PART I - ADMINISTRATIVE

Section 1. General administrative information

Title of project

Evaluate Effects Of Hydraulic Turbulence On The Survival Of Migratory Fish

BPA project number: 20054
Contract renewal date (mm/yyyy): ☐ **Multiple actions?**

Business name of agency, institution or organization requesting funding
Oak Ridge National Laboratory

Business acronym (if appropriate) ORNL

Proposal contact person or principal investigator:

Name	Dr. Glenn F. Cada
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NPPC Program Measure Number(s) which this project addresses
5.6A.14, also contributes information to many other items in 5.6 and 5.7

FWS/NMFS Biological Opinion Number(s) which this project addresses
NMFS Biological Opinion - Reinitiation of Consultation on 1994-1998 Operations of the Federal Columbia River Power System and Juvenile Transportation Program in 1995 and Future Years (March 2, 1995) - Conservation Recommendation No. 5

Other planning document references
Snake River Salmon Recovery Plan Task Nos. 2.2.a., 2.2.d., 2.3.a., 2.3.b., 2.3.d., and 2.8.a.2. Also, Wy-Kan-Ush-Mi Wah-Kish-Wit recommendations to improve juvenile salmon passage by (1) optimizing the operations of turbines and retrofitting existing turbines with advanced designs to decrease fish mortality, (2) implementing controlled spill to enhance fish passage, and (3) evaluating predator control programs.

Short description
Design, construct, and operate a laboratory apparatus to study effects of turbulence on fish survival and swimming performance. Intensities and scales would be the same as within hydroelectric turbines, fish bypass systems, spill, and vessel passage.

Target species
Initial test species would include salmonids (rainbow trout; Atlantic salmon) and American shad; experimental apparatus and techniques that will be developed can be applied to any other fish

Section 2. Sorting and evaluation

Subbasin
Systemwide

Evaluation Process Sort

CBFWA caucus	Special evaluation process	ISRP project type
Mark one or more caucus	If your project fits either of these processes, mark one or both	Mark one or more categories
☒ Anadromous fish ☒ Resident fish ☐ Wildlife	☐ Multi-year (milestone-based evaluation) ☐ Watershed project evaluation	☐ Watershed councils/model watersheds ☐ Information dissemination ☐ Operation & maintenance ☐ New construction ☒ Research & monitoring ☐ Implementation & management ☐ Wildlife habitat acquisitions

Section 3. Relationships to other Bonneville projects

Umbrella / sub-proposal relationships. List umbrella project first.

Project #	Project title/description

Other dependent or critically-related projects

Project #	Project title/description	Nature of relationship

Section 4. Objectives, tasks and schedules

Past accomplishments

Year	Accomplishment	Met biological objectives?

Objectives and tasks

Obj 1,2,3	Objective	Task a,b,c	Task
1	Assess state-of-the-art in turbulence studies	a	Review literature and determine turbulence values to test
		b	Evaluate existing experimental apparatus

2	Develop test apparatus	a	Engineering design
		b	Construction and installation
		c	System shakedown
3	Hydraulic evaluation of test apparatus	a	Flow measurement and calibration
		b	Velocity mapping
		c	Detailed description of turbulence in the system
4	Biological evaluation of test conditions	a	Evaluate fish injury and mortality caused by turbulence
		b	Evaluate reduced swimming performance
5	Data analysis		Characterization of velocity field (turbulence scale and intensity) and biological effects
6	Report preparation	a	Progress report (literature review and final design of test apparatus)
		b	Final test report

Objective schedules and costs

Obj #	Start date mm/yyyy	End date mm/yyyy	Measureable biological objective(s)	Milestone	FY2000 Cost %
1	10/1999	1/2000			11.00%
2	11/1999	1/2000		Progress report	20.00%
3	1/2000	5/2000			22.00%
4	2/2000	6/2000			22.00%
5	2/2000	7/2000			15.00%
6	8/2000	9/2000		Final report	10.00%
				Total	100.00%

