It has balanced out what once was a lopsided choice to obtain Master of Science in engineering management. Behind this change is a native recognition by young military engineers that their duties are tied to the ground. They are experiencing an Army shifting its combat approaches from management to technical and tactical. The officers' experiences in the long war of Iraq/Afghanistan show they will play multiple roles over repeated deployments and have a variety of missions that necessitate personal expertise in engineering.

The reading lists of the military engineer authorities, Chief of Engineers and the Army Commandant when taken in whole show that scholarship from military engineers has weakened over the last generation. Substantial contributions whether toward drawing out historical reviews, memoirs and personal accounts are not keeping pace with the works and lessons from other war periods. The articles submitted in the intellectual records – *Army Engineer*, *Engineer* and *The Military Engineer* fall short of scholarship in most ways. Important works at the strategic level of thinking are published in thoughtful military journals such as *Parameters* and *Military Review*. These allow senior and midcareer officers to air their observations. These latter journals are becoming dominated by geopolitical and managerial concerns rather than engineering and geological understanding. Even important works like *Military Geography for Professionals and the Public* (Collins 1998) are not mentioned in important military discourses.

Large national civil works are still being commissioned and the Corps of Engineers is still an execution agency. Yet the Corps has tacitly accepted its weakened role in engineering leadership retitling their geographic authorities from district and division 'engineer' to district and division 'commander'. The professional authority has shifted from the military engineer to contracted commercial firms and bureaucrats. A "Building Great Engineers" campaign was undertaken by the U. S. Army several years ago in hopes of reversing this trend and was successful where the effort was sustained.

PAPER

I. BUILDING A GEOINT CLUSTER IN THE GREATER ST. LOUIS REGION

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ABSTRACT

Work was published in the "US Geospatial Intelligence Foundation State and Future of GEOINT 2019". This article describes a deliberate multi-institutional approach in Greater St. Louis covering the contributions and roles of GEOINT companies, organizations and government agencies. The premise is that a significant federal reinvestment in "N2W", the new facility for NGA West, provides an opportunity to create a go to destination for the geospatial industry. It could become a center of excellence for future GEOINT innovation and tradecraft education covering tradecraft development, national security, geospatial research in biosecurity, disease treatment and outcomes, urban health, education, crime, economic development, environmental and food security, air pollution, climate response, agricultural disease forecasting, water and food security, urban development and social equity. It responds to three "2018 State and

Future of GEOINT" articles on Strengthening the St. Louis Workforce and changing the approach to preparing, training and educating a GEOINT workforce. The article describes the design to focus on growing and training internal talent pipelines and forming a regional geospatial academic consortium to support the effort with funding and resources. This is a team-written article with this author providing significant contributions including – outlining the response, using the competency model, leveraging the essential body of knowledge and laying out the stepwise planning.

1. INTRODUCTION

The greater St. Louis region has come to be known for its excellence and robust ecosystem around health care and life sciences. The region has been growing as an innovation hub for other sectors including cybersecurity and information technology. Now there is a focus on making St. Louis a go-to destination for the geospatial industry and a center of excellence for geospatial intelligence (GEOINT) innovation, tradecraft and education. The greater St. Louis region has long hosted a number of companies, organizations and government agencies that play a pivotal role in advancing the impact of GEOINT. The geospatial work occurring in the greater St. Louis area ranges from national security issues to urban planning decisions and includes a plethora of efforts like geospatial research in biosecurity, monitoring the environment for threats to human health, water supply, and agriculture, promotion of economic development, support to urban safety and distribution-of-services programs, and preparation of earth science education. The National Geospatial-Intelligence Agency's (NGA) decision to build its

$1.75 billion western campus in North St. Louis affords massive potential for economic development by anchoring the development and growth of the commercial geospatial and location based technology industry within the region. St. Louis must support the growth of a cutting-edge geospatial cluster with tools, resources and networks to encourage and incentivize innovation and entrepreneurship; attract and retain geospatial and locational expertise and research; and develop long-term strategies to leverage opportunities for sustainable, inclusive economic growth. Economic trend experts expect the geospatial industry to grow from an estimated $299.2 Billion in 2017 to $439.2 Billion in 2020, with a rapid growth rate of 13.6%—even faster than a growth rate of 11.5% between 2013 and 2017. Technological advancements and the democratization of geospatial information have accelerated industry growth. The rapid expansion of the industry is being experienced across the world, with double-digit growth in emerging markets such as Asia Pacific, the Middle East and Africa. However, North America remains the dominant economic engine of geospatial industry growth due to an innovation-centric model. The resulting exponential demand and delivery of geospatial data characterizes the "Big Data" mandate to manage and analyze the volumes of raw and processed data that are now available or can be developed.

Although the defense sector (represented primarily by NGA) is an anchor for the geospatial cluster in the St. Louis region, GEOINT and analysis is a tool for all industries including precision agriculture, oil and gas exploration, high-velocity logistics, marketing and retail, smart cities, the Internet of Things, and autonomous vehicles. The region's geospatial cluster will make possible the GEOINT center of excellence, supported by three fundamental factors:

1. A thriving educational eco-system focused on training all aspects of the U.S. Department of Labor's Geospatial Competency Model (see Figure 1.) providing a continuous, highly trained, highly qualified workforce.

2. A prosperous incubator environment supporting the creation and growth of start-up companies, small businesses, and the research and development (R&D) community.

3. A robust R&D community that continually tackles complex geospatial issues and strives to provide meaningful innovations that drive progress across the full spectrum of the geospatial industry.

To ensure the advancement of the GEOINT tradecraft in the greater St. Louis region, from which the impact extends to the state and country, a focus on growing and training internal talent pipelines is paramount. In the 2018 State and Future of GEOINT report article titled "Strengthening the St. Louis Workforce," the authors discuss the challenges presented by the constantly growing need for talent. Rethinking traditional talent curation processes and replacing them with innovative training models breaks down these barriers and produces a stronger geospatial workforce.

2. FOCUSING GEOINT TRAINING

Civilian education systems, public and private, play the role of attracting and winnowing talent into the GI&S sector and transitioning talent into the workforce pipeline. Universities expand that civilian education function in graduate schooling to deepen intellectual bases in study, to explore new potentialities in research, to distill new thought leaders for the science and application of why, where, and when, and to prepare the future academic leaders. Co-operating academic institutions throughout the St. Louis region are striving to integrate all these functions from often-disconnected, competitively pre-existing, and scattered programs. These institutions receive encouraging support from industry and community partners that come together with academia, using guidance from USGIF to form the St. Louis Area Working Group (SLAWG). Much of that guidance can be found within USGIF's GEOINT Essential Body of Knowledge (EBK), which identifies four competency areas: GIS & Analysis Tools, Remote Sensing & Imagery Analysis, Geospatial Data Management, and Data Visualization. Those areas coincide with the "Industry Sector Technical Competencies" layer of the DOL GTCM in Figure 1. The Geospatial Technology Competency Model framework was developed through a collaborative effort involving the Employment and Training Administration (ETA), the GeoTech Center, and industry experts.

Over the course of 2013-2014 and again in 2017-2018, the GeoTech Center and industry subject matter experts updated the model with guidance from ETA to reflect the knowledge and skills needed by today's geospatial technology professionals.

Each EBK competency is defined with a group of topic areas and within each of those a set of skills or knowledge points. The EBK framework is based upon capturing each phase of a GEOINT task to ensure accurate reflection of GEOINT most current practices. As an example, one might track the GIS analysis task to some specific degree or certification that requires understanding the geospatial data fusion topic, as provided by some course work—like Data Fusion 101—and which includes as a study area knowledge of metadata standards.

The SLAWG was essentially established to bring together community, government, industry and academic partners in the region to form a self-reinforcing market of programs, degrees and certifications that "fill in" the educational and training aspects of each block in the competency model. Academic institutions throughout the region are using the EBK to form a common aim point in terms of student learning somewhat akin to the current concept of "a common core." This relatively simple approach makes a consistent guide for the academic design. In parallel with teaching programs aligned to the EBK, regional institutions are incorporating more of the GTCM— blending the tools with aspects of "Industry-Wide Technical Competencies," "Management Competencies," "Workplace," "Academic" and "Personal" competencies. Increasingly, both improvisers and practitioners are diving more deeply into the human-machine system interfaces, which can profoundly affect the efficacy of the geospatial industry. Institutions through the greater St. Louis region are creating a portfolio of training and education programs for needed competencies. Multiple institutions support a diverse array of pathways, with some foundation criteria, for students to secure the talents and skills to support the GEOINT market throughout the region, state, and nation.

Geospatial education and training programs (some explicitly certified by USGIF) are used by defense, intelligence, and civil federal agencies, like NGA and the U.S. Geological Survey—both in Missouri. These programs are designed for competency in specific job tasks and are dynamically adaptive over time as technology advances and requirements are refined. Companies like Esri and ERDAS, among others, award geospatial certificates for technical competency using their tools and applications. For professional certifications, the American Society for Photogrammetry and Remote

Sensing, the GIS Certification Institute, and USGIF have established field-specific eligibility criteria and specialized testing for professionals. All these efforts help standardize expectations for recognized proficiencies.

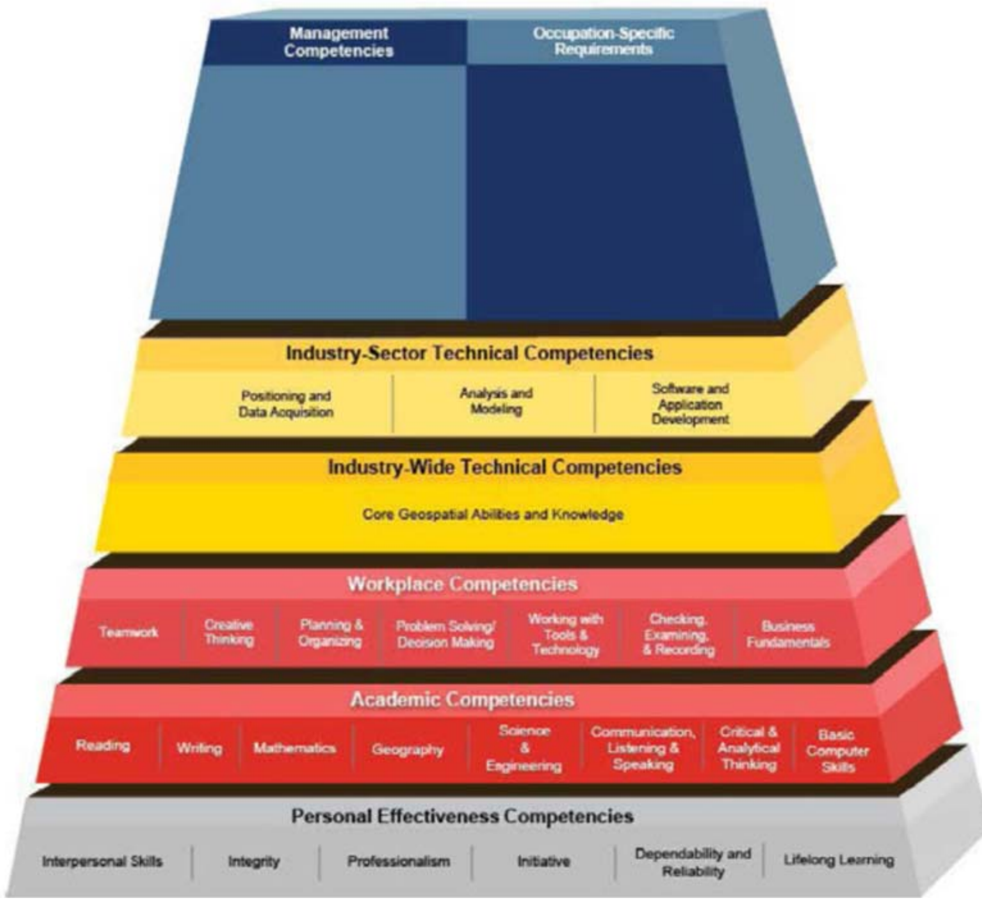

Figure 1. U.S. Department of Labor Geospatial Technology Competency Model.

3. INNOVATIVE TRAINING OPPORTUNITIES

Traditional education pathways have proven successful in producing quality GIS talent. Solidifying the St. Louis region as a GEOINT hub will require embedding some unconventional solutions. One of the nonprofits successfully providing new, non-traditional training in St. Louis is LaunchCode, which began working with NGA at the end of 2017.

LaunchCode provides instruction and courses supporting two types of developer pipelines. LaunchCode's free, intensive, six-month long "zero- to-developer" courses, LC101 and female-focused CoderGirl, cultivate a diverse, job-ready pool of junior web developers. Graduates typically have unconventional resumes but demonstrate the drive and aptitude that make great GEOINT professionals. LaunchCode's GIS DevOps course produces a second, more advanced pipeline of individuals equipped specifically with the specialized skills in high-demand by the GEOINT Community. The innovative curriculum, created by LaunchCode in partnership with NGA, Boundless, and Pivotal, blends classroom instruction and mentorship with self-guided, project-based learning. During the 10-week instruction portion of the course, students have the benefit of support and camaraderie while the five weeks spent on their projects provide valuable, real-world experience. The project focuses on using geospatial technology to create geographic and time-based trends (such as Zika virus outbreaks). Applying open-source technology in a hands-on, project-based learning environment not only promotes exploration and critical thinking by nature, it prepares students to excel in the GEOINT field by encouraging them to find the right tool for the problem at hand. Many of the emerging research trends and needs in GEOINT require innovative and cross-disciplinary tools, which proliferate in the open-source world. Students emerge as more flexible and stronger spatial thinkers, and therefore, better prepared to excel in solving real-world GEOINT challenges.

4. GROWING OPPORTUNITIES FOR GEOSPATIAL STARTUPS

The St. Louis GEOINT community is collaborative and multifaceted. About 25 possible “homes” for startups exist in the metro area, including incubators, accelerators, and co-working spaces. By May 2018, nearly 80 entrepreneur support organizations were providing funding, community support, resource networks, and advice. As the GEOINT Community grows in the St. Louis region, new organizations, programs, and events have created a community of practice around geospatial research and technologies. Two key sites characterize the eagerness of the St. Louis region to support a geospatial center of excellence. Just four miles from Downtown St. Louis, the Cortex Innovation Community is a 200-acre urban innovation district in midtown St. Louis focused on the generation and growth of tech-based businesses and jobs. Cortex is home to 350 jobs and about 4,500 employees. A significant number of companies in Cortex use and/or develop geospatial technologies, including Esri, Boeing, Aerial Insights, Microsoft, and aisle411, among others. Cortex also hosts several innovation centers and activities that support startups and entrepreneurs with space, mentoring, funding, networking opportunities, and other resources. The Cambridge Innovation Center (CIC-St. Louis), for example, continues to expand a community of entrepreneurs by offering low-cost space and memberships for startup companies and corporate project teams. Venture Café, St. Louis' flagship event, is the Thursday gathering that regularly attracts more than 500 attendees to informally reinforce creativity and entrepreneurship. Accelerators such as Capital Innovators fund cohorts of companies from all over the world. These Cortex-sited initiatives encourage the St. Louis Region cluster concept.

