# CALIFORNIA STATE UNIVERSITY, LONG BEACH

## College of Engineering

# CAMPUS AS LIVING LAB

## Integrating Sustainability into Undergraduate Curricula: Development of a Hybrid Module-Based Introductory Course in Environmental Engineering with Focus on Water Resources, Sustainability, and Renewable Energy


Proposed by:

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# REPORT OF WORK PERFORMED

## INTRODUCTION

The College of Engineering at California State University, Long Beach (CSULB) is planning to establish a new program in Environmental Engineering, which will offer courses with a strong focus on sustainability, energy, and the environment to respond to the national and local need for environmental engineers. In line with this plan we proposed to develop a one-unit course, ENV 101 "Introduction to Sustainable Water Resources, Renewable Energy, and Environmental Engineering", which will be included as a freshman introductory course in the curriculum of the new program. The course consists of lecture modules coupled with hands-on projects to introduce students to fundamental physical principles and applications in environmental engineering, water resources, water treatment and reuse, land-atmospheric interactions, and wind and solar energy production. The modules and the projects were developed by a multidisciplinary team of engineering faculty from Civil, Mechanical, and Chemical Engineering. The main objective of this multidisciplinary project is to expose students to sustainability concepts in engineering and to engage them in practical design projects to increase their awareness of problems related to water conservation, water quality, alternative energy, and environmental protection issues.

Once the development of the course is finalized and the material is tested, the course will be submitted for GE certification. This will provide a very broad student body of engineering and non engineering students in STEM disciplines – the majority of them from minority and historically under-represented groups with the opportunity to become familiar with sustainability issues. The completion of the proposed projects will also provide the Facility Management Office with data and analysis on the efficiency of several water and energy conservation strategies as well as design solutions that could be implemented on campus.

## COMPONENTS OF THE PROPOSED COURSE

The proposed ENV 101 course was designed using a hybrid modular and project-based approach. The theoretical material is presented in a modular format that consists of online lectures, quizzes and tests and in class discussions. The design concepts are introduced through hands-on team projects that include the conceptual development, design, and testing of a sustainable system or process as well as data collection and analysis.

The class projects were developed in two steps. First a specific problem is discussed at the global and regional scale. In the second step, the problem is identified at the local scale, specifically on the CSULB campus. The students are responsible for analyzing the problem, and implementing and evaluating a sustainable solution, using the campus as a living laboratory.

The following is a description of the modules and the projects for the proposed course.

**Module 1: Introduction to Sustainability and Environmental Engineering**
1. What is Sustainability and Why it is Important
2. Implications for Engineering Practices
3. Impact of Human Activities on Air, Soil, and Water Quality
4. Fundamental Concepts in Environmental Engineering

**Module 2: Introduction to Water Resources Availability, Management and Conservation**
1. Water Availability and the Water Use
2. Water Conservation and Sustainability Strategies
3. Fundamentals of Surface and Subsurface Hydrology
4. The Water Budget

**Module 3: Introduction to Water Quality Protection and Treatment Technologies**
1. Surface, Subsurface and Coastal Water Pollution
2. Health Risks Related to Water Pollution
3. Treatment of Contaminated Water
4. Emerging Technologies for Water Treatment

**Module 4: Introduction to Clean Energy**
1. Traditional Energy Sources and Their Availability
2. Environmental Impact of Energy Production Processes

3. Alternative Source of Energy: Solar and Wind Energy and Efficiency
4. Emerging Technologies for Renewable Energy

**PROJECT 1: Design of a sustainable system to maximize water conservation on campus. (*Component of Modules 2 and 3*)** This project builds on the results of an on-going project funded by the Metropolitan Water District of Southern California that focuses on the design of an innovative irrigation and recycling system for sustainable water conservation. Students will analyze and test a system for the collection of surplus irrigation water from a turf area located next to the Vivian Engineering Center (VEC) building. The project will involve six to eight students who will perform the following tasks:

**PROJECT 2: Water quality testing and improvement at the Japanese garden. (*Component of Module 3*)** The koi fish pond in the Earl Burns Miller Japanese Garden at CSULB is one of the main attractions in Long Beach. Water conservation and quality are major issues for the maintenance of the pond. In this project, students will collect water sample from the koi fish pond analyze the samples, treat the water, and collect data to determine the efficiency:

**PROJECT 3: Water budget at CSULB. (*Component of Module 2*)** Increased enrollment at CSULB has resulted in an increased demand of fresh water by the campus community. In this project, students will identify the current and future demand for water on campus and investigate sustainable strategies to satisfy water demand.

**PROJECT 4: Carbon and energy footprint analysis of campus activities. (*Component of Module 4*)** Data pertaining to on campus electricity consumption, energy used by people commuting to school, amount of water used, amount of paper used on campus etc. will be gathered and analyzed to illustrate the impact of campus activities on the carbon emission to the atmosphere. The energy-saving strategies that are implemented or could be implemented on campus such as automatic light switches and automated faucets will be evaluated to determine the potential energy savings.

**PROJECT 5: Storm water management on the CSULB campus. (*Component of Module 3*)** Non-point source pollution is one of the major causes of deteriorating surface water quality. Filters are the only treatment strategies for minimizing the impact of polluted runoff water from urban areas on rivers or oceans. In this study, runoff generated on campus will be collected to evaluate the impact of filter installation. The quality of storm water before and after filtering will be compared with surface water standards and average surface water quality.

**PROJECT 6: Conditions for healthy environment and energy management. (*Component of Module 4*)** In this project students will collect data pertaining to the management and control of air circulation and temperature within the campus buildings. They will test air quality, evaluate comfort levels and investigate sustainable solutions for energy savings.

## STATUS OF THE PROJECT

During the Academic Year 2013-14 faculty developed the general plan for the course and worked on the outlines of the modules and the projects. A draft for a pilot module, Module 2, complete with example problems, pop-up questions and discussion topics has been developed. It is ready to be converted in the online version and to be tested. The draft of the module is attached to this report. Furthermore, a student packet has been prepared based on the plan, which contains a syllabus, the description of the course, and the description and outlines of the projects. The packet is also attached to this report.

### CHANGES IMPLEMENTED

During the planning of this project some necessary modifications to the original proposal were made and they are listed below.

- The College of Engineering has postponed the development of the new program in Environmental Engineering for budgetary constraints. Therefore the initial plan of offering the course as part of the new curriculum had to be modified. However, in order to be able to still assess the effectiveness of the proposed modules in introducing the students to sustainability issues, we plan to incorporate each module and the related projects separately in existing courses in Spring 2015 and Fall 2015. Potential courses where modules could be implemented are CE 101, ChE 100, MAE 101A, and MAE 101B.

- The submission of the ENV 101 course to the curriculum committees of the Civil Engineering, Chemical Engineering, and Mechanical Engineering Departments and to the College Curriculum Committee will be postponed until the College finalizes the Environmental Engineering program. The submission of the course to the GEGC for GE classification will follow.
- As mentioned in the proposal, project 1 builds on the results of a student project funded by the Metropolitan Water District of Southern California that focuses on the design of an innovative irrigation and recycling system for sustainable water conservation. During the Academic Year 2013-14 the project has been completed and data were collected and analyzed. Based on the results, some modifications to the original format proposed for Project 1 in this proposal were introduced. For example, the scale of the project had to be revised to match the time frame of the class. Furthermore, due to the relative short duration of the course and the time required to optimize the design and install the system, we decided that the system will be designed by the instructor and installed prior to the start of the course by personnel from the Facilities Management Office and students involvement will be limited to the analysis of the system, collection and analysis of data to determine the water saving efficiency.

## CHALLENGES ENCOUNTERED

We faced two types of challenges during the planning of the proposed course. The first type pertains to the course material, the second type pertains to the implementation of the course in the curriculum.

- **Development of material**

Our goal during the development of the course was to provide students with sufficient technical and non-technical information to enable them to identify and analyze engineering problems and still keep the content basic enough to be grasped quickly by freshman engineering and non-engineering students. To attain this goal we developed a pilot module to be tested in one of our existing GE certified engineering courses. In this module, the concepts are covered in a sequential fashion that leads the students from very basic general concepts to more advanced engineering concepts that are clarified through the use of example problems. Problems were designed so that calculations are simple and require only knowledge of freshman mathematics and physics.
Projects were also developed based on the expected knowledge of the targeted student population. Design concepts are introduced through simple hands-on activities while major design calculations will be performed by the instructor and results will be provided to the students for analysis. Students will be responsible for collection of data, laboratory testing and analysis of results.

The format of the class had to be designed in a way that all the material, the quizzes and the projects could be completed within a reasonable time frame, enhance student interest in the subject, and promote critical thinking. For this purpose we chose a hybrid format for the class where the material is introduced in a modular interactive format, the tests and quizzes are taken online, and the projects are carried out on campus. The novelty approach is in the manner the material is covered. We require the students to review the material prior to the lecture, answer pop-up quizzes, search for information in documents available online, and prepare for a class discussion. In class the instructor will review the concepts covered in the modules, solve sample problems when appropriate, and moderate a discussions on the topics highlighted in the module. This strategy was devised to encourage the development of independent thinking and learning skills at the very beginning of the students' academic career, skills that will greatly help them to succeed in more advanced courses.

