AC 2012-4252: UNDERGRADUATE ENVIRONMENTAL ENGINEERING RESEARCH EXPERIENCES IN A PREDOMINANTLY UNDERGRADUATE TEACHING INSTITUTE

Dr. Sudarshan T. Kurwadkar, Tarleton State University

Sudarshan Kurwadkar is an Assistant Professor and a board-certified Environmental Engineer. He teaches environmental engineering and general engineering courses at the freshman, junior, and senior level. His research areas include fate and transport of micro-pollutants such as pharmaceuticals and neonicotinoid insecticides in soil and aquatic environment. He is a Co-faculty Advisor for the engineering club and French club at Tarleton State University. Kurwadkar is also a licensed Professional Engineer in the states of Texas, Ohio, and Missouri.

Dr. Daniel K. Marble, Tarleton State University

Daniel Marble earned a B.S. in electrical engineering from the University of Houston, with an M.S. and Ph.D. in accelerator-based nuclear physics from the University of North Texas. Marble began his academic career as an Assistant Professor of physics at the U.S. Military Academy in West Point in 1994. In 1998, he was hired to develop the first engineering program at Tarleton State University (engineering physics), where he presently serves as Head of the Department of Engineering and Physics. In addition to interests in ion solid interaction, physics of sports, accelerator technology, and materials characterization, Marble is actively involved in K-16 science and engineering education and teacher training. He has served as a physics content consultant for the Texas Center for Inquiry at the Fort Worth Museum of Science and History, President of the Texas Section of the American Association of Physics Teachers, and on the Texas High School Physics TEKS Committee.

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Undergraduate Environmental Engineering Research Experiences in a Predominantly Undergraduate Teaching Institute

Abstract

Undergraduate research experience broadens the educational experiences of environmental engineering graduates by preparing students for industry and graduate school and by enabling them to utilize their class room understanding to solve real world problems. The research experience in our undergraduate environmental engineering program offers the students an invaluable opportunity to work on sophisticated analytical instruments, hands-on experimental design, data analysis and interpretation, and also helps them hone their technical writing skills to meet the demands of graduate school and future employers. Furthermore, the addition of a research experience to a core environmental engineering curriculum provides an excellent means of not only teaching, but also assessing a large number of environmental engineering criteria outlined by the Accreditation Board for Engineering and Technology (ABET) including the ability to conduct laboratory experiments and the ability to critically analyze and interpret data in more than one major environmental engineering focus area. This paper discusses three environmental engineering undergraduate research projects that were funded through internal grants and completed between 2009 and 2011 by individual students under the mentorship of environmental engineering faculty. At the completion of their research projects, students presented their research work through a variety of poster presentations at symposiums and conferences and through publication in peer reviewed technical journals. The research experience, research methodology, problem formulation, difficulties encountered and lessons learned, along with the respective roles of undergraduate researcher and faculty mentor are presented.

Introduction

Traditionally environmental engineering education has been at the post-baccalaureate level with Civil Engineering graduates pursuing specialized environmental education at the graduate level. With the increase in the demand for trained environmental professionals, environmental engineering has recently emerged as a distinct engineering discipline with 59 universities in the United States now offering ABET accredited environmental engineering programs at the baccalaureate level including Tarleton StateUniversity.[1] Although the number of schools offering undergraduate environmental engineering program is increasing, the number of graduates awarded baccalaureate degrees in environmental engineering is still small compared to the number of graduates receiving civil engineering degrees (726 to 8,935) during 2005-2006.[2] This small number of graduates requires that universities be efficient in instructional practices while ensuring that environmental engineering graduates possess adequate skill sets in terms of knowledge, leadership, innovation and an ability to critically analyze and comprehend the problems in more than one environmental focus area such as air, soil and water system. While the traditional classroom instruction will groom students in problem solving and comprehending technical material, other attributes such as innovation, critical thinking and independent judgment can be most efficiently taught through research or independent study projects. The senior level capstone project included in engineering curriculums provides one opportunity for students to improve their skills in these areas. Undergraduate research experience in addition to the capstone experience provides both an effective means to assess program compliance with ABET criteria and a valuable opportunity for environmental engineering students to further develop valuable skills needed for their careers.

