CURRICULUM AND SYLLABI

M.Tech.

in

WATER RESOURCES ENGINEERING

(With effect from Academic Year 2018-2019)

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY CALICUT

CALICUT - 673601

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY CALICUT

Programme Educational Objectives (PEOs)

1. Mould students for productive and successful careers in the profession, with the capability to apply the knowledge gained to solve contemporary problems
2. Develop in students the motivation for continuous learning, and the urge to contribute to the organizations they work in through leadership and team work.
3. Provide a strong foundation in basic, applied, and advanced fields related to water resources, such as the mechanics of static and moving water, the occurrence, distribution, circulation, availability, and management of the resource, contamination of water resources and its management etc, thereby enabling students to excel in careers in various fields related to water such as mechanics of fluids including dynamics, hydrologic and water resources engineering, water contamination and remediation and allied fields, both at the national and international levels.
4. Impart in-depth knowledge in both conventional and state of the art methods and tools in the broad field of water resources engineering to the students, so as to enable them to meet contemporary challenges in academics including research as well in the industry.
5. Understand and acquire modelling, and programming skills and expose them to state of the art software and hardware in the field.
6. Develop strong communication skills - both verbal as well as technical writing skills.
7. Develop expertise in laboratory and experimental work.
8. Mould sensitive students with an open eye and mind towards various problems that they may face in the profession as well as to the needs of the society for which their conceptions are meant, and with creative and logical thinking capabilities, so as to be able to achieve real sustainable solutions that address relevant environmental concerns as well.
9. Prepare students to face challenges in the profession by encouraging interaction with the professional field, carrying out project works that are of relevance and importance to the profession, and involving them in consultancy projects.
10. Create good engineers with strong commitment to the profession and the community and good academicians and researchers, so that the profession, the country and humanity as a whole are benefitted.

Programme Outcomes (POs)

1 Graduates will develop the most vital attributes to grow into good academicians and researchers in their career

2 Graduates will develop into successful engineers, contributing immensely to the profession, the country, and humanity as a whole

3 Graduates will acquire the ability to identify, formulate, investigate, and solve complex problems in the profession

4 Graduates will utilise creative and logical thinking capabilities to solve field problems

5 Graduates will have an open eye and mind towards the needs of the society for which their conceptions are meant

6 Graduates will have the ability to understand the impact of human activities and engineering on the society

7 Graduates will address environmental concerns and sustainability issues related to infrastructure development in this sector

8 Graduates will possess the skill to use modern engineering tools, software and equipment to analyse and solve problems in this field

9 Graduates will be able to communicate effectively - both verbally and in writing

10 Graduates will develop the right aptitude and attitude for self-education and life-long learning

Department of Civil Engineering

CURRICULUM

M.Tech. (Water Resources Engineering)

First Semester

Sl. No.	Code	Title	L	T	P/S	C
1	CE6501D	Advanced Fluid Mechanics	3	0	0	3
2	CE6502D	Surface Water Hydrology and Hydrologic Systems	3	0	0	3
3	CE6503D	Remote Sensing and GIS Applications in Water Resources Engineering	3	0	2	4
4	******	Elective I	3	0	0	3
5	******	Elective II	3	0	0	3
6	CE6591D	Water Resources Engineering Laboratory	0	0	2	1
7		Communicative English				
TOTAL CREDITS = 11 (Core) + 6 (Electives) = 17						

Second Semester

Sl. No.	Code	Title	L	T	P/S	C
1	CE6511D	Water Resources Systems Analysis and Design	3	0	0	3
2	CE6512D	Flow and Transport in Porous Media	3	0	0	3
3	CE6513D	Computational Hydraulics and Hydrology	3	0	0	3
4	******	Elective III	3	0	0	3
5	******	Elective IV	3	0	0	3
6	******	Elective V	3	0	0	3
7	CE6592D	Seminar	0	0	2	1
TOTAL CREDITS = 10 (Core) + 9 (Electives) = 19						

Third Semester

Sl. No.	Code	Title	L	T	P/S	C
1	CE7598D	Project – Part 1	0	0	20	10
TOTAL CREDITS = 10						

Fourth Semester

Sl. No.	Code	Title	L	T	P/S	C
1	CE7599D	Project – Part 2	0	0	28	14
TOTAL CREDITS = 14						

LIST OF ELECTIVES

Sl. No.	Code	Title	Credits
1	CE6521D	Statistical Methods in Hydrology	3
2	CE6522D	Hydraulic Modelling	3
3	CE6523D	Finite Element Method in Hydro Engineering	3
4	CE6524D	Applied Hydraulic Modelling	3
5	CE6525D	Hydrogeology and Groundwater Development	3
6	CE6526D	Environmental Impact Assessment of Water Resources Projects	3
7	CE6527D	Water Quality Modelling and Management	3
8	CE6528D	Hydropower	3
9	CE6529D	Watershed Management	3
10	CE6530D	Environmental Hydraulics	3
11	CE6531D	Soft Computing in Water Resources Engineering	3
12	CE6532D	Urban Hydrology and Drainage	3
13	CE6533D	Coastal Engineering and Coastal Zone Management	3
14	CE6534D	Pollution Science and Engineering	3
15	CE6535D	Hydroclimatology	3
16	CE6536D	Disaster Management	3
17	CE6537D	Environmental Flows	3
18	CE6538D	Dam Safety	3
17		Any other related subject offered in the Institute with the approval of the Course Coordinator	

Notes:

1. A minimum of 60 credits have to be earned for the award of M Tech degree in this Programme.
2. Students have to credit five electives in the first two semesters. Communicative English and Audit courses are optional.
3. Industrial training during summer is optional.

CE6501D ADVANCED MECHANICS OF FLUIDS

Prerequisite: Nil

L	T	P	C
3	0	0	3

Total Hours: 39

Course Outcomes:

CO1: Mathemtical formulation of fluid flow phenomena.
CO2: Application of mathematical formulations to various flow systems.
CO3: Familiarization with potential flow theory.
CO4: Application of potential flow theory to various flow systems.

Module 1: (13 hours)

Stress at a point for a stationary or uniformly moving fluid, and for nonviscous flows. Stress transformation for viscous fluid motion. Acceleration of a fluid particle. Irrotational flow and its relation to viscosity. System approach and control volume approach. Reynolds transport equation. Basic laws for finite systems and finite control volumes. Conservation of mass. Linear momentum for control volumes fixed in inertial space. Moment of momentum for systems and inertial control volumes. Moment of momentum equation applied to pumps and turbines. Differential forms of the basic laws – conservation of mass, Newton's laws, Euler equation, Bernoulli's equation.

Module 2: (13 hours)

General incompressible viscous flow – Navier-Stokes equation. Navier-Stokes equation for laminar incompressible flow. Parallel steady laminar flow problems – flow between infinite parallel plates, flow in pipes, flow in an annulus, Couette flow. Simplified Navier-Stokes equation for a very thin layer of flow. Dynamic similarity law from Navier Stokes equation. Turbulent flow – mean time averages for steady turbulent flow. Navier-Stokes equation for mean time average quantities. Apparent stress. Eddy viscosity.

Module 4: (13 hours)

Potential flow – Mathematical considerations. Circulation. Stokes' theorem. Circulation in irrotational flows. Velocity potential. Stream function and its relation with velocity field. Stream lines. Two dimensional sources and sinks. Simple vortex. Doublet. Superposition of 2D flows – sink plus vortex, flow about a cylinder without circulation. Rotating cylinder. Lift and drag for a cylinder with circulation. Axisymmetric 3D flows. Stokes' stream function. Relation between stream line, stream function, and velocity field. 3D sources and sinks. 3D doublet. Steady flow about a sphere.

References

1. Irving H. Shames, *Mechanics of Fluids*, McGraw-Hill, Inc,1962
2. S. W. Yuan, *Foundations of Fluid Mechanics*, Prentice-Hall of India, 1976
3. William F. Hughes, and John A. Brighton, *Fluid Dynamics*, Schaum's Outline Series, McGraw-Hill.1967
4. I. G. Currie, *Fundamental Mechanics of Fluids*, CRC, Taylor and Francis.1974

CE6502D SURFACE WATER HYDROLOGY AND HYDROLOGIC SYSTEMS

Pre-requisite: Nil

L	T	P	C
3	0	0	3

Total Hours: 39

Course Outcomes:

Students will be able to:

CO1: Understand the functions of the hydrologic cycle and the hydrological processes

CO2: Perform water balance computations of a watershed

CO3: Perform flood routing in reservoirs and rivers

Module 1: (14 hours)

Hydrologic cycle, Systems concept, Hydrologic system model, Hydrologic model classification.
Hydrologic Processes – Continuity equations, Momentum Equations, Energy balance
Precipitation – Rainfall characteristics, Development of a design storm, Depth-Area Adjustment, Average areal rainfall, Estimating missing rainfall data, Gauge consistency
Infiltration – Process, Factors affecting infiltration, Measurement, Modelling – Richard's equation, Green-Ampt model, Philip Two Term model, SCS model
Evaporation and Transpiration – Factors affecting evaporation, Measurement, Transpiration, Evapotranspiration, Penman equation

Module 2: (14 hours)

Interception and Depression storage – Factors affecting interception, Estimation of interception, Factors affecting depression storage, Estimation of depression storage. Streamflow – Sources of streamflow, Streamflow hydrograph, Excess rainfall and direct runoff
Hydrograph analysis – Baseflow separation, Estimation of initial abstraction, Separation of losses and rainfall excess, separation of losses using infiltration capacity curves, Introduction to unit hydrograph, Rainfall excess reciprocal method, S-hydrograph method. Snowfall and Snowmelt

