TARANG KHANGAONKAR, Ph.D., P.E.

Director – *Salish Sea Modeling Center*
University of Washington, Puget Sound Institute
&
Principal Program Manager
Pacific Northwest National Laboratory
Seattle, Washington

EDUCATION

Ph.D.	Applied Marine Physics/Ocean Engineering, University of Miami	1990
M.S.	Ocean Engineering, University of Miami	1988
B.S.	Naval Architecture, Indian Institute of Technology	1986

QUALIFICATIONS

Dr. Khangaonkar is the Director of the *Salish Sea Modeling Center* (SSMC) at University of Washington Puget Sound Institute through a dual appointment with Pacific Northwest National Laboratory. He brings the necessary enthusiasm, expertise, experience and vision to SSMC. This includes goals such as advancement and use of state-of-the-art models of the Salish Sea ecosystem, to foster a transparent and collaborative environment for ocean modeling, and, to continue expansion, and development of the Salish Sea Model – Operational Forecast System for our community.

At PNNL. Dr. Khangaonkar is a Principal Program Manager specializing in *Coastal Ocean Modeling*. He provides senior leadership to PNNL's activities in numerical modeling studies related to estuarine hydrodynamics, water quality, sediment transport, and fate and transport analysis. He has over 30 years of experience with various types of models capable of circulation, and water quality kinetics and has been involved with a number of water quality pollution management studies. They include simulations of temperature response, calculations of dissolved oxygen (DO) depletions, sediment deposition, long-term effluent flushing and pH buffering, and performing diffuser design optimization. Many of these studies have been water quality impact assessments in support of hydropower relicensing, mixing zone analysis for effluent discharge permitting, and total maximum daily load assessments.

In response to a growing demand by the statewide community for a practical oceanographic modeling tool for water quality and ecosystem management, Dr. Khangaonkar and his team have led the development of a high resolution 3-D finite volume hydrodynamic and transport model for the Pacific Northwest region of Puget Sound & Georgia Basin (the *Salish Sea*), through support from USEPA and in collaboration with Washington State Dept. of Ecology. This model includes a comprehensive biogeochemical component and is now the "workhorse" for the analysis of water quality and circulation, nutrient pollution management. It is also being used to assess response to sea level rise, climate change, and ocean acidification. Dr. Khangaonkar and his team have already conducted numerous applications of this tool to assist with nearshore habitat restoration planning and design, and analysis in support of re-establishment of fish migration pathways, and assessment of basin-wide water quality impacts. Dr. Khangaonkar currently serves on a steering committee for the Puget Sound Ecosystem Monitoring Program - Modeling work group and is helping shape the region's ecosystem modeling and analysis activities through a collaborative effort between agencies (USEPA, Ecology, NOAA, WDFW and others).

RESEARCH INTERESTS

- Coastal circulation and hydrodynamic modeling
- Water quality and biogeochemical processes modeling
- Effluent mixing and fate and transport modeling
- Nearshore habitat restoration design
- Climate change and sea level rise
- Ocean acidification
- Sediment transport and littoral processes
- Toxics fate and transport modeling

- Integrated modeling of riverine, floodplain, estuarine, and coastal watersheds

SYNERGISTIC ACTIVITIES

- *Research Professor - School of interdisciplinary Arts and Sciences at the University of Washington Tacoma (UW)* – Collaborative research with UW- Puget Sound Institute in connection with hydrodynamics and water quality using the Salish Sea Model.
- *Editorial Board of Ecological Modelling*, a peer reviewed journal published by Elsevier - provide editorial reviews for papers annually and arrange for peer reviews for submitted articles covering areas of Coastal Ocean Modeling - Hydrodynamics and Biogeochemical Modeling.
- *Research Professor – Huxley College of the Environment, Department of Environmental Sciences, Western Washington University* - provide seminars and mentor WWU graduate students, pursue opportunities for joint research programs, and identify and engage WWU students in research
- *Estuarine & Coastal Modeling Conference* Organizing Committee (2017 to present) – Serves on the organizing committee for ECM the conference.
- *PSEMP* –Modeling Work Group – (Lead) objective of this work group of local experts on modeling in the Puget Sound Ecosystem is to complement and supplement Puget Sound Environmental Monitoring (PSEMP) work groups that focus on data collection. Helped convince the stakeholders and U.S. EPA region 10 to select Salish Sea Model as the water quality management tool for the region.
- *NWMOD* – Invited speaker at the annual meeting and a member of the *Northwest Modelers Group* (U.S. EPA), which is a panel of regulatory agency experts on the use and application of water quality models.
- *SC*^{2} – Founding member of Skagit Climate Science Consortium. A scientific body of technical experts from academia, federal, and state agencies, focused on climate change effects on Skagit watershed

SELECTED RESEARCH EXPERIENCE

Research Grants

- *Principal Investigator*: ***Salish Sea Model - Continuing Development of New Capabilities and Applications (Interagency Agreement between USEPA & PNNL #DW-089-92483101) - Fate and Transport of Toxic Contaminants in Puget Sound – Development of a Toxics Module for the Salish Sea Model Using Polychlorinated Biphenyls (PCBs (2019 - present)*** – Through this EPA grant, administered via USEPA and PNNL interagency agreement, PNNL will target a major scientific topic of interest and area of research-need expressed by Puget Sound scientific community in connection with toxic contaminants (especially PCBs) that are impacting biota and hindering the recovery of a healthy Salish Sea ecosystem. This work will be conducted in collaboration with our partners Washington State Department of Fish and Wildlife (WDFW) and University of Washington (UW).

- *Principal Investigator:* ***Salish Sea Model – Development of a Effluent Plume Dilution and Transport Module and Validation to Dye Study Data. Washington State Department of Ecology Contract No. C1900025) (2018-2019)***. Through this project, PNNL will develop the ability to conduct detailed exposure assessment from wastewater and storm water effluent. Cumulative effects of nearly 100 outfalls will be simulated using FVCOM-Plume module developed by PNNL. This will provide the ability to analyze catastrophic failures of treatment plants and accidental releases of untreated wastewater during extreme events.

- *Principal Investigator:* ***COMT-2018 Towards an Operational Forecast System for the Salish Sea – Refinement, Improvement, and Testing for Transitioning of the Salish Sea Model to NOS. (IOOS Grant # NA18NOS0120160) (2018 – 2021)*** The objective of this project is to develop the next version of the Salish Sea Model through refinement and robust testing. The model will be brought to readiness level over a three-year period suitable for transition to NOS for the implementation of an Operational Forecast System for the Salish Sea (SSM-OFS). The project includes expansion of the model domain into Columbia River and testing of biogeochemical simulation and oil fate and transport modules. The work scope and

approach has been developed with the expectation that SSM-OFS will be transitioned to CO-OPS and NANOOS (IOOS Regional Association) for continued maintenance and operation.

- *Principal Investigator*: ***Salish Sea Model - Continuing Development of New Capabilities and Applications (Interagency Agreement between USEPA & PNNL #DW-089-92483101) (2017-present) -*** Development and application of the Salish Sea Model through addition and testing of new capabilities, and continuing improvement in performance. Provide support to USEPA and partner agencies for the development, maintenance, and future applications of SSM. Included in this period of performance are addition of modules related to turbidity and light, eelgrass, zooplankton, and coupled simulation of effluent plume dilution and mixing.

- *Principal Investigator:* ***Hood Canal Bridge Impact Assessment – Nearfield Hydrodynamic Analysis (Long Live the King/Salmon Recovery Fund Board Grant) (2016-2018).*** Proposed the hypothesis that the floating Hood Canal Bridge may be affecting the ecosystem due to increase time of flushing due to the bridge. Led the hydrodynamic data collection modeling components of the Hood Canal Bridge Impact Assessment project as part of a team of researchers from NOAA, WDFW, S'Klallam Indian Tribes and Long Live the Kings. The objective of the project is to assess the impact of the floating Hood Canal Bridge on the circulation and water quality in the nearfield environment and potential impacts on out migrating steelheads. Large impacts to water quality (temperature, algae, and DO) are also of interest and will be addressed in subsequent phases.