Schedule constraints
Availability of appropriate fish for testing

Completion date
FY 2000

Section 5. Budget

FY99 project budget (BPA obligated):

FY2000 budget by line item

Item	Note	% of total	FY2000
Personnel	ORNL (35K) Conte Anadromous Fish Research Center (95K) Idaho National Engineering Laboratory (5K)	%39	135,000
Fringe benefits	ORNL (15K) CAFRC (34K) INEEL (2K)	%14	51,000
Supplies, materials, non-expendable property	Pipes, reducers, pump, timber, pressure and velocity transducers, flow meters, etc.	%7	25,000
Operations & maintenance	Utilities, fish tests, etc.	%1	3,500
Capital acquisitions or improvements (e.g. land,	High speed video system, PCs and software	%27	95,000

buildings, major equip.)			
NEPA costs			0
Construction-related support			
PIT tags	# of tags:		
Travel		%1	6,000
Indirect costs		%7	25,500
Subcontractor			
Other			
		TOTAL BPA FY2000 BUDGET REQUEST	$341,000

Cost sharing

Organization	**Item or service provided**	**% total project cost (incl. BPA)**	**Amount ($)**
		Total project cost (including BPA portion)	$341,000

Outyear costs

	FY2001	**FY02**	**FY03**	**FY04**
Total budget				

Section 6. References

Watershed?	**Reference**
☐	Cada, G.F., C.C. Coutant, and R.R. Whitney. 1997. Development of biological criteria for the design of advanced hydropower turbines. DOE/ID-10578. Report to the Idaho Operations Office, U.S. Department of Energy, Idaho Falls, ID. 85 p.
☐	Gordon, N.D., T.A. McMahon, and B.L. Finlayson. 1992. Stream hydrology: An introduction for ecologists. John Wiley & Sons, New York, NY. 526 p.
☐	Killgore, K.J., A.C. Miller, and K.C. Conley. 1987. Effects of turbulence on yolk-sac larvae of paddlefish. Transactions of the American Fisheries Society 116:670-673.
☐	Vogel, S. 1981. Life in moving fluids: The physical biology of flow. Princeton University Press. Princeton, Mew Jersey. 352 p.

PART II - NARRATIVE

Section 7. Abstract

It has been recognized by numerous investigators that excessive turbulence associated with turbine passage, spill passage, and fish bypass systems at hydroelectric dams may have adverse effects on downstream migrating fish. Although this fluid stress has been poorly studied, it is suspected that excessive turbulence at scales comparable to the size of a fish can cause direct injury and mortality, and at larger scales can disorient fish so that they become more susceptible to predation.

In response to the goal of developing an improved understanding of the mechanisms of fish mortality (FWP Measure 5.6A.14), we propose to design and construct an experimental apparatus to generate known intensities and scales of turbulence in the laboratory, expose migratory fish (juveniles and smolts) to these levels of turbulence, and quantify the biological responses. Biological responses would be measured in terms of injuries, direct mortality (short-term and long-term), and changes in swimming capacity that might alter susceptibility to predation. Results of the studies would be used to develop biologically based criteria for turbulence that could be used by regulators and in the design of turbine systems, bypass systems, and spill procedures. The laboratory study would be accomplished during FY 2000, and the results would be conveyed by a progress report, a final test report, and open literature publications.

Section 8. Project description

a. Technical and/or scientific background

Turbulent flow occurs when fluid particles move in a highly irregular manner, even if the fluid as a whole is traveling in a single direction. That is, there are intense, small-scale motions present in directions other than that of the main, large-scale flow (Vogel 1981). Unlike laminar flow, which can be described by a linear equation, turbulent flow can only be defined statistically (Gordon et al. 1992); descriptions of the overall motion within turbulent flows cannot be taken as describing the paths of individual particles.