Module 3: (11 hours)

Watershed concepts and modelling
Flood routing – Hydrologic and hydraulic routing, Hydrologic river routing, Hydrologic reservoir routing, Governing equations for hydraulic river routing, Kinematic wave routing, Hydraulic river routing.
Hydrologic simulation models – steps in watershed modelling, description of major hydrologic models, HEC flood hydrograph models
Design of drainage collection systems

References

1. Chow, V.T., Maidment, D.R., and Mays, L.W., Applied Hydrology, McGraw Hill, 1st Indian edition, 2010
2. Mccuen, R.H., Hydrologic Analysis and Design, Pearson, 4th edition, 2016
3. Singh, V.P., Elementary Hydrology, Prentice Hall, 1991
4. Bedient, P.B., Huber, W.C., and Vieux, B.E., Hydrology and Floodplain Analysis, Prentice Hall, 2007
5. Elizabeth M. Shaw, Keith J. Beven, Nick A. Chappell, and Rob Lamb, Hydrology in Practice, 4th edition, CRC press, 2011
6. David R Maidment, Handbook of Hydrology, 1st edition, McGraw-Hill Education, 1993

CE6503D REMOTE SENSING AND GIS APPLICATIONS IN WATER RESOURCES ENGINEERING

Pre-requisites: Nil

L	T	P	C
3	0	2	4

Total hours: 65 (L-39, P-26)

Course Outcomes:

Students will be able to:

CO1: Understand the principles of remote sensing and select appropriate remote sensing data for intended application.

CO2: Perform digital image analysis to extract data from the remote sensing images.

CO3: Perform spatial analysis by understanding the principles of GIS and basic GIS operations.

CO4: Apply remote sensing and GIS techniques for solving problems in the field of water resources engineering.

Module 1: (13 hours)

Remote Sensing Concepts

Concepts and foundations of remote sensing- Energy sources and radiation principles- Energy interactions in the atmosphere – Energy interaction with earth surface features - Spectral reflectance of vegetation, soil and water - Atmospheric influence on spectral response patterns

Remote Sensing Satellites

Remote sensing platforms – Sun synchronous systems- Geosynchronous systems-Across track and along track scanning systems – Types of sensor resolutions (Spatial, Spectral, Radiometric and Temporal resolution) – Mutispectral and thermal scanners – Characteristics of Remote sensing satellites and sensors (IRS, Landsat, SPOT, IKONOS)

Microwave remote sensing – Active and Passive remote sensing systems - Radar development – Side looking Radar System Operation - Synthetic Aperture Radar – Geometric characteristics of side-looking Radar imagery

Module 2: (13 hours)

Satellite Image Interpretation

Visual Image Interpretation – Standard False Colour Composites – Elements of visual image interpretation

Digital Image Analysis

Digital Image Processing – Storage formats (BSQ, BIL, BIP) – Sources for Geometric and Radiometric distortions in images – Image rectification and restoration – Image histogram – Image enhancement – level slicing, contrast stretching, convolution filtering, Band ratioing (NDVI, SAVI, NDWI) – Image classification – Supervised and unsupervised classification algorithms – Accuracy assessment – land use/ land cover mapping - Principal component transformation

Digital Elevation Models – SRTM, LIDAR Techniques

Module 3: (13 hours)

Concepts of GIS

GIS - Definition, Spatial and attribute data, Components of GIS, DBMS – Geospatial data representation (Raster, Vector) -Sources of GIS data – Data input - Raster geospatial data analysis - Output functions of raster geoprocessing – Vector GIS analysis functions - Vector geoprocessing output functions

Applications

Application of Remote Sensing and GIS with specific reference to landuse land cover mapping hydrological modelling and watershed management, drainage delineation,soil moisture estimation, DEM Applications

Practical Exercises: (26 hours)

1. Preparation of Standard False Colour Composite (SFCC) and visual interpretation
2. Application of various radiometric enhancements – contrast enhancement, histogram equalization
3. Application of geometric enhancements – image domain - convolution filtering
4. Preparation of vegetation indices
5. Image registration/geo-referencing and supervised classification – Land use /Land cover map preparation
6. Unsupervised classification – Land use /Land cover map preparation
7. Digitizationand preparation of vector GIS database of well locations, drainage network, water bodies etc
8. Generating DEM and ground water contours using spatial interpolation techniques
9. Extraction of drainage network from DEM and watershed delineation using GIS
10. Computation of Area-Capacity for a reservoir using GIS

References

1. Thomas. M. Lillesand, Ralph. W. Kiefer and Jonathan W. Chipman, Remote Sensing and Image Interpretation , John Wiley and Sons, Inc., Sixth Edition, 2011
2. John R. Jenson, Remote Sensing of the Environment: An Earth Resource Perspective, Pearson Education India, Second edition, 2013
3. George Joseph, Fundamentals of Remote Sensing, Universities Press, Second edition, 2005
4. John A. Richards and XiupingJia, Remote Sensing Digital Image Analysis: An Introduction, Springer (Sge), Fourth Edition, 2008
5. Lo C. P and K.W. Yeung, Concepts and Techniques of Geographic Information Systems, Pearson Education, Second edition, 2016

CE6511D WATER RESOURCES SYSTEMS ANALYSIS AND DESIGN

Prerequisite: Nil

Total Hours: 39

L	T	P	C
3	0	0	3

Course Outcomes:
CO1: Realization of the importance of optimizing water resources systems' performance
CO2: Identification of different characteristics of water resources systems.
CO3: Formulation of problems in water resources systems modeling and management.
CO4: Familiarization of different techniques of optimization and their applications to water resources systems.

Module 1: (10 hours)

Concept of System and Systems Analysis - definition of a system, types of systems, systems approach, systems analysis. Systems Techniques in Water Resources – optimization of functions of single and multiple variables using calculus. Linear programming – problem formulation, simplex method, dual simplex method, sensitivity analysis, piecewise linearization. Dynamic Programming – characteristics of a DP problem, recursive relations, multiple state variables.

Module 2: (10 hours)

Economic Considerations in Water Resources Systems – general principles, discount factors, amortization, comparison of alternative plans, market demand and supply, aggregation of demand, water resources as a production process, conditions of optimality, benefit cost analysis – cost and benefit curves, cost and benefit estimation. Multiobjective Planning – noninferior solutions, weighting method and constraint method for plan formulation, plan selection, fuzzy multiobjective optimization.

Module 3: (10 hours)

Modelling of Reservoir Systems: (1) Deterministic Inflow – reservoir sizing, sequent peak analysis, reservoir capacity estimation using LP, storage yield function. Reservoir operation – standard operating policy, optimal operating policy using LP, standard policy using DP, simulation of reservoir operation for hydropower generation. (2) Random inflow – chance constrained LP, linear decision rule, deterministic equivalent of a chance constraint, reliability-based reservoir sizing.

Module 4: (9 hours)

Linear Programming Applications – irrigation water allocation for single and multiple crops, multireservoir system for irrigation planning, reliability capacity tradeoff for multicrop irrigation, reservoir operation for irrigation, reservoir operation for hydropower optimization. Dynamic Programming Applications – optimal crop water allocation, steady state reservoir operating policy for irrigation.

REFERENCES

1. S. Vedula, and P. P. Mujumdar, *Water Resources Systems – Modelling Techniques and Analysis*, Tata McGraw-Hill Publishing Company Limited, New Delhi,2005
2. D. P. Loucks, J. R. Stedinger, D. A. Haith, *Water Resources Systems Planning and Analysis,* Prentice-Hall, Inc., Englewood Cliffs, New Jersey,1981
3. L. W. Mays, and Y-K. Tung, *Hydrosystems Engineering and Management,* McGraw-Hill, Inc.1989
4. W. A. Hall, and J. A. Dracup, *Water Resources Systems Engineering*, Tata McGraw-Hill Publishing Company Limited, New Delhi,1970
5. P. R. Bhave, *Water Resources Systems*, Narosa Publishing House, New Delhi.2011

CE6512D FLOW AND TRANSPORT IN POROUS MEDIA

Pre-requisite: Nil

L	T	P	C
3	0	0	3

Total Hours: 39

Course Outcomes:

Students will be able to

CO1: Understand the basics of groundwater flow and transport in groundwater.

CO2: Perform groundwater resource and recharge estimation and plan schemes for recharge

CO3: Perform numerical modelling of flow and transport problems in the subsurface

Module 1: (14 hours)

Groundwater and the hydrologic cycle.Occurrence and movement of groundwater - origin, age, distribution, types of aquifers. Darcy's law, hydraulic head and fluid potential, hydraulic conductivity and permeability, heterogeneity and anisotropy of hydraulic conductivity, porosity and void ratio, compressibility and effective stress, transmissivity and storativity. Steady State and transient flow - formulation of the governing equations, limitations of the Darcian approach. Ground water and well hydraulics - steady flow to a well fully penetrating an aquifer (confined and unconfined), unsteady radial flow to a well fully penetrating an aquifer (confined, unconfined and leaky), effect of well bore storage.

Module 2: (14 hours)

Multiple well systems, partially penetrating wells, bounded aquifers, characteristic well losses, specific capacity. Slug tests.Introduction to flow in the unsaturated zone and flow in fractured formations. Saline water intrusion in coastal aquifers: occurrence, shape and structure of the interface, upconing, control of saline water intrusion. Groundwater modelling, Inversemodelling in groundwater.Artificial recharge of aquifers - concepts, hydraulics and methods.Groundwater budget.Groundwater resourceestimation.