- *Principal Investigator:* ***Integrating Mitigation & Adaptation Considerations in Climate Change Programs within the Puget Sound Basin (U.S. Army Corps of Engineers Grant via U.S. EPA/Ecology Intergovernmental Agreement with PNNL) (2016-2018).*** Adapted and improved the Salish Sea Hydrodynamic and Water quality model to address the effects of climate change in the near shore intertidal environments in Salish Sea and Puget Sound, WA. The overall objective was to provide USACE, EPA and their partners with new and valuable insights on how mitigation and adaptation initiatives might relate to, even interact with each other in estuarine/near-shore environments impacted by climate change. This included linkage of downscaled climate-change models (meteorology and hydrology) for Puget Sound to the Salish Sea Model to simulate future (Year 2100) conditions for two separate emissions scenarios.

- *Co-Principal Investigator:* ***Research on Oil Spill Response Operations on the U.S. Outer Continental Shelf (BSEE Grant - Solicitation Number: E14PS00054, through a subcontract from DOE – National Energy Technology Laboratory) (2015-2016)***. Led the development of a linkage between FVCOM based hydrodynamic model of the Salish Sea and leading NOAA Oil Spill model – GNOME. Explored the challenges of accurate simulation of spill trajectories in Salish Sea using the historic (2003) Pt. Wells Spill. Preliminary tests showed that use of available hydrodynamic solutions while suitable for large scale water quality assessments may not be sufficient for surface oil transport predictions. Sensitivity tests were conducted with model grid resolution, dispersion coefficients, and wind forcing to improve the hydrodynamic solutions for use in Oil Spill Trajectory predictions.

- *Principal Investigator:* ***Swinomish Channel Federal Navigation Project – FVCOM model study (U.S. Army Corps of Engineers, Seattle District MIPR W68MD941907050) (2015 to 2016)***. USACE provided PNNL a MIPR grant to improve the existing Finite Volume Coastal Ocean Model (FVCOM) model developed by PNNL for the Skagit-Padilla Bay tidal basin. The objective of the work is to obtain a calibrated/validated model for predicting sediment transport in Skagit Bay and Swinomish Channel for the current baseline condition. The model is to be used by the Corps at a later date to assess various repair alternatives to the navigation structures located on the Swinomish Channel. The work is intended to be collaborative in nature allowing PNNL and USACE to work side by side and learn from each other through various stages of the study process.

- *Principal Investigator:* ***Skagit Delta Hydrodynamic Modeling Project (TNC/NOAA/WDFW Grant Agreement 66266) (2015 to 2017).*** The overall objective of the Skagit Delta Hydrodynamic Modeling project is to develop a suite of projects that are well supported to achieve long-term viability of Chinook

salmon tidal delta habitat and community flood risk reduction in a manner that protects and enhances agriculture and drainage. This would be accomplished through a modeling based alternative analysis. Modeling of restoration projects, processing and analysis of results will be conducted using an updated version of the hydrodynamic model of Skagit River delta previously developed by PNNL.

- *Principal Investigator:* ***Development of an Ocean Acidification Model for Salish Sea (EPA/Ecology Grant Agreement No. CE-960744-3) (2014 – 2018).*** The scope of this project is to develop and implement an approach to expand the Salish Sea model previously developed by the Ecology-PNNL team to evaluate pH and aragonite saturation state. This includes simulation of total dissolved inorganic carbon and alkalinity as state variables including source/sink terms related to air-sea exchange, respiration, photosynthesis, nutrient gains and losses, sediment fluxes, and boundary conditions. Boundary conditions would account for both Pacific Ocean upwelled water and regional contributions. The purpose of this investigation is to simulate acidification parameters under current conditions and to distinguish how much of that signal results from regional human sources. Results could be used to prioritize management actions to control nutrient releases and air emissions.

- *Principal Investigator:* **Development of Sediment Diagenesis Model for Salish Sea (EPA/Ecology Grant Agreement No. PC - 00J20101)** ***(2014 – 2017)***. The objective of this model development is to add the sediment diagenesis capability (dynamic simulation of the sediment-water exchanges to the Salish Sea model previously developed by the Ecology-PNNL team. This includes material fluxes to the sediment from the water column, biogeochemical processes that release some of the nutrients back to the water column, and the associated consumption of oxygen. The revised model will be used to reevaluate scenarios to identify the relative influences of climate effects, local human nutrient sources, and the Pacific Ocean on dissolved oxygen.

- *Co-Principal Investigator*: ***20% more Eelgrass (Zostera marina) by 2020: Restoration Site Selection and Testing, and Resolving Regulatory and Social Barriers to Conservation and Recovery. (WDNR – Grant # 11-0034)(2012 to 2014)*** - The goal of our project is to locate sites within Puget Sound and the Strait of Juan de Fuca suitable for successful eelgrass restoration, with specific focus to identify sites that would be conserved from future anthropogenic disturbances and resilient to climate change. A hydrodynamic and biogeochemical model of Puget Sound and Georgia Basin was used to generate time histories of oceanographic parameters for use in simulation of eel grass life cycles. The results will be used in combination with existing eelgrass distribution data, eelgrass habitat requirements, field surveys, experimental plantings, knowledge of eelgrass stressors, and regulatory assessments to identify a list of restoration sites and appropriate restoration actions.

- *Principal Investigator:* ***Puget Sound Circulation and Dissolved Oxygen Model 2.0: Human Contributions and Climate Influences. (US EPA - EPA-R10-PS-1004) (2010 to 2012)*** - PNNL is supporting Ecology in the capacity of a CO-PI in developing a comprehensive Water Quality Management Tool for the Salish Sea including Puget Sound and Georgia Basin. PNNL's responsibility is in the area Puget Sound Model refinement, improvement, and application. The focus of this phase of work is on refining the model, improving the performance, and applying the model to a selected set of questions including the effects of climate change on Puget Sound Water Quality.

- *Co-Principal Investigator:* ***Sustainable Coastal Habitat Restoration in the Pacific Northwest: Modeling and Managing the Effects, Feedbacks, and Risks Associated with Climate Change. (US EPA -G2005-STAR-L1) (2007 – 2012) (****In collaboration with Western Washington University and Skagit River System Cooperative)* – The overall objective of this project is to develop a predictive landscape simulation model, incorporating non-linear feedbacks, of the ecological and geomorphological consequences of climate-induced sea-level rise and river flow alteration in two of the most ecologically significant estuarine systems in Puget Sound, Padilla Bay and Skagit Bay. The goal is to use the model to guide the course of restoration and management efforts, given climate change, as they relate to salmon habitat in Puget Sound.

Hydrodynamics/Water Quality/Sediment Transport Modeling Analysis Experience

- *Project Manager**: Hood Canal Bridge Environmental Impact Analysis – Zone of Influence (ZOI)**. Long Live the Kings. (2016-2018)*. Assessed the ZOI from Hood Canal (Floating) Bridge, located within the 110 km long fjord-like Hood Canal sub-basin in Salish Sea, Washington. A field data collection program allowed nearfield validation of a three-dimensional hydrodynamic model of Hood Canal with the floating bridge section embedded. The results confirm that Hood Canal Bridge, with a draft of 4.6 m covering 85% of the width of Hood Canal, obstructs the brackish outflow surface layer. This induces increased local mixing near the bridge, causes pooling of water (up-current) during ebb and flood, and results in shadow/sheltering of water (down-current).

- *Project Manager: **Simulation of Salish Sea Response to Climate Change and Sea Level Rise Scenarios. U.S. EPA and U.S. ACE (2017-2018)**.* A proof-of-concept level effort to evaluate the feasibility of simulating nearshore estuarine response using off-the-shelf products available from the climate change research community. Future response within the Salish Sea fjord-like environment was examined using downscaled outputs from global Community Earth System Models for the Pacific Northwest, functionally linked to the Salish Sea Model. A 95-year change under the RCP8.5 greenhouse gas emissions scenario was simulated. The results confirm that higher temperatures, increased nutrient loads, lower pH, and DO levels, evident in the upwelled shelf waters from global predictions would propagate into the Salish Sea resulting in an average temperature rise of 1.8˚C, DO depletion of 0.7 mg/L, and acidification of 0.12 units in the future Y2095 relative to historical Y2000 conditions.