T-REX is a 501(c)3 non-profit innovation center in downtown St. Louis that provides incubator, co-working, meeting, and event space to entrepreneurs; programming to support technology entrepreneurs; and a community and network of support to assist tech-focused startups. T-REX is home to several startup accelerators as well as nonprofit funding and support organizations focused on technology entrepreneurship. But the organization offers more than just office space. It is a rare combination of an extraordinarily diverse community, valuable programming, and entrepreneurial culture. T-REX has developed special relationships with NGA and the GEOINT Community, including important R&D initiatives the community can most productively conduct in unclassified spaces. A Memorandum of Agreement between USGIF and T-REX also brings significant activity with NGA and the geospatial industry to the T-REX facility. T-REX's momentum in advanced information and intelligence technology innovation provides an excellent foundation for the R&D of a geospatial innovation hub. The organization is completing a $10 million capital campaign to renovate its historic downtown facility and is in the process of upgrading space its 160,000 square-foot building. As part of its renovation plan, T-REX will build and outfit a Geospatial Resource and Innovation Center to support the growing geospatial cluster.

5. ANOTHER DIMENSION TO INNOVATION

Throughout the St. Louis region and across the state, various entities, including but not limited to, large companies, small businesses, NGA and academic institutions are conducting numerous R&D efforts that are pushing the limits of geospatial science. The R&D footprints of Cortex and T-Rex warrant attention for the cluster concept mentioned earlier but notable R&D advances in other locations. As another example, Saint Louis University's (SLU) sponsors a number of initiatives to grow geospatial research, and innovation, while also educating the future entrepreneurs and workforce. GeoSLU is an internally-funded initiative, recognizing the interdisciplinary scope of remote sensing and GIS, that coordinates and expands the geospatial capabilities across the university in Earth & atmospheric sciences, biology, computer science, civil engineering, epidemiology & biostatistics, aerospace and mechanical engineering, political science, chemistry, and the school for public health and social justice. GeoSLU is also developing the business model for a planned Geospatial Institute at SLU that will coordinate geospatial research efforts across the university, provide data analysis and mapping support, coordinate community outreach and geospatial workforce development, and grow training, degree, and certificate offerings in geospatial and allied domains. SLU is pioneering research on drone technology, remote sensing, open-source indicator and predictive tools, and educational research. The university is coordinating with the St. Louis community to integrate the emerging SLU Geospatial Institute with the growing St. Louis area geospatial enterprise through a new Cooperative Research and Development Agreement with NGA, participation with Arch-to-Park, presence at T-Rex and Cortex, and the GeoSLU Advisory Board of local business leaders. NGA and SLU are co-sponsoring a new geospatial conference in Saint Louis to bring together government, academic, and industry partners who can grow the region's geospatial enterprise.

6. CONCLUSION

The greater St. Louis region and state of Missouri are steadfast in their intent to serve as a center of excellence for the geospatial industry, where leading companies look for geospatial expertise, talent stability, idea stimulation, business magnetism, and information protection. When NGA chose St. Louis for its future state-of-the-art facility, the city, region and state along with numerous companies, academic institutions, and non-profit organizations made a commitment to succeed on many social, educational, economic, environmental, security, and political levels. This success will reap merits globally as the St. Louis region takes its deserved position as an acknowledged center of geospatial excellence.

II. THE TRADECRAFT OF ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING

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ABSTRACT

Geospatial intelligence changes to tradecraft with the introduction of artificial intelligence and machine learning was published in the US Geospatial Intelligence Foundation State and Future of GEOINT 2019 this article describes the dynamics nature and innovations that provide new ways to practice GEOINT. Fundamental challenges posed by the integration of Artificial Intelligence (AI) and Machine Learning (ML) and an expected paradigm shift in comparison to previous technical innovations that dramatically changed and advanced the tradecraft. Implications in weak and strong AI, trustworthiness, human-machine interactions, teaching geospatial intelligence, coding and implied additional innovations are covered. The article addresses integrating and adapting existing skills and expertise in programming or coding, process management, quality management, testing and evaluation, and algorithm development / mathematics.

1. INTRODUCTION

The tradecraft of geospatial intelligence (GEOINT) is always evolving. However, the integration of artificial intelligence (AI) and machine learning (ML) into GEOINT tradecraft presents a significant paradigm shift, and like previous technical innovations that dramatically change and advance the tradecraft, a thoughtful, broad-reaching approach to the adoption of these technologies is necessary. AI and ML go beyond the introduction of technical innovation such as the conversion of film and print media to digital media or 3D stereoscopic capabilities.

The introduction of AI and ML into GEOINT will cause analysts and practitioners to interact with technology in a new way. In addition to learning new technical skills they will learn to teach geospatial science to AI. They will also oversee geospatial workflows and practices to determine where AI and ML can be inserted into processes to provide automation and augmentation. The merger of AI and ML within the GEOINT tradecraft will continue to advance toward a place in which its practitioners possess the knowledge and skills to be a steward of the GEOINT practice and the practitioner can leverage AI and ML to create new points of innovation. In the early stages of this inclusion of AI and ML we can already identify strong steps being made where Data Scientists work alongside GEOINT analysts to achieve mission outcomes.

2. INCORPORATING INNOVATION

The defense and intelligence communities have previously described enhancements of system performance and functionality in existing or deployed capabilities by inserting new or significantly improved technology. A vertical insertion enhances a single capability from bottom to top at components, equipment, subsystems, systems, system of systems, and kits. A horizontal insertion is the utilization of a new or improved technology in similar but distinct platforms or disciplines. The GEOINT Community should view the incorporation of AI and ML as the latter. Historically, horizontal insertion of new technology can require a full generation to achieve. This is caused by an insertion model that waits for senior personnel to retire and entry-level personnel are the focus of training on the new technology. The GEOINT Community does not have a full generation to incorporate AI/ML technology. Insertion of AI/ML within the GEOINT tradecraft must move faster to keep pace with the exponential growth of data collected and to stay a step ahead of U.S. adversaries. If the GEOINT Community waits a generation to fully incorporate AI/ML, we will become irrelevant (and perhaps be dominated by our adversaries). Thus, new and aggressive education and insertion models must be adopted.

Recent history provides many examples of new technologies being adopted for national security purposes. Often, complex scientific and engineering concepts have been translated into layman's terms to enable training forces to employ new weapons or new enabling capabilities. For example, maritime navigation is based on geophysics and other scientific principles that might require an advanced degree to fully comprehend. Yet, the

National Geospatial-Intelligence Agency (NGA) and its predecessor organizations have for years produced a widely used reference for laymen without such advanced degrees who successfully navigate the world's oceans. The adoption and operational employment of RADAR in World War II and the operational deployment of nuclear weapons after World War II provide other examples. In each case, doctrine, training, and procedures had to be developed and implemented to allow airmen, sailors, marines, and soldiers with relatively little scientific or engineering knowledge to successfully operate complex and potentially lethal systems. To be successful, the GEOINT Community must create a culture within the tradecraft in which analysts and practitioners come to trust automated systems. It must cultivate a culture that has an eagerness to use AI/ML to replace manual, human-driven processes. The GEOINT Community must grow beyond its current educational programs and credentials to include new skills and knowledge. It must integrate the skills that support AI/ML within existing education and training programs. To achieve accelerated adoption of AI/ML, the GEOINT Community requires a multiechelon educational offering related to AI/ML technology.

3. EDUCATION ECHELONS

These echelons are nested such that tradecraft practitioners at various seniority levels and of varying types of expertise receive tailored education and training that provide them the skills to employ AI/ML approaches such as using database platforms, structuring data warehouse environments, information storage and retrieval systems, web search engines, text mining, collaborative filtering, and recommender systems. These entry-level tasks may be appropriate subjects for instruction at the associate degree-level or in the form of industry certifications focused on specific hardware and software. These base-level skills in both hardware and software have a shorter shelf life due to constant improvement and rapid expansion. At the next level up are the data scientists. They are likely to need a mix of bachelor's and master's degree-level understanding of regression, classification, resampling methods, model selection, regularization, decision trees, support vector machines, principal component analysis, and clustering. Analysts who draw on data science talent must first know the GEOINT domain and will succeed through collaboration with data science models and tools. GEOINT analysts in collaboration with data scientists will need to draw upon their combined talents and expertise to operate AI/ML comfortably across the GEOINT mission.

Beyond analysts, the top-echelon of decision-makers will require special instruction and education. Executives are drawn from many disciplines and don't necessarily lead the ranks they grew up in. It is more likely they have a variety of experiences in many fields and will have to be coached, more than educated, in how to best understand AI/ML-derived interpretations. Here the transition state equals the end state. High-level decision-makers are to be helped by learning an overarching understanding of the tradeoffs of using AI and ML, understanding the nuance associated in accepting AI/ML-augmented processes and products, and being prepared to invest in the maturation of the art and science of interpreting data via machines.

At the outset of using AI/ML within GEOINT processes, analysts, engineers, supervisors, and executives all need to understand that a product or recommendation for decisions based on AI/ML-dependent analysis should be treated with caution, possibly needing more verification by experienced humans until a consistent record of prediction has been statistically correlated with established tradecraft techniques. At the same time, these practitioners must be given training that allows them a depth of understanding that supports a willingness to invest in refining processes, algorithm development, datasets, etc. Additionally, this education needs to provide the fundamental acumen on which they can measure the maturity of the inserted AI/ ML technology.

At another scale, an analyst should have a very different training in the AI/ML system—perhaps how it is coded, or the selection of filters, the segmentation of data, the speed of analysis, and the comparison of error. Within the GEOINT Community each practitioner (i.e., manager, engineer, data scientist, and analyst) must work together, leveraging their different skills and expertise to improve the technology through methodologies such as mining, scraping, manipulating, transforming, cleaning, visualizing, summarizing, and modeling large-scale data as well as supervised and unsupervised machine learning algorithms applied in various mission scenarios.

AI and ML have the potential to greatly improve the productivity, capacity, and capability of GEOINT analysts, enabling them and their organizations to capitalize on the ever-increasing amount of data available. In the near-term, advances in computational power, artificial neural networks (ANNs), and computer vision enable new approaches to GEOINT tradecraft. NGA Director Robert Cardillo has said eight million more GEOINT analysts would be needed to analyze all the data expected to be available as remote sensing systems and other geospatial data sources proliferate. Since educating, training, and employing millions of additional GEOINT analysts is unlikely if not impossible, incorporating AI and ML into GEOINT tradecraft might help us keep up. But discussions of how to best incorporate AL and ML into GEOINT tradecraft can reveal disparate views.

Some assert that anyone wishing to apply AI/ML must have an advanced degree in computer science, math, or statistics and be proficient in coding and writing software. The thinking is it would be dangerous for anyone without such education and skills to apply AI and ML. Such an approach would certainly provide practitioners greater confidence in applying AI/ML to GEOINT tradecraft, but it would likely also significantly slow speed of adoption. We might also find that people eager to be GEOINT analysts don't necessarily have the same passion for being computer scientists or mathematicians.

In order to successfully determine where AI and ML can be inserted into GEOINT processes, engineers and practitioners tasked with its implementation or development need to gain a substantial understanding of the fundamentals of AI/ML algorithms. This typically requires a solid background in probability and statistics, linear algebra, and calculus. Proficiency in probability and statistics is not only important for engineers who want to understand and implement AI/ ML methods, but it is also a critical skill for analysts and end users who apply AI/ML methods—even if the methods themselves are treated as a black box. Users of AI/ML techniques need to understand, interpret, and judge both input and output to AI/ML algorithms applied to practical problems.

The educational echelons of the GEOINT Community will need to ensure fundamentals such as linear algebra and calculus, which are foundational to the understanding of AI/ML algorithms. Conversely, the developers and Robert Cardillo, Director of the National Geospatial-Intelligence Agency, remarks delivered at the GEOINT 2018 Symposium, 23 April 2018, available at https://www.nga.mil/MediaRoom/SpeechesRemarks/ Pages/GEOINT-2018-Symposium-.aspx. engineers tasked with implementation of AI/ML technology, whether from scratch or existing implementations, are approaching AI/ML from a computer science perspective. They require proficiency in data structures and algorithms (including complexity analysis).

As there is no one ML method that solves all problems, engineers will have to acquire a basic understanding of the strengths and weaknesses of the state of-the art methods. Further, it is important to understand the ML workflow and how to evaluate and compare algorithms in a sound and scientific manner as well as how to internalize the process of comparing and evaluating algorithms on various application domains. Engineers will have to dive deeper into the learning algorithms that typically leverage non-linear optimization and advanced calculus. At the core is a focus on understanding, implementing, and analyzing AI/ML algorithms, however related fields of study such as computer vision, big data processing, and cloud computing should be considered in a holistic AI/ML education.

By recognizing the different needs of GEOINT Community, a multi-echelon educational approach advocates teaching AI/ML as a series of courses or programs that allow students to achieve the level of familiarity with AI/ML methods their role within the GEOINT Community requires. Providing multiple courses, paths, and tracks covering the introduction of AI/ ML at undergraduate and graduate levels ensures the variety of roles, positions, and seniority levels within the community are provided the education and training needed to successfully adopt AI/ML.

4. GROWING CONFIDENCE IN AI/ML

The community is in the early phase of applying AI/ML to GEOINT tradecraft. Defense and intelligence organizations such as NGA have pilots underway that should shed light on the best approaches. These pilot programs have helped reveal and identify challenges in inserting AI/ML into GEOINT workflows. Some of these challenges include but are certainly not limited to data scarcity, lack of data diversity, difficulty in scaling AI/ML, and legacy systems that were designed around human perception and performance. Each of these challenges must be overcome to fully realize the benefits of AI/ML.

However, perhaps the greatest challenge from the perceptive of the GEOINT tradecraft is that of confidence in use of the emerging technologies. AI/ML offers a future in which analysts are freed from much if not all of the manual data management tasks that consume a large amount of their time. They are freed from tasks such as data labeling and allowed to focus on mission-related analysis and production. However, those analysts must have confidence in the AI system.

