# Mosul Dam - A Study in Complex Engineering Problems

**Lt. Col. Jakob C Bruhl, U.S. Military Academy**

Lieutenant Colonel Jakob Bruhl is an Assistant Professor in the Department of Civil and Mechanical Engineering at the United States Military Academy, West Point, NY. He received his B.S. from Rose-Hulman Institute of Technology, M.S. Degrees from the University of Missouri at Rolla and the University of Illinois at Urbana/Champaign, and Ph.D. from Purdue University. He is a registered Professional Engineer in Missouri. His research interests include resilient infrastructure, protective structures, and engineering education.

**Prof. Joseph P Hanus, U.S. Military Academy**

Colonel Joseph Hanus is the Civil Engineering Program Director at the U.S. Military Academy, West Point, NY. He received his B.S. from the University of Wisconsin, Platteville; M.S. from the University of Minnesota, Twin Cities; and Ph.D. from the University of Wisconsin, Madison. He is an active member of ASEE and is a registered Professional Engineer in Wisconsin. His research interests include fiber reinforced polymer materials, accelerated bridge construction, and engineering education.

**Mr. Paul M Moody P.E., U.S. Military Academy**

Lieutenant Colonel Paul Moody is an Associate Professor at the U.S. Military Academy, West Point, NY. He received his B.S. and M.S. from Massachusetts Institute of Technology and Ph.D. from the University of Massachusetts, Amherst. He is an active member of ASEE and a registered Professional Engineer in Virginia. His research areas include climate change impact on water resource systems and infrastructure.

**Dr. James L Klosky P.E., U.S. Military Academy**

Led Klosky is a Professor of Civil Engineering at the United States Military Academy at West Point and a past winner of ASEE's National Teaching Medal. He is a licensed professional engineer and works primarily in the areas of infrastructure, subsurface engineering and engineering education.

# Mosul Dam
# A Study in Complex Engineering Problems

The United States Military Academy (USMA), at West Point, NY, seeks to educate and inspire their civil engineering students through a rigorous and realistic academic program. Recognizing that civil engineers often face complex problems that encompass technical engineering and societal, political, and economic challenges, USMA has established an Infrastructure Engineering course to prepare their students for these problems. A key element is an established model of infrastructure analysis, which is introduced in the course and applied in follow-on experiences in the program. Faculty members draw upon their engineering experiences to provide relevant challenges for the students to apply the model, such as the Mosul Dam in northern Iraq. These challenges are often multi-dimensional and include difficult questions which require the student to advocate for solutions which do not satisfy all stakeholders.

The Mosul Dam is a piece of critical infrastructure on the Tigris River in Iraq which provides hydroelectric power, irrigation, water supply and flood control for the nearby city of Mosul and the surrounding area. The Mosul Dam has well-known technical engineering and other challenges and was presented as a case study to the senior civil engineering students in their culminating professional seminar course. Students were provided technical data, environmental conditions, and the social, political and economic context in which the project functions. Students were challenged to assess the dam with the established infrastructure model, develop creative mitigating measures, and outline the inter-related technical and non-technical concerns.

The result of the student's experience in wrestling with the Mosul Dam addressed several of the program's ABET student outcomes which require students to incorporate knowledge of contemporary issues into the solution of engineering problems, anticipate the impact of engineering solutions in a global and societal context, and explain the basic concepts of business and public policy. The assessment of these specific ABET student outcomes included direct and indirect embedded indicators. Additionally, the impact on the cognitive and affective developmental domains is considered with respect to educating and inspiring our future civil engineers. Assessment data demonstrated that the students achieved the program outcomes by engaging a challenging engineering problem which was influenced by a variety of non-technical issues. As a result of this educational experience, the students were confident with their abilities to deal with problems they will likely face in the future.

## Introduction

The mission of the United States Military Academy (USMA) has evolved since the institution's inception in 1802:[1]

> To educate, train, and inspire the Corps of Cadets so that each graduate is a commissioned leader of character committed to the values of Duty, Honor, Country, and prepared for a career of professional excellence and service to the Nation as an officer in the United States Army.

The Department of Civil and Mechanical Engineering is one of 11 departments at the Academy, and both the civil and mechanical engineering programs are ABET accredited. The mission of the Department of Civil and Mechanical Engineering parallels the Academy's mission, while focusing on educating and inspiring students in the fields of civil and mechanical engineering:[2]

> To educate cadets in civil and mechanical engineering, such that each graduate is a commissioned leader of character who can understand, implement, and manage technology; and to inspire cadets to a career in the United States Army and a lifetime of personal growth and service.

The civil engineering program established 16 student outcomes to achieve the mission and meet the ABET accreditation requirements. Among these are three which require the application of engineering within a broad context and require students to draw on knowledge of disciplines affected by and influencing engineering solutions:

11. Incorporate knowledge of contemporary issues into the solution of engineering problems.
12. Draw upon a broad education to anticipate the impact of engineering solutions in a global and societal context.
15. Explain the basic concepts of business and public policy.

Recognizing that the Department's mission statement includes educating and inspiring, the civil engineering faculty have sought to develop their program appropriately along a set of commonly accepted educational taxonomies; that is, Bloom's Taxonomy. These widely known taxonomies are based on the seminal work of the 1950's educational committee chaired by Benjamin Bloom. The committee established a set of taxonomies in three domains of learning: cognitive, affective and psychomotor. The cognitive domain taxonomy is widely accepted in many fields and has been identified as, "arguably one of the most influential education monographs of the past half century."[3] The taxonomies are a language that describes the progressive development of an individual in each domain and are defined as follows:[4]

- Cognitive: of, relating to, being, or involving conscious intellectual activity.
- Affective: relating to, arising from, or influencing feelings or emotions.
- Psychomotor: of or relating to motor action directly proceeding from mental activity.

A set of development levels for each domain are available in the literature. [5-7] Each domain has multiple levels defined in increasing complexity which guide educators to develop a variety of educational experiences with course, lesson, and project objectives targeted at specific levels within the domains.