- **Curriculum Development**

The major challenge we faced in this area was to incorporate this course within the existing engineering curriculum without affecting the 120 unit limit requirement and yet offer a course that covers all the significant concepts on sustainability and offers students the opportunity to learn those concepts through hands on activities using campus resources. We hope that the proposed 1-unit course will achieve this goal. In the future we will consider the possibility to use the format and the strategies implemented in this course as the basis for a more advanced 3-unit upper division course on sustainability for engineering students.

Finally, due to the postponement of the Environmental Engineering program, the challenge we will face in the near future will be the incorporation of the developed modules in existing courses, and the assessment of the effectiveness of the proposed strategies. This will require some modification for both the modules and the outline of the existing courses in addition to the approval of the curriculum committees of the departments in which those courses are offered. We will work with our colleagues to facilitate this process and we hope to be able to offer and test the first module and related project in Spring 2015.

**BUDGET**

The budget allotted to this project was $12,000 and was justified according to the following table.

| EXPENSES | FUNDS REQUESTED | MATCHING FUNDS | DESCRIPTION |
|---|---|---|---|
| **Salaries** | **$ 2721.60** | **NA** | **Salaries for Ground Workers to install equipment for projects 90.0 hours at $30.24/hr** |
| **Benefits** | **$2138.40** | **NA** | **Benefits for Ground Workers to install equipment for projects 90.0 hours at $23.76/hr** |
| **Stipend** | **$ 0.00** | | |
| **Travel** | **$ 0.00** | | |
| **Equipment/Supplies & Services** | **$6340.00** | | **Purchase of equipment and supplies for projects such as pipes, geotextiles, rain gauges, meters, chemicals and laboratory material.** |
| **Hospitality** | **$0.00** | | |
| **Evaluation** | **$0.00** | | |
| **Dissemination** | **$800.00** | | **Funding is requested for publishing and display material to disseminate results during outreach and other campus events** |
| **TOTAL** | **$12,000.00** | **NA** | |

We have not used any money from the budgeted amount yet as most of the money has to be devoted to the implementation of the projects, which are still in the final planning phase. By the end of October 2014, the faculty responsible for each project will submit a list of supplies and material needed and purchases will be made. The amount allotted to salaries pertains to Project 1 and it will be spent during Spring 2015 when Module 2 and Project 1 will be implemented and tested in an existing course.

# CALIFORNIA STATE UNIVERSITY, LONG BEACH

## DEPARTMENT OF (TBA)

## ENV 101- Introduction to Sustainable Water Resources, Renewable Energy, and Environmental Engineering

## FIRST DRAFT

### Fall Semester 20XX

**Instructor:** TBA. **Office:** TBA

**Phone:** TBA **E-mail:** TBA

**Office hours:** TBA

**Class Time:** TBA **Classroom:** TBA

**Catalog Description:** Introduction to fundamental physical principles and applications in environmental engineering, water resources, water treatment and reuse, land-atmospheric interactions, and wind and solar energy production with focus on sustainability issues. The course material is complemented by basic practical design projects and activities that emphasize the ethical, social and environmental issues in professional practice. Letter grade (A-F) only. (Lecture-problems 1 hour)

**Textbook:** Lecture modules.

**Course Objectives:**

The purpose of the ENV 101course is to introduce freshman and sophomore students to sustainability concepts in engineering and to engage them in practical design projects and activities to increase their awareness of problems related to water conservation, water quality, alternative energy, and environmental protection issues. Upon successful completion of the course, the student will be able to:

1. Understand the importance of sustainability practice in engineering projects.
2. Identify current trends, social, environmental and ethical issues in engineering
3. Apply sustainability concepts to the design of simple systems
4. Analyze the impact of sustainability practices on availability of natural resources.

**Student Outcomes:**
The Course, ENV 101- Introduction to Sustainable Water Resources, Renewable Energy, and Environmental Engineering - satisfies the following ABET outcomes:

***a*** - Ability to apply knowledge of mathematics, and general scientific and engineering principles.

***e*** - Ability to identify, formulate, and solve engineering problems

***d*** - Ability to function on multi-disciplinary teams

***g*** - Ability to communicate effectively, in written, oral and graphical formats

***h*** - Achievement of the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

***i*** - Recognition of the need for, and the ability to engage in life-long learning

***k*** - Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

**Course Methods:** lecture modules coupled with hands-on team projects and class discussions are the principal methods of instruction.

**Outcome Measures and Assessment:**

1) Class discussion and preparation (includes answers to pop-up questions in the lecture modules).
2) Quizzes.
3) Final exam. Students are required to take the exam during the dates and times specified in the University Catalog. No exemptions will be granted on the final exam.
4) Project reports (one project per team will be assigned during the semester)
5) Oral presentation. Oral presentation will be based on the projects. Each member of the team will be required to present. Grade will be based on group performance.

**Grading:**

| | |
|---|---|
| Class Discussions, and Preparation | 10% |
| Quizzes (4) | 20% |
| Project Report | 25% |
| Final Exam | 15% |
| Oral Presentation | 15% |
| Total | 100% |

**Scale: A = 90-100%, B = 80-89%, C = 70-79%, D = 60-69 %, F < 60%**

**Beach Board:** This course will be set up on Beach Board (http://beachboard.csulb.edu). This will enable you to access the course syllabus, announcements, lecture modules and project reports online. In addition, all the quizzes and the final exam will be set up online.

If you need help on how to use Beach Board, please contact the technology help desk (helpdesk@csulb.edu; Phone: (562) 985-4959).

**Attendance:** Due to the nature of the class and the projects, class attendance and participation are mandatory. A total of 5 points will be withdrawn from your total grade if you miss more than two classes. The theoretical material will be presented in a modular format that will consist of set of slide lectures that will be available online. Students are responsible to study the material **prior to the lecture** and to answer multiple choice questions embedded in the module to verify the understanding of the material presented. Each module will include pop-up questions each one worth 10 points. Furthermore, students will be required to prepare for class discussion according to the guidelines provided in the module. Comprehensive online quizzes will be assigned after the topics have been discussed in class. The design concepts will be introduced through hands-on team projects that include the conceptual development, design, and testing of a sustainable system or process as well as data collection and analysis.

Students are responsible for all the information and material presented in class, whether they were present or not. See the University's policy on Class Attendance in CSULB Catalog, section on General Regulations and Procedures.

**Assignments and Exam:** Please check the Exam Schedule on the University website for final examination dates.

Students who do not submit answer for answer the quizzes by the due date or do not attend the final exam will receive a zero grade unless the absence is excusable. A make-up quiz or final will be possible only under **very special** circumstances. If you know in advance that you will not be able to attend the exam on specified date, you need to discuss the reason for missing the exam with the instructor in advance. Be prepared to show any documentation.

**Cell Phone Use and Other Electronic Media.** Cell-phones and other electronic devices should be turned off during lectures and examinations. The use of cell phones will not be allowed during examinations. Laptop computers should be used solely for activities related to this class and if requested by the instructor.

**Cheating and Plagiarism:** Honesty is expected and required of all students. Ensure that your work, especially your project report, is properly documented. See the University's policy on Cheating and Plagiarism in the CSULB Catalog.

**Special Accommodation:** Please notify the instructor of the need for accommodation of a University verified disability by the end of the second week of the semester.

**Schedule for Fall 20XX**

| WEEK | TOPIC/ACTIVITY |
|---|---|
| 1 | Introduction and Course Overview**.** Discussion of class format and requirements. Introduction to projects. Organization of student teams.<br><br>**Online material to study for next week:**<br>**Module 1: Introduction to Sustainability and Environmental Engineering.** What is Sustainability and Why it is Important. Implications for Engineering Practices. Impact of Human Activities on Air, Soil, and Water Quality. Fundamental Concepts in Environmental Engineering. Fundamental Concepts in Environmental Engineering. |
| 2 | Review of Module 1 and class discussion. Online Quiz 1<br><br>**Online material to study for next week:**<br>**Module 2: Introduction to Water Resources Availability, Management and Conservation.** Water Availability and the Water Cycle. Fundamentals of Surface and Subsurface Hydrology. Surface-Subsurface-Atmospheric Interaction. Water Conservation and Sustainability Strategies. |
| 3 | Review of Module 2 and class discussion. Online Quiz 2<br><br>**Online material to study for next week**<br>**Module 3: Introduction to Water Quality Protection and Treatment Technologies.** Surface, Subsurface and Coastal Water Pollution. Health Risks Related to Water Pollution. Treatment of Contaminated Water. Emerging Technologies for Water Treatment |
| 4 | Review of Module 3 and class discussion. Online Quiz 3<br><br>**Online material to study for next week:**<br>**Module 4: Introduction to Clean Energy.** Traditional Energy Sources and Their Availability. Environmental Impact of Energy Production Processes. Alternative Source of Energy: Solar and Wind Energy and Efficiency. Emerging Technologies for Renewable Energy |
| 5 | Review of Module 4 and class discussion. Online Quiz 4 |

| | |
|---|---|
| 6 | Projects description, planning and organization |
| 7 | Laboratory session (work on project) |
| 8 | Laboratory session (work on projects) |
| 9 | Laboratory session (work on projects) |
| 10 | Laboratory session (work on projects) |
| 11 | Laboratory session (work on projects) |
| 12 | Laboratory session (work on projects) |
| 13 | Oral Presentations |
| 14 | Oral Presentations |
| 15 | Oral Presentations (Project Report Due) |
| 16 | Final Exam |

**NOTE: Please note that the above schedule is tentative and may be subject to change.**

## CLASS FORMAT

This class is a combination of lecture modules coupled with hands-on projects that will be carried on in teams of four to five students.