5. CONCLUSION

In these early days of applying AI/ML to GEOINT tradecraft, it seems teaming analysts with data scientists is yielding successes. The GEOINT analysts have seen significantly increased productivity and are confident in applying ML to their analytical problems. Today, GEOINT analysts participating in these pilot programs depend on close collaboration with data scientists. The data scientists develop models and implement ML algorithms. GEOINT analysts work with the data scientists to help validate the models but the data scientists do the development and write the code. The collaboration seems to be instilling a level of understanding and confidence in AI/ML. In the longer-term, when AI/ ML tools and processes are implemented at an enterprise scale, the GEOINT Community will need to determine how to build confidence in its analysts and leadership and determine whether constant collaboration with data scientists will diminish over time or become an institutionalized change within the community's tradecraft.

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III. THE ARMY IS ALWAYS IN NEED OF WATER

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ABSTRACT

Water for the Army is an article that explores current applications of environmental geology applied to contemporary military field operations. Published in the summer of 2018 in *Engineer The Professional Bulletin of Army Engineers*. the article described the deployable baffled bio-reactor offered by Tricon and Frontier Environmental Technology LLC and its experimentation with Contingency Base Integration and Technology Evaluation Center and the Construction Engineering Research Laboratory at Fort Leonard Wood. It offered the tradeoff of treated and captured water instead of more groundwater development. It went into detail on water needs by quality and quantities in basecamp situations.

1. INTRODUCTION

In the spring of 2015, Frontier Environmental Technology, LLC assembled the Tricon deployable Baffled Bioreactor (dBBR) © at Fort Leonard Wood, Missouri. The system removes nitrates, phosphates and biomass from sewage and releases incredibly clean effluent. System highlights include ease of deployment, ease of operation, and minimal energy use. The dBBR performed as expected, producing effluent that surpassed Army requirements.

The dBBR was selected for further testing at Fort Bliss, Texas, during the fall of 2015. Using newly trained Army personnel, the innovative dBBR treatment capability performed wonderfully and exceeded Army test requirements.

2. DEMONSTRATOR

A larger–size dBBR, made from a 20-foot-long shippingcontainer, is currently being demonstrated in the 15-home Southwood II Subdivision in Rolla, Missouri. This dBBR operates only 8 to 10 hours per day and is on “sleeping” mode (a unique feature of the dBBR to save energy during low-flow periods) the rest of the time. The effluent from this 20-foot dBBR meets Army standards for discharge as well as the more stringent requirements set by the Missouri Department of Natural Resources. The permit requirements and actual dBBR effluent data are provided in Table 1.

The deployment of this technology should fit well with the base sustainment strategy developed by the Contingency Base Integration and Technology Evaluation Center and the Construction Engineering Research Laboratory. It is important to realize that many communities across the Nation that were hit with devastating floods and hurricanes could benefit from the dBBR as a means of emergency wastewater treatment. The dBBR could also be deployed to refugee camps.

Table 1. Concentrations of biological oxygen demand, total suspended solids, and ammonia from the dBBR operating in Rolla, Missouri.

Date	BOD_5 (mg/L)	TSS_5 (mg/L)	Ammonia (mg/N/L)
11 October	2.0	1.8	0.45
25 October	2.0	1.8	0.16
9 November	2.4	1.8	0.11
24 November	2.4	5.0	0.10
7 December	2.5	5.6	0.37
21 December	1.3	0.6	0.05
Permitted	**30**	**30**	**2.9**

Legend:
5 - five-day average
BOD - biochemical oxygen demand
mg - milligram
L - liter
N - nitrogen
TSS - total suspended solids

Currently, our deployed forces are typically provided with water produced by reverse-osmosis (RO) technology. This energy-intensive technique supplies potable water for cooking and non-potable water for showers, laundry, and latrines. This process of water production is extremely costly in a monetary sense. Given certain assumptions of generator size and efficiency, about 200 gallons of diesel fuel are required to generate the electricity needed to produce 2,500 gallons of water using RO.

RO systems must be back-flushed, releasing highly saline water that must be stored in a holding pond on base. The pond must be dug and secured. The water is then allowed to evaporate or slowly migrate into groundwater systems, where it can become an environmental hazard. More importantly, the number of causalities inflicted on troops bringing fuel and water to a base is very high. Therefore, there is a desire to reduce the fuel and water requirements on base.

There is no requirement to provide water that has been treated with expensive RO technologies to a latrine. The dBBR can produce this water. The dBBR produces effluent that can be used directly or disinfected to meet the health requirements for consumption. The use of recycled water is termed "purple pipe" reuse. Figure 1 shows the typical purple pipe base camp system for the reuse of water. The average person uses a latrine 10 times a day. It takes about 1 gallon of water to flush a urinal and about 1.5 gallons to flush a stool. So, if we assume an all-male unit with 100 personnel, the water use should be from 11 to 15 gallons per person per day, or a total of 1,500 gallons per day, that are not required to be produced by RO technology. Purple pipe reuse creates a nearly closed-loop, self-sustainable latrine water system. Although a certain amount of dBBR water must be wasted through the sludge-producing process, this water loss is minimal because nearly all the sludge is digested within the dBBR. For some field dBBR installations, sludge has not had to be removed for several years, resulting in no waste. In addition, make-up water from other sources such as gray water from the laundry room, black water from the dining facility, and harvested rainwater is added to the treatment system. Therefore, the dBBR can supply enough water for a camp's latrine use.

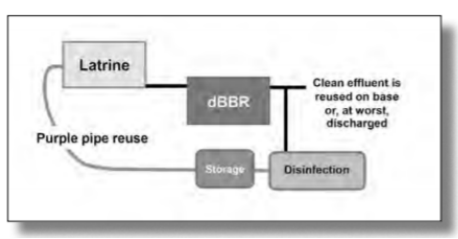

Figure 1. A simplified diagram of a "purple pipe" system of water reuse demonstrating a sustainable wastewater recovery system that saves thousands of gallons of processed water.

In many areas, harvesting water can be a significant contribution to the water budget. Therefore, the placement of gutters on buildings to harvest rainwater is the next engineering feat to be championed. In some arid locations, this may have limited utility but would still be useful to minimize erosion from sudden intense storms. In other areas, the water harvest could be significant. For example, a barracks hut (B-hut) has a footprint of 512 square feet. If we assume a 1-inch rain, the single B-hut harvests some 300 gallons of water. Although B-huts hold 10 enlisted Soldiers, senior noncommissioned officers (NCOs) and officers are allowed more space. Therefore, per space requirements, 100 Soldiers equates to some 14 B-huts. Given about the same number of square feet for work and equipment storage, 35 B-hut equivalent structures (sleeping, mess, maintenance, latrines, laundry, storage, and work areas) would be required. This roof area would harvest about 10,000 gallons of water. This engineering solution is shown in Figure 2.

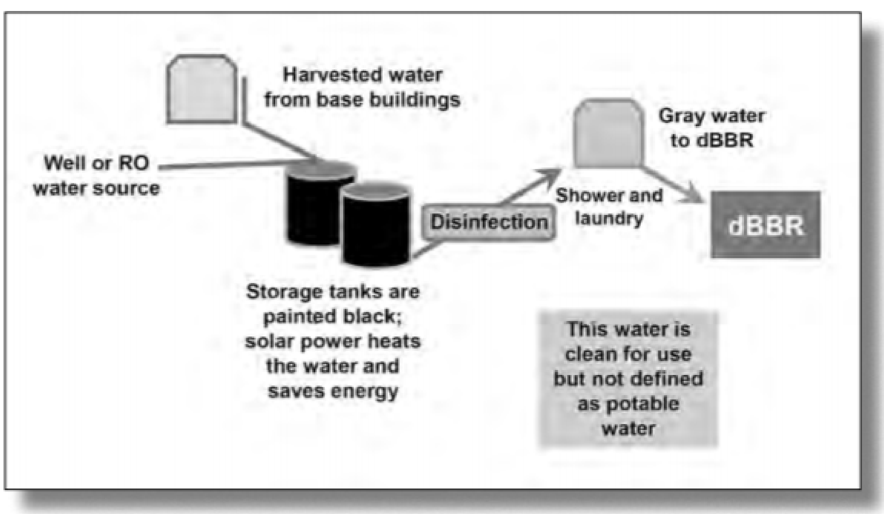

Figure 2. The ability to harvest water on a base greatly reduces the amount of potable water required for daily activities.

Now, let's assume that the command restricts showers to 3 to 5 minutes; given a 2-gallon-per-minute flow rate, an individual uses 10 gallons of water per shower per day at most. This is a 1,000-gallon-per-day requirement. Given a 10,000-gallon rain harvest, the camp has some 10 days of non-processed water or "free water" showers. This saves a lot of water, which saves energy and requires fewer convoys on the road. Fewer convoys reduce Soldier causalities related to moving materials to the base.

Laundry also consumes large amounts of water. Washers typically use 15 to 30 gallons of water per load. Let's assume that the typical male Soldier does two loads of laundry per week. Let's further assume that the Soldier uses 25 gallons of water per load, or 50 gallons of water per week per Soldier. For 100 Soldiers, this would be 5,000 gallons of water per week. 5,000 gallons divided by 7 days per week yields 714 gallons per day. Other typical water assumptions include: 1 gallon per day per Soldier for personnel hygiene, or 100 gallons total; 1 gallon per day per Soldier for drinking, or 100 gallons total; at least 400 gallons total per day for food preparation and clean up; 100 gallons total per day lost to leaks and dripping pipes; and some 200 gallons total per day for mopping and latrine cleaning. This equates to an estimated water budget that hovers around 26 gallons per day per Soldier. If shower length and quantity of laundry are not strictly controlled, the water use rate will quickly approach 50 to 60 gallons per day per Soldier. If we consider a unit with females, water use goes up due to the use of stools rather than urinals and an increase in laundry loads per week.

Studies show that using a dishwasher is generally more water-efficient than hand-washing dishes. The use of lightweight, nearly indestructible plates, bowls, cups, glasses, and metal utensils results in a one-time purchase and haul, whereas a continual influx of non-reusable paper, Styrofoam products, and plastic ware requires repetitive buying and resupplying. Non-reusable products also require a large amount of covered storage space and a considerable labor force to stock and move the items. Furthermore, the solid waste generated by mess operations must be either hauled away and burned off-base (at some expense) or burned on base in an open burn pit. The burning of No. 3 plastic or polyvinylchloride (PVC), which make up a significant portion of product packaging, is hazardous. These materials react with soot in low-temperature burns to create dioxins and furans—both of which have been shown to cause cancer and are surely contributing factors in respiratory illness. Therefore, to reach self-sustainability goals, it is important to plan for the use of dishwashers in base camps.

There is a great benefit in using dishwashers on a base of 100 Soldiers. In such situations, dishwashers alleviate the generation of nearly 300 pounds of solid waste in the form of non-reusable plates, bowls, cups, glasses, and packaging per day (Figure 3).

Figure 3. Daily trash collection at New Kabul Compound, Afghanistan, in 2010. The black trash bags are predominately dining facility paper ware, and the preponderance of cardboard is the packaging for the paper plates.

The water that is used on a base is either produced from a well or from a surface source—and then it is usually run through an RO process. However, the 1,200 gallons needed to flush the toilets on a 100-Soldier base per day is not required to be generated by the costly RO method since that water does not need to be disinfected to meet potable water standards. Instead, assuming that everyone eats every meal and dishwashers and rinse water use are efficient, only some 350 to 400 gallons of potable water are required per day for a 100-Soldier unit. By using the dBBR, the base can recover well over 95 percent of the gray and black water generated and return it to the purple pipe system. One day of dBBr effluent reuse saves enough water to supply 3 days of dishwasher use.

Studies have shown that military convoys typically convey 50 percent fuel, 20 percent water, and 30 percent other material. The metrics vary as to number of casualties generated by gallons of fuel delivered or number of convoys; however, reducing the number of convoys is the ultimate goal. Figure 4 shows an integrated approach to water use that greatly reduces the amount of fuel and new water needed to be hauled to a base. Using black tanks for water storage allows solar energy to warm the water. Using photovoltaic panels reduces energy needs that are normally met by burning fuel that is convoyed onto a base. Due to the low energy requirement of the dBBR (2–3 watt-hours per gallon of water treated), the electricity produced by a reasonably sized photovoltaic assembly can be used to power the dBBR for water production—at least on clear days.

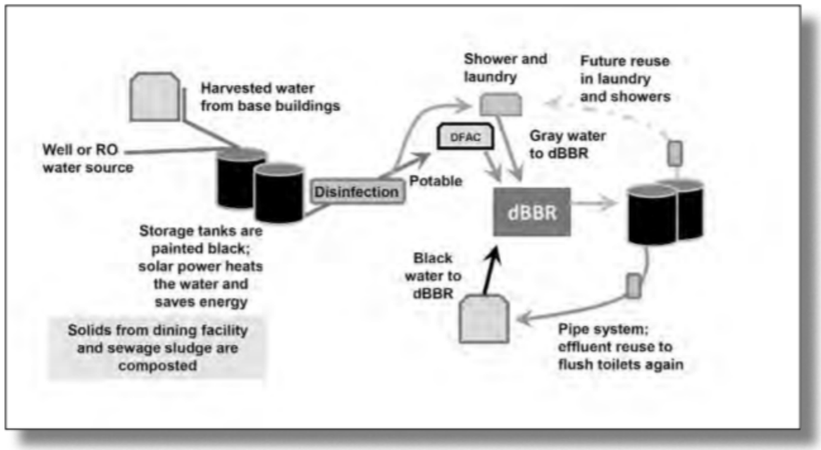

Figure 4. Base camp water treatment and reuse strategies

An innovative method of filtering dBBR effluent water combines Hesco® bastions and engineered piping, shown in Figure 5. The bastions, which are stacked inside the perimeter for security, are useful for water harvesting, producing electricity with photovoltaic-containing tarps, running pipes under the tarps to heat water, and using solar panels to further heat water.

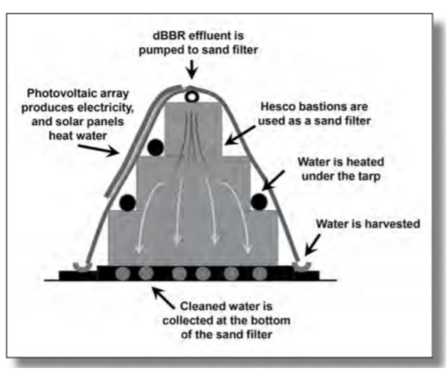

Figure 5. Cross section of a Hesco bastion dBBR effluent sand filter, photovoltaic and solar panel support system, and water-harvesting site.