The authors recognized that their institutional mission statement expects both education (cognitive domain) and inspiration (affective domain) in their program with limited emphasis on the psychomotor domain. Furthermore, the authors believe that the engineering education profession is setting an expectation for student development in both of these domains. In particular this trend is evident in the American Society of Civil Engineers (ASCE) Body of Knowledge 2 (BOK2)[8] and has been studied in detail by the lead author.[9-13] As such, courses in the Academy's civil engineering program strive to develop their students in both domains.

The purpose of this paper is to present the structure and assessment of a learning experience in one of the core civil engineering program courses (CE400 – Professional Practice Seminar) at the United States Military Academy. The experience involves a complex civil engineering problem that encompasses a wide range of issues - technical, environmental, social, political, and economic. The senior civil engineering students are challenged to assess the problem with established infrastructure models, develop creative mitigating measures, and outline the inter-related technical and non-technical concerns. This project was developed to contribute to student achievement of the three program outcomes described above and provide an experience for students to develop higher level skills within the cognitive and affective domains. This paper details the course, the complex problem and the established infrastructure models. The paper also reviews pedagogy on teaching students to develop solutions for such problems and describes integration of these methods in the course. An assessment is presented with respect to the course scope and objectives, the program student outcomes, and department mission to educate and inspire.

## Background

This section provides information about the course, motivation for presenting complex problems in engineering courses, details and contributing issues for the complex problem used in the course (the Mosul Dam), and the infrastructure model taught to our students in a previous course and used in the analysis within this course. This information is presented to understand the setting, the complex problem specifics for the learning experience, and the importance of such learning experiences.

### *CE400 – Civil Engineering Professional Practice Seminar*

CE400 is a senior-level course in the West Point Civil Engineering program. The course scope focuses on issues related to the professional practice of civil engineering, and is intended to augment and enrich the student's civil engineering core courses. Topics include professional registration and practice, engineering ethics, contemporary issues, and fundamental concepts of business, management, and public policy. The course objectives are:

a. Apply the ASCE Code of Ethics to the solution of an ethical problem confronting a practicing engineer,
b. Explain the elements of project management in the military, public service, and private sectors,
c. Describe the business and public policy issues for public and private practice,
d. Demonstrate an appreciation of the challenges facing civil engineers in professional practice now and in the future,
e. Develop short-term and long-term professional goals, to include consideration of continuing education and professional registration,
f. Communicate effectively in writing.

### *Motivation for Complex Problems in Engineering Courses*

The problems graduates will face are generally not the well formulated text book or study guide problems that help them learn the fundamentals, but complex and finely nuanced problems. These problems have multiple, conflicting stakeholders and are vague or ill-posed. Rittel and Webber (1973) described a class of policy problems as "wicked problems" based on their complexity and resistance to solution.[14] Integral to CE400 is presenting the students with real-world civil engineering problems. "Theory without practice is as lifeless as practice without theory is thoughtless."[15] It is well researched and documented that problem based learning (PBL) is well suited for engineering programs. PBL allows students to engage in complex, ill-formed, and open-ended problems which fosters flexible thinking and supports intrinsic motivation.[16] These characteristics can be further encouraged by group discussion of potential solutions, critical instructor feedback, and essential self-reflection during and following the learning event.

A. Kolb and D. Kolb define Experiential Learning Theory as the "process whereby knowledge is created through transformation of experience. Knowledge results from the combination of grasping and transforming experience."[17] As defined, students undergo experiential learning through concrete experiences (actual personal experiences) and abstract conceptualizations (simulations). Through reflection, direct observations and external feedback, the students gain a deeper understanding and, ultimately, knowledge.

Andresen et al. outline student development through experience-based learning (EBL) as follows:[18]

1. Students engaged in EBL are involved through their senses, feelings, and intellect, at varying levels,
2. Students can recognize and relate lessons to personal learning experiences,
3. Students can reflect upon earlier experiences and transform them into deeper understanding.

In addition to technical competency and experience, creativity plays a central role in creating effective engineering solutions. Engineers must apply their knowledge to new problems and understand contributing factors in a design (e.g. social and economic challenges), which stretches their thinking beyond traditional technical issues that most associate with engineering practice. This requires more preparation than simply taking humanities courses; it requires opportunities for students to practice creative problem solving in engineering courses. Cropley challenges educators to connect creativity and engineering and recommends strategies to do so. Students must first become technically competent engineers but must also be encouraged to generate a variety of possible solutions to ambiguous problems. To do this, educators, course and program design should strive to include open-ended problem statements, encourage risk taking, and teach students to identify and surmount obstacles.[19]

Instructors play a key role in these PBL and EBL experiences. Hmelo-Silver states that they should they be facilitators, serve as motivators, guide students through various stages of the experience, monitor the group experience, and aid in self-reflection through well-directed questioning to individual students.[16]

The Mosul Dam presents a variety of technical, social, political and economic design challenges and can serve as a strong example to support exercises and design problems intended to challenge students. The multi-faceted problem of the Mosul Dam has many of the characteristics of a “wicked problem”, which allows the students to be creative about formulating solution strategies that are based on sound engineering yet incorporate their knowledge of contemporary issues and societal context. Since there is no single or correct answer, students can evaluate their solutions on how well they satisfy the many competing requirements and demands. The lead authors experience in a recent deployment that involved the Mosul Dam in Iraq was the motivation for incorporating the complex real-world problem it into the CE400 course. The other authors also had experience with the Mosul Dam and an interest in integrating the challenge in CE400.