- *Project Manager: **Calibration of the Salish Sea Model and Simulation of Hypoxia**. Washington State Department of Ecology. (2017-2018*). Successfully simulated estuarine circulation, inter-basin-exchanges, and annual biogeochemical cycles in a single modeling framework in the inner waters of Puget Sound, Georgia Basin, San Juan Islands, and the Northwest Straits. Demonstrated a key performance measure – the ability to reproduce recurring hypoxia in the Salish Sea—an elusive goal that has stymied ecosystem modeling research and nutrient management efforts in the region for decades. The results also showed that hypoxia in the Salish Sea is affected by land-based anthropogenic loads.

- *Project Manager: **Detailed Hydrodynamic Assessment of the Preferred Restoration Alternatives near Leque Island and zis a ba, Washington**. 2016-2018. Ducks Unlimited.* A hydrodynamic feasibility study to assess the capability of the proposed actions to restore tidal functions such as periodic inundation, suitable currents, desired habitat/salinity levels, and examines sediment impacts, including the potential for excessive erosion or sedimentation requiring maintenance. A hydrodynamic model of the site, including Skagit Bay, Port Susan Bay, and the interconnecting region of Leque Island, was developed. The model was used to simulate tidal inundation, tidal currents, and salinity intrusion in the study area for the existing condition and to evaluate potential hydrodynamic changes following future restoration in Leque Island. The results were used by the project sponsors to select the preferred restoration design.

- *Project Manager*: **Development of a Fine Grid Resolution Model of Lake Billy Chinook – Post Construction Validation of Selective Water Withdrawal.** Portland General Electric. 2016-2017* PGE contracted with PNNL to assess the performance of a selective water withdrawal (SWW) structure at Lake Billy Chinook Dam on the Pelton Round Butte Hydroelectric Project, OR. The SWW was designed to provide dual benefit of managing downstream temperature and water quality and improve collection and downstream passage of juvenile fish. A 3D model of Lake Billy Chinook was established using SUNTANS model to simulate hydrothermal behavior of the reservoir for Year 1999 (pre-dam) and Year 2015, and 2016 (post-construction). The model will be used to assess the efficiency of SWW structure and develop recommendations to improve its operation and performance.

- *Project Manager: **Development of Temperature Models of Pelton Round Butte Hydroelectric Project Reservoirs, Deschutes River, OR**. Portland General Electric. 2014-2015.* PGE contracted with PNNL to upgrade the temperature and water quality models of the reservoirs impounded by three dams. PNNL developed models of Lake Billy Chinook, Lake Simtustus, and Reregulation Reservoir using the CE-QUAL-W2 model. PNNL also conducted an assessment of natural temperatures that would occur without

the dams. The results showed that there was significant influence of an external source of heat to the system through ground water.

- *Project Manager*: ***Development of a 3-D Temperature Model for Hells Canyon Reservoir*****,** *Idaho Power Corporation / McMillen LLC, 2014-2015.* Idaho Power Corporation contracted with PNNL to help them design selective withdrawal operations at the Hells Canyon Dam for downstream temperature management. PNNL proposed a 3D model of the system to help define the availability of cool water stored in the system annually. Years 2013 and 2014 were selected model calibration based on monitoring data. The model will be applied to design operatinal and structural modifications at th eHells Canyon Dam. PNNL used FVCOM model based on unstructured finvite volume technique to allow high resolution definition of the dam forebay.

- *Task Manager*: ***Extraction of Uranium from Seawater: Effect of Kelp-like Submerged Braid Adsorbent Mooring Farms on Ambient Hydrodynamics and Circulation***, *U.S. Department of Energy, 2013*. Dr. Khangaonkar managed a modeling based assessment of potential environmental impact of proposed braid adsorbent farm technology for extraction of Uranium from Seawater. The design calls for deployment of 60 m long kelp like braided moorings distributed over a large area similar to a kelp forest. A module was developed to simulate the resistance to flow and implemented into FVCOM. Sensitiity tests were conducted to assess the effects of prposed technology on ambient currents and tidal circulation.

- *Project Manager:* ***Puget Sound Dissolved Oxygen Modeling Study: Intermediate-scale Model Development,*** *Washington State Department of Ecology, 2008 – Present.* Dr. Khangaonkar in collaboration with U.S. EPA and Washington State Department of Ecology developed a strategy for a comprehensive Ecosystem Model of Puget sound with a focus on simulating nutrients, dissolved oxygen (DO) and algal kinetics. He is managing the construction and testing of Puget Sound wide hydrodynamic and water quality models to address mangement concerns such as as (1) are current nitrogen loadings from point and nonpoint sources in and around Puget Sound significantly impacting water quality at a large scale? or (2) are periodic episodes of low DO primarily natural events caused by the unique fjordal oceanographic conditions and poorly flushed deep waters? and (3) What level of nutrient reductions are necessary to reduce or eliminate human impacts to biomass and dissolved oxygen levels in sensitive areas?

- *Project Manager:* ***Temperature Modeling of Boundary Reservoir – Pend Oreille River TMDL****, Seattle City Light, 2006 – Present.* Dr. Khangaonkar is the project manager the Temperature Model development for the Boundary Reach of Pend Oreille River, Washington. PNNL has developed a temperature model for use in the development of temperature TMDL on Pend Oreille River. The model developed through support from Seattle City Light has been delivered to washington State Department of Ecology for Waste Load Allocation. The model is also being used by Seattle City Light in connection with Section 401 Water Quality Certificate Application for the Boundary Hydroelectric project operated by Seattle City Light. Dr. Khangaonkar also provides consulting support to Seattle City Light in connection with the TMDL and temperature management and compliance planning efforts.

- *Project Manager:* ***Leque Island Restoration Assessment,*** *Stillaguamish River, WA. Ducks Unlimited, 2007- 2008.* Dr. Khangaonkar managed the hydrodynamic modeling analysis of Leque Island as part of the restoration feasibility study. A three dimensional (3-D) hydrodynamic model for Leque Island and the surrounding nearshore areas was developed to simulate the tidal inundation and currents from both Skagit Bay and Port Susan Bay. The predicted effect of the restoration project on the hydrodynamic condition near Leque Island, such as the water surface inundation, current, and salinity changes, were analyzed as part of the feasibility evaluation.

- *Project Manager:* ***Cottonwood Island Restoration Assessment,*** *Skagit River, Mt. Vernon, WA. Skagit Watershed Council, May 2006 – 2007.* Dr. Khangaonkar managed the hydrodynamic and sediment transport modeling analysis for the proposed restoration at Cottonwood Island site. Proposed restoration actions included dike setback and channel dredging to maintain the functioning of fish habitat in the west channel around Cottonwood Island. The feasibility of proposed channel configuration and long-term maintenance dredging requirements were estimated.

- *Pricipal In Charge*:, ***Hydrodynamic Modeling of the Snohomish River Estuary,*** *The Tulalip Tribes, October 2006 – September 2007*. In the capacity of Technical Group Manager and Pricipal in Charge, provided oversight and technical review. A 3D hydrodynamic model for the Snohomish River Estuary was developed to evaluate the performance and efficacy of four restoration projects in the Snohomish Estuary Delta. The model was used to evaluate the potential individual and cumulative impacts on the hydrodynamics, morphology and fish habitat in the entire project area including the extended region near the river mouth. The study domain covered the entire Snohomish River Estuary and adjacent coastal waters. The results were used to fine tune the proposed restoration designs at Qwuloolt Marsh location and yielded insight on estuary wide effects of proposed actions.

- *Project Manager:* ***Rawlins Road / Fir island Restoration Study****, Skagit Delta, Mt. Vernon, WA. Skagit Watershed Council, May 2005 – 2007.* Dr. Khangaonkar is the project manager for the Rawlin's Road restoration study near the mouth of North Fork of Skagit River, WA. The project is evaluating alternatives to restore natural tidal estuarine functions to an area that is currently diked off for agriculture eliminating the wetlands marshland habitat. In this study, a three-dimensional tidal circulation model (FVCOM), coupled with a one-dimensional hydrological model (UNET), was developed for the Skagit River delta to assist estuarine restoration in the Fir Island area. The models are being applied to simulate different restoration alternatives and provide guidance for estuarine restoration and management. Specifically the models are being used to help select and design configurations that would improve supply of sediment and freshwater to the mudflats and tidal marsh regions outside of diked regions.