### LECTURE COMPONENT, QUIZZES AND EXAM

Before class, students are required to study the lecture slides available online, answer multiple choice pop-up questions, and prepare questions and topic for discussion according to the guideline provided in the module. Once the class meets, the instructor will review the fundamental concepts presented in the lectures, solve basic problems when appropriate and moderate the class discussion. After each module is completed, the students will take an online quiz that focuses on the issues presented in the lectures and discussed in class. The final exam consists of a comprehensive quiz that will cover all the material presented in the lectures during the semester.

### PROJECT COMPONENT

Each module is complemented with a set of projects and activities that are designed to introduce students to fundamental physical principles and applications in environmental engineering, water resources, water treatment and reuse, land-atmospheric interactions, and wind and solar energy production. The class projects will be developed in two steps. First a specific problem will be discussed at the global and regional scale. In the second step, the problem will be identified at the local scale, specifically on the CSULB campus. The students will analyze a sustainable solution to the problem, and will implement a pilot project on campus for the purpose of collecting data and evaluate the efficiency of the proposed strategy.

Each team will select a project to work on among a set of potential projects proposed by the instructor. They will also be able to propose their own project provided they submit the proposal in advance to allow time for the appropriate approval procedure by the University. The majority of field work pertaining to the projects will be performed mostly during class time unless additional time is required for installation of parts and testing. Projects will be supervised by the instructor with the help of student assistants. The Facility Management Office will be responsible to supply man power for installation of parts and instruments..

During the last three weeks of the semester, students will be required to present their project to the class. The presentation should be about 20 minutes longer and should focus on the problem addressed by the project, a discussion on the strategy adopted, the purpose of the activity and a preliminary analysis of the results.

On the last day of class, students are required to submit a final report that will include a complete analysis of the data collected. A copy of the reports will be made available to the Facility Management Office.

## PROJECT DESCRIPTION

Each lecture module will be coupled with a set of projects in which the fundamental concepts presented in the lectures will be applied to the design, implementation and analysis of a system to target specific problems. All the project activities will be performed on the CSULB campus which will be our “living laboratory”.

The following is a brief description of the proposed projects. Students are welcome to propose their own project related to one of the lecture modules, provided that sufficient time is allowed to obtain the required permission by the University.

### PROJECT 1: Design of a sustainable system to maximize water conservation on campus. (*Component of Modules 2 and 3*)

**Project Description:** This project builds on the results of an on-going project funded by the Metropolitan Water District of Southern California that focuses on the design of an innovative irrigation and recycling system for sustainable water conservation. Students will analyze and test a system for the collection of surplus irrigation water from a turf area located next to the Vivian Engineering Center (VEC) building. The system, previously designed by the instructor and a team of CSULC graduate students, will be installed with the support of the Facility Management Office. The system consists of a set of collection pipes and installed in gravel trenches excavated in a 6ftx6ftx2ft area. Irrigation water percolating through the soil will be captured by the underground pipes and will be conveyed to a treatment unit. The water will undergo chemical and/or mechanical filtration and it will be stored in an underground reservoir before being re-used for irrigation. The students will perform the tasks described below.

**Project Outline**

1. Review material and attend lectures about water availability, sustainability and conservation and a general introduction to hydrology and water resources engineering (Wks 2-3).
2. Plan for project (Wk. 6)
3. Review and discuss the design purpose and plans (Wk 7)
4. Run the first irrigation test and collect effluent water (Wk 8)

5. Measure the concentration of pollutants such as pesticides and fertilizers and measure the amount of water collected within a specified time interval. Determine the need for treatment. (Wks. 8-10)
6. Run multiple irrigation tests after treating the effluent water and evaluate the efficiency of treatment and the effectiveness of the designed recycling system in reducing water demand for landscape irrigation (Wks 11-13)
7. Evaluate maintenance and operational costs to extend it to the entire campus (Wks 12-15).
8. Prepare a final report and oral presentation (Wks 12-15)

**Goals**:
1) to illustrate an example of implementation of conservation practices according to the recommendations of the California *20x2020 Plan*
2) to demonstrate the effectiveness of recycling on the reduction of demand for landscape irrigation water

**Number of Students**: 5-6
**Duration**: 10 Wks
**Software**: Microsoft Office (Word, Excel and Access)
**Cost**: $6500 (Personnel and material)

## PROJECT 2: Water quality testing and improvement at the Japanese garden. (*Component of Module 3*)

**Project Description:** The koi fish pond in the Earl Burns Miller Japanese Garden at CSULB is one of the main attractions in Long Beach. Water conservation and quality are major issues for the maintenance of the pond. In this project, students will collect water samples from the koi fish pond and perform the activities described below.

**Project Outline**

1. Review material and attend lectures about principles of water quality and conservation and introduction to catalysts.(Wks 4-5)
2. Plan for project (Wk 6)
3. Collect water samples from the Japanese garden (Wk 7)
4. Analyze the water sample from Japanese garden using our DO meter, pH meter, and COD meter currently available in reaction engineering lab. (Wks 8-10)
5. Treat the water sample using titanium dioxide catalyst in the presence of a UV lamp. (Wks 11-12)
6. Analyze the water sample after treatment and compare it with the data before treatment. (Wk 12-13)
7. Perform concentration calculations. (Wks 13-14)
8. Prepare a final report and oral presentation (Wks 12-15)

**Goals**:
1) to illustrate the methods to analyze water quality and use of catalysts
2) to demonstrate the effectiveness of treating water with titanium dioxide

**Number of Students**: 5-6
**Duration**: 10 Wks
**Software**: Microsoft Office (Word, Excel and Access)
**Cost**: $1500 (Laboratory supply)

## PROJECT 3: Water budget at CSULB. (*Component of Module 2*)

**Project Description:** Increased enrollment at CSULB has resulted in an increased demand of fresh water by the campus community. In this project, students will identify the current and future demand for water on campus and investigate sustainable strategies to satisfy water demands according to the following steps:

**Project Outline**

1. Review material pertaining to water availability, water cycle and hydrology and water resources engineering (Wks 2-3).
2. Review Hydrologic cycle and discuss the hydrologic cycle on the CSULB campus. Plan for project (Wk. 6)
3. Gather data associated with water usage, number of students and employees on campus for the past 5 years from the PPFM Office or other offices. (Wks. 7-8)
4. Analyze water usage trend and associated cost. (Wk 9)
5. Study the spatial and temporal distribution of rainfall on the CSULB campus and collect rainfall from different locations. (Wks 9-11)
6. Analyze the quality of the collected rain water and estimate the annual amount of water that can be collected from rain and how it will contribute to the campus total water usage. (Wk. 12)
7. Investigate/discuss other sustainable water sources that can contribute in alleviating the overall cost of water consumption. (Wk. 13)
8. Prepare a final report and oral presentation (Wks.12-15)

**Goals**:
1) To illustrate why conservation of water are getting important with the increase of number of students.
**Number of Students**: 5-6
**Duration**: 10 Wks
**Software**: Microsoft office (Word, Excel)
**Cost**: $1,000 (Equipment)

## PROJECT 4: Carbon and energy footprint analysis of campus activities. (Component of Module 4)

**Project description:** Investigating carbon and energy footprint in an individual organization in short and long terms are essential to minimize adverse consequences created in that location to the environment and to determine the most effective strategies to reduce the carbon and energy footprint at a particular source. Since each University has a large number of people involving with various types of activities, compiling a list of all activities occurred on campus such as electricity consumption, number of students driving to the school, water usage and amount of paper used will be compiled. The mathematical models will then be developed to assess the amount of carbon emitted to the atmosphere based upon the gathered on campus activities data. The energy-saving strategies and other new alternatives (such as automatic light switch systems, automated faucets and online class materials) to reduce carbon emission will also be evaluated. Finally, all analyzed carbon and energy footprint data from campus activities will be compared with the global warming indicators, including ambient temperature, sea water temperature and amount of rainfall (both campus and global scale) in order to demonstrate the effects of the campus activities to the atmosphere. This project will require the participation of six or seven students performing the following tasks displayed in the outline below

**Project Outline**

1. Review material and attend a lecture about principle of carbon emission and carbon/energy footprint. Plan for project (Wks 5-6)
2. Gather data pertinent to energy, water and other resources consumptions on campus from the PPFM Office, Parking and Transportation Office or other facilities. Data include but not limited to: monthly power consumption, monthly water usage
number of vehicles commuting to school, types of vehicle, number of trips and average mileage, amount of office paper used, number of construction projects, and
amount of natural gas used on campus, solids waste generated (Wk 7)
3. Research a conversion factor for each activity for converting the activities in step 2 to amount of carbon or energy footprint. (Wk 7)
4. Determine the amount of carbon emission and energy consumption for each activity stated in step 2. (Wk 8)
5. Analyze trends for each data set and perform the overall data analysis over a 5-year-time period. (Wk 9)
6. Identify the impact of facility improvement such as automatic light switches, automatic faucets, online classroom and online class materials on the carbon emission from school activities. (Wk 10)
7. Explore effective and sustainable strategies to reduce carbon emission and energy consumption on campus. (Wk 11)
8. Determine the consequences of the campus activities on the global warming by using ambient temperature, sea water temperature and amount of rainfall (both campus and global scale) as indicators. (Wks 12-13)
9. Prepare a final report and oral presentation (Wks 12-15)