### *Mosul Dam – Critical Infrastructure*

Water resources for Iraq depend predominately on the Tigris and Euphrates Rivers with the headwaters for both lying outside of the country.[20] Rainfall mainly occurs between December and February and has large fluctuations between years. These conditions make effective irrigation and flood control programs critical for a reliable agriculture economy in Iraq. With groundwater aquifers limited throughout the country, 94% of irrigation water is provided by surface water retained behind dams. In addition to providing irrigation water and flood control, hydroelectric dams also provide 17% of the power for Iraq.[21]

The Mosul Dam is the largest dam in Iraq and its reservoir capacity of nearly 12-km$^3$ makes it the fourth largest in the Middle East.[22] This piece of critical infrastructure on the Tigris River is located 60-km northwest of Mosul, Iraq and roughly 80-km from Iraq’s borders with Turkey and Syria. The dam, constructed in the early 1980s, provides hydroelectric power, irrigation, water supply and flood control for Mosul and much of northern Iraq and has well-known technical engineering challenges associated with solubility of the geology on which it was built. Due to these technical challenges, the dam does not provide the irrigation water and hydropower as originally intended. The regional security situation, social factors, political factors (both national and international), and economic factors further compound the issues and complicate potential courses of action to remediate the dam.

The dam, originally named the Aski-Mosul dam and subsequently referred to as the Saddam Dam, was originally designed to store 7.7-km$^3$, irrigate 750,000-hectares, and provide 750-MW of power. Design and construction of the dam was a multi-national effort which began in the late

1950s and continued through the 1980s. Detailed geological investigations were conducted by French and Swiss companies, construction of the dam and surrounding facilities was the responsibility of German and Italian companies, and construction of the power station was accomplished by Japanese, Austrian, and Italian companies. The dam consists of a clay core, earth fill, and a rock face. Concrete spillways on the left abutment discharge water when the reservoir is at its maximum level of 338-m (normal operation level is 330-m and crest level is 341-m). The right abutment houses the power generation facilities.[23]

The principal engineering challenge of the Mosul Dam lies in the complexity of the geology on which the dam was constructed. The dam sits on karstified gypsum and limestone beds which are water soluble. This geological condition was known before construction began and sinkholes, caves, and cracks began appearing near the dam's foundation during construction (see

Figure ***1***). To address this, grouting to fill the subsurface voids began during construction and has continued nearly uninterrupted for the life of the dam (see

Figure ***2***). Dissolution has been exacerbated by the reservoir pool and additional surface evidence has continued to appear (see Figure 3). The presence of the reservoir increases the rate of subsurface erosion. In a detailed study of the dam in 2007, the US Army Corps of Engineers recommended maintaining the reservoir at a depth no greater than 318-m; this elevation is below the level required for irrigation operations but necessary for safety of the dam,[24] further degrading the utility of the dam by forcing hard choices between safety and functionality.

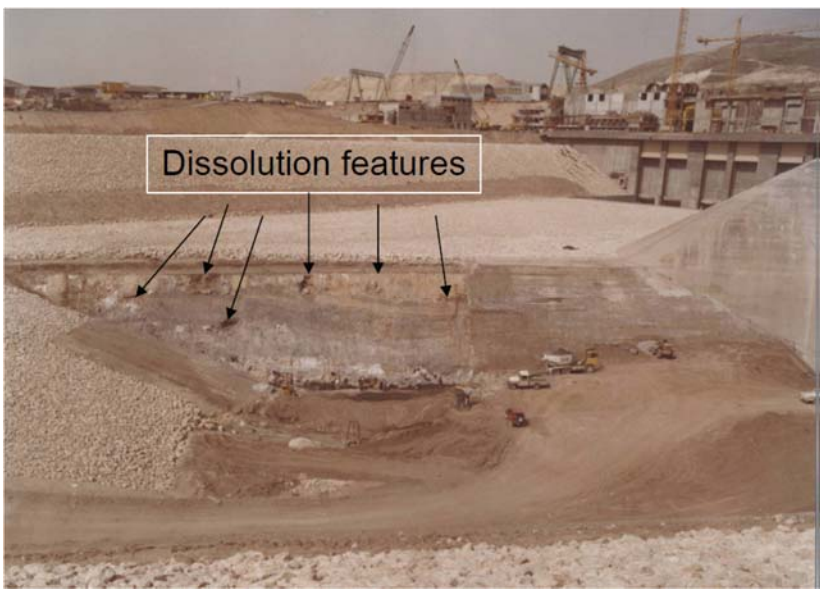


**Figure 1**. Photo taken during construction of Mosul Dam showing dissolution features[24]

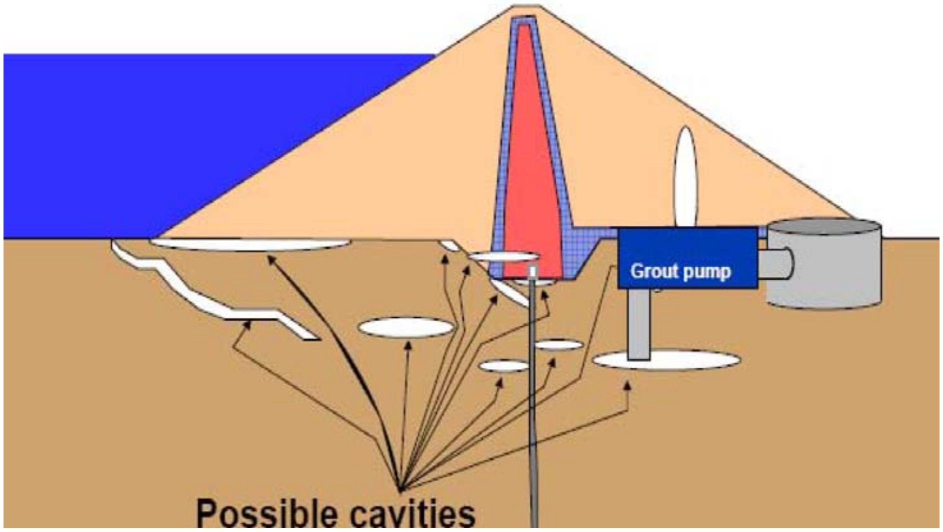


**Figure 2.** Illustration of Mosul Dam's grouting program[25]


(a) Example sinkhole (b) Sinkhole beneath paved area (c) Example seepage
**Figure 3.** Examples of dissolution features[25]

***Contributing Issue: Water Control***

All of the flow of the Euphrates River comes from outside Iraq (94% from Turkey; 6% from Syria) and about two-thirds of the flow of the Tigris River comes from outside Iraq (55% from Turkey; 12% from Iran).[26] The flow in the Euphrates River as it enters Iraq has been generally decreasing as seen in

Figure ***4*** due to development in the neighboring countries.