Module 3: (11 hours)

Introduction to groundwater contamination. Quality of groundwater - measures of quality, groundwater samples, physical, chemical and biological analyses, water quality criteria, and salinity. Transport and transformation of contaminants in groundwater - processes, formulation of the governing equations and initial and boundary conditions, modelling, solutions for simple cases.

References

1. R.A. Freeze and J. A. Cherry, *Groundwater*, Prentice Hall, Inc. 1979.
2. C. W. Fetter, *Applied Hydrogeology*, 4th ed., Prentice Hall, Inc. 2001.
3. C. W. Fetter, *Contaminant Hydrogeology*, 2nd ed., Waveland Press, 2008.
4. P. A. Domenico and F. W. Schwartz, *Physical and Chemical Hydrogeology*, 2nd ed., John Wiley & Sons, Inc., 1998.
5. F. W. Schwartz and H. Zhang, *Fundamentals of Groundwater*, John Wiley & Sons, Inc., 2003.
6. D. K. Todd and L. W. Mays, *Groundwater*, 3rd ed., John Wiley & Sons, Inc., 2004.
7. A. K. Rastogi, *Numerical Groundwater Hydrology*, Penram International Publishing (India) Pvt. Ltd., 2007.
8. VedatBatu, *Applied Flow and Solute Transport Modeling in Aquifers*, Taylor and Francis/ CRC Press, 2006.
9. E. Scott Bair, Terry D. Lahm, *Practical Problems in Groundwater Hydrology*, Pearson Prentice Hall, 2006.

CE6513DCOMPUTATIONAL HYDRAULICS AND HYDROLOGY

Pre-requisites: Nil

Total hours: 39

L	T	P	C
3	0	0	3

Course Outcomes:

CO1: Understanding the fundamentals to solve problems of linear, nonlinear, algebraic, differential and partial differential equations
CO1: Understanding finite difference schemes for modelling open channel flow and solve engineering problems
CO3: Understanding finite difference schemes for modeling groundwater flow, contaminant transport and solve engineering problems

Module 1: (14 hours)

Introduction to computational methods. Accuracy and precision, definitions of round off and truncation errors, error propagation Linear system-Solution for Banded and Sparse systems using Gaussian elimination and Gauss, Jordan methods, Gauss seidel method – Nonlinear equations –Newton-Raphson methods, interpolation – Newton's and Lagrange's interpolation. Introduction to Finite Differences. Solution of System of Non Linear Algebraic equations using Newton and Picard Method. Numerical solution of Ordinary differential equations-Initial and Boundary value problems, Solutions using Euler Method, Modified Euler Method, Fourth –order Runge-Kutta method. Computation of gradually varied flow using numerical techniques.

Module 2: (12 hours)

Introduction to Partial Differential Equations-Elliptic, Parabolic and Hyperbolic equations. Boundary conditions. Explicit and Implicit Finite Difference schemes. Application of finite difference method to steady and unsteady open channel flows. introduction to Method of Characteristics. Introduction to finite volume method, Modeling using HEC-RAS and HEC-HMS

Module 3: (13 hours)

Application of finite difference method to saturated and unsaturated flow. Application of finite difference method to grounwater transport problem. Advection, Diffusion and Advection-Diffusion equations .Convergence, stability and consistency of finite difference schemes. Modeling using MODFLOW and MT3D

References:

1. Chapra S C and Canale R P, *Numerical Methods for Engineers*, McGraw Hill, 1989.
2. Santhosh K.Gupta, *Numerical Methods for Engineers*, New age international publishers, 2005.
3. John D Anderson, *Computational Fluid Dynamics*, McGraw Hill ,1995
4. C.Zheng, and G.D. Bennett. *Applied Contaminant Transport Modeling*, 2nd ed. New York: John Wiley & Sons, 2002
5. Chow, V.T., Maidment, D.R., and Mays, L.W., *Applied Hydrology*, McGraw Hill, 2010
6. A.W.Harbaugh, E.R Banta, M.C. Hill, and M.G McDonald, *MODFLOW-2000, the U.S. Geological Survey modular ground-water model – User guide to modularization concepts and the ground water flow process*. U.S. Geological Survey Open-File Report 00-92, 121, 2000.
7. C.Zheng, Chunmiao, and P.P. Wang, *MT3DMS—A modular three-dimensional multispecies transport model for simulation of advection, dispersion and chemical reactions of contaminants in ground-water systems. Documentation and user's guide*: Jacksonville, Fla., U.S. Army Corps of Engineers Contract Report SERDP-99-1, 1999.

CE6591D WATER RESOURCES ENGINEERING LABORATORY

L	T	P	C
0	0	2	1

Pre-requisite: Nil

Total Hours: 28

Course Outcomes:

The student will be able to

CO1: Formulate models for simulating flow in pipe networks
CO2: Formulate numerical models for simulating groundwater flows
CO3: Simulate wet weather and dry weather flows in sewers
CO4: Carryout flow routing in channels and reservoirs

Practical Exercises:

1. Flow and transport problems in pipelines
2. Flow and transport problems in open channels including rivers
3. Modeling lakes and reservoirs
4. Groundwater flow and transport
5. Flow and transport in the vadose zone
6. Coastal circulation and sediment transport
7. Storm and sanitary sewer design
8. Flow routing in channels and reservoirs.

CE6592D SEMINAR

L	T	P	C
0	0	2	1

Pre-requisite: Nil

Total Hours: 28

Course outcomes

CO1: Identify current trends and topics of relevance in Water Resources Engineering

CO2: Develop the ability of data collection on a specific topic and documenting the relevant details in a given format

CO3: Develop presentation skills for effectively conveying the subject matter to an audience

Individual students will be asked to choose a topic in any field of Water Resources Engineering, preferably from outside the M.Tech syllabus and give seminar on the topic for about thirty minutes. Also, they have to submit a brief report of their seminar talk. A committee consisting of at least two faculty members specialized on different fields of Water resources engineering will assess the presentation of the seminars and report and award marks to the students.

CE7598D PROJECT – PART 1

L	T	P	C
0	0	20	10

Pre – requisite

A student should have registered for all theory and laboratory courses in the first and second semester of the programme and secured a grade other than ‘W’

The primary objective of the course ‘Project’ is to introduce the students to various sub-fields in Water Resources Engineering. It is aimed at exposing the students to current development and research activities in the above mentioned fields. The students are also trained to gather in-depth information on specified areas or topics. The students are made proficient to make proper technical documentation on the selected topic. Moreover, the course would also provide training to students to make effective technical presentations.

CE7599D PROJECT – PART 2

Pre-requisites: **CE7598D PROJECT – PART 1**

L	T	P	C
0	0	28	14

This course is a continuation of the work initiated in third semester and the student is expected to submit a consolidated report of the work undertaken in the third and fourth semester, at the end of the fourth semester.

CE6521D STATISTICAL METHODS IN HYDROLOGY

Pre-requisites: Nil

L	T	P	C
3	0	0	3

Total hours: 39

Course Outcomes:

The students will be able to

CO1: Perform probabilistic analysis of problems in water resources engineering.
CO2: Identify the suitable probability distribution and estimate parameters of hydrologic random variables.
CO3: Establish the relationship between two variables.
CO4: Analyze and model hydrologic time series.

Module 1: (9 hours)
Randomness of hydrologic variables – total probability and Bayes theorems. Univariate, bivariate, marginal and conditional distributions of hydrologic random variables. Independence. Derived and mixed distributions. Properties of hydrologic random variables – moments and expectation, moment generating functions. Measures of central tendency, dispersion, symmetry, and peakedness. Moments and expectation of jointly distributed hydrologic random variables, covariance, correlation coefficient, parameter estimation, Chebyshev inequality.

Module 2: (11 hours)

Discrete Probability Distributions of Hydrologic Random Variables – hypergeometric distributions, Bernoulli process – binomial, geometric, and negative binomial distributions. Poisson process – Poisson, exponential, and gamma distribution, multinomial distribution. Continuous Probability Distributions of Hydrologic Random Variables – general and standard normal distributions, central limit theorem, constructing normal curves for hydrologic data, normal approximations of binomial, negative binomial, and Poisson distributions. Uniform, exponential, gamma, lognormal, extreme value, beta, and Pearson distributions. Chi-square, t-, and F-distributions.

Module 3: (9 hours)
Probability Plotting and Frequency Analysis –probability plotting, analytical hydrologic frequency analysis, regional frequency analysis, frequency analysis of precipitation data and other hydrologic variables. Linear and nonlinear regression, transformation of nonlinear models.Correlation, correlation and regional analysis. Multivariate analysis, principal component analysis, univariate and multivariate data generation.

Module 4: (10 hours)
Hydrologic time series – definition, autocorrelation, spectral analysis, applications of autocorrelation and spectral density functions in hydrology. Stochastic hydrologic models – purely random stochastic models, first order Markov process, first order Markov process with periodicity, higher order autoregression models, multisite Markov model, Markov chain models of hydrologic processes.

References:

1. C. T. Haan, Statistical Methods in Hydrology, Wiley-Blackwell; 2nd edition, 2002
2. M. Shahin, H. J. L.vanOorschot, and S. J. de Lange, Statistical Analysis in Water Resources Engineering, Aa-Balkema, Rotterdam, Brookfield, 1993
3. V. Yevjevich, Probability and Statistics in Hydrology, Water Resources Publications, Fort Collins, Colarado, USA, 2nd edition, 2010.
4. V. Yevjevich, Stochastic Processes in Hydrology, Water Resources Publications, Fort Collins, Colarado, USA, 1970.
5. P. Jayarami Reddy, A Text Book of Stochastic Hydrology,Laxmi Publications, New Delhi, 2nd edition, 2016.