Undergraduate Research

The emphasis on including a research component at the baccalaureate level is well founded with several studies documenting the importance of undergraduate research. [3, 4, 5]In these studies, students doing research reported an enhanced learning experience including improved technical and critical thinking skills, a perceived greater personal and professional development, a greater understanding of the importance of team work, and improvement in working through setbacks compared to students doing a non-research curriculum. The findings also showed that students who participated in a summer research experience indicated additional benefits from the research experience in terms of an enhancement of their professional and academic credentials and a clarification of their career path.[4]

Given these and other similar studies, universities are increasingly looking for ways to integrate research into undergraduate curriculum with undergraduate research activities proliferating across the United States and faculty members increasingly engaging undergraduate students to pursue research activities.[6] The Boyer Commission on Educating Undergraduates in the Research University has called for action towards engaging undergraduate students in research and emphasized 'learning based on discovery of new knowledge.'[7] There has been a sustained growth in local undergraduate research conferences, symposiums and journals at various Universities[8] while at the national level, targeted programs and conferences such as "Research Experiences for Undergraduates" (REU) funded through the National Science Foundation and the National Conference on Undergraduate Research has provided additional impetus to include research experience as holistic learning experience at the baccalaureate level. This emphasis on undergraduate research is now present in the mission statements of several Carnegie I Institutions and clearly enumerated in the National Science Foundation 2011-2016 strategic plan to transform undergraduate education.[9]

While research experience enhances the learning experience for undergraduates, many university faculty members have expressed concern regarding both the time and financial commitments needed to mentor undergraduates and the net outcomes of such efforts.[10] Faculty members at the University of Wisconsin who were involved in an eight week summer undergraduate research program designed to expose minority students to research and encourage them to pursue graduate school reported that, many undergraduates did not make any significant research contributions during the summer research program. Other faculty members did not see merit in supporting undergraduate research students when balanced against the time and money that could have been invested in graduate research.[10] Faculty at smaller public institutions with heavy teaching loads indicate concerns about the time required for research mentorship and the availability of sufficient financial and equipment resources given their institutions' lack of graduate research facilities and teaching assistants. This paper documents a pro-active approach taken by a primarily undergraduate teaching institution to facilitate undergraduate research.

Undergraduate Research at Tarleton State University

Tarleton State University is a small, public undergraduate teaching institute of less than 8,000 students with no graduate engineering programs. The university requires faculty members to teach a minimum of 12 contact hours of classes each semester as well as to perform university service and scholarship. All classes and labs are taught by the faculty with no staff or graduate teaching assistants to help with lab setups. While quality teaching is essential for tenure and promotion, scholarship is still required of all faculty members especially for promotion to the rank of full professor. To promote research, the university has several internal funding programs including the Office of Student Research and Creative Activities (OSRCA), [11] and the University Research Committee (URC). This paper documents the experiences gained and results obtained while working with two summer undergraduate research assistants funded by OSRCA and one undergraduate student supported through Organized Research Grant (ORG).

a) OSRCA Funding

OSRCA's mission is to facilitate the engagement of students in scholarly activity related to their disciplines by providing resources that support both student scholars and faculty mentors. Any full-time undergraduate student with at least a 2.8 GPA may apply for a research assistantship by developing a research proposal with a faculty mentor. The faculty mentor submits a proposal for undergraduate research assistantship funding to OSRCA that includes the project title, project description, expected outcome, role of the student researcher, and role of faculty mentor. Proposals are then evaluated based upon the following criteria: (1) Originality of the project, (2) the mentoring relationship between the student and faculty mentor, and (3) the project's dissemination plan. Although there are no fixed award amounts, typically OSRCA funded undergraduate research assistantship have been in the amount of $1,000 per fall and spring semesters with the student working 6 to 8 hours per week and $4,000 for summer when the student must concentrate on research with no course-work or external employment allowed. Additional OSRCA programs provide for $2,000 research grants to faculty who mentor undergraduates and student travel grants for up to $1,000 to cover dissemination costs. In 2010-2011 academic years, OSRCA awarded 18 summer and 20 fall and spring undergraduate research grants as well as 34 student travel grants.