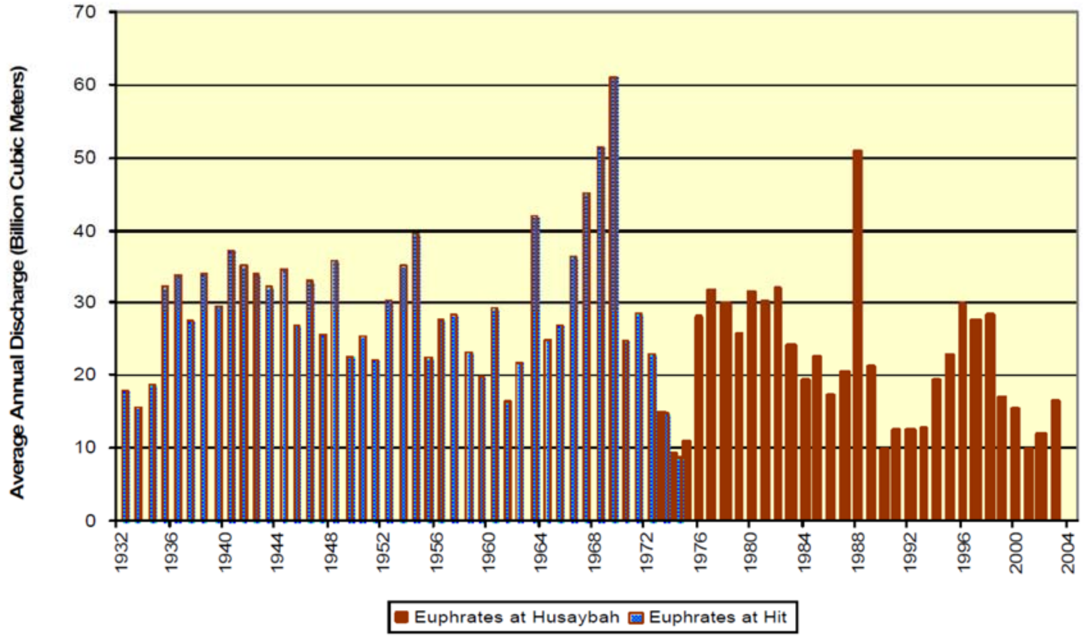


**Figure 4.** Euphrates inflow to Iraq (1932-2003)[26]

***Contributing Issue: Regional Security and International Politics***

Concerns about the geotechnical stability of the Mosul Dam have appeared in the international press several times over the years. Shortly after the 2003 invasion of Iraq, concerns about the stability of this critical piece of infrastructure by US military leadership made headlines.[27] By 2005, the US Army Corps of Engineers (USACE) had funded stabilization projects to prevent catastrophic failure.[28] USACE reports published in 2007 renewed international concerns about the geological condition of the dam.[24,29] Ambassador Crocker and General Petraeus advised Iraqi Prime Minister al-Maliki in a 3 May 2007 memo that the dam presented “unacceptable risks” and would have devastating effects if it failed: 500,000 civilian deaths, putting Mosul under 20 meters of water.[25] The major cities of Tikrit, Samarra, and Baghdad would also be at risk of massive flooding and bridges along the Tigris would likely destroyed in the deluge.[30]

In August 2014, the dam again appeared in the news as ISIS militants seized control of the critical piece of infrastructure.[31] Iraqi military forces, supported by US airstrikes, regained control of the dam about two weeks later an operation which highlighted political tensions between Iraqi and Kurdish leadership.[32] Although ISIS no longer controls the dam, their forces do control much of the surrounding territory, including Mosul, making warning or evacuating citizens a challenge for the Iraqi government.[30]

It is not only regional politics that influence decisions made concerning the Mosul Dam; international politics also play a critical role. After control of the dam was regained, a US interagency team in cooperation with Iraqi personnel installed instruments to measure pressure on the dam and sediment in nearby water to assess the dissolution rate and structural stability of the dam. The US concern was increased because of the threat dam failure poses to US citizens living and working at the American Embassy in Baghdad, but the Obama administration ruled out supervising, funding, or securing repair efforts. In January 2016, President Obama recommended to Iraqi Prime Minister Al-Abadi that emergency repairs be made to the Mosul Dam and the Iraqi government officially warn its citizens, advise them about necessary precautions, and make evacuation plans in the event of a dam failure. The Trevi Group, an Italian company, has negotiated with the Iraqi government to make $380 million worth of repairs and the Italian Prime Minister has agreed to deploy their own military forces to provide security if the Trevi Group is awarded the contract. The Iraqi government is divided in their response to this offer of the Italian government: Iraq's ambassador to the US, Lukman Faily, has no objection to additional security forces from Italy but the head of Iraq's Ministry of Water Resources, Mohsin al-Shammari, does not want "foreign support" for security of the dam.[30]

In short, the political situation surrounding the dam remains uncertain and tense and is drawing international attention at the highest levels. Despite this, a long-term plan for resolving the dam's severe safety and performance shortfalls has not yet been agreed upon.

### *Infrastructure Models*

In the West Point Civil Engineering program, an Infrastructure Engineering Course (CE350) was added as a required course as part of a program evolution.[33-35] Of particular interest are the West Point Infrastructure Models, which were developed as theoretical and practical frameworks for understanding, visualizing and describing the infrastructure environment. These models were summarized by Hart, Klosky et al in a report to the Army[36] and are intended to support deep thinking and clear communication of complex infrastructure issues, particularly as seen from a systems point of view. As such, the models link closely with the Army's concept of describing the operational environment in terms of operational variables: political, military, economic, social, information and infrastructure (PMESII – a much-used Army acronym).[37] These models, two of which are described below, form the backbone of the CE350 Infrastructure Engineering course, which is taught to engineering and humanities majors, and provide a clear framework for discussions, exercises and design events related to the Mosul Dam project.