CE6522D HYDRAULIC MODELLING

L	T	P	C
3	0	0	3

Prerequisite: Nil

Total Hours: 39

Course Outcomes:

The students will be able to

CO1: Perform numerical analysis of problems in water resources engineering.
CO2: Develop physical models.
CO3: Model the open channel flow.
CO4: Model the coastal processes and near shore structures.

Module 1: (9 hours)

Review of theoretical background required for hydraulic modelling – basic mathematics, hydraulics, and numerical techniques.

Module 2: (10 hours)

Development of physical models – dimensional analysis and principles of similitude, non-dimensional numbers employed in hydraulic modelling, tools and procedures.

Module 3: (10 hours)

Modelling of open channel systems, closed conduit systems and urban drainage systems. Environmental modelling of open channel systems.

Module 4: (10 hours)

Modelling of estuaries, coastal processes, nearshore structures, and hydraulics structures.

REFERENCES

1. Pavel Novak, Vincent Guinot, Alan Jeffrey, and Dominic. E. Reeve, *Hydraulic Modelling – An Introduction*,Spon Press.2010
2. James. J. Sharp, *Hydraulic Modelling*, Butterworths, 1981
3. Helmut Kobus and Gerrit Abraham, *Hydraulic Modelling*, Parey,1980.
4. S. N. Ghosh, *Tidal Hydraulic Engineering,* Oxford and IBH Pub. Co. Pvt. Ltd., 1998
5. Vedat Batu, *Applied Flow and Solute Transport Modeling in Aquifers*, Taylor and Franics.2006
6. James. L. Martin and Steven. C. McCutcheon, *Hydrodynamics and Transport for Water Quality Modeling*, Lewis Pub, 1999

CE6523D FINITE ELEMENT METHOD IN HYDRO ENGINEERING

Prerequisite: Nil
Total hours: 39

L	T	P	C
3	0	0	3

Course Outcomes:
The students will be able to

CO1: Formulate and solve finite element models for flow analysis.
CO2: Perform linear and nonlinear analysis of pipe networks.
CO3: Perform two dimensional flow analysis.
CO4: Carryout isoparametric formulation and numerical integration.

Module 1: (10 hours)

Review of Basic Equations of Fluid Mechanics and Pipe Network Analysis, Linear finite element analysis of pipe networks, total system of equations, boundary conditions, solution of system of equations, non-linear analysis of pipe networks, computer algorithms for linear and non-linear analyses.

Module 2: (10 hours)

One-Dimensional Flow Analysis, Interpolation functions, C^m continuity. Governing differential equations, finite element formulations and solutions for (i) laminar flow through pipes, (ii) viscous flow on an inclined flat surface, and (iv) radial flow in an unconfined aquifer.

Module 3: (10 hours)

Two-Dimensional Flow Analysis, Potential Flow Analysis Euler‘s equation of motion, stream function formulation, potential function formulation, finite element solution of groundwater flow and flow around a cylinder.

Module 4: (9 hours)

Isoparametric formulation. Isoparametric triangular and rectangular elements, Numerical integration – Newton Cotes and Gauss-Legendre quadrature formulas, Integration formulas for isoparametric triangular and rectangular elements. Serendipity elements.

REFERENCES
1. Reddy, J. N., An Introduction to the Finite Element Method, McGraw Hill Book Co; 1993.
2. Rao, S. S., The Finite Element Method in Engineering, Elsevier, 2004.
3. Zienkiewicz, O. C., and K. Morgan, Finite Elements and Approximation, John Wiley and Sons, 1983.
4 .Zienkiewicz, O. C., R.L. Taylor, and J. Z. Zhu, The Finite Element Method –Its Basics and Fundamentals, Elsevier, 2005.

CE6524D APPLIED HYDRAULIC MODELLING

Prerequisite: Nil

Total Hours: 39

L	T	P	C
3	0	0	3

Course Outcomes:

The students will be able to

CO1: Design water distribution networks.
CO2: Design pipelines for transient flow conditions.
CO3: Design open channels and open channel networks.
CO4: Carryout dam break analysis.

Module 1: (10 hours)
Conservation laws - mass, momentum and energy. Governing equations of fluid flow, initial and boundary conditions. Pipe flow - review of basic hydraulic principles of analysis and design of pipelines, losses in pipelines, pumping and gravity mains, economic analysis for pipe choice, pipe materials, specification for pipes, pipe appurtenances, design principles - internal pressures and external loads, analysis of distribution networks - Hardy Cross, equivalent pipe and Newton Raphson methods, computer applications in distribution network analysis, maintenance of distribution systems, methods of control and prevention of corrosion.

Module 2: (9 hours)
Pump-pipeline and turbine-pipeline systems. Transients in pipelines - causes, simple analysis by finite difference method and method of characteristics, transient control using surge tanks, air chambers and control valves

Module 3: (9 hours)
Open channel flow - canal network and hierarchy of canals, afflux and energy loss, critical flow and uniform flow concepts, flow in erodible channels, channel design - design of erodible and lined channels for clear and sediment-laden flows - CBI & P method, tractive force method, regime methods. Gradually varied flow - classification and computation of profiles, compound channels, canal delivery problem, channel networks, spatially varied flow.

Module 4: (11 hours)
Rapidly varied flow - hydraulic jump, analysis of surges, design of spillways, energy dissipators, and channel transitions. Dam break analysis.Main canal and flow distribution control, decentralised control, canal automation - purpose and selection ofscheme, automation application, hardware and software components in automation systems, a typical automation system.

References

1. Ven Te Chow, *Open Channel Hydraulics*, Mc Graw Hill, Inc, 1985
2. Richard. H. French, *Open Channel Hydraulics*, Water Resources Pub, 1986
3. M. Hanif Chaudhry, *Open Channel Flow*, Springer.1993
4. Hubert Chanson, *TheHydraulics of Open Channel Flow – An Introduction,* Elsevier Butterworth-Heinemann,2004
5. E. B. Wylie and V. L. Streeter, *Fluid Transients,* Mc Graw Hill, Inc,1978
6. M. Hanif Chaudhry, *Applied Hydraulic Transients*, Van Nostrand Reinhold.2014
7. John. A. Fox, *Transient Flow in Pipes, Open Channels, and Sewers*, Ellis Horwood,1989
8. Thomas. M. Walski, *Analysis of Water Distribution Systems*, Van Nostrand Reinhold Co,1984
9. Bruce. E. Larock, Roland. W. Jeppson, and Gary. Z. Watters, *Hydraulics of Pipeline Systems*, CRC Press,1999
10. Thomas. M. Walski, Donald. V. Chase, Dragan. A. Savic, *Water Distribution Modeling*, Haestad Press, 2001.
11. CBIP, *Canal Automation*,2014
12. P. R. Bhave and R. Gupta, *Analysis of Water Distribution Networks,* Narosa Publishing House,2012

CE6525D HYDROGEOLOGY AND GROUNDWATER DEVELOPMENT

Pre-requisite: Nil

Total Hours: 39

L	T	P	C
3	0	0	3

Course Outcomes:

Students will be able to:

CO1: Understand the status of groundwater development, problems involved, and legal aspects

CO2: Identify appropriate methods and perform groundwater exploration

CO3: Identify appropriate water lifting devices and design these devices

Module 1: (14 hours)

Groundwater and the hydrologic cycle, problems and perspectives, groundwater balance, status of groundwater development and utilization – international and national scenarios, influence of physiography and climate on groundwater availability, major hydrogeologic formations in India, groundwater quality/ contamination in India. Basic concepts of groundwater management, investigations and data collection, conjunctive use of surface and groundwaters, legal aspects of groundwater. Basic geologic and hydrogeologic investigations including surface and subsurface investigations of groundwater, water divining/witching. Types of wells, design and construction of open wells, open wells in alluvial and hard rock formations, failure of open wells, contamination and disinfection of open wells.

Module 2: (14 hours)

Types of tube wells, multiple well system, radial wells and infiltration galleries, design of tube wells - casing, bore size and depth, design of well screen and gravel pack, contamination of tube wells, failure of tube wells, rehabilitation of tube wells. Construction of bored and driven tube wells – drilling equipment and methods, hand boring, mechanical percussion boring, direct and reverse circulation hydraulic rotary drilling, air rotary drilling, principles of rock drilling, drilling with foam, core drilling, calyx drilling, jetting. Installation of well screens and check for well alignment. Well development and well completion.

Module 3: (11 hours)

Pumps used for lifting water - indigeneous water lifts, positive displacement pumps, centrifugal pumps, vertical turbine pumps, submersible pumps, propeller and mixed flow pumps, jet pumps, air lift pumps, selection of pumps, power requirement, efficiency and economics.

References

1. D. K. Todd and L. W. Mays, *Groundwater*, 3rd ed., John Wiley & Sons, Inc., 2004.
2. F. W. Schwartz and H. Zhang, *Fundamentals of Groundwater*, John Wiley & Sons, Inc., 2003.
3. S. D. Khepar, A. M. Michael and S. K. Sondhi, *Water Wells and Pumps*, McGraw Hill Education (India) Private Ltd., 2008.
4. A. M. Michael, *Irrigation Theory and Practice*, Vikas Publishing House Pvt. Ltd., 2009.
5. Robert A. Bisson, Jay H. Lehr, *Modern Groundwater Exploration*, John Wiley & Sons, Inc., 2004.
6. K. R. Karanth, *Groundwater Assessment: Development and Management*, Tata McGraw Hill, 1987.
7. H. P. Patra, S. K. Adhikari, and SubrataKunar, *Groundwater Prospecting and Management*, Springer, 2016.
8. Websites of the Ministry of Water Resources, River Development, and Ganga Rejuvenation, Govt. of India, CGWB, and State GWDs.