b) Organized Research Grant (ORG) Funding

The University Research Committee provides larger Organized Research Grants (ORG) to assist faculty in establishing research programs and as seed money to obtain external funding in the faculty member's area of expertise. Any university faculty member may submit a research proposal to the URC during the fall with or without student participation. Proposals are primarily judged based upon the quality of the proposal, the investigators' past publication and funding history including result of any past ORG funding, as well as the probability that the present project funding will result in external funding and scholarly publications. A preference is given to newer faculty setting up research programs and to faculty who involve students. While award amounts vary depending on projects, ORG award expectations and award amounts are usually significantly higher than OSRCA awards and often include a month to a month and a half of summer salary for the faculty member. Faculty members receiving funding are expected to pursue additional external funding for the project as well as professional publication of the project's results.

Undergraduate Research Projects

a) Photolysis of Selected Neonicotinoids

This project was funded as a summer undergraduate research assistantship by OSRCA. The objective of the project was to analyze and mathematically model the stability of neonicotinoid insecticides such as dinotefuran (DNT), imidacloprid (IMD) and thiamethoxam (THM) in aqueous and terrestrial environment in post application scenario. Neonicotinoids are one of the most preferred classes of insecticides routinely used for controlling sucking insects, soil insects, termites and grassy winged sharpshooter. They have been particularly effective in controlling Pierces' Disease (PD) in vineyards.[12, 13] Effective vector management is very crucial for survival of vineyards and citrus orchards, and as such use of neonicotinoids has been increased extensively. Although, these neonicotinoids have greatly reduced the incidence of vector and PD outbreak in vineyards, lawns and other agriculture applications, their persistence in the environment and potential human health and ecological consequences have largely been ignored. Neonicotinoids have been studied in the past; however, most of these studies were focused on evaluating the effectiveness of neonicotinoids in controlling the various pests. This undergraduate research project was aimed at studying the fate of neonicotinoids in the environment thereby demonstrating their persistence in natural environment.

This research project evolved through several initial stages such as experimental set-up, soil sample collection and characterization, development of analytical protocol, and analytical quantification of neonicotinoids using High Performance Liquid Chromatography (HPLC), analytical data analysis and mathematical modeling. A detailed research log-book was maintained to document every experiment and the results obtained thereof. Photolysis experiments were initially carried out on pure analytical grade aqueous solutions of DNT, IMD and THM (Figure 1 a). Once aqueous phase photolysis was completed similar experiments were conducted on thin layer of homogeneously mixed soil bound DNT, IMD and THM (Figure1 b, c). The insecticides concentrations were determined using HPLC (Figure 2). This research provided a unique opportunity to the undergraduate student to utilize his classroom understanding of concepts of environmental engineering to solve real life problems. The student successfully conducted the experiment and comprehended the fate of organic pollutants in the environment.

b) Column Leaching Experiments to Assess the Mobility of Potentially Toxic Insecticides in Vineyards Soil

This project was funded as a summer undergraduate research assistantship by OSRCA. Occurrence of neonicotinoids, particularly the first and second generations of neonicotinoids such as IMD and THM in the environment, is well documented. However, not much research has been conducted regarding the mobility of third generation neonicotinoid - DNT in soil environment. Considering the growing concern about the occurrence of neonicotinoids in the environment and its potential human health and ecological impact, this study was aimed at reducing that knowledge gap through the evaluation of mobility of neonicotinoids in vineyard soil. A soil sample for this research project was collected from a local vineyard which is also an application site for these insecticides. Prior to purchasing materials, a preliminary design of an experimental set up was established (Figure 3). A series of column studies was performed in both instantaneous and continuous modes. A known amount of a pulse of insecticide was instantaneously injected on to the fully saturated column (Figure 3). The column eluent was collected at predetermined time intervals. The eluent was filtered and analyzed using HPLC. Each column was replicated to statistically evaluate the reproducibility of the column study data. This research project has provided the undergraduate student an opportunity to study the transport mechanism of neonicotinoid insecticides, identify the soil properties that influence the transport of insecticides to the groundwater and study the chemical properties of neonicotinoids, particularly their solubility and its impact on mobility in vineyard soil.

