APPENDIX A

PANEL MEMBER RESUMES

Steven V. Amarl
Charles C. Coutant
William P. Dey
Gregg Garner
Karin E. Limburg
William A. Richkus
Kenneth A. Rose

STEPHEN V. AMARAL

Director, Fisheries

EXPERIENCE SUMMARY

Mr. Amaral is the Director of fisheries staff and resources for Alden's Environmental Group. Mr. Amaral has extensive experience in the assessment and resolution of fish passage and protection issues at all types of water intakes. This experience has been developed over the past 14 years through the management of laboratory and field evaluations of developing and existing fish passage technologies. Mr. Amaral also performs evaluations of aquatic resource impacts for Federal Energy Regulatory Commission Environmental Impact Statements and for meeting Clean Water Act Section 316(b) requirements. Mr. Amaral is the author of several comprehensive reports describing the status of fish passage technologies and he was the lead in the development of a guideline document for turbine entrainment and survival studies. Recent projects that Mr. Amaral has been the lead biologist for include a biological evaluation of a Fish-Friendly Turbine, the development of an entrainment and impingement database for cooling water intakes, estimation of turbine and spillway survival at small hydro plants, laboratory and field evaluations of cylindrical wedge-wire screen entrainment and impingement, and an evaluation of estuarine fish responses to behavioral deterrents.

EXPERTISE

- Laboratory and field evaluations of downstream and upstream fish passage technologies - responsible for study design, performance, data analysis, and reporting/publications.

- Design of physical and behavioral fish guidance systems - site-specific designs of fish guidance systems for all types of water intakes with respect to biological considerations and effectiveness.

- Field Sampling techniques for fisheries applications - experience with various fish collection methods, habitat assessment techniques, and fish-tracking technologies.

- Literature-based estimates of turbine entrainment and survival at hydro projects - analysis of existing data to develop site-specific estimates of turbine entrainment and survival, eliminating the need for costly field studies.

- Assessment of aquatic resource impacts for FERC licensing and CWA Section 316(b) permitting requirements.

- Expert witness for issues related to the application and biological effectiveness of fish passage technologies.

SELECTED PROJECTS - REFERENCE AND GUIDELINE DOCUMENTS

Review of Fish Protection at Cooling Water Intakes (EPRI Report No. TR-114013) - lead author in the development of an EPRI report reviewing the current status of fish protection technologies for application at cooling water intakes. This report includes an assessment of available technologies and summaries of past research that has evaluated technologies during field and laboratory studies. The final report will serve as a reference and guidance document for the assessment and mitigation of Clean Water Act 316(b) issues.

Review of Downstream Fish Passage and Protection Technologies (EPRI Report No. TR-111517) - lead author in a review of downstream fish protection technologies for application at water intakes. Recent research efforts were summarized and the status of available technologies was assessed. This report was developed as an update to similar reports prepared by the Electric Power Research Institute that were published in 1986 and 1994.

Guidelines for Evaluating Fish Passage Technologies - co-author in the development of guidelines for evaluating fish protection technologies. This document was being prepared by a committee established by the Bioengineering Section of the American Fisheries Society. After public review, the final manuscript probably will be published in the AFS Fisheries magazine.

Nationwide Review of Fish Protection and Passage Technologies (EPRI Report No. TR-104122) - co-author of a comprehensive review of currently available and emerging technologies. This report has been widely utilized as a standard reference source on effectiveness studies conducted since EPRI published its initial review in 1986.

Fish Protection/Passage Technologies Evaluated by EPRI and Guidelines for Their Application (EPRI Report No. TR-104120) - co-author of a guideline presenting extensive information on design considerations, performance testing, and cost data for high velocity screening systems, barrier nets, and behavioral guidance systems.

SELECTED PROJECTS - FISH PROTECTION AND DOWNSTREAM FISH PASSAGE

Evaluation of Wedgewire Screen Entrainment and Impingement (Laboratory and Field Studies) – project manager for laboratory and field evaluations of fish entrainment and impingement associated with the use of cylindrical wedgewire screens. During the laboratory evaluation, fish eggs and larvae of several freshwater and estuarine species were evaluated to estimate entrainment and impingement rates with respect to screen slot size, through-slot velocity, and channel velocity. Field testing will be conducted at two sites using a barge-mounted test facility. The laboratory study was completed in 2002 and field testing will begin in the spring of 2004. Funding for both studies was provided by EPRI and the United States Environmental Protection Agency.

Evaluation of Behavioral Technologies for Application at a Cooling Water Intake – project manager for a laboratory study examining the ability of strobe light, sound, and an air bubble curtain to repel several estuarine species susceptible to impingement at a cooling water intake. The evaluation of these technologies was performed as part of a multi-phase study that includes the laboratory evaluation, an off-site field evaluation, and, based on the results of the first two phases, an evaluation of effective technologies at the plant's intake.

Evaluation of Alden/Concepts NREC Turbine – project manager for the biological evaluation of a new turbine runner designed to minimize fish injury and mortality. Nearly 45,000 fish were evaluated during a two-year laboratory effort to assess the ability of various species and size classes of fish to safely pass through the new runner. Fish injury and survival were evaluated for several operating conditions (operating head, turbine rotational speed) and to determine the effects of wicket gates. This study was being sponsored by the U.S. Department of Energy as part of their Advanced Hydro Turbine Systems Program (AHTS).

Evaluation of Entrainment and Mortality and the Effectiveness of Downstream Fish Passage Technologies for a Proposed Hydro Project – prepared technical documents that estimated turbine and spillway mortality rates for a proposed hydro project in Alberta, Canada. Also estimated the potential effectiveness of downstream fish passage systems for selected species. Served as an expert witness at a government hearing for determining the environmental and social impacts of the proposed project. Provided testimony on turbine and spillway mortality and effectiveness of proposed downstream fish passage technologies.

Evaluation of Angled Bar Racks and Louvers for Guiding Fish at Hydro Projects – project manager for a laboratory evaluation of angled bar rack and louver fish guidance efficiency. Several riverine fish species and the catadromous American eel were evaluated for their ability to effectively guide along several configurations of angled bar racks and louvers. Tests parameters that were examined included bar slat angle (i.e. bar rack vs. louver), slat spacing, structure angle to the flow, and approach velocity. This study was primarily funded by EPRI with additional support provided by Northeast Utilities, Wisconsin Electric Power Company, Wisconsin Department of Natural Resources, U.S. Fish & Wildlife Service, and the Menominee Indian Tribe of Wisconsin.

Evaluation of Behavioral Guidance Technologies for Diverting Chinook Salmon Smolts at the Roza Dam Screening Facility, Yakima, Washington - assisted with the evaluation of chinook salmon responses to behavioral guidance devices (strobe lights, a drop light, and an infrasound generator). Field efforts included cage testing with each device using a portable test facility constructed by Alden. Conducted data analysis of fish responses and prepared final report.

Evaluation of Fish Behavioral Barriers (EPRI Report TR-109483) - performed field sampling and data analysis and prepared the final report for a study that examined the ability of behavioral devices to elicit avoidance responses during cage tests and to reduce entrainment during field tests at a hydroelectric project on the Menominee River in Wisconsin.

Modular Inclined Screen Biological Evaluations - assisted in the design and implementation of a biological evaluation of the Modular Inclined Screen (MIS) in a laboratory setting for the Electric Power Research Institute. Assisted in the field evaluation of a prototype MIS at the Green Island Hydroelectric Project on the Hudson River. Conducted data analysis and prepared the final reports for both laboratory and field study.

Alternative Fish Protection Technology Assessments - addressed biological issues for alternative fish protection technologies that had potential for application at the Prairie Du Sac Hydroelectric Project (Wisconsin Power and Light), at three steam electric projects located on the Hudson River (Orange and Rockland Utilities), at the Glenn-Colusa Irrigation District's intake canal on the Sacramento River, and at the St. Anthony Falls and Hennepin Projects (Northern States Power).