3. CONCLUSION

The dBBR has outstanding wastewater treatment capabilities that greatly exceed Army wastewater effluent standards. It is time to begin using proven technology and innovation to build more self-sustaining bases. Coupling trained, uniformed engineers and geoscientists with innovative technology will improve camp function. The dBBR provides a quality effluent that can be disinfected and reused in a purple pipe system to flush toilets over and over, saving thousands of gallons of water per week on even small bases. This savings removes any excuse for omitting dishwashers from bases. This small policy change would virtually remove tons of paper, plastic, and Styrofoam ware that is thrown out each day, helping to resolve the monstrous solid waste management issue on our camps. Of course, this wasted material must be brought in and stored at a significant cost in money, material, and Soldier casualties. Burning this refuse causes health issues for personnel near the burn pits. The reduction of water use further reduces the need for fuel to pump water from an aquifer or treat water through RO. Who would have imagined that deploying a highly efficient, extremely low-maintenance wastewater treatment system could reduce the amount of fuel required on a base while also virtually eliminating the solid waste management issues experienced on our current bases? It is time for the Army to begin to incorporate the dBBR in planning and deployment practices as the linchpin to make more self-sustaining base camp infrastructure a reality. Bringing more Soldiers home without injuries to lungs and limbs must be our goal, and the humble dBBR is that bridge to base camp self-sustainment.

REFERENCES

1. Tucker, Robert, et al, “Wasting Less Water” *Engineer*, May–August 2016, pp. 46–48.

2. Tucker, Robert, “Military Toxic Exposure: Burn Pits” 15 April 2018, <https://cck-law.com/news/Military-toxic-exposure-burn-pits>, accessed on 10 May 2018.

IV. ANNOTATED BIBLIOGRAPHY FOR MILITARY ENGINEERS

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ABSTRACT

An annotated bibliography of military geology and geological engineering writings and research is presented as a useful reference for those engaged in study of the profession or development of future capabilities. Rather than comprehensive, this is meant as a selected list. The articles included cover the major mission areas of assured mobility, geospatial-intelligence, base camps, installation resilience and force protection. Other categories include resource development, civil infrastructure restoration or improvement, disaster recovery, engineer talent development and historical precedencies. For the purpose of future updates, the author solicits contributions of articles that may have been missed in the preparation of this bibliography.

1. INTRODUCTION

US Army Engineer Commandant's reading list and the recommended publications from the Corps of Engineers history office (Bookshelf) relates the documented history of wars, battles, memoirs and philosophies. As such, it reveals select experiences useful for comparison and contrast to contemporary circumstances.

In contrast, this annotated bibliography is intended to be a useful for those engaged in extending and updating American military engineering from a geological perspective. This is a selective list that springs from the author's investigation into technical aspects of military engineering, including combat and geospatial engineering, force protection and transportation engineering and realization that military engineering is heavily dependent on the ground, surface and subterranean, and its strengths, risks and economic impact.

2. SUGGESTED READINGS

The following works are suggested professional updates for the military engineer.

- Aikins, M. (2010). The Treasure of the Humble. Popular Science, (September), 4–9. Military experience in Afghanistan came on the heels of the Russian invasion of that land and systematic attempts to find and exploit the mineral wealth. Aikins is an easy read for the military engineer who may be asked to opine on artisian mining and the Pentagon conspiracy to steal Afghanistan's natural resources ala USSR in the 1980s.

- Allan, T. (2001). Middle East Water Question, The. London, UNKNOWN: I.B.Tauris. This work was written between the Gulf Wars and would be a useful scan for the purpose of (a) introduction to MENA (b) water as a geopolitical issue and (c) seeing some tricky thinking about accounting for virtual water and environmental approaches.

- Amos, W., Evgeniy, T., & Anderson, N. (2009). Bridge deck assessment using ground penetrating radar (GPR). In Proceedings of the Symposium on the Application of Geophyics to Engineering and Environmental Problems, SAGEEP (Vol. 2, pp. 671–687). (Amos, Evgeniy, & Anderson, 2009) looks into bridge decks and how they fail. The mechanisms and diagnosis of the problems is of real value in this work - the GPR discussion describes the state of the art at the time of writing.

- Andersen, M. C., Thompson, B., & Boykin, K. (2004). Spatial risk assessment across large landscapes with varied land use: Lessons from a conservation assessment of military lands. Risk Analysis, 24(5), 1231–1242. This work, Andersen, Thompson & Boykin, answered White Sands Missile Range and Fort Bliss assessment need for management of threats to biodiversity using USGS/Army GIS-based spatial decision-support tools for spatial habitat models, land-use scenarios, and species-specific impacts. Military engineers are sometimes charged to carry out the environmental stewardship of training lands.

- Anderson, N. L., Ismael, A. M., & Thitimakorn, T. (2007). Ground-penetrating radar: A tool for monitoring bridge scour. Environmental and Engineering Geoscience, 13(1), 1–10. Anderson, Ismael & Thitimakron used ground-penetrating radar (GPR) across shallow streams and/or drainage ditches - recorded by moving antennae, not touching the water, from bank to bank monitoring water depths.

- Ayyub, B. M., Braileanu, H. G., & Qureshi, N. (2012). Prediction and Impact of Sea Level Rise on Properties and Infrastructure of Washington, DC. Risk Analysis, 32(11), 1901–1918. Ayyub, Braileanu & Qureshi used GIS and graphical visualization to make some guesses about global warming's sea-level rise effects on Washington DC.

- Balbach, H., Goran, W., & Latino, A. (2014). From protection to projection: An overview of location considerations for U.S. military bases. Reviews in Engineering Geology, 22, 27–38. Balbach, Goran & Latino, is part of an edited volume Military Geosciences in the Twenty-First Century. This is worth a thoughtful read rather than a quick scan as it sets context for the selection of locations for US military bases, past, present and future.

- Baraboshkina, T., & Kuznatsova, A. (2014). GEOCHEMICAL FACTORS OF SOCIALLY-ECONOMICAL RISKS IN NORTHERN EURASIA. Proceedings of the International Multidisciplinary Scientific GeoConference SGEM, 2, 393–400. Engineers get to clean up after disasters including flood; earthquakes; spills; harvest loss; forest clearing; and water shortages. Hazardous areas are then susceptible to erosion, slides, earthquakes, or other geological processes. This study looks at northern Eurasia to create a system of 'geoindicators' to reduce risk of the disaster rather than focus on negative geochemical, geophysical effects.

- Baranoski, E. J. (2008). Through-wall imaging: Historical perspective and future directions. Journal of the Franklin Institute, 345(6), 556–569. This article although a bit dated is a good layout of where DARPA is on getting military engineers the see through the wall capability.

- Barbour, P. E. (1917). Notes on military engineering. Journal of the Worcester Polytechnic Institute. Barbour wrote and illustrated this WWI trench construction and considerations which still has some applicability to field fortifications. He was a first lieutenant at the time studying at WPI.

- Barry, B. E., White, G. K., & Ozer Arnas, A. (2011). Engineering ethics education: A military academy point of view. In 24th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, ECOS 2011, July 4, 2011 - July 7, 2011 (pp. 177–185). Novi Sad, Serbia: Nis University. Setting the standard for ethical considerations in military engineering Barry, White & Ozer Arnas has a certain authority to it from West Point approaches.

- Bauer, S. J., Ehgartner, B. L., & Neal, J. T. (1997). Geotechnical studies associated with decommissioning the strategic petroleum reserve facility at Weeks Island, Louisiana: A case history. United States. The Navy was asked to help develop the strategic oil reserve and used geological reservoirs for the purpose. This forensic case, one that went wrong and had to be abandoned, is a fair primer on what to look for in such cases.

- Berry Jr, T. E., Morgan, J. C., Furey, J. S., Demoss, T. A., Kelley, J. R., & McKenna, J. R. (2012). Extensive goniometric spectral measurements at desert sites for military engineering. In Reflection, Scattering, and Diffraction from Surfaces III, August 13, 2012 - August 16, 2012 (Vol. 8495, p. The Society of Photo-Optical Instrumentation Engin). San Diego, CA, United states: SPIE. Berry has an intimidating title - but in short form the report is about IR being able to pick up on disturbed soil very quickly and tell where there has been military activity.

- Bertha, C. (2014). Ethics and military engineering operations. In 2014 IEEE International Symposium on Ethics in Science, Technology and Engineering, ETHICS 2014, May 23, 2014 - May 24, 2014. Chicago, United states: Institute of Electrical and Electronics Engineers Inc. Betha gives an Air Force Academy take on military engineer ethics based on experiences in Afghanistan. His external explanation of Army engineering to his Air Force audience is a helpful perspective.

- Black, W. M. (1916). Military service for civil engineers. Connecticut Society of Civil Engineers. Colonel William Black gives a lecture to civilian engineers with the aim of getting them involved in the looming WW1 'over there' operations anticipated. In this very readable work one gets a sense of the state of engineering and construction.

- Bozzano, F., Cipriani, I., Mazzanti, P., & Prestininzi, A. (2014). A field experiment for calibrating landslide time-of-failure prediction functions. International Journal of Rock Mechanics & Mining Sciences, 67, 69–77. A math/technical heavy approach but the value, to the military engineer, is describing techniques and successes in estimating when slopes will fail, how they fail and what changes with mitigation activities. Those engineers charged with estimating the geological risk to forces may wish to review.

- Brown, D. E., Army War College (U.S.). Strategic Studies Institute, & Army War College (U.S.). Press. (2013). Africa’s booming oil and natural gas exploration and production : national security implications for the United States and China. Carlisle, PA: Strategic Studies Institute and U.S. Army War College Press. Infrequently the Army War College writes on topics of military engineering. Brown's paper is one on Africa’s energy future and the explorations for petroleum. Given that Africa and AFRICOM are becoming competitive theaters, this work gives an engineering feel for the issues and capabilities.

- Bryan, B. W., United States. Department of the Army. Joint Readiness Training Center., Fort Polk (La.), & Geological Survey (U.S.). (2007). Effects of hardened low-water crossings on periphyton and water quality in selected streams at the Fort Polk Military Reservation, Louisiana, 1998-99 and 2003-04. Scientific investigations report. Reston, Va.: U.S. Geological Survey. Water quality was not changed by low-water crossings modified on three streams due to military operations.

- Cablk, M. (2014). Experiencing nature in militarized landscapes: If a bomb drops in the desert, do we still call it wilderness? Reviews in Engineering Geology, 22, 205–215. Cablik demonstrates that DoD held lands are in much better shape and shelter more rare, threatened, and endangered species on its lands than any other public landowner.

- Cao, Y., Xie, Y., & Gebraeel, N. (2018). Multi-sensor slope change detection. Annals of Operations Research, 263(1–2), 163–189. Contemporary intelligent systems with multi-sensory monitoring are being widely deployed for large scale systems such as CBRN threats (WMD) and ground movements (slope creep). Cao, Xie & Gebraeel dig into the probability issues of sorting out false alarms, sparse data (only one or few sensors pick up) and data streams.

- Cech, T. V. (2009). Principles of Water Resources: History, Development, Management, and Policy (3rd ed.). United States: John Wiley & Sons. Water security as a major driver of future conflict possibilities. Cech provides a solid background for military and civil engineers with a complete history of water availability, government development, and management, policies of water usage, international water issues, water measurement, and telemetry. With potable water becoming a factor in stability operations, the military engineer is well served having the background offered by Cech's work.

- Clatworthy, J. C. (2007). Specialist Maps of the Geological Section, Inter-Service Topographical Department: Aids to British Military Planning During World War II. Cartographic Journal, 44(1), 13–43. Three reasons suggest the military engineer look over Clatworthy's maps. (a) Meet the co-author 'Ted' Rose (b) understand that US geospatial heritage is strongly tied to the British and (c) see past difficulties to come up with military maps in comparison to today.

- Clatworthy, J. C., & Nathanail, C. P. (2006). Specialist Maps Prepared by British Military Geologists for the D-Day Landings and Operations in Normandy, 1944. Cartographic Journal, 43(2), 117–143. This report differs from the previous in that it has a much sharper focus on the effect of geology maps in contrast to the normal topographic maps and it covers the well-known and often visited, by engineers at least, Normandy coast.

- Collins, J. M. (1998). Military Geography for Professionals and the Public (Vol. 1st Brasse). Washington, D.C.: University of Nebraska Press. General Collins is a must read for military engineers at senior levels.

- Corradi, P. A. (1965). Military engineering in Vietnam. Civil Engineering (New York), 35(11), 47–50. Short but illuminative read on military engineering/construction in Southern Asia, carried out by U S Navy Bureau of Yards and Docks, which is often neglected and not folded into the lessons learned.

- Dickerson, R., & Malczyk, N. (2014). Quaternary geologic studies on playas of the Nevada Test and Training Range in support of the Nellis Air Force Base training mission. Reviews in Engineering Geology, 22, 159–176. US Army was intently interested in desert warfare and still seems to gravitate toward that scenario. This dry work focuses on mobility across playas.

- Doe, W. W., Hayden, T. J., Lacey, R. M., & Goran, W. D. (2014). Overview of Department of Defense land use in the desert southwest, including major natural resource management challenges. Reviews in Engineering Geology, 22, 109–118. Western training ranges include large bases are one of our more important military assets.

- Doel, R. E. (2003). Constituting the postwar earth sciences: The military's influence on the environmental sciences in the USA after 1945. Social Studies of Science, 33(5), 635–666. Doel shows the strategic influence of geosciences in the post WW2 era. That strategic influence has not fundamentally been reinstituted after the geographic stagnation of the Cold War.

- Doll, W. E., Beard, L. P., Gamey, T. J., Bell, D. T., Holladay, J. S., & Lee, J. L. C. (n.d.). Comparison of Airborne Magnetic and Electromagnetic Data From a Bombing Target. Society of Exploration Geophysicists. (2003), 1191-1194 A useful comparison conducted by Oak Ridge National Laboratory over of time-domain electromagnetic (EM) supplementing magnetic surveys for UXO investigations.

- Dow, R. I. L. ., & Rose, E. P. F. . (2012). Hydrogeology in support of British military operations in Iraq and Afghanistan 2003 to 2009. Geological Society Special Publication, 362(1), 241–252. Dow & Rose reminds engineers of their geological roles in finding groundwater. It may be a useful comparison for American military engineers who also conducted ground water missions while deployed in the Global War on Terror.