c) Preliminary Studies on Occurrence of Monensin Antibiotic in Bosque River Watershed

This research project was funded by ORG. The objective of this research project was to conduct a preliminary investigation into the occurrence of monensin antibiotic in the Bosque River Watershed (BRW). Pharmaceuticals used in livestock animal agriculture, such as concentrated animal feeding operations (CAFO) including the poultry and dairy industries have been detected in various environmental matrices such as soil, groundwater and surface water. Occurrence of antibiotics in the environment potentially perturbs ecology and may pose a serious threat to human health. Monensin is an ionophoric antibiotic widely used in dairy operations to improve feed efficiency for milk production.[14] Studies have shown that, orally administered monensin is not completely metabolized by cattle, and nearly 50% of the administered dose is excreted as monensin metabolite and the rest as a parent compound.[15] In this study, 26 surface water samples were collected from areas proximal to dairy operations (Figure 4). The samples were analyzed using the commercially available Enzyme-Linked Immunosorbent Assay (ELISA) test. Monensin was detected at levels from 0.1µg/L to 1.7µg/L in samples collected downstream from the large dairy operations. Concentrations of monensin were higher in samples immediately downstream from the high density dairy operations. Very little or no matrix effect was observed when the samples were filtered and analyzed. Through this research, the student was able to comprehend how the nation’s water resources are being impacted due to non-point pollution sources. ELISA assays are very time consuming and demand meticulous attention to detail. The student initially faced some difficulties but through perseverance and strong determination, successfully completed ELISA assays and quantified the results. The student followed up this research experience with a summer NSF funded Research Experiences for Undergraduate (REU) at Virginia Tech.

Skill Enhancement through Research Experience

The research experiences gained through participation in three research projects equipped undergraduate students with analytical instrumentation skills such as working with HPLC, ELISA, and a microtiter plate reader. These experiences also polished and refined their existing laboratory skills and groomed them for future research studies. The laboratory skills acquired through the research projects are highly sophisticated and require certain finesse because the experiments are not intended for grade submission but for a larger audience at national and international levels and subjected to greater scrutiny than traditional laboratory curriculums. Some of the routine work such as sample collection, sample storage and preservation, sample integrity, preparing standard solutions of analytical grade chemicals, preparing blank and control samples, establishing standard curves, instrument calibration, and experimental reproducibility helped students enhance their understanding of research work compared to what they could have gained in traditional laboratory classes. Teaching of core research values such as independent judgment and critical thinking in terms of experimental set-up, experimental design and coping with difficulties such as errors in instrumentation calibration, HPLC failure under high pressure, ghost peaks in HPLC, cross contamination issues, demands on instruments, teamwork and non-availability of resources were possible only through these research experiences. Prior to setting up their experiments, students were able to do exhaustive literature surveys through various tools such as Google Scholar. Through this experience students learned to effectively conduct literature searches, including comprehending and summarizing new scientific material published in a technical journal. All three students were able to successfully complete their research experiments in a timely manner. Students also learn to compile raw instrument data, final data analysis and critically evaluating the data and asking such questions as, “Does this data make sense?”

Students were able to disseminate their research findings through symposiums and regional conferences. One of the student posters was recently adjudged as a distinguished poster in the 9th Annual Texas A&M Research University System Pathways. Students had extensive technical writing practice through literature review and manuscript preparation for peer reviewed journal publication. Currently three manuscripts have been prepared for publication in peer reviewed journals.