Behavioral Barrier/Guidance Testing - conducted cage and field tests and performed data analysis for the following studies: (1) sonic fish deterrence study at the Salem Generating Station (Public Service Electric & Gas Company); (2) strobe light and high-frequency sound diversion of juvenile American shad at the York Haven Hydroelectric Project (Metropolitan Edison); (3) strobe light diversion of juvenile American shad at the Holtwood Hydroelectric Project (Pennsylvania Power and Light); (4) strobe light diversion of juvenile blueback herring at the Green Island Hydroelectric Project (Niagara Mohawk Power Company).

SELECTED PROJECTS - FERC LICENSING

Environmental Impacts of Hydroelectric Projects - evaluated the impacts of hydroelectric projects on aquatic resources as part of the development of Environmental Assessments for FERC relicensing. EAs were prepared for three projects located on Otter Creek in Vermont and one on the Shetucket River in Connecticut. Each impact assessment included evaluation of instream flow modifications, turbine entrainment and survival, and the need for downstream and upstream passage.

Turbine Entrainment and Survival Study Plans - prepared study plans for turbine entrainment and survival evaluations conducted at the St. Anthony Falls and Wissota Hydroelectric Projects (Northern States Power Company). These studies were conducted as part of the relicensing activities for each project.

EDUCATION

B.S., University of Massachusetts, 1989, Fisheries Biology
M.S., University of Massachusetts, 1996, Fisheries Biology

Additional Training

Massachusetts Cooperative Fish and Wildlife Research Unit, "Bioenergetics Modeling," 1992
Lotek Engineering, "Radio Telemetry Techniques for Fisheries Application," 1992
Hydroacoustic Technology, Inc., "Using Hydroacoustics for Fisheries Assessments," 1993

PROFESSIONAL ACTIVITIES

Member, American Fisheries Society
Editor, AFS Bioengineering Section Newsletter
Co-Chair, Fourth Fisheries Bioengineering Symposium, AFS Annual Meeting, 2002

SELECTED PUBLICATIONS/PRESENTATIONS

The Use of Angled Bar Racks and Louvers for Protecting Fish at Cooling Water Intakes, presented at the Symposium on Cooling Water Intake Technologies to Protect Aquatic Organisms, sponsored by the U.S. Environmental Protection Agency, 2003.

Laboratory Evaluation of Wedgewire Screens for Protecting Fish at Cooling Water Intakes, presented at the Symposium on Cooling Water Intake Technologies to Protect Aquatic Organisms, sponsored by the U.S. Environmental Protection Agency, 2003.

Biological Evaluation of Angled Bar Racks and Louvers for Guiding Silver American Eels, (lead author), *In*: Biology, Management, and Protection of Catadromous Eels, American Fisheries Society Symposium 33, 2003.

Engineering and Biological Evaluation of the Alden/Concepts NREC Turbine, (co-author), *In*: HydroVision 2002, HCI Publications, St. Louis, MO.

Biological Evaluation of Angled Bar Racks and Louvers for Guiding Lake and Shortnose Sturgeon, (lead author), In: Biology, Management, and Protection of North American Sturgeon, American Fisheries Society Symposium 28, 2002.

Assessing Guidance Efficiency of Angled Bar Racks and Louvers, (lead author), Hydro Review, Volume 21, No. 3, June 2002, p. 52-59.

Review of Downstream Fish Passage Technologies Developed for Use at North American Hydro Projects, presented at the Second Nordic International Symposium on Freshwater Fish Migration and Fish Passage, Iceland, 2001.

Reaction of Chinook Salmon, Northern Pikeminnow, and Smallmouth Bass to Behavioral Guidance Stimuli, (lead author), *In*: Behavioral Technologies for Fish Guidance, American Fisheries Society Symposium 26, 2001.

Fish Diversion Effectiveness of a Modular Inclined Screen System, (lead author), *In*: Innovations in Fish Passage Technology, American Fisheries Society, 2000.

Field Evaluations of the New Modular Inclined Fish Diversion Screen, (co-author and presenter), Waterpower 97, Proceedings of the International Conference on Hydropower.

EPRI Guidelines and Database for Turbine Entrainment and Survival Studies, (lead author and presenter), Proceedings of the Fish Passage Workshop, Milwaukee, WI, 1997.

New Concepts for Bypassing Fish at Water Intakes, 1995 International Conference on Water Resources Engineering, Special Section on Fish Bypass Systems, San Antonio, Texas.

Recent Advances in Sonic Fish Deterrence, (co-author), Waterpower '95, Proceedings of the International Conference on Hydropower.

Cost-effective Approaches for Protecting Fish at Hydroelectric Projects, (co-author), 1994 Annual Meeting of the Association of State Dam Safety Officials, Boston, MA.

Biological Evaluation of a New Modular Fish Diversion Screen, (co-author), Proceedings of the American Fisheries Society Bioengineering Symposium, Portland, OR, September 1993.

Use of Strobe Light and Sound Technologies for Protecting Juvenile Clupeids at Hydroelectric Projects, presented at the Pennsylvania American Fisheries Society Chapter Meeting, State College, PA, November 1993.

Differences in Stocks of American Shad from the Columbia and Delaware Rivers, (co-author), Transactions of the American Fisheries Society Volume 121, 1992, p. 132.

BRIEF RESUME

Charles C. Coutant, Ph. D.
Distinguished Research Ecologist, Environmental Sciences Division
Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6036
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Education: BA 1960 (Lehigh); MS 1962 (Lehigh); PhD 1965 (Lehigh).

Previous Positions: (1) Battelle-Pacific Northwest Laboratories, Richland, Washington (1965-70): Research Scientist, Columbia River Thermal Effects Studies;
(2) Oak Ridge National Laboratory (1970-present): Manager Thermal Effects Program (1970-79), Leader Multimedia Modeling Project (1979-82); Manager DOE Global Carbon Cycle Program (1985-86); Manager ORNL Exploratory Studies Program (1989-1991); Senior Research Staff (1982-85, 1986-88, 1992-present).

Professional Affiliations: American Association for the Advancement of Science (Fellow); American Institute of Fishery Research Biologists (Fellow); American Fisheries Society (AFS; Presidents of Water Quality Section, Tennessee Chapter, Southern Division, and full Society; Co-Editor of journal Transactions); American Society of Limnology and Oceanography; American Society for Testing and Materials (Chair Environmental Fate Models Task Group); Ecological Society of America (Vice Chair Applied Ecology Section); Sigma Xi (Southeast Regional Lecturer, President Oak Ridge Chapter); Water Pollution Control Federation (Literature Review Committee-Thermal Effects).

Honors: Darbaker Prize in Microbiology, Pennsylvania Academy of Science; Director's Award, Battelle-Northwest; Excellence in Fisheries, TN Chapter AFS; Outstanding Publication, Martin Marietta Energy Systems (operator of ORNL); Distinguished Publication, American Society for Information Science; Distinguished Service Award, AFS; Outstanding Achievement Award, Southern Division, AFS; 2002 ORNL Distinguished Scientist.

Publications: refereed articles in journals-48; non-refereed articles in journals-21; book chapters-29, symposium articles-31; laboratory or agency reports-87; book reviews, news articles, editorials-20; contributions to Environmental Impact Statements-9; total 246 (as of 1999; about 50 untallied since then).