- *Senior Technical Reviewer:* ***Port Susan Restoration Project****, Mt. Vernon, WA. The Nature Conservancy, October 2005 – 2006.* Dr. Khangaonkar is providing senior techinal review and oversight to the Port Susan Restoration project near the mouth of the Stillaguamish River, WA. The project is evaluating alternatives to restore natural tidal estuarine functions to an area that is currently diked off for agriculture eliminating the wetlands marshland habitat. In this study, a three-dimensional tidal circulation model (FVCOM), was developed for the Stillaguamish River delta to assist feasibility of estuarine restoration at a diked off area owned by The Nature conservancy. The models are being applied to predict the hydrodynamic changes (water surface elevations and distributions of salinity and velocities) under different restoration alternatives and to provide a general interpretation of how these changes may alter the distribution of sediment, channels, and tidal habitats in the estuary.

- Project Manger: ***CFD Modeling of Willamette Falls Dam Forebay***, Portland, OR, Portland General Electric, November 2003 - 2005. Provided consultation to PGE's relicensing team and developed a combination of CFD and free-surface 3-D hydrodynamic modeling approach for the Willamette Falls project. A three-dimensional hydrodynamic model using EFDC code was developed in the pre-forebay region of the Willamette Falls project to simulate the hydrodynamics near the spillways for assessment of improvement of downstream fish passage directly over the falls. The model was calibrated using ADCP data collected in the pre-forebay region. The calibrated pre-forebay model was applied to simulate flow fields under different flow control structures around the falls. A high resolution of CFD model was also developed in the forebay region of the T. W. Sullivan based on U2RANS model for evaluating potential enhancements and modifications of the intake hydraulics, bypass structures and operations. The high-resolution forebay model was calibrated using physical model data that was collected previously.

- *Project Manager:* ***Indiana Dunes – Bacteria Model Development****, Chicago, IL. USEPA, June 2003-2004.* Dr. Khangaonkar is a project leader for the USEPA work assignment to develop a prototype computer model for prediction of beach bacteria concentrations in Lake Michigan. He managed the development of a site specific 3-D hydrodynamic model of wind and flow induced circulation near the Indian Dunes Park using the model EFDC. The model was used to simulate the transport and far-field dilution of the bacteria plume discharged by the Burns Ditch entering the study area. The analysis showed that wind induced circulation word result in shoreward transport of the plume resulting in relatively high exposure risk to beach users.

- *Project Manager,* ***Clackamas Hydroelectric Project****, Portland, OR. Portland General Electric,*

May 2003-Present. As part of Portland General Electric's FERC re-licensing team, Dr. Khangaonkar is currently managing the water quality model development and preparation of the associated CWA 401 Water Quality Certificate for the Clackamas River System. The model CE-QUAL-W2 was used to develop temperature and water quality model of the system using synoptic data collected over a 2-year period. The study shows that operations effect on water quality is limited since the system is oligotrophic and is little affected by changes in the flow regimes due to the operation of the dams. The water quality in general is very good with high DO and low algal growths. The assessment of the impact on in-stream and discharged waters is in progress.

- *Expert Consultant:* ***Willamette River TMDL****. Northwest Pulp and Paper Association, June 2003 to Present*. Dr. Khangaonkar participates in the NWPPA's Willamette River Mills meeting in the capacity of expert consultant providing recommendations and technical opinion as required. In that capacity, Dr. Khangaonkar conducted a review of the modeling analysis to obtain a better understanding of the processes that might be leading to PSU's modeling results and DEQ conclusions.

- *Corporate Sponsor:* ***Black River Hydrologic Study****, WA. The Nature Conservancy /U.S. Fish & Wildlife Service, July 2002-April 2003* Dr. Khangaonkar provided technical oversight, and expert consulting support to the PM and the client to define the scope, develop the approach, and recommendations on staffing to conducting the hydrologic evaluation of the Black River watershed. The objective of the study is to evaluate whether an existing natural gas pipeline that crosses the Black River has impacted the hydraulic and hydrologic behavior of the Black River system. This assessment was accomplished through field data collection and HEC-HMS/HSPF modeling to develop an understanding of flow distribution in the Black River watershed distribution. Dr. Khangaonkar provided review and guidance in the development of a phased cost effective approach for the study that best meets client's needs and expectations.

- *Project Manager:* ***Temperature Improvements at McNary Dam****, Walla Walla, WA. USACE, Walla Walla District, July 2002-April 2003.* Dr. Khangaonkar managed the development of a computational fluid dynamics (CFD) model of the McNary Dam forebay as part of USACE's Temperature Improvement efforts. The model selected was U2-RANS developed by University of Iowa. The CFD model for the McNary Dam will be setup and calibrated in collaboration with University of Iowa as a subcontractor to Foster Wheeler. The objective of the effort is to identify causes of occurrences of extreme temperatures during certain operating conditions, and use the model to design structural and operational modifications to improve the downstream fish passage conditions.

- *Project Manager:* ***Box Canyon Hydroelectric Project****, Newport, WA. Pend Oreille PUD / EE&S, June 2002-September 2002.* Dr. Khangaonkar supported the PUD of Pend Oreille County's re-licensing application. In collaboration with EE&S, he conducted temperature modeling of Box Canyon Reservoir to evaluate the effect of the Box Canyon Hydroelectric project operation on the reservoir and downstream temperatures. Dr. Khangaonkar provided specialized modeling skills to setup and calibrate a dynamic, vertical-2D temperature model (CE-QUAL-W2). He used the model results to demonstrate that the upstream boundary conditions and the meteorological forcing primarily control the temperatures in the reservoir. Dr. Khangaonkar also showed that the construction of the project did not cause significant adverse effects on the downstream temperatures.

- *Project Manager:* ***Chinook River Restoration Project****, Chinook, WA. Ducks Unlimited, September 2001-April 2003.* Dr. Khangaonkar managed the hydrologic and hydraulic evaluation of the Chinook River watershed in support of the Chinook River Restoration project. The project evaluated the feasibility of restoring the natural estuarine and riparian wetlands habitat by restoring tidal flows natural conditions through the study area. He developed a field data collection plan to support development and calibration of predictive hydrologic and hydrodynamic models. The calibrated models were applied for the proposed alternate configurations to predict the flows, velocities, and water surface elevations to help identify the best option for the restoration project. The model results were used to address specific questions, such as ability to provide a fully functional tidal habitat, ability to move floodwater out, and salinity intrusion.

- *Project Manager:* ***Discharge Modeling for Contaminated Sediments Cleanup Decisions****, Seattle, WA. King County, December 2002-April 2003.* Dr. Khangaonkar managed the development of a modeling software/tool for King County in collaboration with Washington Department of Ecology and U.S. EPA. Contamination of sediments resulting from nearshore discharges, such as combined sewer overflows (CSOs) and storm drains (SDs) is a major issue of concern. Currently a modeling tool that can predict or define the footprint of toxic contamination of sediments underneath outfalls or the natural recovery of these sediments does not exist. The project involved development of an integrated modeling system, calibrating and validating the system, and applying the modeling system in specific site cleanup or permitting actions. The project also involved future application of the model in the Duwamish/Elliot Bay region for application for sediment impact zones (SIZ).

- *Project Manager:* ***Temperature TMDL Modeling of the Columbia River Using 1-D Model RBM-10****, WA and OR. Northwest Pulp and Paper Association, October 2001-October 2002* Dr. Khangaonkar provided expert consulting support to Northwest Pulp and Paper regarding the temperature total maximum daily load (TMDL) of the Columbia River and its impact on the pulp mill discharges. The Columbia River was placed on the list of "water quality limited" waterbodies for temperature in 1996, and a TMDL analysis using 1-D RBM10 model is in progress. He conducted analysis to demonstrate that the impacts of larger magnitude point sources are relatively small on a regional scale. First, a run was performed with a point source effluent flow of 1,000 cfs approximately 10 times that of a typical single point source in the Columbia River. The analysis using RBM10 model has led to the conclusion that most point source discharges are unlikely to cause detectable increases in the large scale Columbia River temperature regime.