Turbulence exists at all scales in nature, from the swirling motion created when a salmon scoops out a redd (scales smaller than the size of the fish) to large whirlpools in a river (scales much larger than a fish). Turbulence near a large vessel, such as a barge, may vary considerably in both intensity and scale. Similarly, near a hydropower facility turbulence occurs at different intensities and scales, depending on location. High-intensity, small-scale turbulence, which occurs throughout a fish's passage through the turbine system, can distort and compress portions of the fish's body. Large-scale turbulence, which may be most pronounced in the draft tube and tailrace or in association with spill, creates vortices (swirl) which spin the fish and may cause disorientation. It is believed that this turbulence-caused disorientation, while perhaps not injuring the fish directly, may leave turbine-passed fish more susceptible to predators in the tailrace.

The effects of high levels of turbulence on fish survival are poorly known (Cada et al. 1997). In one of the few published experimental studies, Killgore et al. (1987) placed paddlefish yolk-sac larvae in circular containers and exposed them to differing frequencies and intensities of turbulence created by water jets. Low turbulence (1,774-1,902 dynes/cm^2) caused 3 and 13 percent direct, short-term mortality, whereas high turbulence (6,219-6,421 dynes/cm^2) resulted in 87 and 80 percent short-term mortality. Longer-term direct mortality, indirect mortality, and physiological stress were not examined. Based on these laboratory studies and field measurements of pressures near commercial barges (which sometimes exceeded 50,000 dynes/cm^2 near the propellers), Killgore et al. (1987) suggested that turbulence generated in the immediate vicinity of commercial vessels could cause mortality among paddlefish larvae. The sensitivity of other species, including salmonid smolts, to turbulence near large vessels such as barges has not been studied. Furthermore, the responses of fish to excessive turbulence associated with hydroelectric dam passage (turbine passage, spill, or fish bypass systems) is unknown.

Under the goal of improving Columbia and Snake River salmon passage, Task 5.6A.14 calls for the Corps of Engineers and other parties to conduct laboratory studies, numerical analysis, hydraulic model studies and prototype testing to develop an improved understanding of the mechanisms of fish mortality in turbines. This information should be used to develop biological design criteria in advanced turbine designs or modified unit operations to increase fish survival.

b. Rationale and significance to Regional Programs

See Subsection c for a description of related efforts of other organizations. The conclusion of numerous workshops and meetings sponsored both the U.S. Department of Energy and the U.S. Army Corps of Engineers is that development of advanced (fish friendly) turbines is hindered by a lack of information about the biological effects of potential injury mechanisms associated with turbine passage. One of these mechanisms, turbulence, can reach very high levels not only within a turbine, but also in the tailrace (associated with spill passage), and within fish bypass structures. Although little is known about the biological effects of excessive turbulence, it has been suggested that turbulence can cause direct injury and mortality, or at the least disorient fish so that they become more susceptible to predators.

We propose to design and construct an experimental apparatus to generate known intensities and scales of turbulence in the laboratory, expose migratory fish (juveniles and smolts) to these levels of turbulence, and quantify the biological responses. This has never been done for juvenile and adult fishes. Biological responses would be measured in terms of injuries, direct mortality (short-term and long-term), and changes in swimming capacity that might alter susceptibility to predation. Results of the studies would be used to develop biologically based performance criteria for turbulence that could be used by regulators and in the design of turbine systems, bypass systems, and spill procedures.

Because the research would be conducted on the East Coast, it will not be possible to utilize Pacific salmon in the proposed experiment. Instead, other smolt-sized salmonids (rainbow trout, perhaps Atlantic salmon smolts) would be studied. Other species found in both the Pacific Northwest and the East Coast could also be used, e.g., American shad, largemouth bass, sunfish, and channel catfish. The relationships between the independent variables (turbulence intensity and turbulence scale) and the dependent variables (mortality, injury, disorientation) would be established for these species. Turbulence would be expressed in standardized terms, e.g., root mean square of variations in flow velocity. Expressing the various turbulence-generating activities that occur in Pacific Northwest rivers (e.g., hydropower facilities; barges and other large vessels) in the same terms will permit the prediction of biological effects.