Synopsis of Significant Technical Contributions: Field study of thermal discharge effects on invertebrates of Delaware River; Laboratory and field studies of thermal effects of Hanford reactors on Columbia River salmonids and other aquatic life; annual reviews of thermal effects publications 1968-1980; evaluation of aquatic thermal effects information to provide national water temperature criteria recommendations by the National Academy of Sciences; participation in development of EPA guidelines for Clean Water Act §316(a) thermal studies of power stations; development of biological data and criteria for environmental impact assessments of steam electric power plants; participant in the establishment of the Electric Power Research Institute and member of its national Advisory Council; development of electronic temperature telemetry of fishes as a research tool for thermal behavior studies; lead role in developing guidance for thermal power plant impact assessment for UNESCO and International Atomic Energy Agency; advisor on project evaluation to Bonneville Power Administration (BPA) Fish and Wildlife Program and member of Scientific Review Group; member of Northwest Power Planning Council's (NPPC) Independent Scientific Group; member National Marine Fisheries Service and NPPC's Independent Scientific Advisory Board for Pacific salmon restoration; member NPPC's Independent Scientific Review Panel for review of projects for BPA's Fish and Wildlife Program; elucidation of the thermal ecology of striped bass through laboratory and field research and its application to management of the species in fresh water and estuaries; evaluation of impacts of hydropower on aquatic systems; review and evaluation of §316(a) study plans, studies, and documents for power companies; new concepts for behavioral guidance of salmon smolts.

Synopsis of Management Experience: Leader of several research teams up to about 15 people; manager of Department of Energy intra- and extramural carbon dioxide research program ($4 million/yr); manager of ORNL internal funding program ($6-10 million/yr).

Synopsis of CWA 316(a) and (b) Advisory Roles: Co-author of EPA's 316(a) guidelines (1977); Co-chair of Technical Advisory Committee for Virginia Power Company's North Anna Power Station 316(a) studies (1980s); Co-chair of Technical Advisory Committee for Commonwealth Edison Co. 316(a, b) studies on Upper Illinois waterway (1991-1996); Technical Advisor to Electricity Corp of New Zealand for thermal discharge permitting patterned after 316(a) (1991-1994); Third-party advisor for Georgia Power Co. and the State of Georgia for Plant Branch 316(a) demonstration (1993-1999); Advisor for 316(a) demonstration studies for Carolina Power and Light Co.'s H. B. Robinson Steam Plant (1994-1996); Advisor for 316(a) demonstration by Public Service Electric and Gas Co. for Hudson Station (1995-1998), Mercer Station (1998-2001) and Salem Nuclear Station (1998-2000); Advice for siting a power plant in Portugal (1997); review of Brayton Point Plant 316(a) studies for USEPA (1997-1998 and 2003); Review and testimony on Diablo Canyon thermal effects monitoring for Pacific Gas and Electric (1999-2000); Review and white paper preparation for Hudson River Utilities (2001-2002).

William P. Dey
Senior Scientist/Associate

Mr. Dey has more than 25 years of experience conducting ecological risk, damage, and impact assessments and studies in marine, estuarine, and freshwater aquatic habitats. He has extensive experience in the management, design, data analysis, and technical direction of studies on the potential environmental effects of power plant operation, toxic chemicals, dredging, and ocean dumping.

Education

M.S.; University of Connecticut; Zoology; 1974
B.A.; Lehigh University; Natural Resources; 1972

Professional Affiliations

American Fisheries Society •Estuarine Research Federation •Hudson River Ecological Society •Society of Environmental Toxicologists and Chemists

Certified Professional Fisheries Scientist – American Fisheries Society

President – Hudson River Environmental Society

Experience

Ecological Risk and Impact Assessment—Project manager and senior staff member on comprehensive, multiyear, multiplant impact studies on the effects of power plant operation on fish populations in the Hudson and Delaware River estuaries, Chesapeake Bay and the Southern California Bight under Sections 316(a) and 316(b) of the Clean Water Act. Assessments included population modeling to determine the effects of both thermal pollution and water withdrawals on the early life stages of selected fish species. Served as project manager and principal scientist for an ecological investigation of the effects and independent review of natural resource damage claims of a chemical spill into a high quality trout stream in New York State. Served as a key technical staff member on an independent review of a large CERCLA Type B natural resource claim resulting from sewage treatment effluent, stormwater runoff, and industrial discharges in the Northwest. Served as lead scientist on a study investigating damages due to leachate from a large municipal landfill to the natural resources of Jamaica Bay and adjacent waters of the New York Bight. Project manager and technical director for a research effort to develop a methodology to rank suspected hazardous waste sites according to potential risks to local fish and wildlife resources at suspected hazardous waste sites in New York State. Project manager and lead scientist for a study to assess the ecological risks of chemical treatments to 5 large reservoirs in the New York City Water Supply system.

Aquatic Ecology—Directed a group of research scientists investigating the dynamics of larval and early juvenile fish populations to determine the effects of natural and human-induced stresses on factors such as mortality and growth rates, and subsequent year-class success. Manager and technical director for several large data analysis and report writing projects relating to the spatial and temporal distribution patterns, growth and abundance trends, and relationships with water quality trends for the early life stages of key fish species within the Hudson River Estuary. Assessed spatial and temporal patterns in abundance and long-term trends in abundance for fish in the Delaware Estuary and for fish and benthic invertebrates in the Arthur Kill and Hackensack River. Assessed trends over a 17-year period in the benthic communities of San Diego Bay. Prepared work plans for field and laboratory studies for the assessment of long-term consequences of power plant operation on Delaware Bay and the Southern California Bight. Assessed long-term trends in the composition and abundance of the fish community in the Hudson River estuary.

Aquatic Toxicology—Served as principal investigator on a research grant studying the incidence of liver cancer in the natural population of Atlantic tomcod from the Hudson River Estuary. Study included extensive histological, ultrastructural, and chemical examinations of this fish in an effort to relate the high incidence of cancer to factors such as fish age and growth as well as exposure to toxic chemicals and other environmental stressors. Principal investigator on U.S. Fish and Wildlife Service research grant to study the effects of water quality on the growth, development, and survival of striped bass larvae. Directed bioassay studies on effects of ammonia and high pH discharges on stream fish communities.

Modeling and Biometrics—Participated in the development and implementation of fully stochastic single- and multi-age structural models for the quantitative assessment of the effects of power plant entrainment and impingement on fish populations. Evaluated density-dependent and stock recruitment functions for the assessment of long-term power plant impact. Developed and implemented empirical models to estimate entrainment and impingement losses associated with water withdrawals in the Arthur Kill and Hackensack and Nanticoke rivers. Developed computer-based models to assess the assimilative capacity of streams to oxygen-consuming and ammonia-producing discharges.

Water Quality Assessments—Participated in the assessment of the assimilative capacity of streams in southern New York to receive additional discharges from existing and proposed wastewater treatment facilities. Evaluated impacts of ammonia discharges on stream water quality. Evaluated long-term trends in dissolved oxygen levels within highly impacted areas of the Arthur Kill and Hackensack River as affected by changes in the quality and quantity of effluent from municipal sewage treatment plant. Assessed contaminant concentrations in surface water discharges at 13 facilities owned by a major utility in New Jersey. Provided recommendations for operational changes and modifications to ensure future permit compliance. Project manager and lead scientist for the development of a work plan for establishing a site-specific water quality criteria for dissolved oxygen in South San Diego Bay.

Regulatory Requirements—Experienced in various regulatory environmental exhibits such as 316(a) and (b) demonstrations, FERC exhibits, and natural resource damage assessments. Provided expert testimony at public licensing hearing for siting of a new power plant (CPCN) and for an incidental take permit under the Endangered Species Act. Developed and reviewed testimony and cross-examination questions for major impact assessment cases. Participated in several technical negotiation sessions with regulatory agencies. Provided technical support for operational and mitigative options which could be offered as part of an out-of-court settlement.

Selected Publications and Presentations

Dey, W.P., J.R. Young, S.M. Jinks, N. Decker, J. Black and S. Amaral. 2003. Optimal Slot-Width Selection for Wedgewire Screens Symposium onTechnologies for Protecting Aquatic Organisms from Cooling Water Intake Structures, U. S. EPA, Arlington, VA

Dey, W.P. 2002. Use of equivalent loss models under Section 316(b) of the Clean Water Act. The Scientific World. 2(S1): 254-270.

Young, J. R. and W. P. Dey. 2002. Uncertainty and Conservatism in Assessing Environmental Impact under §316(b): Lessons from the Hudson River Case. The Scientific World Journal, 2(S1):30-40.