**Goals**:
1) to illustrate the consequences of campus related activities to amount of carbon emission
2) to demonstrate the improvements of facility upgrading on the campus' carbon and energy footprints

**Number of Students**: 6-7
**Duration**: 10 Wks
**Software**: Microsoft Office (Word, Excel and Access) and statistical and graphing tools such as SigmaPlot or Grapher
**Cost**: $1000 (Software and office supply)

**PROJECT 5: Storm water management on the CSULB campus. (Component of Module 3)**

**Project Description:** Non-point source pollution is one of the major causes of deteriorating surface water quality. Since the large area on campus is covered with impervious materials, large amount of runoff water can be generated as well as high concentrations of pollutants can be carried to the rivers. Currently, filters are the only treatment strategies for minimizing the impact of polluted runoff water from urban areas on rivers or oceans. In this study, runoff generated on campus will be collected to evaluate the impacts of filter installation. The quality of storm water before and after filtering will be compared with surface water standards and average surface water quality. Parameters of interest include physical parameters (total solids, total suspended solids, turbidity, color, pH, temperature, and dissolved oxygen), chemical parameters (biochemical oxygen demand, chemical oxygen demand and total nitrogen, total organic carbons, fatty oil & grease), and biological parameters (total and fecal coliform). This project will require the participation of six or seven students performing the following tasks displayed in the outline below

**Project Outline**

1. Review material and attend a lecture about hydrological cycle and nonpoint source pollutions. (Wks 3-4)
2. Attend a lecture on filter systems. (Wk 4)
3. Plan for project. (Wk 6)
4. Practice how to analyze each runoff water characteristics stated above (Wks 7-8)
5. Selection of study sites: a) parking lots with filters installed, b) parking lots without filters
6. installed, c) lawns and 4) roof tops of building (Wk 9)
7. Collect storm water the specified location in step 4 and analyze the water quality. (Wks 10-14)
8. Collect the rainfall and calculate the runoff on each selected site. (Wks 10-14)
9. Change the filters in order to compare the performance of each filter system. (Wks 10-14)
10. Analyze data, evaluate the performance of the filters. (Wks 10-14)
11. Prepare the oral presentation and a final report a (Wks 12-15)

**Goals**:1) to assess the performance of the filters
2) to evaluate the impact of stormwater generated on campus on surface water quality
**Number of Students**: 6-7
**Duration**: 10 Wks
**Equipment, supplies and reagents**: rain gauges, water samplers, colorimeter, reagents, chemicals and culture media
**Cost**: $1500

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## PROJECT 6: Conditions for healthy environment and energy management. (*Component of Module 4*)

**Project Description:** In this project students will collect data pertaining to the management and control of air circulation and temperature within the campus buildings. They will test air quality, evaluate comfort levels and investigate sustainable solutions for energy savings. This project will require the participation of four to five students performing the following tasks displayed in the outline below

**Project Outline**

1. Review material and attend a lecture about energy production, clean energy, traditional and alternative energy sources. (Wk 5)
2. Plan for project. (Wk 6)
3. Gather data pertaining to air circulation control and temperature from several faculty offices, classrooms, and laboratories in the College of Engineering. (Wks 7-8)
4. Collect data pertaining to the current energy cost for the College (Wk. 9)
5. Collect published data on comfort levels and compare the collected data (Wks 9-10)
6. Investigate solutions for energy savings, their applicability on campus, and costs. (Wks 11-13)
7. Prepare the oral presentation and a final report a (Wks. 12-15)

**Goals**: 1) to evaluate current practices for air circulation and temperature and their impact on budget and health
2) to analyze alternative strategies and sustainable practices for energy saving
**Number of Students**: 4-5
**Duration**: 10 Wks
**Cost:** $500 (office supplies)

# MODULE 2

# Introduction to Water Resources Availability, Management, and Conservation

# DRAFT

## 2.1 What Is Water Resources Engineering?

Water resources is the branch of civil engineering that studies the occurrence and distribution of water on our planet, the physical principles of fluid flow and their applications to engineering systems.

Hydrology, Fluid Mechanics, Hydraulics, Groundwater Hydrology, Hydraulic Design are all disciplines that deal with water. In the first part of this module, you will become familiar with the basic concepts related to water availability, sustainability, practices in water resources management, and strategies for water conservation. In the second part of the module we will explore the water cycle and introduce several concepts in hydrology. Finally in the third part we will learn how to perform a water budget and to use it as a tool to estimate water availability.

## 2.1.1 Water, Water Availability and Sustainability

Water is the most important natural resource. It is one of the fundamental compounds without which life of plants and animals and human beings would not be possible.
Fresh water is available in rivers, lakes, reservoirs, and underground aquifers. These water bodies supply the water to satisfy the needs of humans and the entire ecosystem.
In the Table 1, estimates on water availability on Earth are presented. The data pertains to all the water on the planet, including ocean water, biological water, and water in glaciers, which not available for consumption.
As we can infer from the table, only about 2.5% of the world water reserves is made up of freshwater that is the water that living creatures can use.

Water resources sustainability refers to the management of water resources from the local to the global scale aimed at ensuring that water quantity and quality are guaranteed to meet the present and future needs of humans and ecosystem and at protecting the resource from any natural and man-made disaster that can jeopardize sustainment of life (Mays, 2007).
Water resources sustainability plans are made at local, national and international levels and include:

- Guaranteeing freshwater supply even during exceptional events such as droughts, natural disasters etc.
- Provide the necessary infrastructure for treating water, distributing, freshwater, collecting waste water and treating it and for the drainage of urban areas
- Creating the appropriate institutions responsible to develop and implement the plans

Guaranteeing sufficient clean water to humans and the environment is a task that faces numerous challenges including:

- Increased population and especially increased size of cities around the world
- Climate changes
- Severe and persistent droughts
- Flooding
- Pollution due to human activities
- Natural and man-made disasters.

The problem we will be facing in the near future will be how to achieve an equitable and sustainable use of the available resources in the face of a steady global population growth, global climate changes, water conflicts, water shortage, and pollution. These issues are of such global concern that the National Academy of Engineers has identified the need to provide access to clean water as one of the Grand Challenges for Engineering in the 21st century. To ensure the future of human beings and all living forms on our planet we must protect and use water responsibly.

| | | | | Percentage of global reserves | |
|---|---|---|---|---|---|
| | Distribution area ($10^3$ $km^2$) | Volume ($10^3$ $km^3$) | Layer (m) | Of total water | Of fresh-water |
| World ocean | 361,300 | 1,338,000 | 3700 | 96.5 | — |
| Groundwater | 134,800 | 23,400 | 174 | 1.7 | — |
| Freshwater | | 10,530 | 78 | 0.76 | 30.1 |
| Soil moisture | | 16.5 | 0.2 | 0.001 | 0.05 |
| Glaciers and permanent snow cover | 16,227 | 24,064 | 1463 | 1.74 | 68.7 |
| Antarctic | 13,980 | 21,600 | 1546 | 1.56 | 61.7 |
| Greenland | 1802 | 2340 | 1298 | 0.17 | 6.68 |
| Arctic islands | 226 | 83.5 | 369 | 0.006 | 0.24 |
| Mountainous regions | 224 | 40.6 | 181 | 0.003 | 0.12 |
| Ground ice/permafrost | 21,000 | 300 | 14 | 0.022 | 0.86 |
| Water reserves in lakes | 2058.7 | 176.4 | 85.7 | 0.013 | — |
| Fresh | 1236.4 | 91 | 73.6 | 0.007 | 0.26 |
| Saline | 822.3 | 85.4 | 103.8 | 0.006 | — |
| Swamp water | 2682.6 | 11.47 | 4.28 | 0.0008 | 0.03 |
| River flows | 148,800 | 2.12 | 0.014 | 0.0002 | 0.006 |
| Biological water | 510,000 | 1.12 | 0.002 | 0.0001 | 0.003 |
| Atmospheric water | 510,000 | 12.9 | 0.025 | 0.001 | 0.04 |
| Total water reserves | 510,000 | 1,385,984 | 2718 | 100 | — |
| Total freshwater reserves | 148,800 | 35,029 | 235 | 2.53 | 100 |

*Source:* Shiklomanov (1993).

**Table 1.** Water availability on Earth (Shiklomanov, 1995, obtained from Mays, 2005)

## 2.1.2. Water Withdrawals and Uses

According to the definition provided by Gleick (1998), withdrawal: refers to the act of taking water from a source for storage or use.
The USGS conducts the national water use information program, which establishes the national system of water use accounting.
Water use is defined from a hydrological perspective as all water flows that are a result of human intervention within the hydrologic cycle.
Water is used for several purposes that include:

-Domestic
-Commercial
-Irrigation
-Industrial
-Livestock
-Mining
-Public use
-Rural use
-Thermoelectric power generation

The major sources of fresh water are surface water and groundwater.
Surface water sources include rivers, lakes, man-made reservoirs. Groundwater is the water stored under ground in geological formations in which the pores are completely filled with water
The demand for freshwater supply increases because of population growth and increasing development

## 2.1.3 Water Use in the U.S.

Figure 1 provides some information regarding the estimated water withdrawals in the United States for the year 2005. As we can see from the figure California and Texas are the two states with the highest water withdrawals as denoted by the dark blue color in the figure. More detailed information can be obtained from the USGS web site.