- *Project Manager:* ***Sensitivity Analysis of a Fate and Transport Model for Sediment Contamination in the Theafoss Waterway****, WA. Puget Sound Energy/Kennedy Jenks, September 1999-August 2000.* Dr. Khangaonkar conducted an independent review of an evaluation of contaminated sediments in the Thea Foss Waterway, located near Tacoma, Washington, as part of a Remedial Investigation/Feasibility Study (RI/FS). He conducted a sensitivity analysis to evaluate the results of sediment recovery modeling using toxic fate and transport model of the Thea Foss Waterway using the WASP model originally developed for the City of Tacoma. The contaminants considered were bis(2-ethylhexyl)phthalate, dibenz(a,h)anthracene, phenathrene, and pyrene. Dr. Khangaonkar utilized pervious experience with a wide variety of models to identify limitations and recommended improvements to the existing models. The primary conclusion was that the model development and calibration conducted previously was insufficient for use in allocation purposes. The recommendations included increased model resolution, revised model calibration, and the elimination of fictitious loads in the absence of data that were used in the existing model setup.

- *Project Manager:* ***Hydrodynamic and Water Quality Modeling of Lake Billy Chinook - Pelton Round Butte Project****, OR. Portland General Electric Co, August 1999–April 2002.* Dr. Khangaonkar managed water quality, temperature, and hydrodynamic modeling of Lake Billy Chinook. He developed a modeling and data collection action plan that laid out the framework for effective use of models and data to assist PGE in designing methods to re-establish fish passage through Round Butte Dam. Use of the calibrated (2-D) water quality model (BETTER), coupled to the 3-D hydrodynamic model (EFDC), allowed evaluation of various proposed flow-modification-structures on reservoir stratification and circulation. The models were used to design structural and operational modifications (selective withdrawal) that would enhance currents for fish passage and allow compliance with water quality criteria.

- *Modeling Task Manager:* ***3-D Modeling of Suspended Sediment and PCB Fate and Transport in Hudson River****, Queensbury, NY. Niagara Mohawk Power Corporation, September 2001-April 2003.* Dr. Khangaonkar managed the development of a 3-D hydrodynamic and suspended sediment and PCBs transport model (EFDC) for the Queensbury site in support of a Remedial Investigation/Feasibility Study (RI/FS). The objective of this component of the study was to evaluate if the dredging operations, proposed as part of the remedial actions at the Queensbury site on Hudson River, will cause extensive re-suspension and transport of PCBs and result in suspended PCBs reaching the water intake. Sediment and PCB fluxes through the sediment bed and water column interface were considered and different scenarios of sediment and PCB transport and their effects on the water quality at the drinking water treatment plan intake due to dredging operation were investigated.

- *Modeling Task Manager:* ***Effluent Solids Transport and Deposition Using Coupled Near-Field Dilution and Far-Field 3-D Circulation And Transport Models****, Port Angeles, WA. Rayonier, Inc., May 2001-April 2002*. Dr. Khangaonkar managed a 3-D modeling based investigation to define sediment impact zone (SIZ) associated with deposition of solids from historic outfalls. This study was conducted in support of a Remedial Investigation/Feasibility Study (RI/FS) being conducted at the former Rayonier Mill site in the Strait of Juan de Fuca. Existing information was used to develop and calibrate a 3-D circulation and sediment transport and deposition model. The model was coupled to outfall dilution models to predict deposition patterns. The results were used to design a cost effective sediment sampling and analysis plan for Rayonier. The results were also used to demonstrate that sensitive areas were not impacted by the effluent and solids discharged.

- *Project Manager:* ***Cumulative Plume Modeling Study, WA. Cherry Point Industry*** *(Arco, Alcoa, and Tosco), July 1999 – September 2000.* Dr. Khangaonkar managed the setup, calibration, and application of a 3-D hydrodynamic model (EFDC) for the Cherry Point coastline in Washington. The hydrodynamic model was calibrated using oceanographic data collected during the study and effluent plume transport model was calibrated using historical dye study data from the site. The study simulated effluent plumes from the three facilities (Arco, Alcoa, and Tosco) simultaneously and showed conclusively that accumulation of effluent does not occur. Distribution patterns for all constituents consistently indicated that water quality standards would not be exceeded in the study area due to Cherry Point discharges.

- *Project Manager:* ***Dilution Ratio and Reasonable Potential Analysis****, WA. U.S. Oil Refining and Marketing Company, January 2000 – August 2000.* Dr. Khangaonkar successfully proposed and negotiated that U.S. Oil's National Pollutant Discharge Elimination System (NPDES) permit limits be revised to incorporate a mixing zone and the beneficial effects of dilution. He prepared a mixing zone study plan for approval by Washington State Department of Ecology. The study reviewed available receiving water and effluent data and designed a focused effluent data collection plan for use in reasonable potential to exceed calculations. Dr. Khangaonkar conducted effluent dilution and mixing evaluations using EPA model UM and dissolved oxygen (DO) simulation to demonstrate that parameters of concern– (DO, copper, mercury, nickel, and sulfide) did not show any reasonable potential to exceed water quality standards and that water quality based limits would not be required.

- *Project Manager:* ***East Bank Fire Boat Dock - Hydraulic Flooding Analysis for a "no-rise certification,"*** *OR. City of Portland/KPFF, January 1999 – April 2000.* Dr. Khangaonkar managed the development of a steady state model of the Willamette River from the Willamette Falls to the Willamette River mouth. The model was calibrated to simulate the water surface elevations for the 100-year flood flow event. The model was also calibrated to account for the effect of bridge piers on water surface elevations. The model was applied to evaluate the impact of the KPFF project (East bank Fireboat Dock Construction) on water surface elevations during the flood events. The study showed that there was no perceivable impact on elevations due to the proposed construction.

- *Project Manager:* ***3-D CFD Model of North Fork Hydroelectric Project****, OR. Portland General Electric Co., August 2000 – April 2001.* Dr. Khangaonkar managed the development of a 3-D computational fluid dynamics (CFD) model of the North Fork Dam forebay using the STAR-CD model. The model predicts (3-D) velocity distribution in the North Fork Dam forebay with and without the proposed nets for exclusion and collection of downstream migrating salmonids. Model results are being used to design the nets (porosity and configuration) and their support structures. The model results are also used to estimate pressure distribution on the nets to evaluate the hydrodynamic loads for the design of structural supports.

- *Project Manager:* ***Water Quality Model of the Lower Deschutes River - Pelton Round Butte Project****, OR. Portland General Electric Co., August 2000 – March 2001.* Dr. Khangaonkar managed the development of a predictive water quality model of the Lower Deschutes River as part of an adaptive management plan to re-introduce anadromous runs through the Pelton Round Butte Project. This was accomplished using the finite element models RMA2 and RMA4q and the available data collected by PGE in 1997 and 1999. The water quality model included the periphyton as the primary driver of water quality variations. The model was used to evaluate the effect of various reservoir modifications on reservoir and downstream water

quality, particularly blending of surface and bottom waters of Lake Billy Chinook. Preliminary results indicate no adverse impact on dissolved oxygen (DO) and only slight increases in pH. Because the residence time is very short, little effect from nutrient changes on water column algae growth occurs. Changes in DO and pH are primarily caused by changes in periphyton growth.

- *Project Manager:* ***Water Quality Model of Lake Simtustus - Pelton Round Butte Project****, OR. Portland General Electric Co., April 2000 – June 2001* Dr. Khangaonkar managed the development of a predictive water quality model of Lake Simtutus using the U.S. Army Corps of Engineers' CE-QUAL-W2 reservoir hydrodynamic and water quality model. This was conducted to support an adaptive management plan for re-establishing natural anadromous fish runs above Round Butte Dam upstream of Lake Simtustus. Model results indicated that the surface/selective withdrawal operation in Lake Billy Chinook improves dissolved oxygen (DO) and lowers the temperatures of Lake Simtustus in the summer. The Chlorophyll *a* and pH levels are slightly elevated during a short period of late fall but are not a major concern considering the temperature and DO benefits provided by the selective withdrawal operation at Lake Billy Chinook above Lake Simtustus.