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CE6526D ENVIRONMENTAL IMPACT ASSESSMENT OF WATER RESOURCES PROJECTS

Pre-requisite: Nil

L	T	P	C
3	0	0	3

Total Hours: 39

Course Outcomes:

Students will be able to:

CO1: Understand the importance and necessity for performing EIA of various projects and related legal aspects

CO2: Perform EIA studies in a scientific manner

CO3: Prepare an EIS and formulate and EMP

Module 1: (14 hours)

Concept of environment and sustainable development. Environmental impact assessment (EIA) – definitions, terminology and overview. Evolution of EIA – major features of the National Environmental Policy Act and the Council on Environmental Quality guidelines. Role of the USEPA. Generalised EIA process flow chart of the UNEP. Evolution of EIA in India – major features of the EIA notification and its subsequent amendments, implementation of EIA in India. Legislation in India pertaining to environmental pollution and waste management. Steps in EIA such as screening, initial environmental examination (IEE), scoping, public participation. Environmental baseline studies. Impact assessment methods such as adhoc methods, checklists, matrices, quantitative methods, environmental indices, networks, overlay etc. Factors to be considered while assessing the environmental impacts of various infrastructure projects.

Module 2: (14 hours)

Prediction and assessment of impacts on land and soil, groundwater, surface water, air, noise, biological, socio-economic and visual environments (including details of various tools that can be employed for prediction of impacts). Guidelines published by the MoEF&CC regarding EIA of specific projects.

Module 3: (11 hours)

Evaluation of alternatives. Preparing the EIA document/ report, Environmental impact statement (EIS). Strategic environmental impact assessment. Environmental monitoring. Environmental audit (EA). Case studies.

References

1. L. W. Canter, *Environmental Impact Assessment*, McGraw Hill, Inc., 1996.
2. Betty Bowers Marriot, *Environmental Impact Assessment: A Practical Guide*, McGraw Hill, Inc., 1997.
3. C. J. Barrow, *Environmental and Social Impact Assessment – An Introduction*, Edward Arnold, 1997.
4. Riki Theriveland Graham Wood(eds.), *Methods of Environmental and Social Impact Assessment (Natural and Built Environment Series)*,4th ed., Routledge, 2018.
5. Evan. K. Paleologos and Ian Lerche, *Environmental Risk Analysis*, McGraw Hill, Inc,2001
6. UNEP, *Environmental Impact Assessment Training Resource Manual*, 2002.
7. Guidelines for EIA published by the Ministry of Environment, Forests, and Climate Change (MoEF& CC), Government of India, 2006
8. Websites of the Ministry of Environment, Forests, and Climate Change (MoEF & CC), Government of India and the Ministry of Water Resources, River Development, and Ganga Rejuvenation, Govt. of India.
9. James. T. Maughan, *Environmental Impact Analysis: Process and Methods*, CRC Press, 2017.

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CE6527D WATER QUALITY MODELING AND MANAGEMENT

Pre-requisites:Nil

Total hours: 39

Course Outcomes:

L	T	P	C
3	0	0	3

CO1: To gain knowledge about the basic transport phenomena

CO2: To study different modeling approaches for analyzing water quality problems in rivers, lakes, estuaries, wetlands, groundwater and pipe network
CO3: To apply the models to solve engineering problems and suggest remedial measures

Module 1: (9 hours)

Water quality, standards, Types of contaminant,contaminants and their harmful effects, fate of contaminants, transformation of contaminants,transport of contaminants, Advection, diffusion, dispersion, simple transport models, chemical reaction kinetics,law of mass action, rate constants, types of reactions, equilibrium principles, Introduction to modeling, brief review of mass, momentum and energy balance, governing equations for contaminant fate and transport*,* Models for Nitrogen, Bacteria, phosphate and toxicants.

Module 2: (9 hours)

Contaminant transport in surface flows,rivers, hydrodynamic processes in rivers, eutrophication, dissolved oxygen in rivers, Streeter-Phelps equation, modification to Streeter-Phelps Equation, models for lakes and reservoirs, biological zones in lakes, eutrophication in lakes, hydrodynamic processes in lakes and reservoirs, stratification, models for estuaries, tidal processes, hydrodynamics of estuaries, stratification of estuaries, eutrophication in estuaries, models for wetlands, characteristics of wetland, hydrodynamics of wetlands, constructed wetlands,

Module 3: (11 hours)

Transport through saturated porous media, groundwater transport phenomena, Groundwater bio reaction and bio kinetics, hydrodynamic dispersion, initial and boundary conditions, unsaturated porous media, capillarity and retention curves, motion equations, initial and boundary conditions fractured media, multiphase flow, flow behavior in pipe networks, quality attenuation, physical characteristics,chemical and biological reactions

Module 4: (10 hours)

Modeling and Management, different types of models, different numerical methods, finite difference method, solution of system of linear equations, Pipe network modeling (EPANET2), surface water quality modeling (QUAL2K),Groundwater modeling (MODFLOW and MT3D), unsaturated zone modeling (SUTRA/HYDRUS), fractured rock (ModelMuse)water quality management, application of optimization techniques to water quality management, case studies.

References:

1. S. Chapra, *Surface water-quality modeling*. Long Grove, Ill.: Waveland Press, 2008.
2. L. Rossman, *EPANET users manual*. Cincinnati, Ohio: U.S. Environmental Protection Agency, Center for Environmental Research Information, 1994.

3. J. Martin, S. McCutcheon and R. Schottman, *Hydrodynamics and transport for water quality modeling*. Boca Raton, FL: CRC Press, 1999.
4. C.Zheng, and G.D. Bennett. *Applied Contaminant Transport Modeling*, 2nd ed. New York: John Wiley & Sons, 2002.
5. R. Boulding, *Practical handbook of soil, vadose zone, and ground-water contamination*. Boca Raton: Lewis Publishers, 2004.
6. S.C. Chapra, Pelletier, G.J. and Tao, H., *QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality, Version 2.11. USA: Documentation and User's Manual*. Civil and Environmental Engineering Department, Tufts University, Medford, 2008.
7. A.W.Harbaugh, E.R Banta, M.C. Hill, and M.G McDonald**,** *MODFLOW-2000, the U.S. Geological Survey modular ground-water model – User guide to modularization concepts and the ground water flow process*. U.S. Geological Survey Open-File Report 00-92, 121, 2000.
8. C.Zheng, Chunmiao, and P.P. Wang, *MT3DMS—A modular three-dimensional multispecies transport model for simulation of advection, dispersion and chemical reactions of contaminants in ground-water systems. Documentation and user's guide*: Jacksonville, Fla., U.S. Army Corps of Engineers Contract Report SERDP-99-1, 1999.

CE6528D HYDROPOWER

L	T	P	C
3	0	0	3

Pre-requisite: Nil

Total Hours: 39

Course Outcomes:

Students will be able to:

CO1: Estimate the water power potential of a stream

CO2: Plan and design a hydel power plant

CO3: Perform dam breach analysis.

Module 1: (14 hours)

Different sources of energy. Hydropower – Place of hydropower in a power system, global and national status of hydropower development. Fundamentals of water power engineering - classification of hydropower plants. Water power estimates – essentials of streamflow for water power studies. Pondage and storage, effect of pondage on plant capacity, benefits from storage. Basic hydrology - mass curve and flow duration curve, influence of reservoirs on floods. Load curve and load factor, utilization factor, capacity factor, diversity factor. Firm power and secondary power.Prediction of load.

Module 2: (14 hours)

Run of the river plants, pumped storage plants. Mini and micro hydel plants.Tidal power plants. General arrangement of a power house, types of power houses. Hydropower structures – intakes, forebay, gates and valves, penstocks, power canals and tunnels, anchor blocks.Joints. Bends and Manifolds. Water Hammer.Surges and Surge Tanks.

Module 3: (11 hours)

Turbines and Generators. Flood routing through reservoirs and channels. Dam breach analysis. Cost and value of water power.

References

1. M. M. Dandekar and K. N. Sharma, *Water Power Engineering*, Vikas Publishing House (P) Ltd., 2015.
2. R. K. Sharma and T. K. Sharma, *A Textbook ofWater Power Engineering*, S. Chand, 2003.
3. M. G. Jog, *Hydro–Electric and Pumped Storage Plants*, New Age International Publishers, 1997.
4. Naresh Lamba, *Water Power Engineering*,Venus Books, 2014.
5. H. K. Barrows, *Water Power Engineering*, McGraw Hill Inc., 1943.
6. William. P. Creager and Joel De Witt Justin, *Hydroelectric Engineering Handbook*, John Wiley and Sons, 1950.
7. Emil Mosonyi, *Water Power Development*, Hungarian Academy of Sciences, 1957.
8. Guthrie Brown, *Hydroelectric Engineering Practice*, Blackie and Sons Ltd; London, 1958.
9. P. S. Nigam, *Handbook of Hydroelectric Engineering,*Nem Chand and Bros., Roorkee, 2008.
10. R. S. Varshney, *Hydro Power Structures*, Nem Chand and Bros., Roorkee, 2014.
11. R. S. Varshney, *Gates and Valves*, Jain Book Depot, 2017.
12. T. S. Bhatti, R. C. Bansal, and D. P. Kothari, *Small Hydro Power Systems*, DhanpatRai, 2004.
13. Tong Jiandong, Zheng Naibo, Wang Xianhuan, Hai Jing, Ding Huishen, *Mini Hydropower*, John Wiley and Sons, 1997.