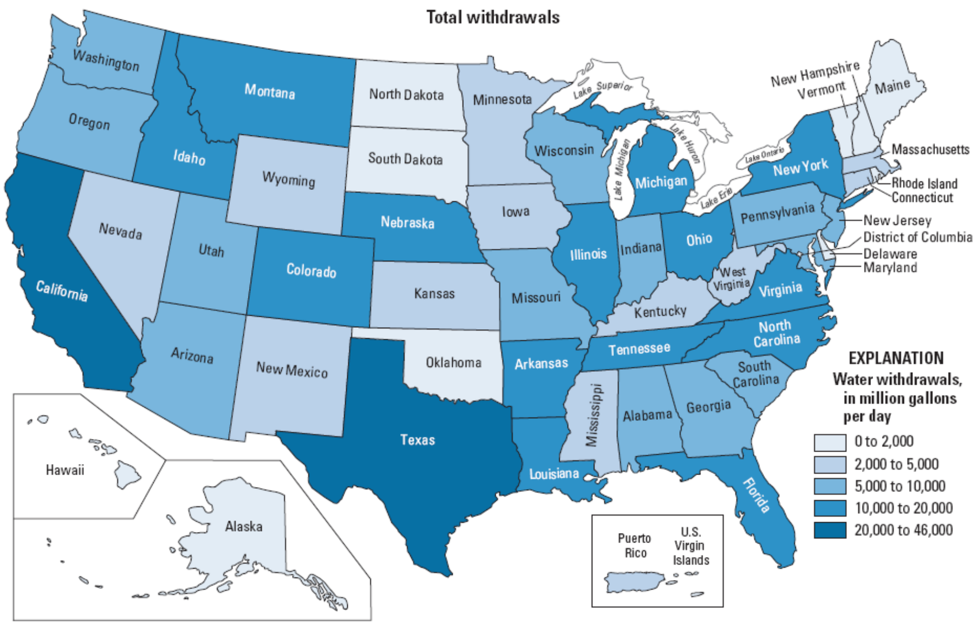


**Figure 1.** “Estimated use of water in the United States in 2005” (from USGS web site: www.usgs.gov)

## 2.1.4 Water Use and Withdrawal in California

According to the Water Data published by the USGS, in California in 2005 the total amount of population served was 36,100,000 people, the total fresh water withdrawals amounted to approximately 45,700 Mgal/d, of which 11,000 Mgal/d were withdrawn from groundwater and 34,700 Mgal/d were withdrawn from surface water.

The water uses in California for 2005 included:

- Public Supply: 6,990 Mgal/d
- Domestic: 486 Mgal/d
- Industrial: 95.6 Mgal/d
- Thermoelectric power (fresh water): 49.6 Mgal/d
- Agricultural: 24400 Mgal/day

According to the California Department of Water Resources, “California is facing one of the most significant water crises in its history—one that is hitting hard because it has so many aspects. Growing population and reduced water supplies are exacerbating the effects of a multi-year drought. Climate change is reducing our snowpack storage and increasing floods. Court decisions and new regulations have resulted in the reduction of Delta water deliveries by 20 to 30 percent. Key fish species continue to decline. In some areas of the state our ecosystems and quality of underground and surface waters are unhealthy. The current global financial crisis will make it even more difficult to invest in solutions”.

## 2.1.5 Los Angeles Area Water Supply

Detailed water data for the Los Angeles area are provided by the Los Angeles Department of Water and Power (LDWP)

- Annual water consumption in Los Angeles today is approximately 660,000 AF. (An acre-foot is equal to about 326,000 gallons, and satisfies the annual water demand of approximately 5 residents in LA.)
- Water is imported from the Sierra Nevada watershed, the Colorado River, and the Sacramento-San Joaquin Delta.
- In addition to surface water, local groundwater supply provides approximately 10 percent of the City’s total water needs. The primary source is located in the San Fernando Basin. Local groundwater is important as it provides a reserve against droughts or emergencies.
- The city of Los Angeles owns water rights in four local groundwater basins: San Fernando, Sylmar, Central, and West Coast.

## 2.1.6 Practices for Water Resources Sustainability and Water Conservation

There are several strategies that can be implemented at all levels, from the community to municipality, to nation and global level, to ensure a sustainable use of the water resources and to guarantee a sufficient amount of clean water to future generations and the environment. A good example of statewide practices for water sustainability is provided by the State of California in the *20x2020 Plan*.

The plan was designed to maximize the urban water efficiency and conservation opportunities between 2009 and 2020, and beyond through a set of activities that aims at achieving the 20 percent per capita reduction in urban water demand by 2020. The plan emphasizes both water conservation and water use efficiency practices and defines water conservation “as a reduction in water loss, waste, or use. The general term water conservation may include *water use efficiency*, in which more water-related tasks are accomplished with the same or lesser amounts of water”.

The Plan recommends the following strategies to achieve its goals:

- Reduce landscape irrigation demand through the design, implementation and development of efficient irrigation systems and enforce the landscape irrigation Best Management Practices (BMP)
- Reduce water waste trough the improvement of water distribution systems and technologies to detect leaks;
- Reinforce efficiency codes and BMP’s
- Implement a statewide water conservation public information and outreach campaign
- Provide enforcement Mechanisms for water conservation
- Investigate Potential Flexible Implementation Measures
- Increase the use of recycled water and non-traditional sources of water

**Class discussion topic:** Be prepared to discuss one of the strategies proposed in the plan and to provide some example of practices within each category. Review Chapter 3 in the *20x2020 Plan* posted on Beachboard and available by clicking the following link: http://www.water.ca.gov/wateruseefficiency/sb7/docs/20x2020plan.pdf

**Multiple Choice Pop-Up Question**

The 20x2020 Plan proposes the replacement of inefficient toilets, showerheads, and urinals as a strategy for water conservation In which of the following categories?

A Reduce water waste trough the improvement of water distribution systems and technologies to detect leaks;

B Increase the use of recycled water and non-traditional sources of water

C Reinforce efficiency codes and BMP’s

D Implement a statewide water conservation public information and outreach campaign

# 2.2.Hydrology

The science that studies the occurrence and distribution of water on Earth is called hydrology. A good definition is provided by the U.S. National Research Council (1991) that defines hydrology as “the science that treats the waters of the Earth, their occurrence, circulation, and distribution, their chemical and physical properties, and their reaction with the environment, including the relation to living things. The domain of hydrology embraces the full life history of water on Earth”.

## 2.2.1 The Water Cycle or Hydrologic Cycle

Water is the only substance that can be found on Earth in all three states of matter: solid, liquid, and gas.
In the atmosphere water is present as vapor in the clouds. Under certain conditions of temperature and pressure, water vapor condensates into a liquid form (rain) or solid form (snow, hail) and falls on the Earth surface. A portion of the water will fall on lakes, rivers, oceans, while the remaining portion will fall on the land. Part of the water that falls on land will be captured by the vegetation, which will return a portion to the atmosphere through evapotranspiration; part will infiltrate into the soil, and the remaining part will form the run-off, which will be collected into rivers, lakes or oceans.
A schematic of the water cycle is represented in Figure 2.
The water cycle is made up of several components that include:

- Precipitation
- Evaporation
- Evapotranspiration
- Infiltration
- Overland flow
- Streamflow
- Groundwater flow

Before we proceed to analyze each component we need to introduce the concept of watershed..

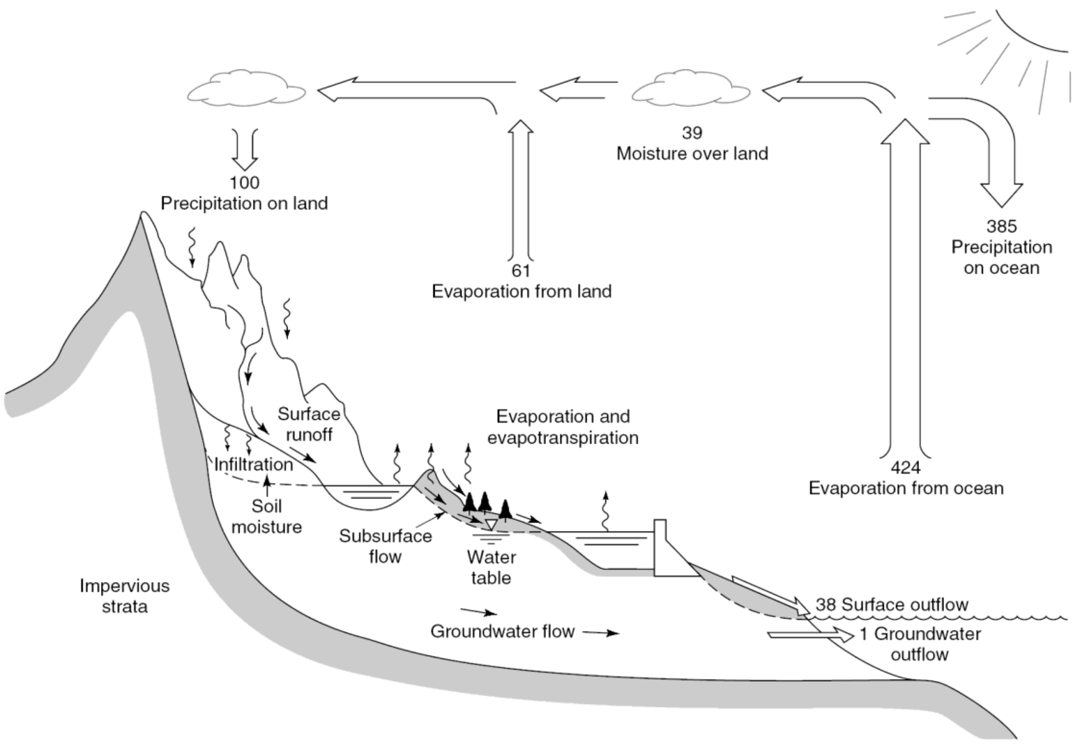


**Figure 2.** Water cycle (Chow et al. 1988, obtained from Mays, 2005).

## 2.2.2 Watershed

A watershed is a continuous area that contributes surface runoff to an outlet.
The watershed is the basic hydrologic unit that we refer to for all measurements, calculations and predictions in hydrology.
The watershed divide or boundary, is the boundary that separates two adjacent watersheds, which contribute water to different outlets (Figure 3).