- *Project Manager:* ***Sediment Recontamination Modeling of the Norfolk CSO****, Duwamish River, WA. King County Department of Natural Resources, 1997-1998.* Dr. Khangaonkar managed the sedimentation and sediment recontamination study as part of the Henderson/M.L. King CSO project. The objective of the study was to evaluate the potential for recontamination of clean site sediments as a result of treated CSO and storm drain discharges through the Norfolk outfall following CSO project completion. He modified Ecology's SEDCAM model and applied it to the evaluation of potential sediment recontamination resulting from the discharge of the five contaminants of concern from the treated CSO and untreated stormwater runoff. The study showed that treated CSOs would not recontaminate the sediments; however, there was a potential for sediments to become recontaminated with bis (2-ethylhexyl) phthalate due primarily to the discharge of this compound in untreated stormwater draining nearshore commercial and industrial areas.

- *Project Manager:* ***Natural Recovery Modeling of Ward Cove Sediments****, AK. Ketchikan Pulp Company, 1997-1998.* Dr. Khangaonkar managed the development and application of discharge fate and transport model in support of a sediment Remedial Investigation/Feasibility Study (RI/FS) project. The scope included development of a predictive model of long-term sediment deposition and contaminant concentrations to support the decision making process of remedial alternatives selection and design in Ward Cove, Alaska. The models used were EFDC (a hydrodynamic model) and WASP/TOXI5 (a toxics fate and transport model). Natural recovery of sediments was simulated with the help of the following processes, including burial by new clean sediments, chemical biodegradation, and diffusion and tidal flushing. Model results showed sediment recovery of TOC and 4-methylphenol. The model was applied for a period of 42 years during the contamination phase and when the industrial outfall was operational. The recovery following source control was conducted for a period of 20 years.

- *Project Manager:* ***Hydrodyanamic, Water Quality, and Sedimentation Modeling****, Nisqually National Wildlife Refuge, WA. Ducks Unlimited and U.S. Fish and Wildlife Service, 1998-1999.* Dr. Khangaonkar managed the hydrodynamic, sedimentation, and water quality modeling study as part of the U.S. Fish and Wildlife's (USFWS) and Ducks Unlimited's Nisqually National Wildlife Refuge (NWR) Flood Relief and Habitat Restoration Project. USFWS is considering modifying the existing artificially created freshwater wetlands habitat to a natural estuarine habitat in the Nisqually NWR. The modeling addressed questions regarding the ability of the system to achieve full tidal transport and estuarine habitat, modifications that may be required to the existing dike system, and sedimentation or erosion due to removal of existing dikes. The study also evaluated the potential for fish to be trapped inside the diked area. The study helped select a design that would move the floodwater off the refuge and reduce flooding impacts to Nisqually NWR. Specific study objectives included oceanographic data collection, 3-D hydrodynamic model setup and calibration (RMA-10), sedimentation/water quality model setup (RMA-11), and model application to identify the best alternative to wetland modifications.

- *Project Manager,* ***Feasibility Study of the Port Kalinga Project****, Overall Circulation and Sedimentation Study, International Seaports, Ltd., Dhamra, Orissa, India, 1998-1999.* Dr. Khangaonkar managed the overall circulation and sedimentation analysis in support of a feasibility study for a port construction

project in Dhamra, Orissa, India. The overall objective of the study was to determine the total sedimentation that would occur in the proposed navigation channel and the maintenance dredging required for the proposed port. The team used coastal engineering modeling techniques to calculate the dredging requirements associated with the riverborne sedimentation, estimated shoreline changes that would be induced by wave activity, and evaluated the impact of the associated dike on tidal circulation and sedimentation. A lateral 2-D finite element hydrodynamic model (RMA-2) for the entire study area (nearly 25 sq km) and used SED2D sedimentation model to calculate the deposition and erosion of the riverborne sediments was set up. The study results showed that with optimization of the size, location, and the orientation of the proposed dike, the adverse impacts on backwater flooding could be minimized and maintenance dredging due to riverine sedimentation would be negligible.

- *Numerical Modeler,* ***Willamette River Basin Water Quality****, OR, Oregon Department of Environmental Quality, 1990-1992.* Dr. Khangaonkar managed the dissolved oxygen (DO) component of the study. Critically reviewed and summarized the available data on DO, biochemical oxygen demand (BOD), temperature, and river flow to evaluate the present condition of the Willamette River. He provided the lead in design of water quality sampling plan. He also established, calibrated, and verified the water quality model QUAL2E on the river using the collected field data. A sensitivity analysis was done using the calibrated model to show that DO levels in the river were most sensitive to river flow rates and sediment oxygen demand.

- *Numerical Modeler,* ***Dissolved Oxygen Steady-State 3-D Model****, AK, Ketchikan Pulp Company, 1994-1995.* Dr. Khangaonkar converted the EPA Region 10 VAX-based total maximum daily load (TMDL) model to run on a PC. The 3-D model was then reapplied to Ward Cove and recalibrated with the new available data. The study showed that dramatic improvement in the dissolved oxygen (DO) levels in Ward Cove was directly related to the biochemical oxygen demand (BOD) loads from the Ketchikan Pulp Company. The DO-BOD water quality model was then used to re-compute an effluent limit that would allow Ketchikan Pulp Company to satisfy the state DO standard.

- *Project Manager,* ***ENSR R&D Committee Development of Sediment Oxygen Demand Sampling Apparatus****, 1993-1994.* Dr. Khangaonkar initiated and managed an R&D project to develop the capability of collecting sediment oxygen demand (SOD) field data. He designed and constructed SOD flux chambers based on an annular design currently favored by the EPA. The field tests of the apparatus were successfully completed, which allowed ENSR to be the first in the northwest region to provide SOD sampling services.

- *Research Assistant,* ***Nonlinear Waterwave Generation and Propagation, FL, Defense Nuclear Agency****, 1988-1990.* Dr. Khangaonkar analyzed nonlinear phenomenon of waves generated by underwater explosions. He mathematically simulated the same by sequential analysis of events that led to a simple but accurate and applicable methodology. In addition, he developed a new equation and applied a unique numerical scheme for water wave propagation resulting in significant reduction of computation time. Momentum Theorem was applied to analyze damping and growth of water waves due to rain/sea interaction and derived the corresponding dispersion relationship.

Mixing Zone Analysis, Diffuser Design and Dilution Ratio Studies

- *Project Manager:* ***Additional Mixing Zone Analysis for Georgia-Pacific Wauna Mill, Wauna, OR*** *– GP Wauna, OR. 2018.* Dr. Khangaonkar managed a study in repose to request from Oregon DEQ to GP. PNNL performed two additional sets of Mixing Zone analyses. The first set of analyses were for computation of applicable dilution ratios for reasonable potential analysis associated with human health criteria. The second set of analyses requested were for thermal impacts to eulachon (also called the candlefish, a small anadromous ocean fish).

- *Project Manager:* ***Mixing Zone Studies*** *– GP Wauna, OR. GP August 2004 – Present.* Dr. Khangaonkar is providing support to GP Wauna in connection with their NPDES permit studies. Dr. Khangaonkar is managing a detailed Mixing Zone Study for GP Wauna which includes field diffuser evaluation (dive survey), computer modeling of mixing during critical conditions, and velocity and temperature isopleths for

the discharge within the mixing zone. This includes an innovative use of 3D CFD model of the ZID including GP Wauna's diffuser and the discharge. The model will be constructed using CFD models such U2RANS (University of Iowa) or CENTAUR-3D (Georgia Tech) setup to reproduce GP Wauna site conditions

- *Project Manager:* ***Mixing Zone Studies*** *– GP Toledo, OR. GP, February 2004 – Present.* Dr. Khangaonkar is managing large multi-disciplinary team of team consisting of modelers, oceanographers, toxicologists, and engineers to support GP Toledo Paper Mill with Mixing Zone Studies Associated with their NPDES outfall. The studies include a Dye Dilution Study, a Receiving Water Quality Study, and Circulation and Effluent Fate and Transport Modeling Study. In addition, Dr. Khangaonkar will also provide a consulting interface between GP and Oregon Department of Environmental Quality as part of their NPDES permit renewal.