The first model, the Infrastructure Component Model, is used to identify all parts of an infrastructure system and is comprised of six steps/components which make up most infrastructure systems: **G**eneration, **B**ulk Transmission, **D**istribution, **U**ser, **W**aste and **C**oordination. These are detailed in ERDC TR 14-14[36] and are generally remembered via the mnemonic **G**rizzly **B**ears **D**on't **U**se **W**ater **C**losets. This method of laying out and classifying infrastructure components is applicable to many different infrastructure systems and is illustrated in Figure 5 with respect to electric and water infrastructure.

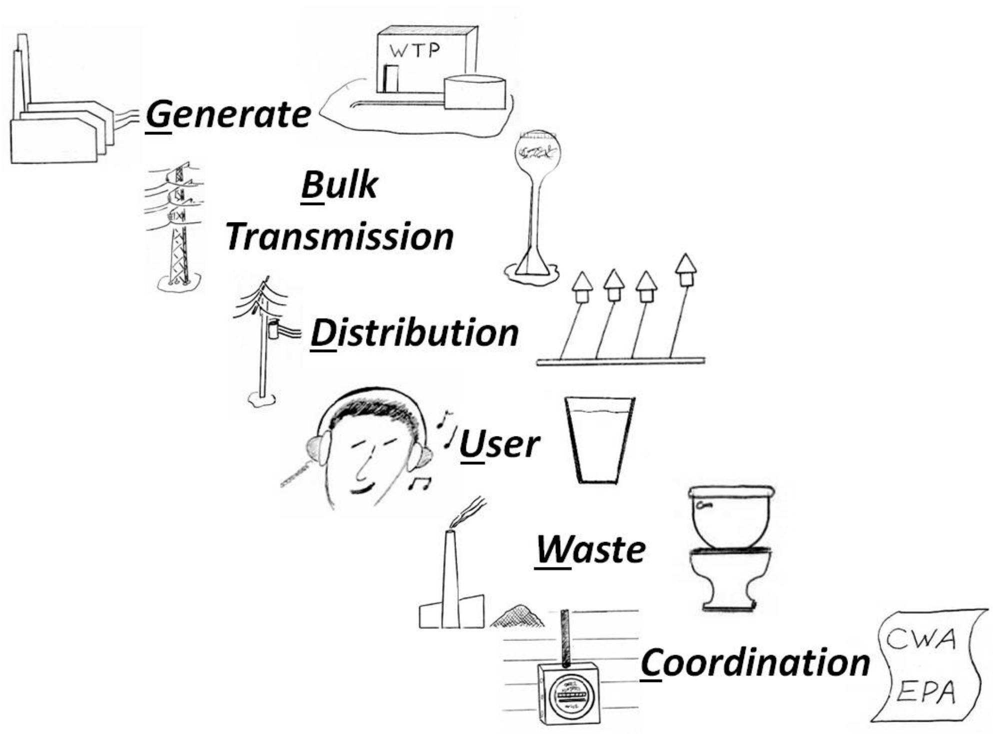


**Figure 5** GBDUWC applied to electrical and water infrastructure (Illustration by Led Klosky)

The second infrastructure model, which is applicable directly to the Mosul Dam problem, is the Infrastructure Assessment Model. This model was developed to support rapid generation of a comprehensive set of questions that would support a complete assessment of a particular infrastructure component or system; the answers to these questions form the backbone of a complete assessment. Detailed in TR 14-14,[36] the Assessment Model can be summarized as six question-generating prompts. Three of these prompts, the so-called "Sunny Day" prompts, are intended to provide a picture of the general operating condition of the infrastructure component or system:

- ***Required*** focuses primarily on the User element of the Infrastructure Component Model. By beginning with user demand, this focus aligns well with current thinking on disaster recovery, development work, and nation building. This prompt identifies the user's needs.
- ***Ready*** focuses on the *Generation, Bulk Transmission,* and *Distribution* elements of the Infrastructure Component Model by asking what these elements are capable of delivering at the current time in their current configuration. The *Ready* prompt leads to the formation of capacity-focused questions.
- ***Organized*** principally assesses the *Coordination* element of the Conceptual Model, leading to assessment questions that are both quantitative and qualitative. Assessment questions focus on all aspects of *Coordination.*

Of course, as important as it is to assess the performance of an infrastructure system during normal operations, it is perhaps more important to assess performance when the system is put under stress. The Assessment Model addresses this through the three "Rainy Day" prompts, meant to generate questions related to projected performance under adverse conditions:

- ***Tough*** is focused on Generation and Bulk Transmission, although key elements of the Distribution systems may also need to be tough. These elements tend to be expensive, hard to replace, and their loss leads to broad delivery disruption. As such, they must be able to survive or quickly recover from adverse conditions and return to service rapidly.
- ***Redundant*** maps well to the Bulk Transmission and Distribution elements of the Component Model, although additional Generation capacity may also be desirable. Transmission and distribution systems are typically spread over great distances and, while these systems are designed to withstand normal circumstances, their size makes it cost prohibitive to harden them against extreme events. Therefore, they either must possess sufficient redundancy to continue functioning with the loss of elements or be rapidly repairable.
- ***Prepared*** applies across an entire infrastructure system, focusing especially on the User to determine if the User is or can be prepared to survive a disruption in the service provided by the infrastructure.