If significant species-specific differences are found, the tests would need to be repeated in the Pacific Northwest to obtain information about effects of turbulence on Pacific salmon. We expect to design the turbulence chamber in a modular fashion, such that it would be relatively easy to reconstruct this experimental apparatus at another location and achieve the same velocity and turbulence fields. Hence, one aspect of this proposal is a proof-of-concept, aimed at developing (1) quantifiable and replicable turbulence regimes and (2) a protocol for examining both direct and indirect (predation) mortality.

This study would satisfy the goals of FWP Measure 5.6A.14, in that it will "develop an improved understanding of the mechanisms of fish mortality in turbines," and can be used "to develop biological design criteria to be used in advanced turbine designs or modified unit operations to increase fish survival." This study would also provide information useful for many other FWP Measures aimed at improving Columbia and Snake River salmon passage (Section 5.6) and reducing predation (Section 5.7).

c. Relationships to other projects

The proposed work is not dependent on results from other projects funded under the FWP. However, it directly complements two related activities within the Columbia River basin. First, the objective of the U.S. Department of Energy's Advanced Hydropower Turbine System Program is to design, build, and test one or more environmentally friendly (fish friendly) turbines. Progress on the development of advanced Kaplan turbines (the type used at many Columbia River hydroelectric plants) has been slowed by a lack of biologically based performance criteria for injury mechanisms such as turbulence. The DOE program is supporting studies to develop these criteria for shear and pressure effects, but because of limited funds is unable to support critically needed studies of turbulence effects.

Second, the U.S. Army Corps of Engineers (Portland District) Turbine Passage Working Group is coordinating research efforts to understand and reduce fish passage losses. Like the DOE effort, the COE is supporting development of advanced turbines that could be used to retrofit existing turbines at their hydroelectric facilities in the Pacific Northwest. Although the COE recognizes turbulence as a potentially important, but poorly understood, mechanism affecting salmon survival, they do not have the resources to study this issue.

d. **Project history** (for ongoing projects)

Not applicable. This is a new project.

e. Proposal objectives

The overall objective of this laboratory study is to examine, under controlled conditions, the responses of fish to varying intensities and scales of turbulence. Responses would be measured in terms of direct mortality (short- and long-term), injury, and disorientation and decreased swimming performance that might lead to increased susceptibility to predation. The general null hypothesis to be tested is that turbulence has no significant adverse effect on fish survival and swimming capacity. This hypothesis will be refined as needed to consider different intensities and scale of turbulence, different species and life stages of fish, and different biological responses (e.g., injury, direct mortality, disorientation and diminished swimming ability). Test fish will be exposed to known levels of turbulence, and their responses will be compared to those of control fish.

Specific objectives are:

1. Assess the state-of -the-art in turbulence studies - Information about the potential adverse effects of turbulence will be updated by means of a literature review and contacts with specialists. Further, the designs of existing turbulence test apparatuses will be evaluated and considered for modification.
2. Develop a turbulence test apparatus - Based on the information obtained in objective 1, a laboratory turbulence test apparatus will be designed and constructed. The first, progress report will present the results of objectives 1 and 2.
3. Perform a hydraulic evaluation of the test apparatus - The velocity structure within the test apparatus will be characterized. Measurements of mean velocities and turbulent velocity fluctuations will be made on a pre-determined grid. This information will be used to insure that appropriate scales and intensities of turbulence are applied to test fish. Also, the velocity field characterization will be overlain on three-dimensional video recordings of the paths of test fish, in order to quantify individual exposures to turbulence.
4. Biological evaluation of test conditions - Fish will be exposed to the test conditions and biological response will be quantified, in terms of survival, specific injury types, disorientation, and changes in swimming performance.
5. Data analysis - Various expressions of the turbulent velocity field (independent variables from objective 3) will be compared to biological responses (dependent variables from objective 4) to develop response curves and biological criteria. This information can be used to guide a variety of activities, ranging from turbine and fish bypass designs to operational limitations on spill and other fish transportation measures.
6. Report preparation - The final report will present the results from objectives 3, 4, and 5, and suggest areas of future research.

f. Methods

1. Conduct a review of turbulence - The review of Cada et al. (1997) will be updated to incorporate any recently published information on damaging effects of turbulence. In addition to an examination of peer-reviewed literature and agency reports, investigators working in the general area of hydrodynamic effects of river/reservoir systems will be contacted to develop a range of turbulence values to be tested that will encompass expected levels of turbulence associated with hydroelectric turbines, fish bypass structures, draft tubes, dam tailwaters, and large vessels. The first progress report will present the results of these reviews and consultations, and outline how the information is reflected in the design of the turbulence chamber.