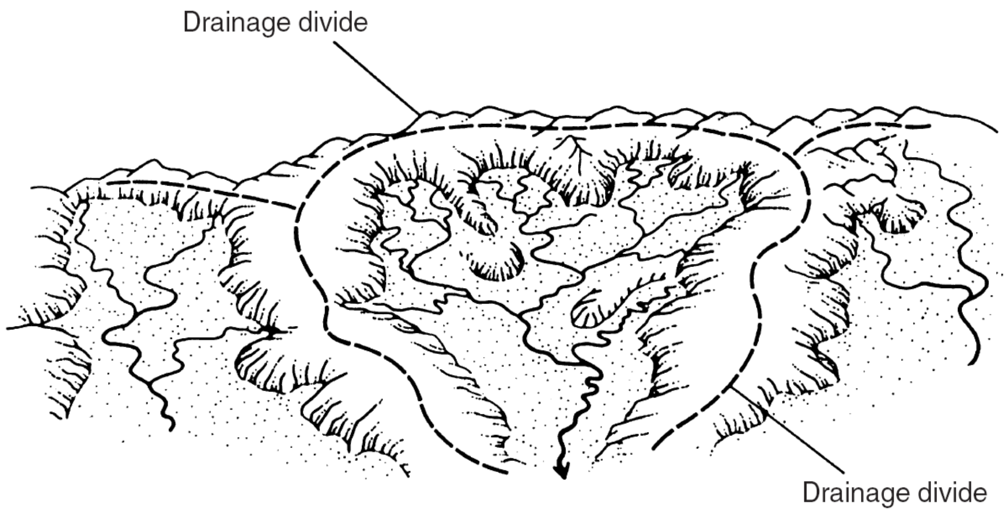


**Figure 3.** Schematic of a watershed. The dashed line is the watershed divide (from Marsh (1987)).

### 2.2.3 Precipitation

Precipitation is the primary source of water in the hydrologic cycle. It replenishes lakes, rivers and oceans, provides water for vegetation and recharges the aquifers.
Precipitation derives from atmospheric water and can occur in the forms of rain, snow and hail depending on climatic factors such as wind, temperature, and atmospheric pressure.

Rainfall and snowfall at specific locations are measured by observation gages that measure the depth of rainfall or snowfall in inches or millimeters during a certain time period. In the United States, precipitation data can be obtained from the National Weather service and from the United States Geological Survey (USGS).
These measurements are point measurement. Precipitation varies spatially, and in general, for a watershed there are several points at which data are recorded.

Engineering applications require that average precipitation over a certain watershed is known and therefore, we need to convert the point data to areal data
One easy method to convert point precipitation into areal precipitation is to compute the arithmetic average of the precipitation data collected from all the station located within the area. This method is called the Arithmetic Average Method and it is not very accurate especially when a limited number of data is available and there is a high variability of precipitation within the watershed..
Other methods include the Thiessen polygon method and the Isohyetal method. To apply these methods we need to use data from stations within the watershed and all nearby stations.

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### EXAMPLE 1

The following picture represents a schematic of a watershed. The numbered dots are the stations inside and adjacent to the watershed where the precipitation data reported in Table 2 were collected. Calculate the average precipitation depth in inches over the watershed

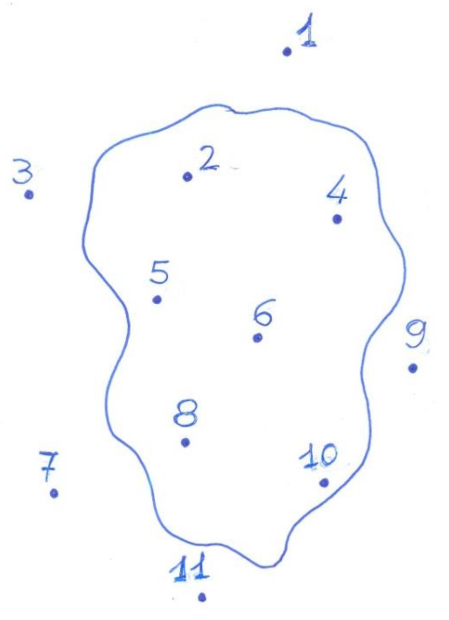


**Table 2**

| Station | Precipitation [in] |
|---|---|
| 1 | 1.0 |
| 2 | 0.9 |
| 3 | 1.1 |
| 4 | 1.05 |
| 5 | 1.2 |
| 6 | 1.25 |
| 7 | 1.3 |
| 8 | 1.15 |
| 9 | 0.85 |
| 10 | 0.93 |
| 11 | 1.04 |

To calculate the precipitation depth over the watershed we first need to identify all the stations within the watershed boundary. There are 6 stations within the watershed: 2, 4, 5, 6, 8, and 10. Using the data collected at these stations, we calculate the precipitation depth as the arithmetic average:

$$\text{Precipitation} = \frac{0.9 + 1.05 + 1.2 + 1.25 + 1.15 + 0.93}{6} = 1.08 \; in.$$

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## 2.2.4 Evaporation

Evaporation is the process by which liquid or solid water from land and surface bodies is transformed into water vapor and transferred into the atmosphere.
Evaporation represents a loss of surface water and it is a significant factor for large-scale water resources studies
Evaporation from large water bodies such as lakes and large reservoirs depends on several factors such as solar radiation, differences in vapor pressure between air and water, temperature, wind.
Water surface evaporation from a lake can be computed using the water budget , the mass transfer or the energy budget methods.
To measure evaporation from a water body, the most common method is the use of an evaporation pan., which is built of galvanized iron, has a diameter of 4ft and a depth of 10 in. The pan is installed on a wooden frame, located 12 in. above ground, and it is filled with water at a depth of 8 in.
The change in water depth in the evaporation pan is measured daily and represents the evaporation. To account for any precipitation occurred during the time interval, the measured value is adjusted using correction factors. The evaporation from the water body is then computed by multiplying the amount of water evaporated from the pan by a pan coefficient that accounts for the lake or reservoir features.

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### EXAMPLE 2

A class A evaporation pan is located near a reservoir to measure the daily evaporation. Every day the water level in the pan is measured. The precipitation values for that day are also recorded. Using the data reported in Table 2, calculate the daily pan evaporation in inches if the coefficient for the pan is 0.75 and report the results in Table 3 (column 4).

**Table 3**

| Day | Precipitation [in] | Water Level [in] | Evaporation [in] |
|---|---|---|---|
| 1 | 0.0 | 8.0 | 0 |
| 2 | 0.35 | 7.94 | 0.31 |
| 3 | 0.8 | 7.86 | 0.66 |
| 4 | 0.85 | 7.71 | 0.75 |
| 5 | 0.4 | 7.62 | 0.37 |
| 6 | 0.2 | 7.5 | 0.24 |
| 7 | 0.07 | 7.38 | 0.14 |
| 8 | 0.01 | 7.29 | 0.07 |
| 9 | 0 | 7.16 | 0.1 |
| 10 | 0.01 | 7.08 | 0.07 |

To calculate the evaporation from the pan we need to compute first the difference in water level that occurred in one day. Next we add the precipitation recorded for the day.
For day one the evaporation is set equal to zero because that is where we start.
For day two, the change in water level is equal to:

$$\textit{Change in water level} = 8 - 7.94 = 0.06 \textit{ in.}$$

The precipitation for the first day is 0.5 in. Then the evaporation from the pan is equal to:

$$\textit{Evaporation from pan} = 0.06 + 0.35 = 0.41 \textit{ in.}$$

To compute the evaporation from the lake, we multiply the evaporation from the pan by the pan coefficient:

$$\textit{Evaporation from lake} = 0.41 x 0.75 = 0.31 \textit{ in.}$$

This value is then reported in column 4 of Table 3. The procedure is repeated to compute the daily evaporation from the lake.