Waldman, J.R. and W.P Dey. 2002. Response by fishes to cleaner waters. Presented at Celebrating the 30th Aniversary of the Clean Water Act. Hudson River Environmental Society, New York City.

Dey, W.P, S. Jinks, and N. Decker. 2002. Changes in the fish community in the Hudson River estuary over the past 30 years. Presented at the American Fisheries Society Annual Meeting, Baltimore, MD. August.

Dey, W.P., S. Jinks., and G. Lauer. 2000. The 316(b) assessment process: evolution towards a risk-based approach. p. S15-S24. In: Power Plants & Aquatic Resources: Issues and Assessment. Enviromental Science and Policy. Vol. 3 Supplement 1.

Dey, W.P., S. Jinks., and G. Lauer. 1997. The Section 316(b) Assessment Process: Past, Present, and Future. Presented at the International Water Conference, Baltimore, Maryland.

Friedman, B.R., W.P. Dey, and S.M. Jinks. 1995. Use of oleophilic pads to achieve high swimbladder inflation percentages among intensively-cultured striped bass, *Morone saxatilis*. Presented at Aquaculture '95. San Diego, CA. 1-4 February.

Dey, W.P., T.H. Peck, C.E. Smith, and G.L. Kreamer. 1993. Epizoology of hepatic lesions in Atlantic tomcod from the Hudson River estuary. Can. J. Fish. Aquat. Sci. 50:1897-1907.

Lauer, G.J., M.V. Bastian, W.P. Dey, R.R. Garton, D.J. Lauren, and A. Pamperl. 1992. Natural Resources Damage Claims. Added new dimensions to "How Clean is Clean?" Presented at DRI Annual Symposium on Environmental, Hazardous Waste, and Toxic Tort Litigation. New Orleans, Louisiana.

Cormier, S.M., R.N. Racine, C.E. Smith, W.P. Dey, and T.H. Peck. 1989. Hepatocellular carcinoma and fatty infiltration in the Atlantic tomcod, *Microgadus tomcod* (Walbaum). Journal of Fish Diseases 12:105-116.

Klauda, R.J., J.B McLaren, R.E. Schmidt and W. P. Dey. 1988. Life history of white perch in the Hudson River Estuary. American Fisheries Society Monograph 4: 89-101.

Young, J. R., R. J. Klauda, and W. P. Dey. 1988. Population estimates for juvenile striped bass and white perch in the Hudson River Estuary. American Fisheries Society Monograph 4: 89-101.

McLaren, J.B, T.H Peck, W. P. Dey and M. Gardinier. 1988. Biology of Atlantic tomcod in the Hudson River Estuary. American Fisheries Society Monograph 4: 102-113.

Young, J. R., T. B. Hoff, W. P. Dey, and J. G. Hoff. 1988. Management recommendations for a Hudson River Atlantic sturgeon fishery based on an age-structured population model. Pages 353-365. In Smith, C. L. (ed.) Fisheries Research in the Hudson River. State University of New York Press, Albany.

Dey, W.P. 1981. Mortality and growth of young-of-the-year striped bass in the Hudson River estuary. Transactions of the American Fisheries Society 110:151-157.

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EDUCATION

Ph.D., ZOOLOGY (ECOLOGY) University of Maine, Orono, Maine. (1984)

M.S., FISHERIES AND WILDLIFE SCIENCES Virginia Polytechnic Institute & State University, Blacksburg, Virginia. (1980)

B.A., BIOLOGY Millersville University of Pennsylvania, Millersville, Pennsylvania. (1978)

PROFESSIONAL APPOINTMENTS

Director, Center for Environmental Studies, Virginia Commonwealth University (1995-present).

Associate Professor of Biology, Virginia Commonwealth University (1991-present).

Visiting NSERC Postdoctoral Fellow, Fisheries and Oceans Canada, Northwest Atlantic Fisheries Centre, St. John's, Newfoundland (1984-1985).

Research Fishery Biologist (GS-12), NOAA, National Marine Fisheries Service, Sandy Hook, New Jersey (1983-1984).

SELECTED GRANTS

Virginia Department of Conservation and Recreation; Co- PI. Biomonitoring and restoration protocols for coastal plain streams (2001-2004); $245,000.

U.S. EPA and NOAA, ECOHAB Program; Co-PI. Distribution of free-living, pathogenic amoebae in Chesapeake Bay tributaries (1998-1999); $50,000.

U.S. Environmental Protection Agency, Office of Science and Technology; PI. Fish tissue analysis for Chlordecone (kepone®) and related analytes in the vicinity of Hopewell, Virginia (1997-1998); $50,000.

U.S. Environmental Protection Agency, Chesapeake Bay Program Office; PI. Patterns of habitat use by anadromous fishes within a large river drainage -- a GIS analysis (1995-1999); $204,000.

SELECTED PUBLICATIONS

Ettinger, M., S. Webb, S. Harris, S. McIninch, G. Garman, and B. Brown. 2003. Distribution of free-living amoebae in the James River, Virginia. Parasit. Res. 89:6-15.

Webb, S., G. Garman, S. McIninch, and B. Brown. 2002. Fish epizootic events in Chesapeake Bay tidal rivers: a role for free-living pathogenic amoebae. J. Aquatic Animal Health 14:68-76.

MacAvoy, S., S. Macko, and G. Garman. 2001. Isotopic turnover in aquatic predators: quantifying the exploitation of migrating prey. Canadian Journal of Fisheries and Aquatic Sciences 58:923-932.

MacAvoy, S., S. Macko, S. McIninch, G. Garman. 2000. Marine nutrient contributions to freshwater apex predators. Oecologia 110:283-293.

MacAvoy, S., S. Macko, and G.C. Garman. 1999. Tracing marine biomass into tidal freshwater ecosystems using stable sulfur isotopes. Naturwissenschaften 85:544-546.

Garman, G. C., and S. Macko. 1998. The possible role of anadromous fishes as vectors of marine-derived nutrients in Atlantic coastal landscapes. J. North American Benthological Society 17:1243-1254.

CURRENT COLLABORATORS

Stephen Macko	University of Virginia
Stephen MacAvoy	American University
Stephen McIninch	Virginia Commonwealth University
Bryan Watts	College of William and Mary
Charles Rice	Clemson University
Stanley Webb	Virginia Commonwealth University
Leonard Smock	Virginia Commonwealth University

Curriculum Vitae – Karin E. Limburg

Faculty of Environmental and Forest Biology
State University of New York
College of Environmental Science and Forestry
1 Forestry Dr.
Syracuse, NY 13210

Education:
Ph. D. Cornell University, Ithaca, NY; Ecology & Evolutionary Biology, 1994
M.S. University of Florida, Gainesville, FL; Systems Ecology, 1981
A.B. Vassar College, Poughkeepsie, NY; Ecology-Conservation + Biology, 1977

Professional Experience (since receipt of PhD):

2003-present	Associate Professor, Biology, SUNY College of Environmental Science and Forestry
1999-2003	Assistant Professor, Biology, SUNY College of Environmental Science and Forestry
1997- 1999	Research Assistant Professor, Dept. of Systems Ecology, Stockholm University (Sweden)
1994- 1997	Postdoctoral associate, Institute of Ecosystem Studies, Millbrook, NY

Professional Affiliations:
AAAS, AIBS, Ecol. Society of America (ESA), American Fisheries Society (AFS), Estuarine Research Federation (ERF), International Society of Ecological Economics, Sigma Xi

Honors and Awards:
SUNY Research Foundation Award for Excellence in Scholarship and Research (2003);Promotion to Docent (roughly equivalent to Associate Professor) in Marine Systems Ecology, Stockholm University (1999); EPRI Graduate Fellowship - Program in Fish Biology (1991-93); Cooperative Education Internship - U.S. Fish and Wildlife Service (1991); Hudson River Foundation Graduate Fellowship (1988); T.T. Polgar Fellowship (1987, 1990).