2. Design and build a turbulence chamber - Based on information developed in (1), the design of an experimental apparatus will be finalized and constructed to expose fish to appropriate scales and intensities of turbulence. The apparatus will be sized sufficiently large to preclude wall effects, and will have Plexiglas viewing ports to allow the use of non-intrusive velocity measuring techniques (e.g., Laser Doppler Velocimetry) and high-speed videotaping. The chamber will allow the introduction and post-exposure collection of test fish with a minimum of stress.

3. Instrument the turbulence chamber and characterize the velocity structure - The turbulence chamber will be fitted with three-dimensional velocity meters to estimate mean water velocities and turbulent

fluctuations (variations in velocity about the mean) on a very small-scale grid. This will enable the expression of turbulence intensities and scales to which test fish are exposed. High-speed cameras will be used to record and subsequently analyze in three dimensions the path of fish through the chamber. Water temperatures and dissolved oxygen concentrations will also be measured to ensure that these values remain within acceptable ranges.

4. Expose fish to pre-established levels of turbulence - Test fish will be introduced to the turbulence chamber singly, pass through at previously measured velocities and turbulence intensities, and collected in a holding chamber for post-exposure examination.

The introduction techniques will not expose fish to rapid velocity or pressure changes prior to passage through the turbulence chamber. Similarly, the post-chamber collection procedure will minimize collection injury. Control fish should be exposed to all aspects of pre-test handling, introduction, collection, and post-test holding as test fish, except for passage through the turbulence chamber. Procedures for selecting and handling both control and test batches of fish will be fully described in the first test report. Although appropriate controls can be used to remove the effects of handling, introduction, and collection, these effects will be minimized in order to increase the power of the tests.

Fish species tested in the turbulence chamber will include both salmonids (because of regulatory interest, sport, and commercial value) and shad (because of their great sensitivity to fluid-induced stresses). The test apparatus will be tested initially with juvenile rainbow trout; these fish can be obtained from a hatchery in large numbers and at a uniform size. They will give an indication of the types of injuries and mortalities that might be expected among similarly shaped salmonids, although they may be less susceptible to descaling than salmon smolts. Juvenile American shad can be obtained directly from the river; this species is expected to be among the most sensitive species to turbulence and other fluid-induced stresses.

The particular species and sequence of testing of species and lifestages will be based to some extent on availability. The list of fish species, sizes, and lifestages will include species of regulatory interest (e.g., salmonids; game fishes; eels; American shad) and fish expected to be sensitive to turbine-passage stresses (e.g., American shad; blueback herring). The sizes and lifestages selected should be representative of those likely to be entrained at hydropower projects, e.g., juveniles and downstream migrants.

All fish will be examined immediately for external injuries (e.g., fin loss, descaling, damage to eye or opercula) and mortality, and then transferred to holding tanks to assess longer-term (24-hr and 48-hr) delayed mortality.

Immediately after passage through the turbulence chamber, some of the uninjured fish will be transferred to a swimming competency chamber to determine whether important expressions of swimming performance (e.g., fast-start behavior; acceleration; maximum swimming speed), have been altered (compared to unstressed controls) by passage through the turbulence chamber. This test would help assess whether fish that are apparently uninjured after exposure to high levels of turbulence may nonetheless suffer mortality due to disorientation, decreased swimming performance, and increased susceptibility to predation. The second report will present the results of all testing in the turbulence chamber.