- Doyle, P., & Bennett, M. (2013). Fields of battle: terrain in military history (Vol. 64). Springer Science & Business Media. WWI battles at Passehendaele Ridge and Ypres are frequently ignored by military engineers in favor of thinking of those fields as the province of the Chemical Defense regiments. But the excavations made in varied soil, often by trail and awful error, are instructive to the engineer whose predecessors sought to protect forces from the King of Battle.

- Doyle, P., & Bennett, M. R. (1997). Military geography: terrain evaluation and the British Western Front 1914-1918. Geographical Journal, 1–24. (Doyle & Bennett, 1997) is a conference report from international Terrain in Military History conference held at the University of Greenwich in January 2000. Historians, geologists, military enthusiasts and terrain analysts from military, academic and amateur were developing terrain visualization tools by looking at historical battlefields. Most of those tools are now mature and ready for use by military engineers.

- Doyle, P., Bostyn, F., Barton, P., & Vandewalle, J. (2001). The underground war 1914-18: the geology of the Beecham dugout, Passchendaele, Belgium. Proceedings of the Geologists Association, 112, 263–274. Doyle, Bostyn, Barton & Vandewalle looks at terrain as a whole in influencing the outcome of British Army operations and battles in the Flanders area of WWI.

- Ehlen, J., & Harmon, R. S. (2001). The environmental legacy of military operations. Reviews in engineering geology. Boulder, CO: Geological Society of America. This compilation is worth skimming. It has the only article I found on terrain evaluation in Bosnia Herzegovina and the sum of the well-done articles demonstrates the transition to digital data and geospatial-intelligence.

- Erdmann, C. E. (1944). Military geology: applications of geology to terrain intelligence. Geological Society of America Bulletin, 55(6), 783–788. Erdmann wrote a WW2 critique of the US Army employment of terrain analysis and geological trained engineers.

- Farrington, P. A. (2009). Discussion of "Terrain evaluation for Allied military operations in Europe and the Far East during World War II: 'secret' British reports and specialist maps generated by the Geological Section, Inter-Service Topographical Department", by EPF Rose & JC Cl. Quarterly Journal of Engineering Geology and Hydrogeology, 42, 389–392. Farrington is a short article laudatory to the author's father and his role in WW2 British terrain evaluation.

- Gilewitch, D. A. (2014). Military operations in the hot desert environment. Reviews in Engineering Geology, 22, 39–47. Gilewitch provides a brief summary of the influences of selected environmental factors on modern military forces operating in hot desert environments: effects of unique desert terrain, aeolian processes and dust, radiation balance with regard to troops, equipment, and tactics.

- Gilewitch, D. A., King, W. C., Palka, E. J., Harmon, R. S., McDonald, E. V, & Doe, W. W. (2014). Characterizing the desert environment for Army operations. Reviews in Engineering Geology, 22, 57–68. A panel of scientists and military officers classified deserts using physical and military considerations to support the military missions of operating, training, and testing.

- Goel, R. K., Singh, B., & Zhao, J. (n.d.). Underground Infrastructures - Planning, Design, and Construction. Elsevier. Goel, Singh & Zhao is a decided unmilitary book from India's Himalayan experiences that sets up arguments and techniques for underground living and working space.

- Golev, A., Scott, M., Erskine, P. D., Ali, S. H., & Ballantyne, G. R. (2014). Rare earths supply chains: Current status, constraints and opportunities. Resources Policy, 41, 52–59. The domination of China in the production of REEs is discussed Golev and the lack of alternatives for their application in electronics, fast growing green technologies, and military and aerospace applications make this a potentially strategic issue.

- González, G. del C. (2011). Metaphors: instruments for understanding and tolerating geological risk. Revista Veredas, 15(2), 12–25. Military engineers have to explain things to the press and general public. Gonzalez is a study on how metaphors are employed to help the general population understand and tolerate geological risk in the State of Colima, Mexico, which has an active volcano and is located in the most seismic zone of the country.

- Greenwood, D. A. (2012). Soil and water: research by the British Army's Committee on Mud Crossing Performance of Tracked Armoured Fighting Vehicles in World War II. Military Aspects of Hydrogeology, 362, 161–186. An allied 'Mud Committee' was tasked to consider the science of soil mechanics and the use of WW2 tracked vehicles. Greenwood explores this committee's work.

- Guth, P. L. (1998). Military geology in war and peace: An introduction. Reviews in Engineering Geology, 13, 1–4. Naval academy faculty member and author of terrain visualization articles and software Peter Guth capsulates the influence of geology on military operations through history.

- Harmon, R. S., Baker, S. E., & McDonald, E. V. (2014). Military geosciences in the twenty-first century. Reviews in Engineering Geology. Boulder, Colorado: The Geological Society of America. Harmon, Baker & McDonald have pulled together a contemporary collection of thoughtful pieces.

- Hertzberg, C. S. L. (1943). Military engineering. Engineering Journal, 26(5), 244–245. Hertzberg was Canada's Chief of Engineers in WW2. This is a short article dealing with select parts of the work done by the Corps of Royal Canadian Engineers.

- Hunt, R. E. (2007). Geologic hazards : a field guide for geotechnical engineers. Boca Raton, FL: CRC/Taylor & Francis. Hunt examines the potential for slope failures, earthquakes, ground subsidence, collapse, and expansion with good explanations on what measures are available to minimize or eliminate the risks.

- Ibarra, J. A., Maerz, N. H., & Franklin, J. A. (1996). Overbreak and underbreak in underground openings Part 2: Causes and implications. Geotechnical and Geological Engineering, 14(4), 325–340. As military engineers are taught demolitions by adding 'P' for 'plenty, this work by Ibarra, Maerz & Franklin might be a welcome contrast treating explosive energy as a measured effect, the 'perimeter powder factor' (PPF), in the context of tunnel-wall rock damage, underbreak, rock quality and overbreak.

- Kaye, C. A. (1957). Military geology in the United States sector of the European theater of operations during World War II. Geological Society of America Bulletin, 68(1), 47–54. WW1 is best envisioned as static trench warfare - not that it was completely in that a lot of march and maneuver took place but once it settled down it stayed stuck on 'no man's land' for good. Geology, war geology, then had far reaching consequences. WW2, not long afterward, had much less. Kaye demonstrates what the technological change to mechanized maneuver warfare meant in terms of geology.

- Kiersch, G. A. (1998). Engineering geosciences and military operations. Engineering Geology, 49(2), 123–176. Professor emeritus at Cornell, Kiersch should be considered one of military engineering’s important voices and perspectives. Pay particular attention to Tullahoma campaign terrain and tactics description, and also the submarine pens at Bergen, Trondheim and Narvik. The treatment of these topics is not well covered by other sources.

- Klinger, J. M. (2015). A historical geography of rare earth elements: From discovery to the atomic age. Extractive Industries and Society-an International Journal, 2(3), 572–580. Rare Earth Elements (REE) are purportedly a new strategic contest with China having financially/legally captured most of the world's mineral rights. Klinger relates the historical geography of REE from their discovery to the atomic age and the relationship between rare earth elements and global political change.

- Knowles, R. B. & Wedge, W. K. (1998). Military Geology and the Gulf War. Reviews in Engineering Geology, 13, 117–124. This work by Bobby Knowles and BG Keith Wedge is a summation of the effect of engineering geologists and hydrogeologists from a Theater Engineer Command and geospatial information with terrain analysis contributed in modern mechanized and speedy campaign. It serves as a benchmark for military engineers who should compare it to experiences 15-20 years later in Iraq.

- Kuloglu, M., & Chen, C. C. (2010). Ground Penetrating Radar for Tunnel Detection. 2010 IEEE International Geoscience and Remote Sensing Symposium, 4314–4317. Ground Penetrating Radar, or GPR systems, have become a major geophysical tools for civilian and military use. Kuloglu & Chen describes the tradeoffs for detecting deep tunnels, performance, soil types, specific targets and subsurface geological features.

- Lighthart, D., Hayhurst, D. T., & Reily, P. (2011). The articulation of military training onto engineering degree plans. In 41st Annual Frontiers in Education Conference: Celebrating 41 Years of Monumental Innovations from Around the World, FIE 2011, October 12, 2011 - November 15, 2011 (p. Am. Soc. Eng. Educ. (ASEE), Educ. Res. Methods (ER). Rapid City, SD, United states: Institute of Electrical and Electronics Engineers Inc. Lighthart, Hayhurst & Reily reports on comparative analysis of Marine Corps engineering training curriculum and ABET-accredited degree program.

- Liu, J., Li, L., Fu, C., & Wu, Z. (2009). A military maneuver engineering support evaluation model based on ANN and super-efficiency DEA. In 2009 International Workshop on Intelligent Systems and Applications, ISA 2009, May 23, 2009 - May 24, 2009 (p. Hubei University of Technology; Huazhong Universit). Wuhan, China: IEEE Computer Society. China's war college takes a systems engineering look at how engineers can support maneuver with data analysis (Liu, Li, Fu & Wu, 2009).

- Luedeling, E., & Buerkert, A. (2008). Typology of oases in northern Oman based on Landsat and SRTM imagery and geological survey data. Remote Sensing of Environment, 112(3), 1181–1195. Finding water in hyperarid deserts has been only accessible at oasis which are usually defined by (planted date palms) vegetation, can be aided by LANDSAT images. The authors Luedeling & Buerkert describe their approach to both identify and classify the water sources by analysis of pre-existing imagery.

- Lundquist White, George H., Bonilla, Alejandro, Richards, Todd E., Richards, Steven C, A. H. (2011). Adapting military field water supplies to the asymmetric battlefield. U.S. Army Medical Department Journal. US Army. Lundquist argues convincingly that the Army ROWPU - great system that it is - is fundamentally limiting, overly expensive and that alternatives exist which engineers may be forced into considering for some future tasks. This is written from a disease prevention, medical point of view.

- Mahaney, W. C., Kalm, V., & Dirszowsky, R. W. (2008). The Hannibalic invasion of Italia, 218 BC: geological and topographical analysis of the invasion routes. Mahaney, W. C., Kalm, V., Dirszowsky, R. W., Milner, M. W., Sodhi, R., Beukens, R., … Kapran, B. (2008). Hannibal’s Trek across the Alps: Geomorphological Analysis of Sites of Geoarchaeological Interest. Mediterranean Archaeology & Archaeometry, 8(2), 39–54.

- Mahaney, W. C., Kapran, B., & Tricart, P. (2008). Hannibal and The Alps: unravelling the invasion route. Geology Today, 24(6), 223–230. and the following citation (Mahney, et alle 2010) are described together in the next paragraph.

- Mahaney, W. C., Tricart, P., Carcaillet, C., Blarquez, O., Ali, A. A., Argant, J., … Kalm, V. (2010). Hannibal's Invasion Route: An Age-Old Question Revisited within a Geoarchaeological and Palaeobotanical Context. Archaeometry, 52, 1096–1109. Mahaney and friends form are a set of articles investigating the fascinating military mystery of Hannibal crossing the Alps.

- Mather, J. D., & Rose, E. P. F. (2012). Military aspects of hydrogeology: an introduction and overview. Geological Society, London, Special Publications, 362(1), 1–18. Mather & Rose provide a primer for military engineers on battlefield water -- supply, countering maneuver and construction or mining, as a contamination distribution vector, and as the raison de guerre.

- McCullough, D. G. (1972). The Great Bridge. New York: Simon and Schuster.Building the Brooklyn Bridge and what we learned about foundation engineering.

- McCullough, D. G. (1977). The path between the seas: the creation of the Panama Canal, 1870-1914. New York: Simon and Schuster. Building the Panama Canal by one of America's greatest storytellers and a famed historian.

- Miller, J. (2013). Pathways and purposes of the “French tradition” of engineering in antebellum America: the case of the Virginia Military Institute. Engineering Studies, 5(2), 117–136. American military engineers are told that their approach to learning engineering came from (a) French textbooks and (b) English experiences. Miller looks deeply into this and concludes we have our own brand cobbled from several traditions.

- Murdoch, M., & Bretz, G. (1996). Development of a Rapidly Deployed Pier (RDP). International Society of Offshore and Polar Engineers. An episodic but important task for military engineers is to move cargo to unimproved beaches. Examples such as the DeLong Piers in southeast Asia, the U.S. Navy Elevated Causeway and the British Flexiport used in the Falkland Islands are historical precedents. Murdoch & Bretz is more of a requirements document than report but is worth scanning to understand the issues and scope of engineering required.

- National Research Council (U.S.). Ocean Studies Board., & National Research Council (U.S.). Commission on Geosciences Environment and Resources. (2000). Oceanography and mine warfare. Washington, D.C.: National Academy Press,. Oceanography and naval mining go in parallel with geospatial and landmines (NRC Ocean Studies & NRC, 2000) makes a comprehensive comparator for military engineers trying to figure out how to move forward in this part of the fight.

- Nelson, C. M., & Rose, E. P. F. (2012). The US Geological Survey’s Military Geology Unit in World War II: “the Army’s pet prophets.” Quarterly Journal of Engineering Geology and Hydrogeology, 45(3), 349–367. Nelson & Rose is a history of the USGS contribution to WW2 and the role of geology in military affairs both WW1 and WW2.

- Nichols, K. K., & Bierman, P. R. (2001). Fifty-four years of ephemeral channel response to two years of intense World War II military activity, Camp Iron Mountain, Mojave Desert, California. Reviews in Engineering Geology, 14, 123–136. Nichols & Bierman report on the very slow recovery of the Mojave Desert drainage age patterns after intensive military operations.

- O’Sullivan, J. J. (1959). Deep underground construction. Santa Monica, Calif.,: Rand Corp. Historical but military engineers haven't put much thought into very deep construction since the earlier days of the Cold War.

- Ogden, I. (2004). Military role in regeneration of civil engineering capability. Proceedings of the Institution of Civil Engineers: Civil Engineering, 157(1 SPECIAL), 16–21. Peace operations have significant tasks and responsibilities for military engineers. Colonel Ogden takes a contemporary look at this mission area.

- Otwell, C. W. (1911). Military engineering. Proceedings of the Engineers' Club of Philadelphia. Young Captain Otwell gives a pre Great War perspective history of the US Army military engineers up to his time.

- Papadopoulos, C., & Hable, A. (2008). Including questions of military and defense technology in engineering ethics education. In 2008 ASEE Annual Conference and Exposition, June 22, 2008 - June 24, 2008. Pittsburg, PA, United States: American Society for Engineering Education. This work argues that ethical questions arising from military, defense, weapons technology, R&D should be formally addressed in all engineering education because such work intrinsically raises serious moral questions and their analysis of employment data and research funding suggests that the probability is significant that engineers will encounter such questions.