14. UNIDO, *Small Hydro Power Series*,1985
15. Bryan Leyland, *Small Hydroelectric Engineering Practice*, CRC Press, 2014.
16. Websites of the Ministry of Water Resources, River Development, and Ganga Rejuvenation, Govt. of India, Ministry of Power, Govt. of India, CWC, NHPC, and NTPC.

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CE6529D WATERSHED MANAGEMENT

Pre-requisites: Nil

L	T	P	C
3	0	0	3

Total hours: 39

Course Outcomes: The students will be able to

CO1: Delineate a watershed.
CO2: Assess land use impacts on watersheds
CO3: Model soil erosion.
CO4: Plan suitable water harvesting method for an area

Module 1: (9 hours)

Watershed - Definition and delineation, Watershed approach, Hydrologic cycle, Watershed components, Water budget, Watershed assessment, Watershed planning, Watershed as a management unit, Total maximum daily load. Characteristics of watershed - Size, Shape, Physiography, Slope, Climate, Drainage, Land use,Vegetation, Geology and Soils, Hydrology and hydrogeology, Socio-economic characteristics,Basic data on watersheds.

Module 2: (10 hours)

Land use and water quality issues - Land use impacts on watersheds, Residential activities, Municipal sources, Construction, Mining operations, Agriculture, Forestry practices, Recreation. Water quality monitoring – Temperature, pH, Dissolved Oxygen and Biological Oxygen demand, Nutrients, Pathogens, Turbidity, Biological monitoring methods, Species indicators, Biological integrity, Habitat index, Land use index, Water resource assessment, Water yield.

Module 3: (10 hours)

Erosion - Factors affecting erosion, Effects of erosion on land fertility and land capability, Soil Erosion Modelling, Erosivity and erodibility, Processes, USLE and modified/ revised USLE models for erosion processes. Land Management - Survey, Preparation and development, Soiland soil moisture conservation, Conservation measures, Ploughing, Furrowing, Trenching,Bunding, Terracing, Gully control, Rockfill dams, Brushwood dam, Gabion, Rain watermanagement, Reclamation of saline soils.

Module 4: (10 hours)

Water Harvesting: Rainwater harvesting, Catchment harvesting, Harvesting structures, Soil moisture conservation, Check dams, Artificial recharge, Farm ponds, Percolation tanks. Ecosystem management: Role of ecosystem, Crop husbandry, Soil enrichment, Inter, mixed and strip cropping, Cropping pattern, Sustainable agriculture, Bio-mass management, Dry land agriculture, Silvi pasture, Horticulture, Social forestry and afforestation. Model watershed – Government and NGO Projects.

References:

1. Randhir, T.O., Watershed Management Issues and Approaches, Milton Keynes UK : Lightning Source UK Ltd., 2010
2. Murty, J.V.S., Watershed management, New Age International 2013
3. Majumdar, D.K., Irrigation Water Management, Prentice Hall 2014

CE6530D ENVIRONMENTAL HYDRAULICS

L	T	P	C
3	0	0	3

Pre-requisite: Nil

Total Hours: 39

Course Outcomes:

Students will be able to:

CO1: Model water quality problems in rivers and lakes

CO2: Model water quality problems in estuaries

CO3: Perform hydraulic analysis of water and wastewater treatment plants

Module 1: (10 hours)

Fundamental relationships for flow and transport - general principles, instantaneous equation for fluid flow and transport, Reynold's time-averaged mean flow and transport equations, model resolution, solution techniques, data requirements. Measurement and analysis of flow - measurement of velocity and flow, tracer studies, estimating design flows.

Module 2: (10 hours)

Models for rivers and streams - Completely mixed systems - reaction kinetics, mass balance and steady state solution, particular solutions, feed-forward systems of reactors, feed-back systems of reactors, computer methods. Incompletely mixed systems - diffusion, distributed systems – steady and unsteady cases, steady state solutions, simple time variable solutions. BOD and oxygen saturation, Streeter-Phelps equation, point and distributed sources.

Module 3: (10 hours)

Rivers and streams- stream hydro-geometry, low- flow analysis, dispersion and mixings, flow model complexity and data requirements, estimating mixing in streams and rivers, hydraulic methods for steady and unsteady flows and solution techniques, routing and water quality problems. Mixing in lakes and reservoirs, water balance. Transport and mixing in estuaries.

Module 4: (9 hours)

Hydraulic analysis of various units in water treatment and wastewater treatment plants. Turbulent jets and plumes, ocean wastewater discharge systems.

References

1. S. C. Chapra, *Surface Water Quality Modeling*, Waveland Press, 2008.
2. H. Chanson, *Environmental Hydraulics of Open Channel Flows*, Elsevier Butterworth-Heinemann, 2004.
3. James. L. Martin and Steven. C. McCutcheon, *Hydrodynamics and Transport for Water Quality Modeling*, Lewis Pub, 1999.
4. Hugo. B. Fischer, E. John List, Robert. C. Y. Koh, JorgImberger, and Norman. H. Brooks, *Mixing in Inland and Coastal Waters,* Academic Press, 1979.
5. Gerard Kiely, *Environmental Engineering*, Tata McGraw Hill Education, 2007.
6. Frank. R. Spellman, *Handbook of Water and Wastewater Treatment Plant Operations*, 3rd ed., CRC Press, 2003.
7. S. N. Ghosh, *Tidal Hydraulic Engineering,* Oxford and IBH Pub. Co. Pvt. Ltd, 1998.
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9. Zhen-Gang Ji, *Hydrodynamics and Water Quality*, Wiley, 2017.

CE6531DSOFT COMPUTING IN WATER RESOURCES ENGINEERING

Pre-requisites: Nil

Total hours: 39

Course Outcomes:

L	T	P	C
3	0	0	3

CO1: To Familiarize with soft computing concepts
CO2: To introduce the ideas of Support Vector Machines, Neural networks, Genetic algorithm, Fuzzy

Logic and Hybrid Systems

CO3: To apply the concepts of softcomputing techniques to Water Resources engineering

Module 1: (9 hours)

Soft Computing: Introduction, requirement, different tools and techniques, usefulness and Applications, Support vector Machines (SVM) , Artificial Neural Networks, Biological neural networks, Model of an artificialNeuron, Comparison between biological neuron and artificial neuron, Basic models of artificial neural network, Learning methods, Hebb's learning, Adaline, Perceptron

Module 2: (9 hours)

Back propagation Networks : Architecture - Multi layer perceptron –Back propagation learning – Input layer, Hidden Layer , Output Layer computations, Calculation of error,Training of ANN, Back propagation Algorithm, Momentum and Learning rate, Selection of various parameters in BP networks- Radial Basis Function Networks, Applications of ANN in Water Resources Engineering

Module 3: (9 hours)

Fuzzy sets and fuzzy logic, Fuzzy sets and crisp sets, ,Fuzzy set operations, Fuzzy relations, Membership functions, Features of the membership functions, Fuzzification, Defuzzification, Defuzzification methods, Fuzzy Rule Base andapproximate reasoning, Formation of rules, Decomposition of rules, Fuzzy Inference Systems, Construction and Working Principle of FIS, Methods of FIS, Mamdani FIS and Sugeno FIS, Application of FLC Systems in Water Resources Engineering.

Module 4: (12 hours)

Genetic Algorithms, Basic Concepts, Creation of off springs, Working Principle, Encoding, Fitness function, Reproduction, Roulette Wheel Selection, Boltzmann Selection, Tournament selection, Rank Selection, Steady State Selection, Elitism, operators in GA, Cross Over, Inversion and deletion, Mutation Operator, Bit wise operators, Convergence of Genetic Algorithm, Stopping Condition, Constraints in GA, Classification of GA, Advances in GA, ,Genetic Programming, Applications of GA in Water Resources Engineering.

Hybrid Soft Computing Techniques, Neuro Fuzzy Hybrid Systems, Genetic Neuro Hybrid systems, Genetic fuzzy Hybrid and fuzzy genetic hybrid systems, Hybrid systems applications in Water Resources Engineering.

References:

1. F. Karray and C. De Silva, *Soft computing and intelligent systems design*, Theory, Tools and Application, Pearson Education, 2004.
2. S. Sivanandam and S. Deepa*, Principles of soft computing*. Wiley India Pvt Ltd, New Delhi: 2013.
3. D.E. Goldberg, *Genetic Algorithms*. Pearson Education India, 2006.

4. S. Haykin, *Neural networks and learning machines*. Upper Saddle River: Prentice Hall, 2009.
5. H. Zimmermann, *Fuzzy set theory-and its applications*. Boston: Kluwer Academic, 2014.
6. T. Ross, *Fuzzy logic with engineering applications*, 3rd ed. Wiley India, 2009.
7. S. Rajasekaran and G.A Vijayalakshmi Pai, *Neural networks, fuzzy logic, and genetic algorithms-Synthesis and Applications*, Prentice Hall of India, New Delhi: 2017

CE6532DURBAN HYDROLOGY AND DRAINAGE

Pre-requisites: CE6502DSurface Water Hydrology and Hydrologic Systems

Total hours: 39

L	T	P	C
3	0	0	3

Course Outcomes:

Students will be able to:

CO1: To perform rainfall and runoff computations for urban catchments.
CO2: To compute overland flow and channel flows.
CO3: To design storm water drainage structures.