5. Data analysis - The precision of the estimates of mortality due to particular turbulence conditions will depend on a number of factors, including the variability in control and treatment mortality and the number of replicates. The anticipated numbers of fish available for testing, the numbers of fish partitioned among treatment and control groups, and the anticipated accuracy and precision of mortality estimates should be developed in the first test report.

6. Report preparation - The first, progress report will present the results of the literature review, values of turbulence intensity and scale that are found in natural rivers and in association with man-made structures, and the design of the turbulence test apparatus that will be used to recreate these turbulence values. The final test report will present response curves (value of turbulence intensity or turbulence scale vs. biological effect) for each species and life stage. These curves could be used to provide performance criteria for the design of turbines and fish bypass systems, operational criteria for spill, and regulatory actions. For example, if the regulatory or design criteria specify zero mortality among juvenile steelhead and 10 percent mortality among largemouth bass, the response curves would be used to estimate the highest possible

turbulence intensities that will comply with these criteria. Potentially, these criteria could even relate to indirect effects, e.g., susceptibility to predation is not significantly increased.

g. Facilities and equipment

The research would be accomplished at the Conte Anadromous Fish Research Center (CAFRC), USGS-Biological Resources Division. The facility is located in Turners Falls, Massachusetts. The Engineering Complex has its water intake on a power canal (Cabot Power Canal) and discharges into the Connecticut River. The facility has three large flumes. Tests will be conducted in one of the 10-foot flumes, which is 21 feet high, and 126 feet long. Flow capacity of the flumes exceeds 300 cubic feet per second (~135,000 gpm). Also, the unique location of the facility makes it convenient for collecting actively migrating fish for the tests. An upstream (Ice Harbor type) fishway and a downstream sampling facility exist and are accessible at Cabot Station.

CAFRC is fully equipped with research instrumentation necessary for hydraulic and biological evaluation of fish passage structures. The model shop at CAFRC and its personnel make fabrication, construction, and installation of test apparatus easy to do in-house.

CAFRC is also fully equipped with instruments, vehicles, boats, electroshockers, wet lab, holding tanks, compressed air, nets, etc. needed for collecting, handling, and holding of fish for testing purposes. Each staff member at CAFRC is equipped with and has adequate experience with personal computers. Data collection and analysis are usually done using instrument-to-computer interfaces for more capacity and accuracy.

h. Budget

Personnel costs are to support the contributions of a fisheries biologist (Cada at ORNL), an environmental engineer (Odeh at CAFRC), and a hydraulics engineer (Garold Sommers at Idaho National Engineering and Environmental Laboratory). All of these investigators have considerable experience in evaluating the environmental impacts of hydropower operations and the interactions of fluid stresses and fish.

Many of the materials needed to construct the turbulence test facility are already in place at the CAFRC; however, state-of-the-art instruments needed to characterize velocity structures within the apparatus would need to be acquired or leased (e.g., Laser Doppler Velocimeter, high-speed video camera system, and software to analyze the measurements from these instruments).

Section 9. Key personnel

Name: Glenn F. Cada

Position: Research Staff Member, Environmental Sciences Division, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, Tennessee, 37831-6036

Telephone: 423/574-7320 **Telefax:** 423/576-3989 **Internet:** gfc@ornl.gov

Higher Education:

1971 Bachelor of Science in Zoology, University of Nebraska
1973 Master of Science in Zoology, Colorado State University
1977 Ph.D. in Zoology, University of Nebraska
Areas of specialization: Fisheries biology and aquatic ecology

Hydropower-Related Work Experience: I have worked at Oak Ridge National Laboratory since 1977, involved in research and assessment of environmental effects of energy development. I have performed hydropower-related research, development, and impact assessment for the U.S.