Synergistic Activities (last 3 years):
National & International: Organizer, "Ecological Economics Approaches to Ecosystem Health, June 2002, International Society of Ecosystem Health conference, Washington, DC; Co-organizer, "SHAD 2001: a Conference on the Status and Conservation of Shads Worldwide" Baltimore, May 2001 (book in progress, to be published by American Fisheries Society); Organizer, "Analysis, Interpretation and Applications of Fish Otoliths and Other Hard Parts: the State-of-the-Art" June 2001 (reviewed in TREE, November 2001); Organizer, thematic session on Ecological Economics of Estuaries, ERF meeting, 1999; Participant, workshop on aquatic ecosystem conservation in the Adirondacks, The Nature Conservancy, June 2002; Participant, workshop on Research Agenda for A Rivers and Estuaries Institute (G. Likens and R. Bell, conveners), West Point, NY, February 2001; Participant, "Valuing the World's Ecosystem Goods and Services" (R. Costanza and S. Farber, PI's), National Center for Ecological Analysis and Synthesis, Santa Barbara, CA.
Regional: Co-convener of a workshop on sustainable development in Dutchess County, NY (June 2004).
On campus: Co-convener of two seminar series; developing interdisciplinary courses in Watershed Ecology; member of Center for Watershed Science and Engineering; member of Urban Ecology Initiative. In addition, I teach Fisheries Biology and graduate seminars.

Selected publications:

Limburg, K.E., K.A. Hattala, and A.W. Kahnle. 2003. American shad in its native range, pp. 125-140 *In* K.E. Limburg and J.R. Waldman, editors. *Biodiversity,Status, and Conservation of Shads Worldwide*. American Fisheries Society Symposium 35.

Limburg, K.E., M. Elfman, P. Kristiansson, K. Malmkvist, and J. Pallon. 2002. New insights into fish ecology via nuclear microscopy of otoliths. *Proc.17th International Conferemce on Applications of Accelerators in Research and Industry* (J.Duggan, editor). AIP Conference Proc. 680: 339-342.

Limburg, K.E., H. Wickström, H. Svedäng, M. Elfman, and P. Kristiansson. Do stocked freshwater eels migrate? Evidence from the Baltic suggests "yes." ***Biology, Management and Protection of Catadromous Eels*** (D.W. Dixon, editor). American Fisheries Society Symposium 33: 275-284..

Limburg, K.E. 2001. Through the gauntlet again: demographic restructuring of American shad by migration. *Ecology* 82: 1584-1596.

Limburg, K.E., P. Landergren, L. Westin, M. Elfman, and P. Kristiansson. 2001. Flexible modes of anadromy in Baltic sea-trout (*Salmo trutta*): Making the most of marginal spawning streams. *Journal of Fish Biology* 59: 682-695.

Limburg, K.E., M.L. Pace, and K.K. Arend. 1999. Growth, mortality, and recruitment of larval *Morone* spp. in relation to food availability and temperature in the Hudson River. *Fishery Bulletin* 97: 80-91.

Limburg, K.E. 1998. Anomalous migrations of anadromous herrings revealed with natural chemical tracers. *Canadian Journal of Fisheries and Aquatic Sciences* 55: 431-437. **Limburg**, K.E. 1996. Modeling the ecological constraints on growth and movement of juvenile American shad, *Alosa sapidissima*, in the Hudson River Estuary. *Estuaries* 19: 794-813.

Limburg, K.E. 1996. Growth and migration of 0-year American shad (*Alosa sapidissima*) in the Hudson River estuary: otolith microstructural analysis. *Canadian Journal of Fisheries and Aquatic Sciences* 53: 220-238.

Limburg, K.E., and R.M. Ross. 1995. Growth and mortality rates of larval American shad, *Alosa sapidissima* (Wilson), at different salinities. *Estuaries* 18: 335-340.

Limburg, K.E. 1995. Otolith strontium traces migratory histories of juvenile American shad, *Alosa sapidissima* . *Marine Ecology Progress Series* 119: 25-35.

Limburg, K.E. and R.E. Schmidt. 1990. Patterns of fish spawning in the Hudson River watershed: biological response to an urban gradient? *Ecology* 71:1238-1245.

Limburg, K.E., M.A. Moran, and W.H. McDowell. 1986. The Hudson River Ecosystem. Springer-Verlag, New York. 331 pp.

WILLIAM A. RICHKUS, Vice President, Operations Manager, Versar, Inc.

EDUCATION:

Ph.D., Oceanography, Graduate School of Oceanography, University of Rhode Island, l974

M.S., Oceanography, University of California (San Diego) Scripps Institute of Oceanography, l968

B.S., Zoology, University of Rhode Island, l966

FIELDS OF COMPETENCE AND EXPERIENCE:

Estuarine and freshwater fisheries biology, ecology and management; sampling and analytical methodologies; resource management; power plant impact assessment; NEPA; program design, implementation and management.

PROFESSIONAL BACKGROUND:

As Operations Manager and Department Director, Dr. Richkus oversees Versar, Inc., ESM Operations activities dealing with:

- Fisheries resource management and planning
- Impact assessment, facility siting, and regulatory review
- Statistical support services
- Data base management and information management
- Experimental design and quality assurance analysis services
- Mathematical and statistical modeling.

In addition to his administrative responsibilities, Dr. Richkus also supports clients in a technical management role, and has directed most of Versar's fisheries and resource management contracts and grants over the past 30 years. His fisheries project experience involves support of USFWS, NMFS, Atlantic States Marine Fisheries Commission (ASMFC), and the fisheries agencies of all the the mid-Atlantic states. His working experience with all East Coast states began when he served as Plan Writer under contract to the Atlantic States Marine Fisheries Commission for two major interstate fisheries management plans. He authored ASMFC's Amendment 4 to the Interstate Striped Bass Management Plan and ASMFC's Anadromous Alosid Interstate Management Plan. In preparation of these plans, Dr. Richkus coordinated the activities of technical personnel from as many as l7 state and federal agencies and prepared documents used in guiding the management of resources on an interstate and intrastate basis. He worked extensively with marine fisheries staff of FWS, NMFS and 17 states for a period of 10 years during and following development of these management plans. At the request of NYDEC, Maryland and New Jersey, he also presented overviews of striped bass management strategies at several public meetings in the coastal areas of these states. He subsequently worked under contract to the Maryland Department of Natural Resources to develop state management plans for American shad, hickory shad, alewife, blueback herring, white perch and yellow perch present in Maryland's Chesapeake Bay watershed. All of the management plans prepared by Dr. Richkus included extensive sections dealing with habitat requirements and habitat needs of the species to be managed, as well as management strategies that took into account population dynamics of the species. He also participated in several Maryland DNR-funded projects in which assessment and catch estimation methods for blue crab and soft shell clams were developed.

Dr. Richkus currently participates as a co-Principal Investigator on a project being conducted jointly with the University of Maryland for the Maryland Department of Natural Resources to conduct an ecological risk assessment of the State's proposal to introduce the Asian oyster into Chesapeake Bay waters. This project entails the development of demographic population models of both the Asian oyster and the native oyster, the application of those models to project trends in population growth under various conditions, and completion of a risk assessment to be conducted in accordance with USEPA guidelines for such efforts. The risk assessment findings will be incorporated into an Environmental Impact Statement to be issued by the Norfolk District U.S. Army Corps of Engineers.

Dr. Richkus developed an evaluation procedure for establishing the environmental acceptability of dredging throughout Delaware's Inland Bays. Under contract to DNREC, he co-authored a report entitled "Methodology for Evaluation of Proposed Dredging Projects in Delaware's Inland Bays" that will be used by DNREC in reviewing of all applications for dredging permits in the Inland Bays.