Infrastructure systems and components serve a societal need. When infrastructure fails, the need does not disappear. Users who are not prepared for adverse events make significant demands on governmental and societal systems that are also in distress, thus compounding problems for all. *Preparation*, when supported by *Toughness* and *Redundancy*, can reduce the overall impact of an adverse event and speed the restoration to normalcy. Detailed examination of critical infrastructure in the context of these three "Rainy Day" questions can lead to in-depth discussions of ethics, needs balancing, stakeholder analysis, social justice, politics and economics. This demonstrates the deep roots of infrastructure in society and the role of engineers as important partners in endeavoring to articulate the future within vital and complex socio-political situations.

The structure of the learning exercise in CE400 focused on the Mosul Dam problem, use of the CE350 Infrastructure models, and assessment of the impact on various metrics is described in the following sections.

## Course Application and Execution

The learning exercise consists of three components: (1) preparation, (2) classroom experience, and (3) a written assignment. Students are required to prepare for class by reading background information on wicked problems and the Mosul Dam, and reviewing the infrastructure models from CE350. The classroom experience begins with a quiz to confirm student preparation before additional background information is presented on wicked problems and the Mosul Dam. The focus of the classroom experience is the in-depth discussions of the CE350 infrastructure models as applied to the Mosul Dam; this discussion comprises the majority of the time in class. The culminating component, prepared outside of class, is an individual written assignment that requires students summarize the Mosul Dam problem and the associated challenges, and making recommendations for US policy with respect to the dam. Details of these three components are provided in the Appendix.

## Assessment

Several assessments were conducted on the Mosul Dam learning experience with respect to different metrics: course objectives, student outcomes, and department mission. There was a direct relationship between the CE400 course objectives and the ABET Civil Engineering Student Outcomes. The course objectives supported by the Mosul Dam learning experience were c and d:

c. Describe the business and public policy issues for public and private practice,
d. Demonstrate an appreciation of the challenges facing civil engineers in professional practice now and in the future,

The ABET Civil Engineering Student Outcomes supported by the Mosul Dam learning experience were 11, 12, and 15:

11. Incorporate knowledge of contemporary issues into the solution of engineering problems.
12. Draw upon a broad education to anticipate the impact of engineering solutions in a global and societal context.
15. Explain the basic concepts of business and public policy.

The wording of course objective *c* clearly links it to outcome *15*. Likewise, the wording of course objective *d* is linked to outcomes *11* and *12*. As such, an assessment of the Mosul Dam learning experience was done with respect to the student outcomes because there were three student outcomes, providing greater fidelity than, but still linked to, the two course objectives.

The quiz was used to assess the student outcomes as follows:

- Question b, *"…list three issues associated with the Mosul Dam that makes it a wicked problem."* Each of the 36 students listed three issues for a total of 108 issues. Reviewing the 108 submitted answers to this question, a key word search was conducted to identify the percentage of students who addressed contemporary issues (outcome 11), global or societal issues (outcome 12), or policy issues (outcome 13). The results are shown in Table 2:

**Table 2.** Key Word Search – Student Outcomes

| Student Outcomes | Key Phrasing | Percentage |
|---|---|---|
| Contemporary Issues | Engineering and O&M issues | (34/108) 31% |
| Global or Societal Issues | Impact of failure, Dangerous Environment | (32/108) 30% |
| Policy Issues | Political, management, leadership and resources | (42/108) 39% |

- Questions c and d addressed the student's review of the CE350 Infrastructure Models. Performance on these questions were related to the broad education in outcome 12. The results are shown in Table 3:

**Table 3.** Student Performance Recalling CE350 Infrastructure Models

| CE350 Infrastructure Models | Average Student Grade |
|---|---|
| Infrastructure Component Model | 95.3% |
| Infrastructure Assessment Model | 94.0% |

The culminating written paper was used to assess outcome 15 because the recommendation for US Policy was linked to this outcome. The average student score was 94.8% (n = 36).

A student survey, administered on the last lesson in CE400, included the following questions with the average results in brackets for each question:

> *The Mosul Dam lessons were intended to generate in-depth discussion of a wicked engineering problem. Considering this experience, rate yourself on a scale of 1 (low) to 5 (high) on your confidence to complete the following:*
>
> a) *Incorporate knowledge of contemporary issues into the solution of engineering problems.* [average 4.1, n = 36 students]
> b) *Draw upon a broad education to anticipate the impact of engineering solutions in a global and societal context.* [average 4.3, n = 36 students]
> c) *Explain the basic concepts of business and public policy.* [average 3.9, n = 36 students]
> d) *Engage in assessing wicked engineering problems.* [average 4.4, n = 36 students]
> e) *Engage in providing recommendations on wicked engineering problems.* [average 3.9, n = 36 students]

From the survey, questions *a* thru *c* align directly with the three student outcomes. Questions *d* and *e* are intended to assess their inspiration to tackle wicked engineering problems, which is meant to be assessed with respect to the Department's mission to educate and inspire. Based on the results, the Mosul Dam learning experience had the desired result: the students engaged a challenging engineering problem which was influenced by a variety of non-technical issues and were confident with their abilities to do so for future problems they will likely face.

## Conclusion

This paper presented the structure and assessment of a learning experience in one of the core civil engineering program courses (CE400 – Professional Practice Seminar) based on the Mosul Dam in Iraq – a wicked engineering problem. The learning experience was assessed with respect to the civil engineering student outcomes, course objectives and the department mission to educate and inspire. The authors hope that the material presented may be of use for other programs interested in developing and including open-ended wicked engineering problems in their curriculum.