Department of Energy (DOE), the Federal Energy Regulatory Commission (FERC), U.S. Agency for International Development (AID), and the Northwest Power Planning Council (NPPC). Since 1982 I have supported the DOE Hydropower Program by reviewing and analyzing environmental issues related to hydropower development (fish passage, water quality, and instream flow mitigation). I am helping develop biological studies in support of advanced turbine designs for the Advanced Hydropower Turbine System Program. I have provided technical support to the FERC Office of Hydropower Licensing for the analysis of impacts to aquatic resources of hydropower development in California, Colorado, and the Nooksack and Skagit river basins, Washington. I was a consultant to the U.S. Agency for International Development to develop site selection methodologies to minimize environmental impacts of small-scale hydroelectric development in Peru. I performed a critical review of the effects of water velocity on the survival of juvenile salmon and steelhead in the Columbia River Basin.

Cada, G.F. and J.E. Francfort. 1995. Examining the benefits and costs of fish passage and protection measures. Hydro Review 14(1):47-55.

Cada, G.F., C.C. Coutant, and R.R. Whitney. 1997. Development of biological criteria for the design of advanced hydropower turbines. DOE/ID-10578. U.S. Department of Energy, Idaho Operations Office, Idaho Falls, ID. 85 p.

Cada, G. F., M.D. Deacon, S.V. Mitz, and M.S. Bevelhimer. 1997. Effects of water velocity on the survival of downstream-migrating juvenile salmon and steelhead: A review with emphasis on the Columbia River Basin. Reviews in Fisheries Science 5(2):131-183.

Cada, G.F. In Press. Fish passage mitigation of impacts from hydroelectric power projects in the United States. Proceedings of the International Conference on Fish Migration and Fish Bypass-Channels, Vienna, Austria, September 25, 1996.

Cada, G.F. 1997. Shaken, not stirred: The recipe for a fish-friendly turbine. pages 374-382 IN Waterpower '97. Proceedings of an International Conference & Exposition on Hydropower. American Society of Civil Engineers, New York, New York.

MUFEED ODEH, Ph.D., P.E.

EDUCATION

1988	Ph.D., Civil and Environmental Engineering Area of
June	emphasis: Hydraulics and Fluid Mechanics
	Utah State University, Logan, Utah
1984	M.S., Civil Engineering
May	Area of emphasis: Municipal Public Works/Hydraulics
	University of Missouri, Columbia, Missouri
1982	B.S., Civil Engineering, (Dean's Honor List)
December	University of Missouri, Columbia, Missouri.

PROFESSIONAL CREDENTIALS

Registered Professional Engineer - Illinois and Massachusetts

AFFILIATIONS

American Society of Civil Engineers (since 1/1983), American Waterworks Association (1989-1990), Western Society of Engineers (1989-1990), American Fisheries Society, International Association for Hydraulic Research.

Adjunct Assistant Professor - Utah State University and University of Massachusetts.
External Advisor - Massachusetts Institute of Technology (MIT)

RESEARCH EXPERIENCE
At Conte Anadromous Fish Research Center I am in charge of all hydraulic research projects and facilities. Hydraulic research at CAFRC includes fish passage structures evaluation, hydraulic scale models and equipment testing and calibration, as well as other basic research in the area of hydraulic engineering. I supervise a research team comprised of engineers and biologists, prepare project budgets, and overlook planning, design and construction of all projects. I implement "Total Quality Management" and "Total Quality Principles."

For almost three years at UWRL, my research activities included hydraulic computer and physical modeling of open channel and closed conduit flows. This included scale modeling of open channel flow, pipe flow, water hammer, dams, spillways, pumping pits, turbine intakes and testing and calibration of numerous types of flow measuring controls.

Used Abu Dhabi distorted scale Tide Model for research on the effect of tides on desalination operations and the salinity of sea water. Also, potential oil spills in the gulf area and their impact on the environment and desalination activities and precaution measures were investigated. My duties included field data collection and analysis, supervision of model testing and remote data acquisition, experiment project design and report writing. I also reviewed contractor expense submittals, model test budgets and research plans.

Section 10. Information/technology transfer

Technical information developed by this study will be distributed by means of two test reports (progress report and final report) and subsequent open literature publications. The test data would be used to develop biologically based criteria for the design of advanced hydropower turbines, fish bypass intakes and outfalls, and spill conditions, and hence are of both commercial and regulatory value.

Congratulations!