Dr. Richkus served as Corporate Principal on Verar's contract with the NYDEC to develop benthic and fish biological indicators for the Hudson River Estuary. These biological indicators will be used by the state in the development of biocriteria for implementation of water quality regulations. These studies included characterization of habitat throughout the Hudson River estuary and descriptions of the fish communities that occupy those habitats. He also contributed to several Versar studies which investigated the role of interactions among environmental conditions in controlling historical Long Island Sound fisheries variability. He served as a consultant on preparation of two FERC Environmental Impact Statements addressing the potential environmental impacts of a proposed gas pipeline crossing in Long Island Sound on essential fish habitat. On this project, his key role was as fisheries assessment reviewer, and he has reviewed and commented on the NMFS Essential Fish Habitat consultation that FERC is required to conduct in compliance with the new NMFS EFH rule.

From 1998 to 2001, he completed several reports on American eel for the Electric Power Research Institute that reviewed current knowledge on life history, behavior, fisheries, and hydroelectric impacts to stocks, examined abundance trends in stocks throughout North America, and reviewed mitigation measures for minimizing impacts. Under the most recent EPRI contract, he conducted a literature review of behavior specific to mitigation of hydroelectric impacts, and of technologies that could be employed to minimize or avoid impacts. In a related project, he currently serves as technical advisor to the New York Power Authority on studies being conducted at the F.D.R. hydroelectric project on the St. Lawrence River to evaluate means of mitigating impacts of that project on American eel stocks. In that role, he works with representatives of the US Fish and Wildlife Service, National Marine Fisheries Service, and staff of Canadian and New York State fisheries management agencies, as well as a number of NGOs.

He was Program Manager and co-author on Versar's NOAA project that entailed an analytical and statistical review of procedures for collection and analysis of commercial data used for management and assessment of groundfish stocks in the U.S. EEZ off Alaska. In this project, he reviewed and summarized currently management procedures applied to in the Northeast Pacific groundfish fisheries and developed recommendations for improved catch reporting to enhance NMFS's evolving ecosystem management approaches. He served as program manager and co-principal investigator on a Maryland Coastal Resources Division project to evaluate the suitability and applicability of fisheries population and yield models for the management of Maryland tidewater fisheries.

Dr. Richkus has for15 years served as Program Manager of Versar's Maryland Department of Natural Resources Power Plant Siting Program's Biology Integrator contract, and has supported PPRP for nearly 28 years in numerous capacities. In his management role, he has technical, fiscal and administrative oversight responsibility projects that include the design, implementation and interpretation of aquatic and terrestrial studies of impacts of existing or proposed power generation and transmission facilities, licensing and permitting review support (e.g., NPDES and 404 permits, CPCN), and contributing to program strategic development and planning. Areas of special technical expertise that Dr. Richkus contributes to the program include fisheries biology, fisheries management, licensing and mitigation. His has been extensively involved in projects that investigated power generation impacts to major resource species in the Chesapeake Bay, including striped bass, menhaden, blue crab and oyster. He has also directed a wide range of terrestrial and wetlands ecosystem studies and assessments within the Chesapeake Bay watershed to meet PPRP requirements, ranging from site specific wetlands delineations to cumulative impact assessments on watershed and landscape levels. Aquatic studies he has designed and managed have ranged from ichthyoplankton, zooplankton, benthic and fish community field studies, to complex population modeling of consequences of ichthyoplankton entrainment on adult fish stocks. He has participated on behalf of PPRP in NRC licensing activities for the Calvert Cliffs nuclear power plant, in numerous Maryland Public Service Commission proceedings for new proposed generating facilities in the state (including review of utility submittals, preparation and presentation of testimony, and preparation of certificate articles),and in FERC licensing proceedings for the Conowingo hydroelectric facility as well as numerous small-scale hydroelectric facilities in the state. He is a nationally recognized expert in assessment of impacts to fish populations from impingement and entrainment and CWA Section 316b compliance, having authored several book chapters and symposium volume sections on these topics.

Dr. Richkus served from 1991 to 1998 as Deputy Program Manager on Versar's NEPA support to the Federal Energy Regulatory Commission. In this role, he directed the preparation of 36 Environmental Assessments and Environmental Impact Statements or sections of such documents for the licensing or relicensing of hydroelectric facilities in 11 states throughout the country. Two of his most complex projects involved multi-disciplinary assessments of a variety of modes of aquatic, terrestrial and socioeconomic impacts as well as compliance with all applicable federal, state and local permitting requirements (e.g., NPDES, CWA Sections 401 and 404, NHPA). These projects also required extensive coordination and consultation with a wide range of federal, state and local agency staff (e.g., fisheries agencies, environmental protection departments and agencies) as well as Non-governmental Organizations (NGOs) and special socioeconomic groups, such as native American tribes.

Dr. Richkus directed the preparation of an Environmental Impact Statement for the USFWS and NJ Division of Fish and Game relating to the proposed introduction of Pacific salmonids to the Delaware River. He also provided extensive technical support to the City of Virginia Beach for assessing potential impacts of a water withdrawal project on anadromous fish, particularly striped bass, in the Roanoke River Basin. For both these projects, he participated in public meetings, often attended by hundreds of interested parties, making technical presentations and responding to participants' questions.

Over a 10 year period, Dr. Richkus managed several major contracts funded by the Maryland Department of Natural Resources, the Maryland Department of Environment, and the Maryland Port Administration to evaluate potential impacts associated with open water disposal of dredged material in the Chesapeake Bay. He served as Program Manager of one five year project that entailed the design and implementation of water and sediment quality studies and biological surveys necessary to characterize site status and project potential impacts, work that included the participation of several university and state agencies groups as well as specialty contractors. He worked with state and federal agencies, citizens groups and non-governmental organizations to develop site selection processes and reach consensus on potential optimal disposal sites. The work also included literature reviews, modeling and analyses, and preparation and publication of agency and public reports and documents. He organized and implemented agency and public meetings to present study findings and elicit comments and concerns. These meetings were attended by as many as 400 people. He currently serves as Versar's Corporate Principal on two contracts from the U.S. Army Corps of Engineers (Philadelphia and Wilmington Districts), funded at a level of >$2M annually, with responsibility for overall contract administration, technical oversight and resource allocation.

As consultant to a national environmental insurance firm, Dr. Richkus participated in Natural Resource Damage Assessment workgroup meetings associated with an acid water spill from a

Mulberry Phosphates mining company containment facility into the Alafia River in Florida. He reviewed impact assessments, resource status reports, and proposed mitigation measures for technical validity and feasibility. Dr. Richkus also served as an Expert Witness for the Department of Justice in a number of Clean Water Act cases, including proceedings against the Smithfield Meat Packing Co (fined $12.6M as a consequence of the court case) and in two proceedings against water treatment facilities in Florida. Support to DOJ included technical review of all material submitted in the cases, development of evaluation and litigation strategies, preparation of testimony and exhibits, and presentation of testimony. Dr. Richkus also contributed technically to two Versar projects funded by the Tampa Bay Estuary Program, one documenting the biota of Tampa Bay, and a second estimating pollutant loadings.

Dr. Richkus has participated in hearings before the Federal Energy Regulatory Commission, Maryland Public Service Commission and federal court. Participation included review of submittals and testimony, development of discovery inquiries, development of cross-examination questions, preparation and presentation of testimony and contributions to preparation and revision of briefs.