## Bibliography


1. United States Military Academy (2008). *Mission Statement*. Accessed Jan 1, 2008. http://www.usma.edu/mission.asp.
2. Department of Civil and Mechanical Engineering, USMA (2008). *Mission Statement*. Accessed Jan 1, 2008. http://www.dean.usma.edu/departments/cme/CME%20Home/mission.htm.
3. Anderson, L.W. and L.A. Sosniak (1994). "Bloom's taxonomy: A forty-year retrospective." Ninety-third yearbook of the Nation Society for the Study of Education (NSSE), Part II. University of Chicago Press.
4. Merriam-Webster's Online Dictionary (2008). Accessed Jan 1, 2008. http://www.m-w.com/dictionary.
5. Bloom, B.S. (1956). *Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain*. New York: David McKay Co Inc.
6. Krathwohl, D.R., B.S. Bloom, and B.M. Bertram (1973). *Taxonomy of Educational Objectives, the Classification of Educational Goals. Handbook II: Affective Domain*. New York: David McKay Co., Inc.
7. Simpson, E. (1972). *The classification of educational objectives in the psychomotor domain: The psychomotor domain*. Vol. 3. Washington, DC: Gryphon House.
8. ASCE (2008). *Civil Engineering Body of Knowledge for the 21st Century – Preparing the Civil Engineer for the Future.* Second Edition. Reston, Virginia: American Society of Civil Engineers.
9. Caldwell, C., Hanus, J., Chalmers, J.(2009), "Integration of Information Technology Software in a Civil Engineering Program, *Proceedings of the 2009 Annual Conference of the American Society for Engineering Education (ASEE)*, Austin, TX.
10. Saliklis, E., Arens, R., Hanus, J. (2009), "Teaching Architects and Engineers – Up and Down the Taxonomy," *Proceedings of the 2009 Annual Conference of the American Society for Engineering Education (ASEE)*, Austin, TX.
11. Hanus, J., Hamilton, S., Russell, J. (2008). "The Cognitive and Affective Domain in Assessing Life Long Learning." *Proceedings of the 2008 Annual Conference of the American Society for Engineering Education (ASEE)*, Pittsburg, PA.
12. Himes, J., Bruhl, J., Hanus, J. (2008). "Teaching Engineering to the Disinterested: A Case Study in Teaching Engineering Principles to Non-Engineering Majors." *Proceedings of the 2008 Annual Conference of the American Society for Engineering Education (ASEE)*, Pittsburg, PA.
13. Hanus, J. P., Russell, J. S., (2007). "Integrating the Development of Teamwork, Diversity, Leadership, and Communication Skills into a Capstone Design Course." *Proceedings of the 2007 Annual Conference of the American Society for Engineering Education (ASEE)*, Honolulu, HI.
14. Rittel, H. W. and Webber, M. M. (1973) *Dilemmas in a General Theory of* Planning" Policy Sciences 4:155-169.
15. Koh, Harold Hongju, (2005). "Lex et Veritas," Legal Affairs, January-February, 2005.
16. Hmelo-Silver, Cindy E. (2004). "Problem-Based Learning: What and How Do Students Learn?" *Educational Psychology Review,* 16 (3): 235-266.
17. Kolb, A., Kolb, D. (2009). "The Learning Way: Meta-cognitive Aspects of Experiential Learning." *Simulation & Gaming,* 40 (3): 297-327.
18. Andresen, L., Boud, D., Cohen, R. (2000). "Experience-Based Learning". In Foley, G.(Ed.). *Understanding Adult Education and Training, 2nd Ed.,* Sidney: Allen & Urwin, *225-239.*
19. Cropley, D. H. (2015). Promoting creativity and innovation in engineering education. *Psychology of Aesthetics, Creativity, and the Arts*, *9*(2), 161–171. http://doi.org/10.1037/aca0000008
20. Al-Ansari, N., Ali, A. A., & Knutsson, S. (2014). Present Conditions and Future Challenges of Water Resources Problems in Iraq. *Journal of Water Resource and Protection*, *6*, 1066–1098. http://doi.org/10.4236/jwarp.2014.612102
21. Food and Agriculture Organization of the United Nations. (2009). *Irrigation in the Middle East region in figures - AQUASTAT Survey 2008*. *Water Reports*.
22. Tomkiw, L. (2014, August 19). Three things to know about Iraq's Mosul Dam. *The Christian Science Monitor*, pp. 3–5. Boston, MA.
23. Al-ansari, N., Issa, I. E., Sissakian, V., Adamo, N., & Knutsson, S. (2015). Mystery of Mosul Dam the most Dangerous Dam in the World : The project. *Journal of Earth Sciences and Geotechnical Engineering*, *5*(3), 15–31.
24. Kelley, J. R., Wakeley, L. D., Broadfoot, S. W., Pearson, M. L., Mcgrath, C. J., Mcgill, T. E., Talbot, C. A. (2007). *Geologic Setting of Mosul Dam and Its Engineering Implications (ERDC TR-07-10)*. Vicksburg, MS.
25. Office of the Special Inspector General for Iraq Reconstruction. (2007). *Relief and Reconstruction Funded Work at Mosul Dam (Mosul, Iraq) (SIGIR PA-07-105).*