- *Project Manager,* ***Combined Outfall Feasibility Study****, WA, Kimberly-Clark Corporation, 1996-1997.* Dr. Khangaonkar conducted a feasibility study to assess the increase in overall dilution that would be achieved through a new proposed outfall. He conducted outfall siting analysis; effluent fate and transport and flushing analysis; hydraulic evaluation of the ability of the existing deep water outfall to increase its capacity from 12 mgd to a combined flow of 40 mgd; and preliminary analysis of construction versus costs.

- *Project Manager,* ***Outfall Relocation and National Pollutant Discharge Elimination System Permitting****, AK, Ketchikan Pulp Company, 1995-1997.* Dr. Khangaonkar managed project to site and design a new wastewater outfall and conduct several studies in support of the outfall extension program. He analyzed oceanographic conditions at the site of the proposed outfall, performed near-field initial dilution modeling and far-field effluent transport and dispersion analysis using RMA-2 and RMA-4. The U.S. Army Corps of Engineers' model (DIFCD) to predict turbidity and dilution of trace metals in discharge plume was calibrated and verified. Dr. Khangaonkar successfully demonstrated that proposed outfall would meet permit requirements and presented findings at public meetings and workshops.

- *Modeling Specialist,* ***San Juan Bay Flushing Study****, Bayaman, PR, Caribbean Petroleum Refinery, 1995-1999.* Dr. Khangaonkar was a Team Member for development of a National Pollutant Discharge Elimination System (NPDES) compliance strategy for the refinery that included facility improvements, engineering controls, source control studies, improved treatment plant performance, and modification of permit limits. An outfall diffuser, which, with an approved mixing zone, would provide substantial dilution, thereby relieving the facility of many permit limitations was designed. A study plan to fully assess the ambient water quality in San Juan Bay and to demonstrate acceptability of the proposed marine discharge was developed. The team Used data obtained from several surveys to develop hydrodynamic and water quality models that provided the basis for designing a diffuser, determining dilution potential, establishing the size of the mixing zone, and assessing the effects of the discharge in the farfield beyond the mixing zone. The models used in this study include UDKHDEN, RMA-2, and RMA-4.

- *Project Manager,* ***Dilution Ratio and Reasonable Potential Analysis****, WA, Tosco Refining and Marketing Company, 1996-1997.* Dr. Khangaonkar managed a review and revision of Tosco's National Pollutant Discharge Elimination System (NPDES) permit limits. Directed a receiving water data collection program specifically designed to provide data best suited for use in dilution ratio calculations. This included a 15-day current meter data time history and bi-weekly collection of salinity and temperature profiles at two stations in the vicinity of the outfall. Conducted near-field (acute dilution) dilution ratio modeling with the EPA-approved UM model and far-field dilution (chronic dilution) using Brook's 4/3rd law. The models were calibrated using dye study data. Through this study, estimates of acute dilution were increased by 50 percent and the chronic dilution increased by 112 percent. Successfully demonstrated that by using the new estimates of applicable dilution ratios neither copper nor mercury had a potential to exceed water quality standards and, therefore, permit limits for copper and mercury were not required.

- *Project Manager,* ***NPDES, 301(h) Program Preparation of NPDES Permit Application****, AK, City of Skagway, 1994-1995.* Dr. Khangaonkar prepared a comprehensive Section 301(h) National Pollutant Discharge Elimination System (NPDES) application package for modification of secondary treatment

requirements for the City of Skagway. In addition to providing general information and basic data analysis, the application also consisted of a technical evaluation. Using water quality and mixing zone modeling, the technical evaluation conclusively demonstrated that the City of Skagway discharge would be adequately flushed and that the receiving water quality will not be impaired.

- *Numerical Modeling Specialist,* ***National Pollutant Discharge Elimination System, 301(h) Program****, Damaged Outfall Impact Analysis, CA, 1992-1993.* Dr. Khangaonkar evaluated the impact on dissolved oxygen (DO) levels and sedimentation rates resulting from a break in Point Loma Outfall, San Diego, California, using numerical models of effluent dilution, far-field DO depletion, and sedimentation.

- *Numerical Modeling Specialist,* ***Calculation of Applicable Dilution Ratio and Acute Toxicity Permit Limits****, OR, Georgia-Pacific, 1993-1994.* Dr. Khangaonkar used the UM model to calculate the zone of initial dilution (ZID), the applicable dilution at the edge of the ZID, and the corresponding appropriate permit limit for acute toxicity.

- *Numerical Modeling Specialist,* ***301(h) Program, Outfall Dilution Study****, PR, National Pollutant Discharge Elimination System, 1994-1995.* Dr. Khangaonkar evaluated the far-field effects on dissolved oxygen (DO) due to an oceanic outfall. He computed the minimum concentrations of DO and coliform bacteria using a far-field coastal dispersion model for water quality criteria evaluation.

- *Numerical Modeling Specialist,* ***301(h) Program, Technical Review of NPDES Permit Application****, AK, National Pollutant Discharge Elimination System (NPDES), 1991-1992.* Dr. Khangaonkar performed a technical review of the effluent and ambient monitoring data submitted by the discharger to evaluate compliance with the NPDES permit. He evaluated the diffuser hydraulics and the resulting dilutions in the near-field and far-field using EPA models.

- *Numerical Modeling Specialist,* ***Outfall Dilution Study****, OR, City of St. Helens, 1991-1992.* Dr. Khangaonkar served as numerical modeler to compute initial dilutions at a paper and pulp mill outfall using EPA-approved models to evaluate the water quality criteria for their National Pollutant Discharge Elimination System permit.

- *Numerical Modeling Specialist,* ***Outfall Dilution Study****, OR, James River Corporation, 1991-1992.* Dr. Khangaonkar performed simulations of near-field outfall plume behavior on the Columbia River and calibrated EPA plume models to fit the results of the field dye study by varying the diffuser configurations. He analyzed the resulting minimum dilutions for the purpose of evaluating water quality criteria at the legal mixing zone.

- *Numerical Modeling Specialist,* ***Outfall Diffuser Design****, AK, Alaska Pulp Company, 1992-1993.* Dr. Khangaonkar designed the diffuser for Alaska Pulp Company's Sitka Mill outfall using the initial dilution model, UM. The diffuser optimization and siting was accomplished based on the criteria of achieving maximum possible dilution and a surfacing plume to ensure minimum accumulation in the bay.

- *Numerical Modeling Specialist,* ***Oceanographic Evaluation****, WA, BP Oil Company, 1992-1993.* Dr. Khangaonkar performed an oceanographic evaluation of the annual variation in density stratification and currents at the outfall site to design a data collection plan for use in a compliance evaluation of the outfall dilution ratio for the National Pollutant Discharge Elimination System permit.

- *Numerical Modeling Specialist,* ***Drilling Mud Discharges, Sediment Depositions Analysis****, AK, ARCO Alaska, Inc., 1993-1994.* Dr. Khangaonkar computed sediment deposition contours, concentrations, and areal extent of impact resulting from the dispersion and deposition of sediments from drilling muds, cuttings, and excess slurry discharges from an offshore drilling rig in North Cook Inlet. The model used in the analysis was DIFCD for dredge spoil disposal.

- *Numerical Modeling Specialist,* ***Diffuser Design and Dilution Ratio Study****, WA, Sonoco Products Company, 1993-1994.* Dr. Khangaonkar conducted an outfall evaluation based on a physical inspection of

the diffuser. He applied an EPA-approved numerical model of near- and far-field dilution to arrive at Sonoco's critical dilution ratio, and designed modifications and repairs to the outfall allowing Sonoco to comply with water quality standards.