OTHER PROFESSIONAL ACTIVITIES:

1974-Present: Journal Referee, *Transactions of the American Fisheries Society*; *Fisheries*; *Fisheries Research Board of Canada*(no longer published); *Canadian Journal of Aquatic Science*; *Estuaries*
1978: Marine Program Chairman, Northeast American Fisheries Society Meeting
1979-1984: Chairman, Current Research Committee, Potomac Chapter, American Fisheries Society
198l-1984: Editor, Proceedings of the Annual Potomac Chapter American Fisheries Society Meeting.
1982: Invited participant, Chesapeake Bay Fisheries - Data Workshop
1982: EPA, Chesapeake Bay Program, Fisheries Management, Peer Review Workshop
1984: Invited Member, Legislative Advisory Committee, Maryland House of Delegates, Environmental Affairs Committee
1984: Program Chairman, Northeast American Fisheries Society Annual Meeting
1984: Appointed Member, Chesapeake Bay Commission Fisheries Management Advisory Group
1985-Present: Proposal Reviewer, Hudson River Foundation (reviews of 8 anadromous fish-related proposals)
1985: President-Elect, Potomac Chapter, American Fisheries Society
1985: Northeast Division Representative, Marine Fisheries Section, American Fisheries Society
1986: President, Potomac Chapter, American Fisheries Society
1986: Invited participant, EPA Estuarine Program, Workshop on Fish as Indicators of Toxic Pollutants
1990: Appointed Member, Communications Work Group, Chesapeake Bay Program
1990-Present: Board Member, Chesapeake Audubon Society

1990: Editorial Advisory Committee, Chesapeake Bay Foundation, State of the Bay Report
1991: Invited participant, ERF Annual Meeting, The Use of Science in Policy Development
1996 - 2001: Chair, Maryland Environmental Business Alliance
1994-Present: Board Member and Vice Chair: Pickering Creek Audubon Center (an environmental education center)
1996: Invited participant, Maryland Strategic Business Development Environmental Business Sector Working Group
1997: BS Environmental Sciences, Curriculum Development Committee, Towson University, Towson, MD
1998: Invited participant, EPRI/EPA 316b Technical Conference
1998: Canadian Embassy Invitee and Speaker, Americana Environmental Business Brokerage Event, Montreal, Canada
1999: MS Environmental Sciences, Curriculum Development Committee, Towson University, Towson, MD
1999 - 2000: Reviewer and Selection Panel Member, Canon National Parks Science Scholars Program, AAAS
2002: Symposium Organizer; American Fisheries Society 2002 Annual Meeting; "History of Chesapeake Bay Fisheries" and "Consequences of Beach Nourishment Projects to Atlantic Coast Fish Communities"

PROFESSIONAL AFFILIATIONS:

American Fisheries Society
Potomac Chapter, American Fisheries Society
Sigma Xi
American Institute of Biological Sciences
Maryland Environmental Business Alliance

PRESENTATIONS AND PUBLICATIONS:

Dr. Richkus has made over 50 presentations at meetings of the American Fisheries Society, American Association for the Advancement of Science, Animal Behavior Society, and American Institute of Biological Sciences; at Northeast Fish and Wildlife conferences; and at Savannah River Ecology Laboratory, among others, and has organized and implemented a number of meetings and workshops dealing with resource management and impact assessment. He has authored or co-authored over 100 publications, including peer reviewed journal articles, numerous NEPA documents, and other project technical reports.

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EDUCATION:
Ph.D., Fisheries Science, University of Washington, 1985.
M.S., Fisheries Science, University of Washington, 1981.
B.S., Biology and Mathematics, State University of New York at Albany, 1979.

PROFESSIONAL EXPERIENCE:
2001-present Professor, Coastal Fisheries Institute and Department of Oceanography and Coastal Sciences, Louisiana State University.
1998-2001 Associate Professor, Coastal Fisheries Institute and Department of Oceanography and Coastal Sciences, Louisiana State University.
1987-1998 Scientist, Environmental Sciences Division, Oak Ridge National Lab.
1983-1987 Scientist, Martin Marietta Environmental Systems (now Versar), Columbia, MD.

Adjunct Faculty: Department of Ecology and Evolutionary Biology, University of Tennessee
School of Natural Resources and Environment, University of Michigan
Department of Marine Sciences, University of South Alabama

SELECTED PROFESSIONAL ACTIVITIES:
Associate Editor: Transactions of the American Fisheries Society, Ecological Applications, Environmetrics.
Fellow of the American Association for the Advancement of Science (AAAS)
Ad-hoc reviewer for over 25 journals
Member of the Science Advisory Committee, Alabama Center for Estuarine Studies (an EPA Center of Excellence)
Member of the Reef Fish Stock Assessment Panel (provides scientific advice to the Gulf of Mexico Fisheries Management Council).
Invited Expert as panel member at the EPA Public Meeting of Technical Experts on Section 316(b) of the Clean Water Act, Washington, DC, May 2001.
Member of the Science Review Panel of the Environmental Water Account Program, and member of the Independent Science Board, of the CALFED (California-Federal) Bay-Delta Restoration Program, 2001-ongoing.
Member of the Science Review Team of the Modeling Workshop, done as part of the Greater Everglades Ecosystem Restoration Program, Ft. Lauderdale, FL, May 2002.
Invited reviewer for the San Antonio Guadalupe Estuarine System (SAGES) Modeling Project, San Antonio, TX, February 2003
Chairperson of 10 graduate student committees; member of another 20 student committees.
Speaker of over 35 invited presentations; co-author on over 100 presentations made by others.

SELECTED PUBLICATIONS (from a total greater than 85):

Winemiller, K.O., and **K.A. Rose**. 1992. Patterns of life-history diversification in North American fishes: Implications for population regulation. *Canadian Journal of Fisheries and Aquatic Sciences* 49:2196-2218.

Clark, M.E., and **K.A. Rose**. 1997. Individual-based model of sympatric populations of stream resident rainbow trout and brook char: model description, corroboration, and effects of sympatry and spawning season duration. *Ecological Modelling* 94:157-175.

Jaworska, J.S., **K.A. Rose**, and L.W. Barnthouse. 1997. General response patterns of fish populations to stress: an evaluation using an individual-based simulation model. *Journal of Aquatic Ecosystem Stress and Recovery* 6:15-31.

Van Winkle, W., **K.A. Rose**, B.D. Shuter, H.I. Jager, and B.D. Holcomb. 1997. Effects of climatic temperature change on growth, survival, and reproduction of rainbow trout: predictions from a simulation model. *Canadian Journal of Fisheries and Aquatic Sciences* 54:2526-2542.

Clark, M.E., **K.A. Rose**, J.A. Chandler, T.J. Richter, D.J. Orth, and W. Van Winkle. 1998. Simulating smallmouth bass reproductive success in reservoirs subject to water level fluctuations. *Environmental Biology of Fishes* 51:161-174.

Breitburg, D., **K. Rose**, and J. Cowan. 1999. Linking water quality to larval survival: predation mortality of fish larvae in an oxygen-stratified water column. *Marine Ecology Progress Series* 178:39-54.

McDermot, D., and **K.A. Rose**. 1999. An individual-based model of lake fish communities: application to piscivore stocking in Lake Mendota. *Ecological Modelling* 125:67-102.

Rose, K.A. 2000. Why are quantitative relationships between environmental quality and fish populations so elusive? *Ecological Applications* 10: 367-385.

Clark, M.E., **K.A. Rose**, D.A. Levine, and W.W. Hargrove. 2001. Predicting climate change effects on brook and rainbow trout populations in southern Appalachian streams: combining GIS and individual-based modeling. *Ecological Applications* 11: 161-178.

Clark, J.S., S. Carpenter, M. Barber, S. Collins, A. Dobson, J. Foley, D. Lodge, M. Pascual, R. Pielke, W. Pizer, C. Pringle, W. Reid, **K. Rose**, O. Sala, W. Schlesinger, D. Wall, and D. Wear. 2001. Ecological forecasts: an emerging imperative. *Science* 293: 657-660.

Rose, KA., J.H. Cowan, K.O. Winemiller, R.A. Myers, and R. Hilborn. 2001. Compensatory density-dependence in fish populations: importance, controversy, understanding, and prognosis. *Fish and Fisheries* 2: 293-327.

Jager, Y., and **K.A Rose**. 2003. Designing optimal flow patterns for fall chinook salmon in a Central Valley, California river. *North American Journal of Fisheries Management* 23:1-21.

Rose, K.A., and J.H. Cowan. 2003. Data, models, and decisions in US marine fisheries management: lessons for ecologists. *Reviews for Ecology, Evolution, and Systematics* 34:127-151.