- Parker, L. (2016). What You Need to Know About the World's Water Wars. National Geographic. Parker's short article lays out the modern story of conflicts over aquifers.

- Patrick, David M & Hathaway, A. W. (1989). Engineering Geology and Military Operations. Bulletin of the Association of Engineering Geologists, XXVI(No 2), 265–276. Patrick & Hathaway dig into and emerging concept of engineering intelligence.

- Price, P. H., & Woodward, H. P. (1942). Geology and War: GEOLOGICAL NOTES. AAPG Bulletin, 26(12), 1832–1838. This period piece is a lament that geologist were not well prepared to assist the war effort.

- Quinn, L. (2004). Infrastructure targeting - The role of the military engineer. Proceedings of the Institution of Civil Engineers: Civil Engineering, 157(1 SPECIAL), 12–15. Air power for US military engineers relates to a pervading philosophy of attacking 'industrial webs'. Quinn looks at effects-based targeting, collateral damage, and post-conflict infrastructure recovery.

- Ray, K. (1946). Military engineering. South African Institution of Engineers -- Journal, 44(5), 144–157. Ray's article is interesting in that it provides a senior level view of an allied sapper effort and the personal reflections - talking to "Mr. Bailey" about reinforcing his bridge - which give some personality to historical accounts.

- Risen, J. (2010). U.S. Identifies Vast Mineral Riches in Afghanistan. New York Times. Risen is instructive in how war correspondence can extrapolate military - geological - economic - political matters to suggest trouble and mixed motives.

- Robins, N. S. & Rose, E. P. F. (2009). Military uses of groundwater: a driver of innovation? Hydrogeology Journal, 17(5), 1275–1287. Robins & Rose argue that applied hydrogeology today is a derivative from military experiences.

- Rogers, J. D. (1997). Spatial geologic hazard analysis in practice. In Geotechnical Special Publication (67th ed., pp. 15–28). Rogers warns against issues with GIS approaches and engineers accepting risks based on authoritative government data and programs. He gives four case examples.

- Rogers, J. D. (2014). The American engineers that built the panama canal. In Engineering the Panama Canal: A Centennial Retrospective - Proceedings of Sessions Honoring the 100th Anniversary of the Panama Canal at the ASCE Global Engineering Conference 2014 (pp. 112–349). Contrasting (Rogers, 2014) with (McCullough, 1977) you have two master story tellers with McCullough writing for history buffs and Rogers writing for engineers. Rogers describes the political fight over the redesign, the personal attributes of the engineers, and the challenges they overcame.

- Rogers, J. D., Kemp, G. P., Bosworth, H. J., & Seed, R. B. (2015). Interaction between the US Army Corps of Engineers and the Orleans Levee Board preceding the drainage canal wall failures and catastrophic flooding of New Orleans in 2005. Water Policy, 17(4), 707–723. Modern saga of the pre-Katrina Orleans Levee Board - which the author clears in this article - and the Corps of Engineers, the large engineering failure in Katrina, public affairs, grantsmanship and governmental responses. This is an instructive read for military engineers in public projects.

- Rose, E. P. F. (2014). Military geosciences before the twenty-first century. Military Geosciences in the Twenty-First Century, 22, 19–26. Rose, as part of a worthy anthology (Harmon, Baker, & McDonald, 2014), offers a somewhat different historical context than (Otwell, 1911) and (Kiersch, 1998).

- Rose, T. (1980). Military engineering geology. The British Geologist, 6(1), 10–13. E F P (Ted) Rose becomes a marvelous writer for military engineers and his career seems to start with this piece done when serving as a British Lieutenant Colonel. Rose is an example for military engineers at ranks of field grade officer, mid-grade warrant and senior NCO to encourage beginning scholarly research and writing.

- Salvador, I., & Vitti, A. (2011). Survey, Representation and Analysis of a World War I Complex System of Surface and Underground Fortifications in the Gresta Valley - Italy. 4th Isprs International Workshop 3d-Arch 2011: 3d Virtual Reconstruction and Visualization of Complex Architectures, 38–5(W16), 319–325. A modern technique, not yet taught to military engineers, is the use of terrestrial scanning, GPS and the total survey station, to recreate the footprint of engineering works of the past. In this Salvador & Vitti lay out the technique in a case that would be appealing to military engineers. It should prove instructive on the applications of this technique and that of LIDAR.

- Sciences, E., Studies, L., & Affairs, G. (2013). Future U.S. Workforce for Geospatial Intelligence. Commercial and other-than-defense agencies are fast becoming the experts in training people for geospatial-intelligence work having outstripped the DoD/NGA recently. This well laid out paper can be reviewed to keep up with the best practices of today.

- Shellum, C. J., & Trudnak, J. T. (2005). GIS-based Geology and Geotechnical Estimates for Military Applications. American Rock Mechanics Association. DTRA hired contractors to invent and promulgate Country Geology Templates in response to requirements levied by the military and an intelligence community for rapid geospatial estimates of the geology and material/engineering properties in a region. This is a country-size approach for the operational/campaign-level of planning.

- Stewart, A. K. (2015). Geological-reasoning training as preparation for the "thinking warfighter" in the next-generation military. Journal of Military and Strategic Studies, 16(1), 1–10. Stewart's article is important in having distilled from his personal Afghanistan deployments some new insights into the roles, approaches and thinking that applies to military engineers and a central role for geosciences.

- Turchetti, S., & Roberts, P. (2014). The surveillance imperative : geosciences during the Cold War and beyond. Palgrave studies in the history of science and technology. New York, NY: Palgrave Macmillan. Turchetti & Roberts dig into a topic that may become a sharp focal point of military engineers in this century - espionage meets environment and the technologies and ethics of geospatial-intelligence.

- Underwood, J. R., & Guth, P. L. (1998). Military geology in war and peace. Reviews in engineering geology. Boulder, Colo.: Geological Society of America. Very nice collection of reports and studies at the prewar point. Reading introductions covers the base and is well worth the military engineer's attention.

- Vogdes, A. W. (1884). Course of science applied to military art; Part I, Geology and military geography; Geology. (U. S. A. School, Ed.), Course of science applied to military art; Fort Monroe Virginia: US Army, Fort Monroe, VA, United States. Vogdes, in historical context, is a reminder to American military engineers of former missions in building coastal fortifications.

- Wang, S. (2011). Study on the construction engineering management mode of military projects. In 2011 International Conference on Transportation, Mechanical, and Electrical Engineering, TMEE 2011, December 16, 2011 - December 18, 2011 (pp. 146–150). Changchun, China: IEEE Computer Society. Wang is instructive of China's thinking of military engineering in a paper that's approach is doctrine meets engineering management.

- Williams, T. D. N. (1988). Implications of Military Engineering. IEEE Proceedings A: Physical Science. Measurement and Instrumentation. Management and Education. Reviews, 135(5), 303–308. Williams is an end of the Cold War analysis of British military equipment development, with the observations fitting US approaches as well, of the technology pushes versus the military requirements. We haven't figured this out yet but here his military engineering is R&D of defense equipment and not the tasks of sappers, topogs, miners and builders.

- Willig, D., & Hausler, H. (2012). Aspects of Military Hydrogeology and Groundwater Development by Germany and its Allies in World War I. Military Aspects of Hydrogeology, 362, 85–103. Willig & Hausler describe the same WW1 story as by (Barbour, 1917) and (Dow & Rose, 2012) but told from the other side and from no-mans' land. This work also is a useful benchmark on how military engineering has increasingly become the hydro source force.

- Xi, Y., Li, X., Duan, Y., & Maerz, N. (2011). Virtual Navigation of Interior Structures by LIDAR. in Proceedings of SPIE - The International Society for Optical Engineering (Vol. 8037). Although Xi, Li, Duan, & Maerz is math-model heavy for most military engineers, it should be taken as a signal that this technology has many applications for the practices of military engineering. LIDAR's utility for military engineering may have significant applications for development of geospatial information and use with unmanned systems.

- Xie, P., Grant, S. L., Putnam, N. H., Anderson, N. L. & Nasseri-Mohgaddam, A. (2014). An Improved Post-Processing Technique for Array-Based Detection of Underground Tunnels. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 7(3), 828–837. Xie, Grant, Putnam, Anderson, & Nasseri-Mohgaddam demonstrates the current status of tunnel detection from the surface and the strong influence that a serving active military officer can have in a research team.

- Zinn, G. A. (1916a). Military engineering. Engineers' Club of Philadelphia -- Proceedings. And Zinn, G. A. (1916b). Military engineering. Engineers' Club of Philadelphia -- Proceedings. and Zinn, G. A. (1916c). Military engineering. Engineers' Club of Philadelphia -- Proceedings. and Zinn, G. A. (1917). Military Engineering. Engineers' Club of Philadelphia -- Proceedings. Colonel Geo Zinn gave a series of four lectures to Engineers' Club of Philadelphia during WW1 on military engineering which are treasures themselves of historical note but even better as an example on how to address a civilian engineer audience.

3. CONCLUSION

Military Engineers need a curated guide to works that will push professional acumen and inspire personal contribution.

V. ENVIRONMENTAL SECURITY: WATER

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ABSTRACT

Authors content that geosciences are a fundamental aspect of military engineering and water supply is a demonstration of the value added by military engineering to the Army and the nation. Water comes from the ground and then returns there, so it fits into the geosciences and should be studied." This article has been accepted by *The Military Engineer* and is coauthored by Dr. Robert Tucker for inclusion in the 'Water Issue' of June 2019.

1. INTRODUCTION

US forces use of water in military and civilian operations is compared between doctrine, use in the 20th century and modern use in 21st century operations. Water supply is a demonstration of the value added by military engineering to the Army and the nation. Water comes from the ground and then returns there, so hydro-geoscience fits into the military engineering body of knowledge.

2. DOCTRINE

UN-Water rightly notes, “The physical world of water is closely bound up with the socio-political world, with water often a key factor in managing risks such as famine, migration, epidemics, inequalities and political instability”. Water is de facto a strategic issue and is covered in doctrine. Joint Bulk Petroleum and Water Doctrine (JP 4-03) introduces the water planning as:

“Water support planning is a continual process beginning with the identification of the force size and planned deployment rate. Total water requirements are placed in the theater water distribution plan developed by the CCDR, with support from the Service component commander.

Considerations for planning water consumption requirements include the region (tropical, arctic, temperate, or arid), infrastructure, personal hygiene, food preparation, laundering, centralized hygiene, hospitals, decontamination requirements, vehicle maintenance, mortuary affairs, aircraft washing, tactical ice plant, refugee/detainee civilian internee/ and prisoner of war camps, and firefighting.

Considerations for water support operations include: water purification, water storage, and water distribution.

DODD 4705.01E, Management of Land-Based Water Resources in Support of Contingency Operations, designates the Secretary of the Army as the DOD Executive Agent for land-based water resources.”

3. ENVIRONMENTAL SECURITY AND WATER

Environmental security applies geosciences to the use of the lithosphere, biosphere, and hydrosphere by societies. Control of water is a point of contention in many wars. Hebrews sought the land that was 'flowing with milk and honey' from Exodus 3 and describe a Middle East underlain with water and overlain with violence. On the small scale, contests over water can be fence wars with some shooting and a lot of litigation. On societal scales they become inflamed conflicts; water thirsty economies of developing nations create contests between 'have nots' and 'haves' for a lion's share of water. Long term contests may invoke US military intercession when 'haves' are able to extend their reach and exploit the land and the population of the 'have nots' in a way that impacts US national interests.

Whether those wars are due to shortages, access or distribution control hardly matters to armies and populations in the contested zone. Dry is dry and thirst is thirst. Surface waters may be plentiful but are frequently fouled by industrial and societal wastes. Surface waters are open to disease, drought and access considerations. Either restricting access to water or deliberate fouling may be despicable tactics but are employed by factions in conflict. Military forces generally see surface water as a point source or an obstacle-impeding maneuver. Groundwater resources are more secure and less susceptible to natural and enemy influence than surface sources. That makes groundwater a 'go to' source either to augment surface waters or entirely replace them. Nevertheless, groundwater itself can be problematic, with significant issues when pumped out aggressively. "Land sinks, civil war is waged and agriculture is transformed" is one summation. Although ground water is almost universally available, it is not always easily accessed and slow recharge rates can make long-term use tenuous. Groundwater, for military operations, becomes vulnerable point sources, even when many wells are drilled.

4. COMPARING DOCTRINE, HISTORICAL AND CONTEMPORARY WATER SECURITY

Military use of water, both as a resource and an instrument of power are compared. Doctrinal aspects are compared in a table with authors' summation of the conflicts in the 20th century (Philippine–American War, Moro Rebellion, Boxer Rebellion, Crazy Snake Rebellion, Border War of the Mexican Revolution, Negro Rebellion in Cuba, Occupation of Nicaragua of the Banana War, Bluff War, Occupation of Veracruz, Occupation of Haiti, Occupation of the Dominican Republic, World War I, Russian Civil War, Posey War (Last Indian Uprising), World War II, Korean War, Operation Ajax, Laotian Civil War, Lebanon Crisis, Bay of Pigs Invasion, Vietnam War, Communist insurgency in Thailand, Korean DMZ Conflict, Dominican Civil War, Cambodian Civil War, War in South Zaire, Lebanese Civil War, Invasion of Grenada, Invasion of Panama, Gulf War, Somali Civil War, Bosnian War, Intervention in Haiti, and Kosovo War) and the 21st century (War in Afghanistan, Iraq War, War in North-West Pakistan, War in Somalia, American-led intervention in Libya, Operation Observant Compass Uganda, Intervention in Iraq and Syria – Inherent Resolve, and Yemeni Civil War). Table 1 shows doctrine versus representative examples from two centuries.

Table 1. Comparison of current U. S. military doctrinal requirement with historical examples.

Doctrine (selected elements)	20th Century	21st Century
Purify water as close to the user as possible	"Concomitant with the build-up of American military forces in Vietnam, there has been a massive well-drilling program. Streams and shallow wells supplied the needs of the first troops to arrive, but as airfields, ports, and base camps were developed the requirement for more extensive and permanent sources necessitated the development of subterranean water supplies." Water for Vietnam By Lt. Cdr. D.W. Harned, CEC, USN, and Lt. j.g. M.H. Ramaeker, CEC, USN, March-April 1967 issue of TME	Reverse osmosis water purification unit | military wikia 
Bulk water support normally is a Service responsibility	 M-50 Truck, Tank, 2 1/2-ton, 6x6, Water, 1000 gal.	 Fort Leonard Wood water tower gets extension By Mr. Mike Bowers (Leonard Wood)September 24, 2015

Table 1. Comparison of current U. S. military doctrinal requirement with historical examples. (cont.)