---

## 2.2.5 Evapotranspiration

Vegetation on our planet utilizes water for its life needs. Water is mainly absorbed from the soil through roots and utilized by the plants organs. Part of the absorbed water is then returned to the atmosphere through small openings in the plant leaves. This process is called transpiration

and is controlled by the same factors that control evaporation: solar radiation, differences in vapor pressure between air and water, temperature, wind.
Evapotranspiration (also indicated as ET) is a combination of evaporation and transpiration. Evapotranspiration is a loss that is controlled by atmospheric conditions; the maximum value of this loss is called Potential Evapotranspiration and it is approximately equal to the amount of evaporation that occurs from a large reservoir or a lake.
Transpiration is very difficult to measure. In field studies an instrument called lysimeter is used to measure the consumptive use (evaporation plus transpiration) of different crops. However for many small projects it is very difficult to perform measurements. In these cases it is common to use equations such as the Penman-Monteith equation that provide an estimate of the seasonal consumptive use of crops.

## 2.2.6 Streamflow and the Hydrograph

The term streamflow refers to the amount of water that flows in river, channels, and streams. The flowing amount of water is also called discharge or flow rate and it is defined as the volume of water that crosses a certain river section in the unit time. It is indicated usually with Q and is measured in $m^3/s$ in the SI system or $ft^3/s$ (cfs) in the U.S. system.

Streamflow is probably the component of the water cycle that is of most interest to engineers as they are concerned with problem such as water supply, drainage and flood prevention and control. Streamflow depends on two factors: rainfall and interaction with groundwater. During dry periods, the groundwater levels are usually higher than the water level in the channels, so water form the soils discharges in to the channel. During storm events, the water level in the channels raises and water will flow from channel into groundwater, which is then replenished.

Streamflow at a certain cross section of a channel is measured by observing the water level elevation and by relating the elevation to the flow rate Q using a chart called rating curve that provides the flow rate at a specified water elevations. One example of rating curve is depicted in figure 4.

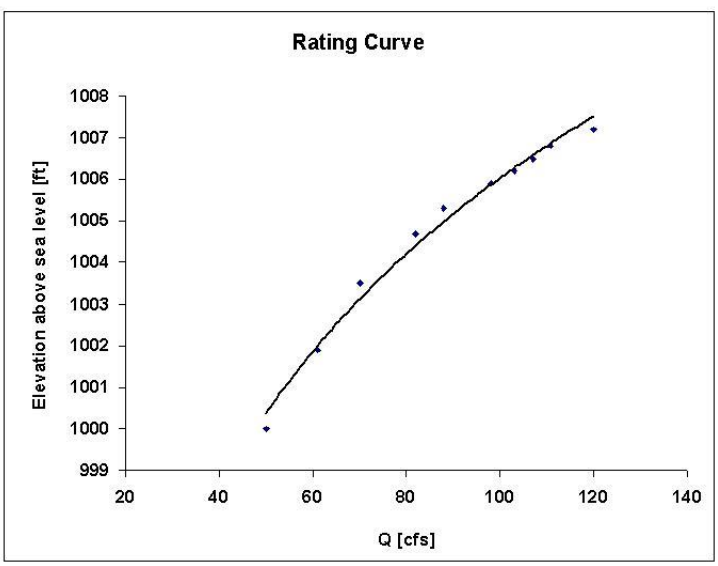


**Figure 4.** Rating curve

A common way to represent streamflow is to use a hydrograph. A hydrograph is a chart in which the flow rates measured at a certain cross section of a river or channel are plotted vs. time. An example of a hydrograph is shown in the figure 5.

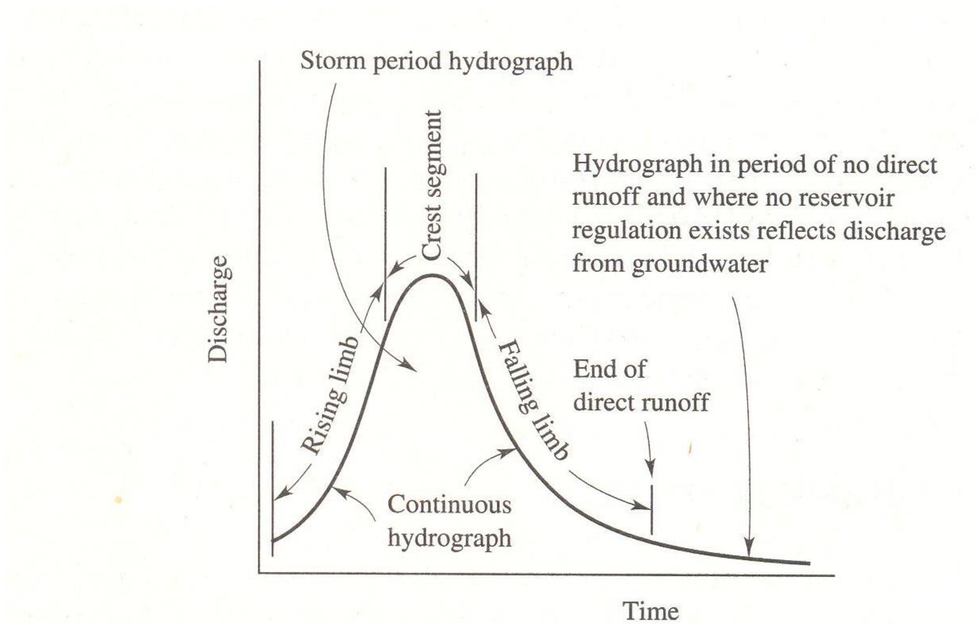


**Figure 5.** Hydrograph and its components (from Viessman and Lewis, 1996)

The rising portion of the hydrograph (the rising limb) is called the concentration curve, the portion around the peak is called the crest segment, and the falling portion (the falling limb) is called the recession curve.
The shape of the hydrograph depends on the rainfall characteristics and the features of the watershed.

---

## EXAMPLE 3

The flow data reported in Table 4 were collected at the outlet of a watershed after a storm. Plot the hydrograph for the storm.

### Table 4

| Time [hr] | 0 | 0.5 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|
| Flow [cfs] | 10 | 14 | 50 | 220 | 330 | 180 | 80 | 35 | 18 | 12 |

We use EXCEL to plot the hydrograph. On the x-axis we report the time in hours and on the y-axis we report the corresponding given flows in cfs. The resulting hydrograph is shown in figure 6

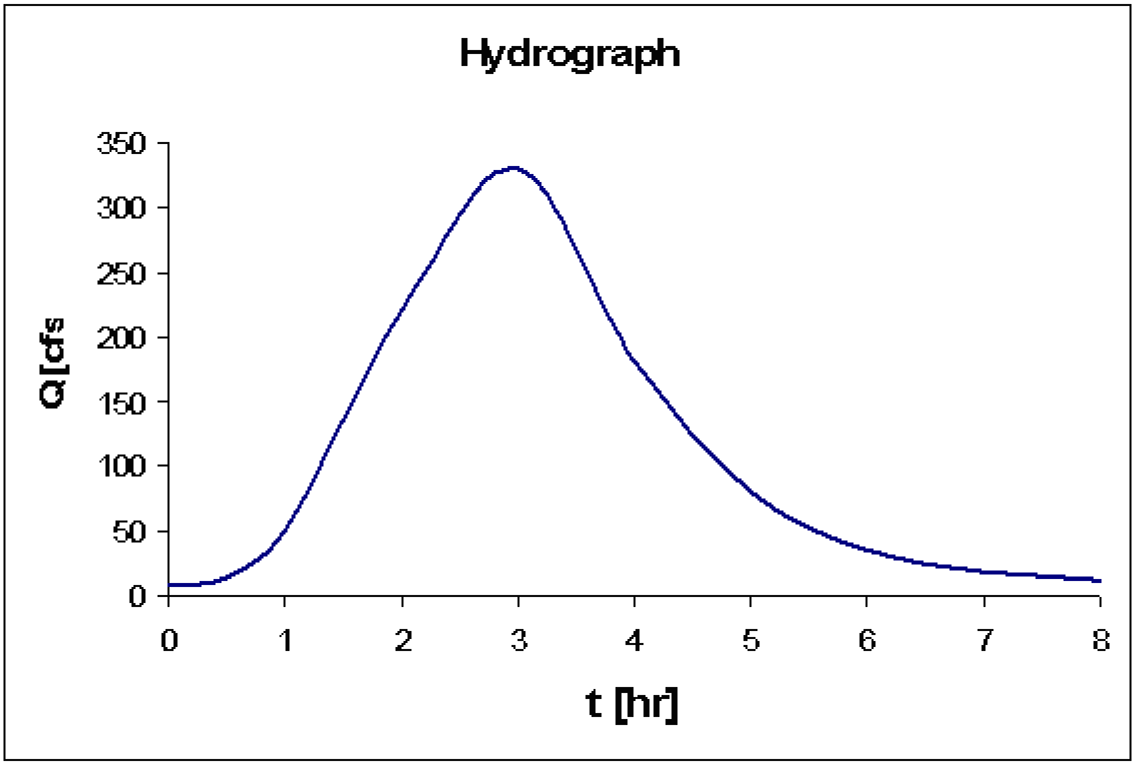


**Figure 6.** Storm hydrograph for Example 4.

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## 2.2.7 Infiltration

When water precipitates on land, a portion of it will enter the soil due to the effect of gravity and capillary forces. The soil can be compared to a sponge that sucks up water. This process is called infiltration. When we subtract the volume of water that infiltrates from the volume of water from a precipitation event the result is the net volume of rainfall, or rainfall excess. The net volume of rainfall represents the portion of the precipitation that contributes to the direct runoff from a watershed area.

Infiltration depends on several factors that include: intensity of precipitation, type of soil, previous conditions of the soil surface (i.e. if dry or wet), and vegetation coverage.