Module 1: (13 hours)
Rainfall and Runoff Computations
Introduction - Urbanization –Storm water runoff quantity and quality issues – Rainfall design for urban catchments – Hydrologic and probabilistic description of rainfall – Design rainfall – Methods for construction of design storm hyetographs – Rainfall excess calculations – Computation of abstractions –Combined loss models
Calculation of runoff rates-basic concepts – elements of urban runoff hydrographs – Time of Concentration –Definition and calculation by various methods – Unit hydrograph method – NRCS method (TR-55)
Module 2: (13 hours)
Channel flow and Overland flow
Open-channel flow – Definitions - States of open channel flows – Open - Channel flow equations – Steady Gradually varied flow – Normal flow – Open channel rating curve – Overland flow – Kinematic wave model – Overland flow on impervious and pervious surfaces – Channel flow routing– simplified and numerical models
Storm Water Drainage
Design of storm water drainage structures –Drainage design for street pavements – Storm sewer systems – Culverts – Surface drainage channels

Module 3: (13 hours)
Storm Water Management
Urban flooding and associated issues – Detention basins – Stage-storagerelationship, Stage-discharge relationship - Detention basin design
Infiltration practices - Infiltration basins, Trenches, Dry wells, Porous pavements
Urban storm water pollution – Modelling storm water quality – Annual pollutant load estimates
Strom water quality control - Concepts of BMPs– Extended detention basins – Retention basins – Water quality trenches –Sand filters – Storm water wetlands – vegetative BMPs
Low Impact Development - Advantages – Urban storm water computer models – HEC-HMS – EPA-SWMM
References
1. Osman Akan, A and Robert J. Houghtalen, Urban Hydrology, Hydraulics, and Stormwater Quality: Engineering Applications and Computer Modeling, John Wiley and Sons, First edition, 2003
2. Ven T Chow, David Maidment, and Larry Mays, Applied hydrology, Tata McGraw Hill, First edition, 2011
3. Subramanya K., Flow in Open Channels,McGraw Hill Education; 4th edition, 2015
4. HanifChaudhry M., Open-Channel Flow, Springer, 2nd edition, 2008
5. National Engineering Handbook, Part 630, Natural Resources Conservation Service, United States Department of Agriculture, 2004
6. HEC-HMS Technical Reference Manual, US Army Corps of Engineers, CPD-74B, March 2000
7. Storm Water Management Model Applications Manual, USEPA - EPA/600/R-09/077, July 2009

CE6533D COASTAL ENGINEERING AND COASTAL ZONE MANAGEMENT

L	T	P	C
3	0	0	3

Pre-requisite: Nil

Total Hours: 39

Course Outcomes:

Students will be able to:

CO1: Estimate wave forces on structures and design these structures
CO2: Estimate littoral transport and coastal erosion
CO3: Plan, design, and execute structural and non structural coastal protection measures.

Module 1: (10 hours)

Coastal Engineering – coastal environment and coastal zone, problems, water level fluctuations – tides, surgesand seiches. Introduction to wave mechanics – wave generation, small amplitude wave theory - formulation and solution, wave celerity, length and period, classification of waves based on relative depth, orbital motions and pressure, standing waves, wave train and wave energy. Wave transformation – shoaling, reflection, refraction and diffraction, Breaking of waves.

Module 2: (10 hours)

Finite Amplitude Waves – higher order wave theories such as Stokes wave theory, Cnoidal wave theory, trochoidal wave theory, solitary wave theory, and stream function wave theory. Numerical wave theory.Wave interaction with currents.Regimes of application of different wave theories.Tsunamis.

Short term and long term wave statistics. Sea as a stationary random process - wave spectral density, mathematical spectrum models. Wind generated waves – wave forecasting and wave hindcasting.

Module 3: (9 hours)

Wave structure interaction – Forces on shore structures due to breaking, broken and nonbreaking waves.Design of rubble mound structures. Wave force on a circular (vertical, inclined and oscillating cylinder) - Morison Equation, wave force on submarine pipelines.

Module 4: (10 hours)

Coastal processes - long term and short term changes in the shoreline, cross shore and long shore currents, onshore-offshore movement of sediments, longshore transport, application of mathematical models, factors affecting equilibrium of beaches. Causes of coastal erosion. Shore protection. Type of beaches.Methods of shore protection – structural and nonstructural methods. Coastal erosion and protection along the Kerala coast. Integrated coastal zone management - resource planning and management, goals and purposes, sustainable use of resources, application of IT.Coastal ecosystems including mangroves.Mudbanks.Legislation in India pertaining to the coastal zone.

References

1. Arthur. T. Ippen (ed.), *Estuary and Coastline Hydrodynamics*, McGraw Hill, Inc., 1966.
2. Robert. M. Sorenson, *Basic Coastal Engineering*, 3rd ed., Springer Verlag, 2006.
3. US Army Corps of Engineers, *Coastal Engineering Manual – Parts I to VI*, 2002.
4. T. Sarpkaya and M. Isaacson, *Mechanics of Wave Forces on Offshore Structures*, Van Nostrand., 1981.
5. Dominic Reeve, Andrew Chadwick, and Christopher Fleming, *Coastal Engineering: Processes, Theory, and Design Practice*, 3rd ed., CRC Press, 2018.
6. J. S. Mani, *Coastal Hydrodynamics*, PHI Learning, 2011.
7. V. Sundar, *Ocean Wave Mechanics: Applications in Marine Structures, Ane Books, 2016.*
8. R. G. Dean and R. A. Dalrymple, *Coastal Processes with Engineering Applications*, Cambridge University Press, 2004.
9. J. W. Kamphius, *Introduction to Coastal Engineering and Management*, World Scientific, 2010.

CE6534D POLLUTION SCIENCE AND ENGINEERING

L	T	P	C
3	0	0	3

Pre-requisite: Nil

Total Hours: 39

Course Outcomes:

Students will be able to:

CO1: Understand and appreciate the major environmental issues facing the 21st century

CO2: Understand and model processes affecting the fate and transport of contaminants in the environment

CO3: Understand legal aspects related to environmental pollution and waste management

Module 1: (10 hours)

Major environmental issues of the 21st century.The extent of global pollution. The environment as a continuum, Overview of environmental characterization. Ecological concepts and natural resources. Brief introduction to chemistry and microbiology in pollution science. Physical and chemical characteristics of soil, water, and the atmosphere, biotic characteristics of the environment.

Module 2: (10 hours)

Physical, chemical, and biological processes affecting fate and transport of contaminants in soil and water.Physical, chemical and biological contaminants.Environmental monitoring.Brief introduction to environmental toxicology.Statistics in pollution science.Risk assessment.Environmental laws and regulations in India.

Module 3: (10 hours)

Pollution and mitigation of pollution of soil and land, and ground and surface waters.Fertilizers, pesticides and sediments as a source of pollution.Atmospheric Pollution.Global atmospheric changes. Introduction to global warming and climate change.

Module 4: (9 hours)

Solid waste treatment and disposal, municipal wastewater treatment, land application of biosolids and animal wastes.Drinking water treatment and water security.Environmental Management.

References

1. I. L. Pepper, C. P. Gerba, and M. L. Brusseau, *Environmental and Pollution Science*, 2nd ed., Academic Press, 2011.
2. G. M. Masters, and W.P. Ela, *Introduction to Environmental Engineering and Science*, 3rd ed., PHI Learning, 2008.
3. Mackenzie Davis, and Susan Masten,*Principles of Environmental Engineering & Science,* 3rd ed., McGraw-Hill Higher Education, 2013.
4. Gerard Kiely, *Environmental Engineering*, Tata McGraw Hill Education, 2007.
5. Frank. R. Spellman, *Handbook of Water and Wastewater Treatment Plant Operations*, 3rd ed., CRC Press, 2003.
6. J. Glynn Henry and Gary. W. Heinke, *Environmental Science and Engineering*, Pearson Education, 1996.
7. W. P. Cunningham and M. A. Cunningham, *Environmental Science – A Global Concern,* 13th ed.,McGraw Higher Ed., 2015.

CE6535D HYDROCLIMATOLOGY

Pre-requisites: Nil

L	T	P	C
3	0	0	3

Total hours: 39

Course Outcomes: The students will be able to
CO1: Select climate variables affecting precipitation at a location.
CO2: Perform risk assessment and mapping with respect to extreme events.
CO3: Extract GCM projections and downscale these for a river basin.
CO4: Perform hydrological impact assessment of projected climate change.

Module 1: (10 hours)

Introduction to hydro-climatology: climate system; climate, weather and climate; overview of earth's atmosphere; vertical structure of atmosphere; radiation and temperature; laws of radiation; heat-balance of earth atmosphere system; random temperature variation; modeling vertical variation in air temperature; temporal variation of air temperature; temperature change in soil; thermal time and temperature extremes.

Module 2: (10 hours)

Hydrologic cycle: introduction; global water balance; cycling of water on land, a simple water balance model; climate variables affecting precipitation, precipitation and weather, humidity, vapor pressure, forms of precipitation, types of precipitation; cloud; atmospheric stability; monsoon; wind pattern in India; global wind circulation; Indian summer monsoon rainfall.

Module 3: (9 hours)

Climate variability: floods, droughts, drought indicators, heat waves, climate extremes. steps of risk characterization - hazard identification, exposure assessment, vulnerability analysis, risk mapping, risk characterization to natural hazards, risk assessment as a distributed process.