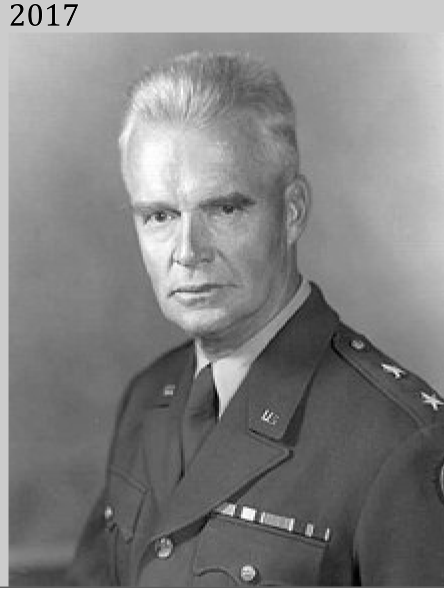
Doctrine (selected elements)	**20th Century**	**21st Century**
Water distribution is the "weak link" of the water support system	"A month after the Korean War broke out, Major General William F. Dean, commander of 24th Infantry Division, was separated from his forces in Taejon while trying to help wounded soldiers. While out seeking water for a particularly injured G.I., he fell down a cliff and was knocked unconscious. He would be isolated in the mountains for the next 36 days, losing 80 pounds in addition to the broken shoulder and head wound he had sustained. When two South Koreans found him, they pretended to lead him to safety, but in fact brought him to a North Korean ambush site" 10 Facts About the Korean War BY DAVID W BROWN APRIL 16, 2017 	 US military relief in Haiti is part logistics, part negotiation to get supplies to the neediest By DIANNA CAHN | STARS AND STRIPES Published: October 15, 2016

Table 1. Comparison of current U. S. military doctrinal requirement with historical examples. (cont.)

Doctrine (selected elements)	20th Century	21st Century
Planners at all levels must include water supply procedures and Guidance in exercises and OPLANs	"General Norman Schwarzkopf delayed deployment of support personnel to maximize combat forces on the ground,11 and since most trained water-support personnel were in the Reserves, an additional callup was required.12 Truce shortages were complicated by the terrain, which hindered movement due to a lack of adequate surface transportation routes.13 There were also concerns over Saudi Arabia and the United Arab Emirates' discontinuing water supplies to US forces." WATER… BULK OR BOTTLED? IT'S A BIGGER ISSUE THAN THAT By Lee O. Wyatt, Lieutenant Colonel, USAF Air Universoty	"Iraq is located in the Middle East. It covers an area of 433,970 square kilometres populated by about 32 million inhabitants. Iraq greatly relies in its water resources on the Tigris and Euphrates Rivers. Recently, Iraq is suffering from water shortage problems. This is due to external and internal factors. The former includes global warming and water resources policies of neighbouring countries while the latter includes mismanagement of its water resources. The supply and demand are predicted to be 43 and 66.8 Billion Cubic Meters (BCM) respectively in 2015, while in 2025 it will be 17.61 and 77 BCM respectively. In addition, future prediction suggests that Tigris and Euphrates Rivers will be completely dry in 2040." Iraq Water Resources Planning: Perspectives and Prognoses, Nadhir Al-Ansari, Ammar A. Ali, Sven Knutsson

Table 1. Comparison of current U. S. military doctrinal requirement with historical examples. (cont.)

Doctrine (selected elements)	20th Century	21st Century
Maintain visibility on waste management by-products (to include wastewater)	"…in the fourth dreadful year of the war, as the American Expeditionary Forces (AEF) assumed fighting strength and prepared their first great offensive against the Germans, the flu struck. By the War Department's most conservative count, influenza sickened 26% of the Army—more than one million men—and killed almost 30,000 before they even got to France.." War Department (US) Office of the Surgeon General, Medical Department of the United States Army in the World War, vol 9: Communicable and other diseases. Washington: U.S. Government Printing Office; 1928.	"To adequately protect the environment and human health, rapidly deployable and operational wastewater treatment facilities are vital for military operations, disaster relief, and humanitarian mission areas where permanent facilities have been damaged or do not exist. The Deployable Aerobic Aqueous Bioreactor (DAAB) developed by ERDC's Environmental Lab with Sam Houston State University, Lamar University and Sul Ross State University is a portable, biological wastewater treatment facility designed for rapid deployment to areas where there are minimal resources and short time constraints." Scott Waisner US Army ERDC
Water consumption requirements are based on the size of the force		 THIELMANN WEW Container Systems GmbH Deployable Modular Military Fuel and Water Systems

Table 1. Comparison of current U. S. military doctrinal requirement with historical examples. (cont.)

Doctrine (selected elements)	20th Century	21st Century
Plan and compute all requirements to include all water supply, purification, and storage requirements	"IFOR military engineers repaired and opened more than 50 percent of the roads in Bosnia and Herzegovina, and rebuilt or repaired over 60 bridges including those linking the country with Croatia. They were also involved in de-mining and repairing railroads; opening up airports to civilian traffic; restoring gas, water, and electricity supplies; rebuilding schools and hospitals; and restoring key telecommunication assets." Lessons From Bosnia: The IFOR Experience Contributing Editor Larry Wentz DoD CCRP/NDU Collaboration	"The Planning Data Branch (PDB) executes CASCOM's mission from TRADOC and the Army G4 to serve as the Army agency responsible for collecting, developing, maintaining, validating, and distributing all logistics planning data used for Army operational planning, force structuring/organizational design, and rapid response requirements to actual warfighting requirements. Our charter comes from AR 700-8, Logistics Planning Factors and Data Management." Combined Arms Support Center
Vulnerability of the water system to CBRN attack, conventional attack, and man-made/natural hazards must be considered	"The threat, as the Seoul Government sees it, comes from a huge North Korean dam and hydroelectric power project that it says could disrupt South Korea's water supply and power generation, upset the ecological balance of the area and unleash disastrous floods in Seoul and its environs." NORTH KOREA DAM WORRIES THE SOUTH By SUSAN CHIRA and SPECIAL TO THE NEW YORK TIMES NOV. 30, 1986	 This Is The Military Base Water Contamination Study The White House Didn't Want You To See By JARED KELLER on June 21, 2018 "After a March DoD report to the House Armed Service Committee.

Table 1. Comparison of current U. S. military doctrinal requirement with historical examples. (cont.)

Doctrine (selected elements)	**20th Century**	**21st Century**
Units make only one trip to the water point per day.	 Latest war in sharp contrast to past efforts By TERRY BOYD AND WARD SANDERSON | STARS AND STRIPES Published: October 16, 2003	'Liquid Logistics Shock,' demonstrates fuel and water readiness By 1st Lt. Hannah Morgan September 25, 2015 
Maximize the use of HN sources if possible.	"Grenadians post-war response was positive despite a heavy anti-American campaign by the New Jewel Movement. Their gratitude to the U.S. forces was expressed with more than words. They gave away fresh fruit, ice water and cases of soft drinks. At Pearls Airport, they cooked rice, meat and fruit for the Marines. The date of the invasion is now a national holiday in Grenada, called Thanksgiving Day …" U.S. Grenada Invasion in General by Brenda Duplantis, October 28, 2013	 Water Bottling Plants in Afghanistan. There has been a shift in importing water from other countries (Pakistan, Uzbeckistan, and others) to letting contracts out to firms that will establish bottling plants next to large U.S. bases such as Bagram or Kandahar. Afghan War News > Logistics > Water and Afghanistan

Table 1. Comparison of current U. S. military doctrinal requirement with historical examples. (cont.)

Doctrine (selected elements)	20th Century	21st Century
Prohibited to attack, destroy, remove, or render useless, objects indispensable to the survival of the civilian population, such as foodstuffs, agricultural areas for the production of foodstuffs, crops, livestock, drinking-water installations, and supplies and irrigation works	 "Choked with debris, a bombed water intake of the Pegnitz River no longer supplies war factories in Nuremberg, vital Reich industrial city and festival center of the Nazi party, which was captured April 20, 1945, by troops of the U.S. Army." 208-AA- 207L-1. National Archives Identifier: 535562	"Al Shabaab has changed tactics and started to cut off liberated cities from their water source so that they can demonstrate some kind of power and presence," says Abdilatif Muse Noor, a member of the Somali parliament. America Abroad August 12, 2014

Authors Peter Engelke and Russell Sticklor state in The National Interest, "As much as oil shaped the global geopolitics of the 20th century, water has the power to reorder international relations in the current century". Figure 1 displays the water contests that have occurred within the last decade. Military logistics and doctrine address part of the problem. But water supply is a demonstration of the value added by military engineering to the Army and the nation.

Figure 1. This map, courtesy of World Water – Water Conflicts since 2010 suggests that the overlap of water and conflict is getting greater.

4. CONCLUSION

Peter Guth writes in “Military geology in war and peace”. “Perhaps the most important, although not the most obvious, contribution of military geology is its development of ways of thinking and presenting data for the use of nonscientists, especially policy makers. The fields of engineering geology and environmental sciences, in their development during the last 50 years, have become much more effective because of the acceptance by our profession of these approaches”

VI. PERSONAL DEVELOPMENT IN THE REGIMENT AND MEETING THE STANDARD IN CIVILIAN WORK

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ABSTRACT

Authors are informing military engineers on personal options to seek credentials, credentialing assistance, apprenticeships and academic study. The work is an invited publication by the Executive Director of the Army Engineer Association for publication in the publication *Army Engineer*. Justin Payne is writing from his assigned formal duties, “The Credentialing NCO”. The paper is under legal review by the Army Judge Advocate General staff before public release.

1. INTRODUCTION

The bad news for the sapper, diver, firefighter, GEOINT specialist, builder or military engineer is the demands on technical and tactical proficiency today are very high and promise to get more complex in a range of interlacing specialties and missions that Army and national leaders are imagining in doctrine. For those who have moved into the industrial work world, or will move there eventually, the demands are getting even tougher than those in the fight are.

The good news is personal skill and intellectual development has never been more accessible or better supported. In today's world credentialing, training and earning degrees is "doable". Every prediction is that learning on a personal scale and attainment of expertise will continue to be easier, faster and maybe even less expensive.

2. CREDENTIALING

Those who are early in military or industrial careers can significantly help themselves by getting credentialed. Assignment and training in an MOS or hiring into a crew with a specific job is a good start. It means that the hiring organization (Army or company) accepts the person as a beginner with basic skills as a start point and then agrees to continue training and experience to push proficiency. But the next organization, assignment or job, will need that proved all over. Since pay and responsibility levels are set at the beginning of a job or hiring, early careerist are often negotiating when their cards are weakest. Credentialing puts a very strong and portable card into the hand of the new employee for bargaining.

Credentials are in essence industrial standards widely accepted as proof of competence. Those who have an industry credential are nearly universally recognized as an expert. Three types of credentials are licensure, certification or apprenticeships.

Licenses are a public-legal deal awarded by government licensing boards at the federal, state or local level. Everyone is familiar with a state driver's license or a county marriage license as examples. For military engineers, a state 'Professional Engineer' or PE license is highly valuable both for work within the Corps of Engineers and for transition to a civilian job. Each state lists the licenses required by profession ranging from accounting to veterinarians. The Army Credentialing Assistance Program and professional societies, including Army Engineer Association's (AEA) sister, SAME, offer extensive assistance in applying for licenses and reimbursement of the exam costs.

Certifications are general optional, rather than legally mandatory, and offered by private authorities. Microsoft certifications are famous and automotive technicians with ASE certification bring a level of comfort to those looking for a good mechanic. For the military MOS and the construction or trades workers these certifications are an excellent pathway and generally doable at modest expense of time and money. PMP (Professional Project Manager) and Certified Construction Manager (CCM) are excellent credentials for the NCO with project experience, the warrant officer manager, civilian foreman and job boss or mid-level engineers who are staking down their experience and reputation. An interesting twist to credentials is 'stacking', that is a person can earn and hold a number of certificates with some at higher levels of the same topic. Certifications vary widely by state and job area – some are even mixed with licensing requirements such as electricians and teachers. Hence, it is wise to do this with deliberation and get help. The military services COOL programs, like the Army Credentialing Opportunities On-Line, are excellent guides. The tricks have been figured out, the schooling has been identified and the costs noted. Plus COOL leads to financial aid for the soldier, the transitioning serviceman and the veteran.

3. APPRENTICESHIPS

Apprenticeships are back but much changed from their ancient roots. Today the apprenticeship is deliberate program organized by companies to hire people and give then the supervised work experience and training to create their own in-house experts. In a large number of industries – advanced manufacturing, construction, energy, finance, healthcare, transportation, information technology (IT) and even healthcare – the intricacies of working within the company's processes and trade secrets make the apprenticeships the one program to truly fine-tune workers. Companies such as Adaptive Construction Solutions (www.goapprenticehip.com) have beaten a pathway for veterans and transitioning soldiers to paying, on-the-job training. As CEO Nicholas Morgan, himself a former sapper, noted the apprenticeship program extends what the transitioning soldier learns beyond what was trained in the MOS. As an example, welding is something easily taught in the apprenticeship but is not included in a construction MOS. Instead of skills being the delimiter, it is the commitment of the soldier/veteran. He noted his company works with seven big firms and hired 148 disabled veterans last year of which 75 were technically homeless. This 'earn while you learn' approach is a shortcut to a high-paying career.

4. COLLEGE DEGREE

A college degree is the better-understood pathway to long-term success. A college degree generally is universally accepted as a mark of an educated person who is adaptable to a range of responsibilities within a technical field. Most supervisors, managers and those that hold titled roles within companies hold some academic degree.

An associate's degree, sometimes called a 2-year degree, is often the first step and a good background to both further academic study and preparation for credentialing. The Air Force, often the thought leader among the services in education, slicked up the best system with the Community College of the Air Force (CCAF) many years ago which generated a lot of academic credit for airmen by crediting their military training as an academic program and nesting CCAF as part of a larger Air University. The Army is experimenting with that model in the newly created Army University that may in the future mature to something helpful to both the proficiencies within the Army and the job market competitiveness of transitioning soldiers. Soldiers have great access to community colleges at post/base education centers and Go Army Education web site. The Army Tuition Assistance program is well worth considering and the Ed Centers have the expertise and councilors to guide personally soldiers and family members to the academic programs and support programs.