Role of Faculty Mentor

The faculty mentor is an essential aspect of a successful undergraduate research. The mentor must understand the similarities and differences between undergraduate and graduate research and ensure that the initial project is within the ability of the student to complete and compliments the student’s educational goals. The faculty mentor provided timely guidance and motivation to students involved in all three research projects. Faculty assisted the students in planning and executing initial experiments prior to letting the students conduct the experiment themselves. The faculty mentor also helped students to become proficient in operating the HPLC instrument, conducting ELISA assays, and using other laboratory instruments. The faculty mentor demonstrated students how to conduct experiments, establish standard curve and quantify the data from unknown samples. Finally, the faculty mentor assisted the students in preparing a poster or manuscript as the case may be. Although in some instances tardiness was exhibited by some of the student researchers, this occurred primarily with over frustration with the inconsistencies in the experimental data and with over HPLC or ELISA problems. Overall, it was the individual student’s motivation and desire to succeed that made a difference.

Students Feedback

Student perception of their research experience is assessed through a survey following completion of the student’s research experience and in alumni survey’s. While the sample size is small due to the program being young, all respondents have rated their research experience as being either “very helpful” or “extremely helpful” and respondents indicate” strongly” to “very strongly” that the experience improved laboratory skills and enhanced their classroom instruction. Examples of respondent comments include:

“My experience as an undergraduate researcher has been very important. It has allowed me to gain hands on experience in my field and has brought what I learned in the classroom into action in the real world. I also got to interact with other researchers like myself. We were all asking the same questions and learning the same things so we were able to motivate each other in our respective projects. Undergraduate research also sparked my interest in graduate school.”

“I recommend every undergraduate student to apply for any and every research experience you can. Not only does it give you hands on experience but it allows you to interact with professionals in your field.”

“Get involved in research opportunities early and find something that interests you.”

“It was very important. I was able to understand a different side of the industry.”

Survey administered to the participants in research project clearly demonstrated that the student valued the research experience as very informative and skill enhancing experience.

Conclusion

This paper presents the experience with three research projects completed by undergraduate environmental engineering students at Tarleton State University. These research projects have provided students with hands-on experience on analytical instruments such as HPLC, ELISA assay and a microtiter plate reader. The students’ work has been presented in the form of poster presentations at symposium and regional conferences as well as helped at least one student to obtain an NSF-REU. Their research work is currently on display in the departmental building hallway where other students can view them and feel encouraged to pursue research activities. The work of two summer undergraduate researchers has been accepted for poster presentation at the 2012 World Environmental & Water Resources Congress being held in Albuquerque, New Mexico. Participation in such national conferences will further expose undergraduate students about the developments in their field and may potentially open new career avenues. All three research projects were consistent with the academic specialization of environmental engineering and provided a unique opportunity to undergraduate student researchers to apply understanding of environmental principles to solve real life problems. This enhanced understanding would not have been possible through traditional classroom instructions. Through research, the students were able to critically think and relate classroom instruction to real life situations.

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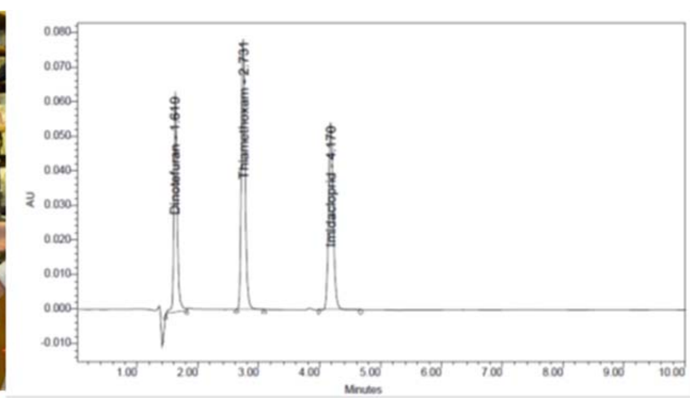
a) Aqueous phase photolysis of sample containing DNT, IMD and THM

b) Initial experiments on soil bound photolysis of sample containing soil slurry and DNT, IMD and THM

c) Homogeneously mixed soil slurry containing DNT, IMD and THM exposed to natural sunlight