- *Numerical Modeling Specialist,* ***Dilution Ratio Study****, WA, Aluminum Company of America, 1994-1995.* Dr. Khangaonkar performed a dilution ratio study of Alcoa's outfall per requirements of their National Pollutant Discharge Elimination System permit. He also performed a hydraulic analysis of Columbia River flows at the site to arrive at the 7Q10 flow and the critical temperature for the application of the numerical models, and determined Alcoa's compliance with the state water quality standards.

- *Numerical Modeling specialist,* ***Diffuser Design and Siting Analysis****, AK, Ketchikan Pulp Company, 1994-1996.* Dr. Khangaonkar managed design of a new outfall with diffuser and its siting in Ward Cove, Ketchikan, Alaska. The design is based on the ability of the diffuser to meet the state water quality standards at the zone of initial dilution, as well as its ability to ensure that effluent is efficiently flushed out of Ward Cove. Diffuser design was refined with a combination of dilution ratio and dissolved oxygen modeling using EPA-approved models.

Clarifier Design

- *Task Manager,* ***Hanahan Sedimentation Basin Modeling****, SC, City of Charleston, 1996-1997.* Dr. Khangaonkar investigated the flow short-circuiting problem in Hanahan sedimentation basin using RMA-2, a 2-D finite element hydrodynamic model. The results showed that the lateral flow was well distributed and that the short-circuiting was probably occurring in the vertical plane. Another 2-D model (CE-QUAL-W2) that operates in the vertical plane was applied and it correctly predicted the observed short-circuiting and the sediment deposition characteristics. The model was then used to design modifications to the basin, eliminating the short-circuiting problem, allowing uniform distribution of sediments, and accomplishing 70 to 100 percent sediment removal efficiency.

- *Task Manager,* ***Plum Island Wastewater Treatment Plant Modeling****, SC, 1997-1998.* Dr. Khangaonkar evaluated the performance of the secondary clarifiers through a combination of physical and numerical modeling of the final settling tanks at the Plum Island Wastewater Treatment Plant. He setup and calibrated a numerical model of the clarifier. The numerical model was used to optimize the length of the sedimentation cells. Floc settling rates obtained from the field-sampling program were used to calibrate the model, and velocity data at the entrance to the sedimentation basin collected from the physical model was used to provide the boundary conditions. Using the calibrated hybrid model, modifications to maximize sediment removal efficiency were designed. Modifications included modifying the port openings and/or installing a solid or perforated reaction baffle.

- *Project Manager,* ***Design of a Primary Sedimentation Basin/Clarifier****, Henderson/M.L. King CSO Project, WA, King County Department of Natural Resources, 1997-1998.* Dr. Khangaonkar managed a sedimentation basin/clarifier design project for King County Department of Natural Resources. The sedimentation basin/clarifier would be used to treat the re-routed CSOs from the Henderson and M.L. King drainage basins. The performance modeling study objective was to ensure that the proposed design, a 12-foot-diameter, 3,600-foot-long tunnel, would function through various types of CSO loads that would occur during the design year. The purpose of the storage/clarifier tank was to ensure that a significant portion of the solids was removed from the effluent prior to discharge to the Duwamish River. Dr. Khangaonkar successfully developed the required clarifier design through a combination of computational fluid dynamics (CFD) modeling and sedimentation modeling based on particle grain size and settling velocity distribution data obtained from settling column tests.

Oceanographic and Bathymetric Surveys

- *Post Doctoral Research Assistant,* ***Ambient Currents, Turbidity and Suspended Sediment Monitoring****, FL, Florida Sea Grant, 1990-1991.* Dr. Khangaonkar collected and analyzed several field-measured quantities, including wave-induced pressure, currents, sediment concentration, and turbidities. He developed and

implemented software to streamline data acquisition and spectral analysis (MATLAB-based). He also participated in periodic coastal instrument deployment and recovery activities requiring SCUBA diving.

- *Task Manager,* ***Bathymetric Survey****, AK, Amerada Hess Corporation, 1995-1996.* Dr. Khangaonkar participated in a bathymetric survey off the barrier islands in Prudhoe Bay. Bathymetric readings were obtained with a fathometer, while a differential GPS system provided ship location with an accuracy of about 1 meter. Both data sets, the location and depth readings, were logged simultaneously using a HYPAK data acquisition system. He performed data reduction and prepared a bathymetric contour map of the area.

- *Sediment/Sampling Field Scientist,* ***Puget Sound Sediment Sampling Survey****, WA, Washington Department of Natural Resources, 1991-1992.* Dr. Khangaonkar participated in a WDNR-sponsored survey of the southern Puget Sound. The survey consisted of sampling 20 stations in the southern Puget Sound known to be sediment depositional areas with high likelihood of contamination. The sediments were analyzed for toxic compounds using Puget Sound Estuary Program protocols.

- *Sediment/Sampling Field Scientist,* ***Columbia River Reconnaissance Survey****, The Lower Columbia River B-State Water Quality Program, 1991-1992.* Dr. Khangaonkar reviewed hydrologic, hydraulic, sediment transport, and geomorphic data on the Lower Columbia River. He evaluated hydrodynamic and water quality models for application to the river system. He summarized the physical and hydrologic characteristics, summarized numerical strategies for water quality modeling, and identified data gaps. He also participated in a sediment and water-quality data acquisition cruise during the reconnaissance survey.

Ocean, Coastal, and River Engineering

- *Research Assistant,* ***Breakwater Design****, FL, Post Buckely Shuh & Jernigan, 1988-1989.* Dr. Khangaonkar designed a vertical wall breakwater for a marina. He computed wave activity and loads resulting from winds and tidal currents, and analyzed transmission coefficients to ensure minimum wave agitation in the marina.

- *Research Assistant,* ***University of Miami Research Projects****, FL, 1986-1990.*Finite element analysis of tidal circulation, scale modeling of a break water, scale modeling of beach erosion, shock wave, and structure response.

Physical Model Studies

- *Project Engineer,* ***Bergen Generating Station****, Sump Study, NJ, Ingersoll Dresser Pumps, 1992-1993.* Dr. Khangaonkar evaluated the proposed circulation system and sump design for the Bergen Generating Station, using a physical model. He performed a model study to investigate sump hydraulics. Sump modifications to ensure satisfactory approach flow to the pumps and eliminated performance problems associated with vortex action, pre-swirl, and air entrainment phenomena were designed. Dr. Khangaonkar was responsible for all aspects of the hydraulic physical model study, designed and supervised the construction of the physical model, conducted and documented the test results, developed modifications, and produced the study report.

- *Research Assistant,* ***Scale Model Study****, Washington D.C., Defense Nuclear Agency Explosion-Generating Water Waves, 1988 – 1990.* Dr. Khangaonkar managed a study to evaluate the ability of nuclear explosions to generate water waves using a small-scale physical model. Nuclear explosions of various magnitudes were simulated using 1 lb. to 50 lb. equivalent TNT explosive charges. The explosive tests were carried out in a 140-foot by 110-foot basin in 4 feet of water, at Waterways Experiment Station, USACE, at Vicksburg, MS. In addition to explosive tests, cylindrical waves similar to those generated by explosions were also generated with the drop of a circular plate on still water. The collected wave data from both sets were processed and used to calibrate a numerical model of explosion-generated water wave propagation.

- *Research Assistant,* ***Beach Erosion, Scale Model Study****, FL, University of Miami 1986 - 1988.* Dr.

Khangaonkar evaluated the impact of wave-induced return flow on beach accretion and erosion processes. He developed a test time history of waves based on spectral analysis of observed data, and modeled the incident waves in a wave flume. The simulated beach was subjected to the waves, and various devices were tested in an attempt to reduce return flow. Impact of the devices on altering the return flow and beach erosion was found to be insignificant. The study also included evaluation of a vertical wall partial breakwater on its ability to prevent transmission of wave energy.

PROFESSIONAL AFFILIATIONS

American Geophysical Union
American Society of Civil Engineers

ADDITIONAL TRAINING AND LICENSES

Registered Professional Engineer, Civil (#32167), Washington State

PUBLICATIONS

Books and Book Chapters

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