Module 4: (10 hours)

Climate change: introduction; causes of climate change; modeling of climate change, global climate models, general circulation models, downscaling; IPCC scenarios; commonly used statistical methods in hydro-climatology: trend analysis; empirical orthogonal functions, principal component analysis; canonical correlation; statistical downscaling with regression.

References:

1. G. S. Campbell, and J. M. Norman, An Introduction to Environmental Biophysics, Springer, 2013.
2. W. M. Washington, and C. L. Parkinson, An Introduction to Three Dimensional Climate Modeling, Oxford University Press, 2005.
3. M. L. Shelton, Hydroclimatology: Perspectives and Applications, Cambridge University Press, 2009.
4. K. McGuffie, and A. Henderson-Sellers, The Climate Modelling Primer 4th edition, Wiley Blackwell, 2014.
5. IPCC, Fourth and Fifth Assessment Reports, 2016.

CE6536D DISASTE

R MANAGEMENT

Pre-requisites: NIL

L	T	P	C
3	0	0	3

Total hours: 39

Course Outcomes:
Students will be able to:

CO1: Understand the basic principles of disaster management
CO2: Understand different types of disasters and issues associated with each of these
CO3: Learn about the national initiatives and framework related to disaster management
CO4: Understand the role of ICT and geoinformatics in disaster management
CO5: Learn about disaster mitigation strategies

Module 1 (13 hours)
Disaster, Hazard, Vulnerability, Resilience, Risks. Natural disasters - hydro-meteorological disasters such as flood, flash flood, cloud burst, drought, cyclone, forest fires etc; geological disasters like earthquake, tsunami, landslides, volcanic eruption. Man made disasters - chemical industrial hazards, major power break downs, traffic accidents, fire hazards, biological hazards, nuclear accidents. Environmental hazards - forest hazards (deforestation, degradation and forest fire), land and soil degradation, desertification and pollution (water, air and soil).Disasters and national losses.Historical perspective of disasters in India and the Indian sub continent.Recent major disasters.Disaster management cycle and its components. Earthquake, Landslide, Flood, Drought, Fire etc - classification, causes, impacts including social, economic, political, environmental, health, psychosocial, etc.- Differential impacts - in terms of caste, class, gender, age, location, disability - Global trends in disasters: urban disasters, pandemics, complex emergencies, Global warming and climate change. Adaptation.Dos and don’ts during various types of disasters.

Module 2 (13 hours)
Disaster cycle - Phases, Culture of safety, prevention, mitigation and preparedness, community based DRR, structural and nonstructural measures, roles and responsibilities of the community, Panchayati Raj institutions/ Urban Local Bodies, States, Centre, and other stakeholders including NGOs. Institutional processes and framework at State and Central Level – National and State Disaster Management Authorities.Prediction and early warning systems.Role of information, education, communication, and training, geoinformatics and IT in disaster preparedness, risk assessment, response, recovery, and management.Role of engineers on disaster management.

Module 3 (13 hours)
Components of disaster relief - water, food, sanitation, shelter, health, waste management, Institutional arrangements for mitigation, response and preparedness, Legislation in India on Disaster Management. National disaster management policy. Other related policies, plans, programmes and legislation relevant to/ pertaining to disaster management. Disaster damage assessment.Disastermitigation.Existing organizational structure for managing disasters in India.Case studies.

References:

1. S. R. Sharma, Disaster Management, A P H Publishers, 2011.
2. Sreeja. S. Nair, Training Manual on Geoinformatics Applications in Disaster Management, NIDM, 2012.
3. Harsh. K. Gupta, Disaster Management, Universities Press, 2003.

4. J. P. Singhal, Disaster Management, Laxmi Publications, 2010.
5. K. VenugopalaRao, Geoinformatics for Disaster Management, Manglam Publishers and Distributors, 2010.
6. Matthews, J.A., Natural Hazards and Environmental Change, Bill McGuire, Ian Mason, 2002.
7. Sulphey, M. M.,Disaster Management, PHI Learning, 2016.
8. Damon P. Coppola, Introduction to International Disaster Management, Butterworth-Heinemann, 2016.
9. ParagDiwan,A Manual on Disaster Management, Pentagon Press, 2010
10. Websites – National Disaster Management Authority, National Institute for Disaster Management, and State Disaster Management Authorities

CE6537D ENVIRONMENTAL FLOWS

L	T	P	C
3	0	0	3

Pre-requisite: Nil

Total Hours: 39

Course Outcomes:

Students will be able to:

CO1: Understand the concept and importance of maintaining environmental flow in rivers and to intervene in field problems and bring about solutions

CO2: Understand and model processes affecting the fate and transport of contaminants in the environment

CO3: Perform realistic assessment of environmental flows and monitoring in the field

Module 1: (10 hours)

Fundamental concept of environmental flow – catchment drainage network and resource regimes – river ecology, the natural flow regime paradigm and hydro ecological principles – reservoir and dam Planning – institutionalising environmental flow through adaptive reservoir operations – defining environmental water status - effects of catchment change and river corridor engineering

Module 2: (10 hours)

River morphology – Meandering of rivers – Control Volume – Mass balance and advective/ dispersive transport –transport in rivers, lakes, wetlands, and estuaries - sediment transport. Paleolimnology

Module 3: (10 hours)

Stream-aquifer interaction - quality of water – factors effecting water quality - control volume – Mass balance and advective / dispersive transport - groundwater aquifers, Darcy's Law and flow nets – Transient well hydraulics, Transport and retardation – Flow in the unsaturated zone, Biodegradation and bioremediation – Gaussian plume modelling

Module 4: (9 hours)

Environmental flow assessment methods – Hydraulic rating and habitat simulation methods – Flow protection methods – flow restoration methods – ecological limits of hydraulic alteration (ELOHA) – environmental flow relationships, models and applications – setting limits to hydrologic alteration – Implementing and monitoring environmental flow – NatCap (Natural Capital Project) – InVest Software tool for mapping, modelling and visualising ecosystem services - eWater toolkit – IHA (Indicators of Hydrologic Alterations)

References

1. Angela H. Arthington, *Environmental Flows: Saving Rivers in the Third Millennium*, Univ of California Press, 2012.
2. Kirstie. A. Fryirs and Gary. J. Brierley, *Geomorphic Analysis of River Systems*, Wiley-Blackwell, 2013.
3. Nancy D. Gordon, Thomas A. McMahon, and Brian L. Finlayson, *Stream Hydrology: An Introduction for Ecologists*, John Wiley and Sons, 2004.
4. A. J. Schleiss and R. M. Boes (eds.), *Dams and Reservoirs under Changing Challenges*, CRC Press, 2011.
5. Wilbert Lick, *Sediment and Contaminant Transport in Surface Waters*, CRC Press, 2009.
6. John. S. Gulliver, *Introduction to Chemical Transport in the Environment*, Cambridge University Press, 2007.

CE6538D DAM SAFETY

L	T	P	C
3	0	0	3

Pre-requisite: Nil

Total Hours: 39

Course Outcomes:

Students will be able to:

CO1: Understand the causes and modes of failure of various types of dams

CO2: Perform inspection and assessment of safety of dams

CO3: Plan and implement an appropriate scheme for instrumentation of dams

Module 1: (10 hours)

Dams - Types & Classification. Considerations governing choice of the type of dam. Design considerations. Dam failures - history of dam failures in India and abroad. Failure of dams - causes of failures of different types of dams – hydrological, structural, non-structural. Geophysical and other investigations for assessment of structural health of dams. Hydrological assessment of dam safety. Remedial and rehabilitation action for safety of dams - structural & non-structural measures. Dam break analysis.Emergency Action Plan - 1D/2D- various tools- input requirements - inundation maps.

Module 2: (10 hours)

\Dam safety inspection - routine-pre-monsoon/post-monsoon comprehensive inspections. Guidelines for dam safety inspection. Role of Central Water Commission. International guidelines –USBR, FEMA, USACE. Need of proper O&M for dams.

Module 3: (10 hours)

Safety evaluation of dams- need of safety evaluation-risk analyses and risk assessment- portfolio risk analyses -techniques & methods in risk analyses and safety evaluation for decision making.Role of Dam Safety Organisations and Dam Safety Review Panels. Legislation for Dam Safety.

Module 4: (9 hours)

Instrumentation in dams-objectives of monitoring dam performance, types of measurements, installation of instruments, frequency of measurement, technical specification of various instruments employed, seismic instrumentation, performance evaluation through instrumentation, automated data acquisition, real time structutal health monitoring, real time data acquisition and early warning system for floods.

References

1. William P. Creager, Joel D. Justin, Julian Hinds, *Engineering for Dams, Vols. I, II, and III, Wiley*, 1945.
2. M. M. Dandekar and K. N. Sharma, *Water Power Engineering*, Vikas Publishing House (P) Ltd., 2015.
3. P.Novak, A.I.B.Moffat, C.Nalluri and R.Narayanan, *Hydraulic Structures*, 4th ed., Taylor and Francis, 2007.
4. R. S. Varshney, *Concrete Dams*, Oxford and IBH, 1982.
5. H. D. Sharma, *Concrete Dams*, CBIP, 1998.
6. Limin Zhang, Ming Peng, Dongsheng Chang, and Yao Tsu, *Dam Failure Mechanisms and Risk Assessment*, Wiley, 2016.
7. *Guidelines pertaining to dam safety* - CWC, FEMA, USBR, 1987
8. Website of the Central Water Commission (CWC), and the Dam Rehabilitation and Improvement Project (DRIP)