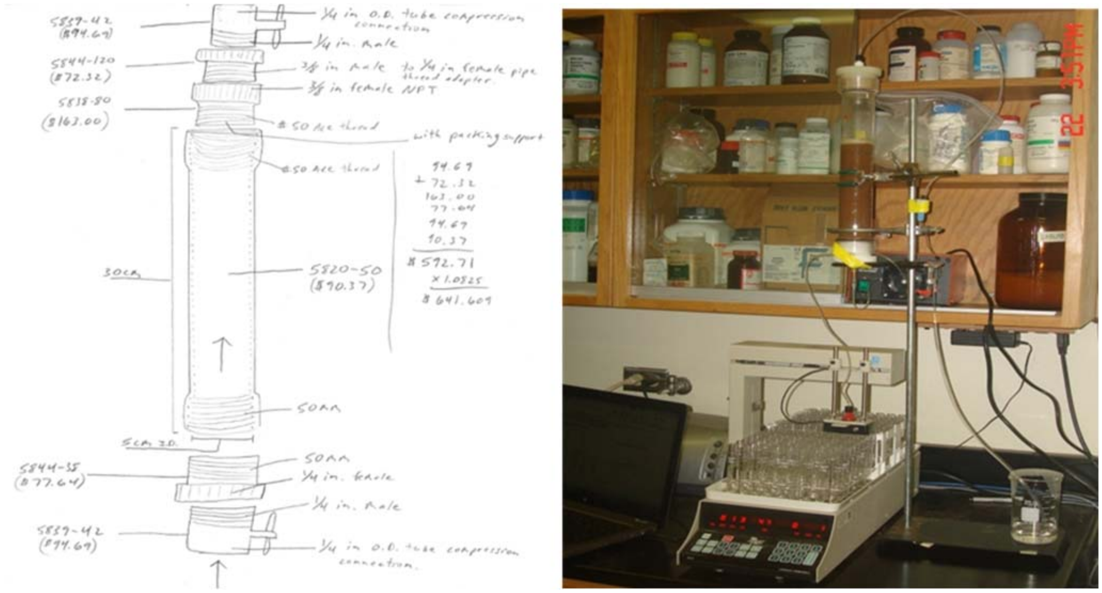
Figure 1: Photolysis of neonicotinoids – DNT, IMD and THM in aqueous and soil phase under natural sunlight