26. World Bank. (2006). *Iraq: Country Water Resource Assistance Strategy: Addressing Major Threats to People's Livelihoods (Report No. 36297-IQ)*.
27. Iraqi dam has experts on edge until inspection eases fears. (2003). *Engineering News Record*, *250*(17), 14–15.
28. Mosul Dam Reconstruction Continues. (2005, December). *Water Environment & Technology*, *17*(12), 18.
29. Wakeley, L. D., Kelley, J. R., Talbot, C. A., Pearson, M. L., & Broadfoot, S. W. (2007). *Engineer Research and Development Center Geologic Conceptual Model of Mosul Dam (ERDC TR-07-6)*. Vicksburg, MS.
30. Gordon, M. R. (2016, January 11). Neglect May Do What ISIS Didn't: Breach Iraqi Dam. *New York Times*, p. A1. New York, NY.
31. Nour, M. (2014, August 11). Mosul Dam's Takeover by ISIS Raises Risk of Flooding; Constant Maintenance Needed to Avoid Catastrophic Failure of Dam's Structure. *Wall Street Journal (Online)*. New York, NY.
32. Nour, M. (2014, August 20). World News: Rivalry Flares After Joint Victory At Mosul Dam. *Wall Street Journal*, p. A.6. New York, NY.
33. Conley, C., & Klosky, J. L., & Meyer, F., & Hanus, J. (2008), "A Global Curriculum To Support Civil Engineering In Developing Nations." *Proceedings of the 2008 Annual Conference of the American Society for Engineering Education (ASEE)*, Pittsburgh, PA.
34. Hamilton, S., & Meyer, F., & Klosky, J. L., & Hanus, J., & Hart, S., & conley, C. (2010). "A "Global" Curriculum To Support Civil Engineering In Developing Nations: The Final Result." *Proceedings of the 2010 Annual Conference of the American Society for Engineering Education (ASEE)*, Louisville, KY.
35. Hart, S. D., & Klosky, L., & Hanus, J. P., & Meyer, K. F., & Toth, J. A., & Reese, M. (2011). "An Introduction to Infrastructure for All Disciplines." *Proceedings of the 2010 Annual Conference of the American Society for Engineering Education (ASEE)*, Vancouver, BC.
36. Hart, SC, Klosky, JL, Katalenich, S, Spittka, B and Wright, E. (2014). *Infrastructure and the Operational Art: A Handbook for Understanding, Visualizing, and Describing Infrastructure Systems.* US Army, Report Number ERDC/CERL TR-14-14 and online at http://acwc.sdp.sirsi.net/client/default.
37. US Army (2012) Army Doctrine Reference Publication (ADRP) 3-0, *Unified Land Operation.* Combined Arms Doctrine Directorate, United States Army Combined Arms Center, accessed 13JAN2016 at http://armypubs.army.mil/doctrine/DR_pubs/dr_a/pdf/adrp3_0.pdf.

**Appendix: Instructional Content**

Warning Order for Quiz– provided to the students the lesson prior

- Dr. Horst Rittel was credited with coining the term “wicked problem.” Research Dr. Rittel and his definition. Be prepared to define this in your own words with respect to engineering wicked problems.
- Read the January 10th, 2016, New York Times Article, “Neglect May Do What ISIS Didn’t: Breach Iraqi Dam.” Be prepared to list three issues associated Mosul Dam.
- Review your CE350 Infrastructure Engineering course material. Be prepared to define and describe the Infrastructure Component Model (Grizzly Bears Don’t Use Water Closets) and the Infrastructure Assessment Model (Required – Ready – Organized – Tough – Redundant – Prepared). For additional information, the models are also available in the US Army Corps of Engineers Technical Report 14-14 ”Infrastructure and Operational Art: A Handbook for Understanding, Visualizing, and Describing Infrastructure Systems.”

Class Outline - two 55-minute lessons

1. Start of class quiz with the following individual questions:
   a. Based on Dr. Rittel’s definition of “wicked problems”, describe in your own words what is meant by wicked engineering problems.
   b. Based on the New York Times article, list three issues associated with the Mosul Dam that make it a wicked engineering problem.
   c. Define the CE350 Infrastructure Component Model (Grizzly Bears Don’t Use Water Closets).
   d. Define the CE350 Infrastructure Assessment Model (Required – Ready – Organized – Tough – Redundant – Prepared).
2. Instructor-led discussion on wicked problems, review the student responses on their quizzes, and present personal experiences with wicked engineering problems.
3. Present the Mosul Dam wicked engineering problem based on recent personnel deployment experience. Provide additional information as necessary to ensure students appreciate the breadth and depth of the issues associated with the Mosul Dam.
4. Discuss applying the CE350 Infrastructure Component Model to the Mosul Dam – specifically the Generate and Coordination Components.
   a. The Mosul Dam classifies as a Generate component for numerous infrastructure systems, including irrigation, public water supply and electrical power. The discussion includes the various systems the dam supports, functions of the dam, and the associated stakeholders.
   b. As stakeholders are identified, their concerns are discussed. The Coordination component of the model is further discussed with respect to the responsibility for the inspections, maintenance, and reporting for the dam.
      i. USACE and FEMA classify dams by size (small, intermediate, and large), by risk or hazard (low, significant, and high), and by condition (good, fair, and poor). These classifications serve to communicate the current risk assessment to the downstream communities. The hazard level is determined by conducting a dam breach analysis.

ii. In the United States, high and significant hazard dams are required to have an emergency action plan that has steps to evaluate, issue alerts, issue warnings, issue evacuation orders and conduct emergency repairs.
iii. Because the timeframe between identifying a potential dam breach situation to a full breach of the dam can be a matter of hours, the coordination component is critical to provide local authorities the maximum notification time to evacuate personnel from the hazard area and protect key infrastructure.
iv. In the case of the Mosul dam, the security situation and local government capability both severely hamper the coordination function.

5. Discuss applying the CE350 Infrastructure Assessment Model to the Mosul Dam with example questions as follows:
   - ***Required***: "How many cubic feet of drinking water and kW of power are supplied by the Mosul Dam?"
   - ***Ready***: "At current Mosul Dam reservoir levels, how much accessible stored drinking water is available and what are the other demands, like power production, on that capacity?"
   - ***Organized:*** "Who is responsible for the maintenance of the Mosul Dam and who should pay for this maintenance?"
   - ***Tough:*** "Does the Mosul Dam require toughness and is it tough in the current state?"
   - ***Redundant:*** "In the event of the loss of the Mosul Dam could the irrigation, public water and power generation functions be replaced? If not, what are anticipated impacts?"
   - ***Prepared:*** "Is Iraq prepared to survive a disruption of the loss of the Mosul Dam?"

6. Following the in-depth discussions of the Mosul Dam with respect to the CE350 Infrastructure Models, groups of three students each are challenged to begin addressing potential recommendations to mitigate risks and challenges. These discussions are meant to help prepare the students for the culminating written requirement.

<u>Written Requirement</u>
Students are required to submit an information paper that is 600-800 words in length. The paper must address the following:
a. Describe the Mosul Dam,
b. Describe the issues associated with the current state of the Mosul Dam.
c. Identify stakeholders and their needs and objectives.
d. Recommend a policy and way forward for the US Government with respect to the Mosul Dam. Defend your recommendation(s) appropriately.