Infiltration is measured using instruments called infiltrometers that consist in rings or tubes inserted in the soil. The rate at which water is added to maintain a constant level in the infiltrometer is recorded.

When direct measurements are not available, infiltration is estimated using other methods based on empirical equations such as the Horton equation, the $\phi$ index method or the Green-Ampt method. These methods require knowledge of principles of water flow in soils.

## 2.2.8 Groundwater

When water infiltrates from the surface it will first penetrate a region immediately below the ground surface where the soil pores are partially filled with water and partially filled with air. This zone is called “unsaturated “ or “vadose” zone.
As the water moves further down, it will reach a portion of the soil where all the soil pore space is occupied by water. This is the “saturated zone”. The separation surface between the unsaturated zone and the saturated zone is called “water table”.
Groundwater is the subsurface water that is found below the water table
Groundwater flows through soils and the flow rate and direction of flow are controlled by the properties of the soil (how well the soil can be penetrated by water), the fluid (its physical properties such as density and viscosity) and the geological features of the subsurface.
Groundwater is an important element of the water cycle and it represents one of the main sources of drinking water.

## 2.2.9 Surface-Subsurface Water Interaction

Groundwater and surface water are interconnected systems and they can be considered as a single resource. Streams and aquifers can interact in three ways:

- When the water table near the stream is higher than the water surface in the stream, water will flow from the aquifer into the stream through the streambed.
- When the water table near the stream is lower than the water surface in the stream, water will flow from the stream into the aquifer through the streambed.
- Water can flow from aquifer into the stream in certain reaches of the stream and can flow from the stream into the groundwater in other reaches.

Figure 7 illustrates the mechanisms of groundwater-stream interaction.

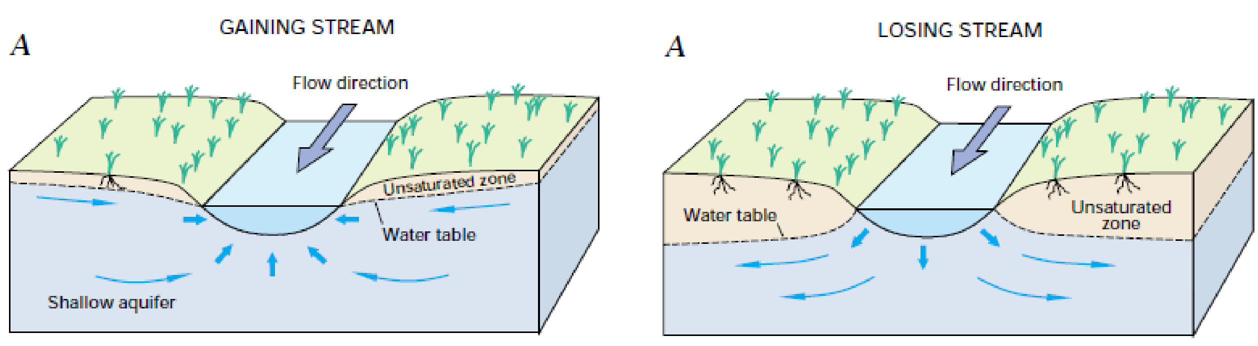


**Figure 7.** Groundwater-Stream Interaction (from Winter, T.C., Harvey, J.W., Franke, O. L., and Alley, W.M., USGS Circular: 1139, 1998)

The continuous exchange between surface and subsurface water can create several issues of concern. For example contaminants can be transferred from aquifers into streams and viceversa creating a long term contamination scenario. Water withdrawals from shallow aquifer near streams or other surface water bodies can reduce the water supply to surface water because part of the groundwater flow that otherwise will end up into the surface water body is captured by groundwater. This can create a significant impact on the water availability for the humans and ecosystem depending on the surface water supply. Because groundwater and surface water interactions are difficult to observe and measure. It is important to improve our knowledge and ability to characterize them.

**Multiple Choice Pop-Up Question**

Which one of the following instruments or diagrams is used to measure evaporation:

A A lysimeter

B A pan

C A rating curve

D A hydrograph

# 2.3 The Water Budget

A water budget is a relationship that accounts for any inflow, outflow of water and storage components for any hydrological unit. The equation is also known as continuity equation and states that the difference between inflow and outflow in a hydrologic system is equal to the change in the amount of water that is stored inside the system.

In mathematical terms we have:

$$I - Q = \frac{\Delta S}{\Delta t} \quad (4)$$

Where I is the inflow [$m^3$/s or $ft^3$/s], Q is the outflow [$m^3$/s or ft/s], and $\Delta S/\Delta t$ = change in storage in time [$m^3$/s, or $ft^3$/s]

Note that $\Delta S$ indicate the change in storage S (calculated as the difference between S at the end of time period and S at the beginning of the time period) that has occurred over a period of time $\Delta t$.

If we perform a water budget over a watershed, the continuity equation can be re-written as:

$$P - R - G - E - T = \Delta S \quad (5)$$

Where:

P = precipitation [$m^3$/s, or $ft^3$/s]

R = surface runoff [$m^3$/s, or $ft^3$/s

G = groundwater flow [$m^3$/s, or $ft^3$/s]

E = evaporation [$m^3$/s, or $ft^3$/s]

T = transpiration [$m^3$/s, or $ft^3$/s]

$\Delta$S = change in storage in a specified time [$m^3$/s, or $ft^3$/s

Note: infiltration is a loss for surface flow and gain for groundwater flow, thus it cancels out in the budget.

Water budgets are very useful tools to estimate the present availability of water, to evaluate sustainability of water resources, and to determine the appropriate strategies to correct problems.

## 2.3.1 The Water Budget for Evaporation

As we mentioned earlier, one of the methods used to estimate evaporation is the water budget method. For example, to calculate the evaporation from a lake, the continuity equation can be re-written as:

$$E = -\Delta S + I + P - O - GW \quad (6)$$

P = precipitation [$m^3$/s, or $ft^3$/s

I = surface inflow [$m^3$/s, or $ft^3$/s

GW = groundwater flow [$m^3$/s, or $ft^3$/s]

E = evaporation [$m^3$/s, or $ft^3$/s

O = surface outflow [$m^3$/s, or $ft^3$/s

$\Delta$S = change in storage in a specified time [$m^3$/s, or $ft^3$/s

NOTE: the minus sign indicates a loss from the water body.

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## EXAMPLE 4

A lake with a surface area of 12,000,000 $ft^2$ has a tributary stream that during the month of July 2008 provided an inflow of 18 cfs. During that month the lake also provided water at a rate of 15 cfs (outflow) to a local water agency and a change in storage $\Delta$S equal to 25 acre-ft. was recorded. The lake also contributed to the replenishment of the local groundwater with a flow of 0.5 cfs. A precipitation gage located at the lake reported a rainfall of 0.5 in. for the month. If the infiltration loss was negligible, calculate the evaporation loss in inches for the lake occurred during July 2008.

[Note: 1 foot = 12 in., 1 acre = 43560 $ft^2$ = 6272640 $in^2$]

Calculate the area of the lake in inches
A= 12,000,000x144=17.28x$10^8$ $in^2$

The evaporation loss for the lake can be calculated by performing a simple water budget using equation (6). The loss will be expressed in inches, so first we need to convert all the data into inches.

Inflow I = 18 cfs = 10x$(12)^3$ = 31104 $in^3$/second
In one month the total volume of inflow will be given by the flow multiplied by the total number of seconds in a month which is 2592000 seconds/month.

The total volume of inflow is then I = 31104x2592000 = 8.06x$10^{10}$ $in^3$

To obtain the depth in inches corresponding to the inflow volume, we divide the volume by the area of the lake:

I = 8.06x$10^{10}$/ 17.28x$10^8$=46.64 in.

We repeat the same procedure for the outflow, but we will perform the calculations in one step.

O = 15x$(12)^3$x2592000/17.28x$10^8$ = 38.88 in.

The contribution to groundwater replenishment that is given as a flow can be obtained in inches by repeating the same procedure.

G = 0.5x$(12)^3$x2592000/17.28x$10^8$ = 1.3 in.

The change in storage is a volume that is provided in acre-ft. We convert the acre-ft in $ft^3$.

$\Delta$S = 25 x43560 = 1089000 $ft^3$

Now we divide the result by the area of the lake in $ft^2$ to obtain the corresponding change in depth due to the change in storage

$\Delta$S = 1089000/12000000=0.091 ft

Finally we convert the ft in inches

$\Delta$S = 0.091x12= 1.09 in

Precipitation is provided in inches, so we can calculate the evaporation loss for the lake from equation (6):

E = I-O-G+P-$\Delta$S = 46.64-38.88-1.3+0.5-1.09 = 6.37 in

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**Multiple Choice Pop-Up Question**
The following data in inches were reported during a certain month for a mountain lake:

Inflow: 75 in
Outflow: 45 in
Groundwater: - 1.0 in (Groundwater provides water to the lake here)
Precipitation: 1.0 in
Change in storage $\Delta S$: 3 in.

The amount evaporated from the lake during the month in inches is:

A 27 in.
B 0 in.
C 32 in.
D 29 in.

**Projects Related to this module:**
PROJECT 1: Design of a sustainable system to maximize water conservation on campus
PROJECT 3: Water budget at CSULB
Information on these projects can be found in the Student Packet posted on Beachboard.

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