a) High performance liquid chromatography

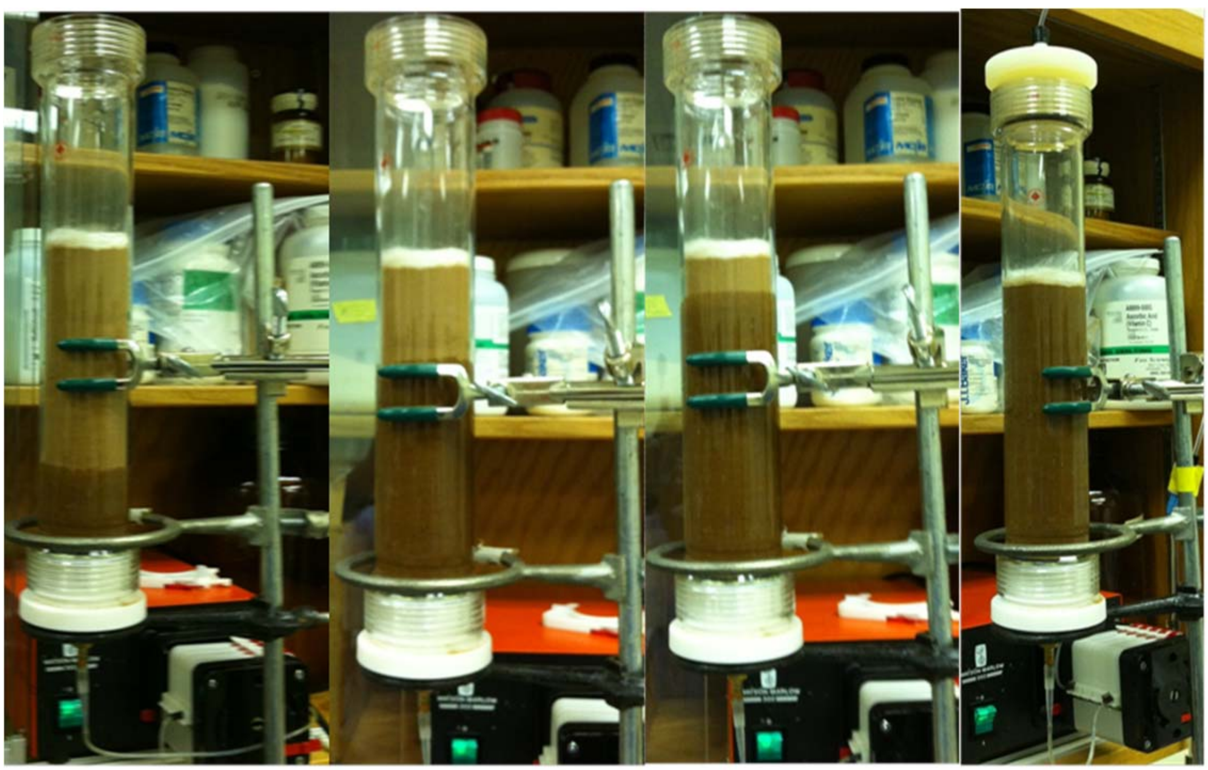


b) Representative chromatograms of DNT, IMD and THM

Figure 2: Analytical determination of DNT, IMD and THM using HPLC



a) Preliminary column study design and final set-up of the column study experiment



b) Column study experiments: pre-wetting to final stage

Figure 3: Column experimental set up to study the mobility of DNT, IMD and THM in vineyard soil

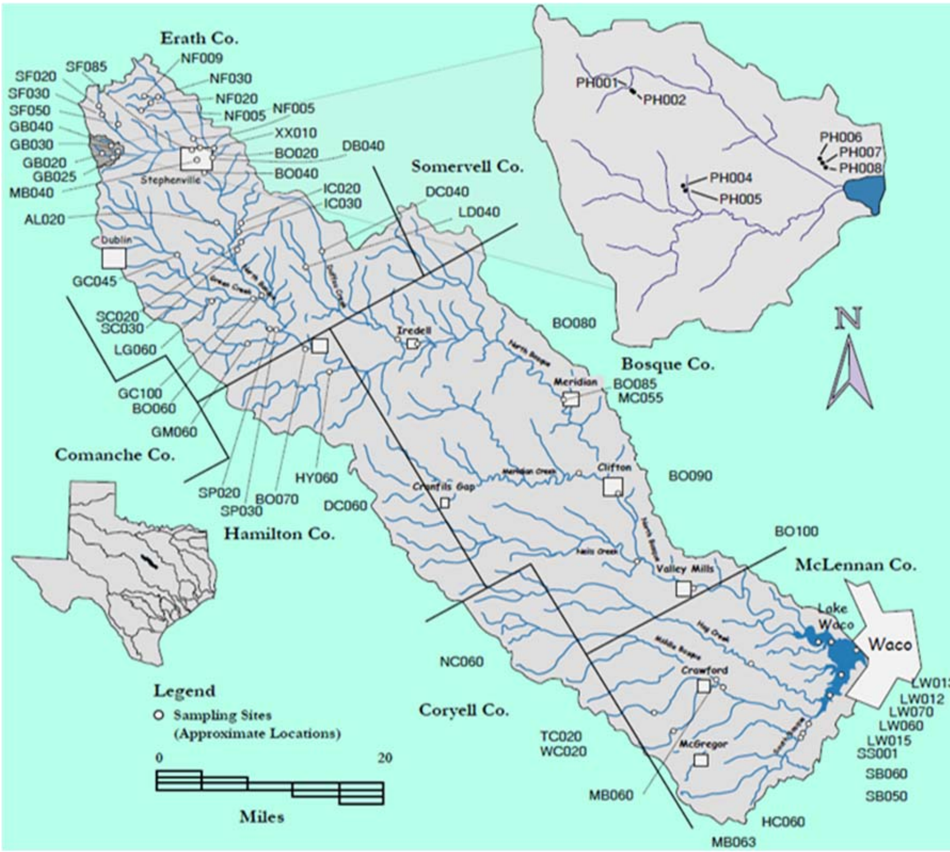


Figure 4. Surface water sampling sites in the Bosque River Watershed