A cautionary note is the transfer of academic credits. Sometimes soldiers misinterpret the 'academic credit' that is earned in MOS training or by taking classes with a college. It seems to the soldier that a personal account exists with so many credits accumulated as indicated in the records of the Joint Services Transcript (JST) or dual college courses listed in high school or college transcripts. Credit levels are promulgated by sources such as the ACE Guide (American Council on Education Guide to the Evaluation of Educational Experiences in the Armed Services) and seem to be bankable credits that are universally accepted. That is not quite true. The soldier is sometimes frustrated, disappointed or downright irate when that stack of academic credits does not shorten the pathway to an academic degree. It is easy to be fooled that the 60 credits earned and shown on the Joint Services Transcript (JST) do not mean admission to a university as a junior with only an additional 60 credit hours left to earn the bachelor's degree. Colleges and universities, and particularly those who operate under an agreement with the Department of Defense (DOD MOU), accept as much of those credits as they possibly can and in good faith shorten the number of courses the student has to accomplish. Only so many credits for physical education and leadership can be applied to specific educational pathways such as healthcare. Moreover, twelve credits for small engineer repair or computer system maintenance may have no relevance to studies leading to a psychology degree. At Missouri S&T, one of the author's home base, all the credits are accepted but only those that are applied to a specific degree program, such as mechanical engineering, add up to meet degree requirements. A student may well earn a bachelor's degree, which requires a minimum or 120 credit hours, but actually have accumulated, paid for and have listed in an academic transcript 150 or more hours.

The bachelor degree, or four year, is a common end point for most students and a transition point for entering the professional workforce. In general, there are Bachelor of Arts and Bachelor of Science degrees although variations from those archetypes are frequent. The primary difference between the "BA" and the "BS" is the focus of the coursework required. BA is typically considered an expansive education with fewer credits that are directly linked to a particular major but instead contain credits in a variety of liberal arts subjects. Courses in the humanities, English, the social sciences, and a foreign language are typically part of this degree program. A BS degree is usually strictly focused on specific subject matter directly linked to a major. Students concentrate on mastering the technical and practical facets of their field and spend less energy on topics outside of the subject of their major. Bachelor of Science degrees are usually offered in technical and scientific areas like engineering, computer science, nursing, mathematics, biochemistry and physics. The base education center, Go Army Ed and the support programs including tuition assistance are very helpful in these degrees. All the offerings at the associate and bachelor levels are called “undergraduate” programs.

Graduate degrees are awarded for those that continue to study after earning a bachelor degree. A master degree (MA or MS following the same logic as BA and BS) is generally an additional 30 or more credit hours of study and research. Master programs often require more independent study and demonstration of mastery of a specific field of study or area of professional practice. For some this means writing and publishing a thesis of original scholarship written under the direction of a faculty advisor. A number of Army Engineers earn an MS while at their Captains Career Course by a cooperative arrangement with Missouri S&T.

Mini-degrees have slipped into the academic mix lately with the unfortunately confusing name of certificate programs. An academic certificate is a collection of several courses specified and taught by a single institution that result in the award of a certificate, rather than a diploma, from that institution. As an example, a popular academic certificate for reserve component sappers is the Military Geological Engineering Graduate Certificate at Missouri S&T. A sequence of four courses (12 credit hours) covers Geomorphology and Terrain Analysis, Geologic Field Methods, Engineering Geology and Geotechnics and finally Applied Geological Engineering that grant the successful student this mini-degree. Although a good way to gain qualification in a specific area, the value of a graduate certificate as a universally understood credential is unproven.

Professional degrees are also graduate level accomplishments and live in their own acronym soup. The reader will have tripped over these from time to time and some are head scratchers. Examples include D.C. (Chiropracy), D.D.S. and D.M.D. (Dentistry), LL.B. and J.D. (Law), M.B. and M.D (Medicine), and Pharm.D. (Pharmacy). More confusing for the dyslexic is O.D. (Optometry) and D.O. (Osteopathic Medicine). Professional degrees are often prerequisites for licenses to practice, which loops the reader back to the beginning of this article. The engineer trespassing into these career fields will generally have to get some outside advice usually from those within the profession and the academic institution.

The last of these academic degrees are jokingly called terminal degrees since there are no further academic levels (other than death). Those earning these degrees may use the courtesy title ‘doctor’. For military engineers these degrees are either a Doctor of Engineering (D. E. is a term associated with the practice of engineering) or the Ph. D. (Doctor of Philosophy, a term associated with research in the field). Equally prestigious, these degrees represent the highest level of achievement and are logical ambitions for military engineers because of the scope of duties and responsibilities faced within a military career. Very few have impact on such a national and global scale either deployed or in domestic projects.

5. CONCLUSION

Accessibility today is greatly enhanced by 'distance' and 'on-line' education. Paradoxically it is harder to get a quality associate's and bachelor's degree by distance studies than it is to find good programs in graduate and even doctoral degrees. Livestream, interactive and hybrid programs (one goes to a campus occasionally) are all in an evolving market experiment that promises both more choices and suggests competitive pricing. As in finding an educational or training source to attend in person the term caveat emptor (buyer beware) is a good rule. Distance students often report the studies to be relatively easier than they thought, more convenient than feared and they control their academic pace selecting only one or two courses per semester. However, they also find the extended duration of such a gentle pace and the disconnection from other students and professors make it harder to remain motivated. A lot of distance scholars linger. Universities can help but there is no substitute for self-discipline and grit.

Personal skill and intellectual development fit into the Army's conceptual pillar of self-development. It increases expertise and competency within Regiment and meets the standard for work in civilian life. The Army, the Veterans Administration, the Regiment, AEA and SAME and a host of colleges, universities all have thrown considerable attention and money behind opening these opportunities. The easy part, commitment, is up to the soldier and veteran. Good luck.

VII. RESEARCH – YOU – ENERGY

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ABSTRACT

This article discusses basecamps and small-setting microgrids and encourages military engineers to participate in an ad hoc research alliance. This article is co-authored by Stephen Menand at Missouri University of Science and Technology and Richard Rodgers US Army Engineer Research and Development Center. It is submitted to *The Military Engineer* and is being considered for the "Energy Issue" spring 2019.

1. INTRODUCTION

Energy – alternative energy – and energy conservation are in a bright spot in time for experimentation and research. With little more than a high-school science background just about anyone can tinker around with energy. We add solar panels to campers and houses, fiddle with generators and wind power, imagine buying hybrids and electrifying bicycles and dabble with weekend projects caulking and sealing and energy management systems. The technophile stirs in the blood of most of us in the SAME universe and between the YouTube videos, commercial products marketed and the peer scuttlebutt many of us are on the path to some degree of expertise.

2. THE DEAL

So here is a deal for you. Connect up with your home university or military school and blend your experimenting in with others. If nothing else you have two places to ‘plug in’. At Fort Leonard Wood Missouri stands the CBITEC (Contingency Basing Integration and Technology Evaluation Center) facility. This base-camp experimentation and demonstration platform is now under the control of the Construction Engineering Research Lab of the US Army Corps of Engineers Engineer Research and Development Centers. For more information on this see “The Joint Forces’ contingency basing engine for innovation” at https://apps.dtic.mil/dtic/tr/fulltext/u2/a570294.pdf.

At nearby Rolla Missouri are two university-owned villages: Solar Village and EcoVillage. These small scale solar neighborhoods started with solar homes designed and built for the Department of Energy Solar Decathlon and are now full- living research and demonstrations laboratories including multiples grid-tied microgrids with multiples types of battery storage technologies. To read more see at “Solar Villages Living Laboratories” https://cree.mst.edu/laboratories/ .

3. CONNECTING TO RESEARCHERS

Plugging in is a wide set of options. You can study or visit those two operations and cherry pick what they have learned. You can ask the contacts, coauthors of this piece, on advice for things that have found to work well and what are dead ends. (*e.g.* mixing and matching the products of various manufacturers is problematic). You can check the published literature about the technologies included in either facility and you are invited to conduct research at either of these facilities yourself. Or perhaps best is you can mess around with your own approaches at work and home and then share what you have observed. As an example – do you have the energy demand curve from your project or camp? That is of interest; we would love to compare it to what loads the use of the CBITEC creates when live loaded with troops in training. Did you mix and match types of generators or solar systems or capture their true costs? That would help build an experience library that can identify what ought to be tried next. Perhaps one of the best ways to share is by publication – and may we suggest here in TME?

You can't change up the designed energy system for the project you are contracted to build and your spouse may complain about the really excellent tin-can window heaters you hang up for the winter. But perhaps you have a construction trailer where experimentation is possible or a small green house or workshop where the black painted beer cans will easily slip into your décor. Keep notes and share them; maybe you will inspire the technophile in others.

More formal research can be an option. Most graduate education encourages research – but before you ever get to that point you have to have a research idea. You have been looking at projects all along and in the back of your engineer notebook you ought to be listing ideas of what could have been better.

Practitioners in the field like a project engineer, a battalion S3, a base civil engineer, a design or QC assistant, Construction Program Manager, construction material tester etc. have a 'cat bird seat' to participate in current and developing practices where we commonly acknowledge they 'learn their craft' and become seasoned engineers, foremen and architects. Particularly younger officers, junior civilian engineers and mid-level foremen, supervisors and NCO are considered to be in a 'development stage' when done right includes mentoring and learning 'how things are done' and 'how to adapt their personal style' to leadership. This is just as true in Energy as in construction or any other application of engineering to a project. This is right, this is proper grounding of talent, this should be SUSTAINED. But it is also INCOMPLETE.

4. CONCLUSION

By nature each of us forms opinions and personal observations particularly in early 'formative' experiences. Thinking back to recent SAME events at the post level and at JETC we may all agree we showcase the expert and the senior practitioners who frequently include context to their stories with personal experiences that often became personal motivators. Most of us have built by observation and experience our approaches to management, technology and even budgeting around the standard practices of the craft as we learned the 'right way' to do things. Again this is a 'SUSTAIN'.

But again this is an incomplete capture of the experience. We, trained in the scientific method and educated in the engineering practice, observe, hypothesize and test. We do so reflectively and most effectively by sharing with our peers. Over time we get a feel for what works for our personal style and in specific circumstances. Most of the technical things – and in this case ENERGY – are largely outside of this native approach to learning and adapting. Instead we apply the current state, or more often the selected and purchased for us, technology and apply our reflectively-learned adaptiveness to integrate or install that into the project.

Make this experience more complete – be a bit deliberate in your observations and record some of the pragmatic and measureable things from these standard approaches. Shift from reflective only to empirical in your learning. Keep notes and share your own experimentation and ever evolving hypothesis. Record a list of ideas and things that need to be improved. Then the day will come when you have a chance to formally research one of these ideas – to review all that has done on the topic and investigate under the guidance of a professor if your ideas work better. When you get to that point, we here in academia are ready for you – but you bring in the ideas to be explored. You bring in the insights from your field experiences and you are the real expert. Few topics today have more potential for experimentation than energy.

SECTION

6. CONCLUDING REMARKS AND RECOMMENDATIONS

Out of context, these writings seem to be papers varying from GEOINT to water to education to energy and to research. Just as confounding is, the papers are prepared for a variety of journals with widely differing readership. What binds them into a coherency is the concept of a broad area of intersection between the disciplines of military engineering and geological knowledge. A large overlap of duties of the military engineer in construction, environmental work, planning, social license, scale and impact exists with the responsibilities in the geological engineers' domain of expertise. The spectrum of underground considerations from economic value to human risk underlay the fieldwork of the military engineer and the spread of topics within the listed writings are mere samples along that spectrum. A great many other topics are both possible and expected to be touched in continuing publications and discourses. In addition, additional forums for outreach and dissemination of the insights gained are readily available for the geologically minded military engineer. Not only is there more research to accomplish, new techniques need experimentation, new approaches need refinement, additional applications need geophysical trails and subterranean facilities need new thinking. Most importantly, an ever-renewing stream of talent is inducted into military engineering and should be invited to become warrior-scholars of geological engineering.

Recommendations on topics to be addressed in further research are included in commentary throughout this paper. This summarized list may be helpful to military engineers following this track of geological engineering study.

1. Historical case studies of geological engineering on the battlefield and lessons learned.
2. Water production and distribution in contingency operations to include asset estimation and costs by source types
3. Groundwater safety, quality and sustainability at installations
4. Climate change and water security
5. Implications of hydrogeology on military operations
6. Polar ice as an asset and as a barrier
7. Oases-date palm- geology interactions
8. Dust – heat – cold – food – water in arid regions as an engineering issue
9. Geology and radiance balances affecting environmental exposure of soldiers
10. Biodiversity versus hydrogeology
11. Mobile offshore basing
12. Drainage and fortifications
13. Cataloging the water solutions of nations in conflict
14. Digging out deeply buried or entrenched facilities
15. Siting geological structures
16. Vulnerability of geological and buried structures
17. Ground freezing as a construction tactic
18. Acceptance by military and public of underground space for work, storage and living

19. Rock reinforcement in blast cycles
20. Projecting mobility challenges to heavy and light maneuver forces
21. Unambiguously describing and mapping the ground mobility
22. Operating on terrain in disrupted information technology environments
23. Doctrine for subterranean war
24. Geological risk management
25. AI/ML improvements to GEOINT
26. Sensors and unmanned platforms
27. Subsurface GIS
28. Geoscience insertion into geopolitics
29. Shallow earth surveys for graves
30. Relationships between public health and the land
31. Mater of Terrain in the information-enabled force and training
32. Understanding geohazards, risks and sensors
33. Mineralization dangers in quarries and borrow pits
34. UXO classification
35. Relationships between agriculture, hydrogeology, geology and security
36. Force risk and societal violence from the interplay of people and location (human terrain)
37. Project management of geological works to include modeling and simulation

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VITA

Stephen Harold Tupper, born Portland Maine and graduate of South Portland High school, attended one year of Chemical Engineering at the University of Maine Orono and transferred to the US Military Academy at West Point graduating with a BS in 1977. He was commissioned as an officer in the Corps of Engineers on active duty until retirement at the grade of Lieutenant Colonel in 2003.

He earned a MS in Electrical Engineering from the Georgia Institute of Technology in 1988 and a PhD in Geological Engineering from Missouri University of Science and Technology in May 2019.

Included in his military assignments were a three-year period as an Associate Professor of Electrical Engineering at West Point and a three-year period as Professor and Department Head on Military Science at Worcester Polytechnic Institute.