Rose, K.A., C.A. Murphy, S.L. Diamond, L.A. Fuiman, and P. Thomas. 2003. Using nested models and laboratory data for predicting population effects of contaminants on fish: a step towards a bottom-up approach for establishing causality in field studies. *Human and Ecological Risk Assessment* 9:231-257.

APPENDIX B

SUMMARY OF PRIOR KWR FISHERIES IMPACT ASSESSMENTS

1.0 Introduction

Environmental impact assessments of the proposed KWR project extend back nearly 15 years, to the time the project was first proposed. Here are summarized the findings of assessments conducted since the U.S. Army Corps of Engineers Final Environmental Impact Statement for the project was issued. Only those aspects of the assessments that address the potential effects of the KWR intake on Mattaponi River fish populations are summarized. This information, presented in chronological order, provided a context for the Panel's evaluations, and assisted in identifying those issues on which there were differing conclusions drawn in prior assessments .

The RRWSG indicated to the Panel that a number of modifications were made to the KWR project subsequent to the release of the FEIS and before the VDEQ Water Protection Permit was issued. None of those modifications (e.g., a reduction in the size of the reservoir; change in location of the reservoir dam) related to the proposed Mattaponi River water intake structure or its location, but they did include imposition of more stringent minimum instream flow requirements, which are described in Section 2 of this report

2.0 Norfolk District, U. S. Army Corps of Engineers Final Environmental Impact Statement

The potential fisheries impact of the proposed KWR project were evaluated in the Final Environmental Impact Statement (FEIS) issued by the Norfolk District U.S. Army Corps of Engineers (USACOE 1997). The conclusions drawn in the FEIS relating specifically to the Mattaponi River intake were as follows:

- With wedge-wire screens having very low entrance velocities (i.e., = 0.25 fps) and very small openings (i.e., 1 millimeter slots), it is unlikely that severe impingement and entrainment impacts would occur.
- Some small fraction of eggs could potentially be damaged while attached to the screens. However, it is expected that eggs which float on the surface over the intake or roll on the bottom would safely pass the intake structures. Also, because American shad, hickory shad, and striped bass eggs are slightly heavier than water, it is likely that the majority of these eggs would be located below the intake entrance and would not be affected.
- While eggs are unable to move away from the intakes, larvae are capable of propelling themselves away from the pull of the intakes. This natural mechanism would help minimize larvae impingement on the intake screens.
- Anadromous fish species should not be measurably affected by any potential changes in Mattaponi River salinity conditions.

3.0 Virginia Department of Game and Inland Fisheries Impact Comments and Recommendations

In a letter dated July 14, 1997 to the Virginia Department of Environmental Quality and the U.S. Army Corps of Engineering, the Virginia Department of Game and Inland Fisheries (VDGIF) offered these comments and recommendations on the Mattaponi River fisheries impacts of the KWR project:

- Supported the use of a 1.0 mm wedgewire intake screen design with through-slot velocities not to exceed 0.25 ft/sec to reduce impacts on anadromous fisheries
- Recommended an anadromous fish instream work time-of-year restriction for all construction activities in the Mattaponi River from 15 February to 30 June to protect spawning individuals
- Recommended hydraulic dredging to reduce suspended sediment (turbidity)
- Supported provision of off-site fish passage to compensate for riverine impacts (in Cohoke Mill Creek) and requested coordination of fish passage site selection and design with VDGIF

4.0 Garman Report on KWR Water Withdrawal Impacts on Mattaponi River Anadromous Clupeids

A report entitled, "Analysis of Potential Effects of Water Withdrawal for the King William Reservoir on American Shad (*Alosa sapadissima*) and Related Anadromous Clupeid Fishes in the Mattaponi River, Virginia" was prepared for Malcolm Pirnie, Inc., the KWR engineering contractor for the KWR project, by Dr. Greg Garman on August 7, 1997, addressing a number of issues raised in comments from the Mattaponi and Pamunkey Indian Tribes on the FEIS. Conclusions presented in this report included:

- There is a paucity of data on anadromous alosids and the ecosystem of the Mattaponi River, which poses a significant constraint on an assessment of potential impacts
- In considering the likelihood of direct ecological impacts from a range of factors relating primarily to withdrawal of water from the Mattaponi River, and on populations of the genus *Alosa*, including hydrologic regime, salinity intrusion, impingement and entrainment of eggs and larvae, and genetic mixing, the potential for direct impacts from KWR was hypothesized to be minor (i.e., not biologically significant), or likely to be ameliorated by mitigating conditions.
- Based on the available information, there does not appear to be a substantial or scientific basis to claims of significant and detrimental impacts to migratory fish populations in the Mattaponi River.

5.0 Virginia Public Interest Review to U.S. Army Corps of Engineers

In a Commonwealth of Virginia Public Interest Review for the KWR project sent by Governor James Gilmore to the USACE Norfolk District on April 30, 2001, Governor Gilmore stated, "The stocks of anadromous fishes have dropped significantly over the past century, primarily due to overfishing and the blockage of potential spawning habitat. The State Water Control Board took a conservative approach in permitting the KWR project to ensure that the project will not harm efforts to recover these stocks. Accordingly, the Virginia Water Protection Permit incorporated all recommendations of the Virginia Department of Game and Inland Fisheries (VDGIF) to protect fisheries resources in the Mattaponi River."

6.0 U. S. Army Corps of Engineers, North Atlantic Division, Decision Memorandum

In a September 30, 2002 Decision Memorandum on the KWR Project issued by General Rhoades of the U.S. Army Corps of Engineers, North Atlantic Division, he states, "…These [fisheries] issues are adequately addressed by special conditions of the Virginia Water Protection Permit/Section 401 Water Quality Certificate issued by the Virginia Department of Environmental Quality on 22 December 1997."

7.0 VIMS KWR Fisheries Impact Assessment for VMRC

The RRWSG submitted its permit application to the Virginia Marine Resources Commission (VMRC) for a Subaqueous Lands Use Permit in 2003. As part of the application review process, VMRC requested that the Virginia Institute of Marine Science (VIMS) comment on the KWR permit application. The result of VIMS' technical review of the KWR application was provided to VMRC on March 12, 2003 (Mann 2003). Their analysis of fisheries and habitat issues within the area of concern was based on VIMS' anadromous fish monitoring program, the doctoral dissertation *Assessment of Spawning and Nursery Habitat Suitability for American Shad (Alosa sapadissima) in the Mattaponi and Pamunkey Rivers* (Bilkovic 2000) and further publications from this work (Bilkovic 2002a, 2002b), and ongoing research. The major conclusions of the VIMS' review were as follows:

- the loss of subaqueous bottom from KWR intake structure fill would be permanent, but would also be expected to have minimal adverse impact upon the littoral system.
- VIMS was unsure of the intake's maintenance requirements and procedures and could not provide guidance on the potential environmental effects associated with that activity.

- VIMS agreed with the findings of Basco (1996) that the KWR intake structure will result in chronic but localized disturbances of flow and sedimentation with minimal associated adverse environmental effects to the benthos and tidal wetlands in the vicinity of the intake.
- river ecology and fish behavior could be affected by the structure's function as a fish attractant and/or from noise during operation; fish eggs and larvae are a food source for higher predators and predator aggregation could contribute to the loss of eggs, larvae, and other prey in the vicinity of the intake; VIMS considered the potential for adverse impacts to general Mattaponi River ecology associated with alterations in localized predator-prey interactions and food chain dynamics to be significant local to the intake and decrease with distance from the intake.
- In the absence of data on potential noise generated by the intake, VIMS' best professional judgment was that the potential for adverse effects from noise is a concern that warrants careful consideration, since chronic disruption of adult spawning behavior could have significant negative effects on anadromous fish stocks.
- VIMS concluded, based on modeling in 1991, that alterations to the Mattaponi River's normal salinity patterns were insignificant and would not affect tidal wetland vegetation (and presumably fish) communities.
- More recent modeling indicated that tidal freshwater marshes and tidal swamp communities may retreat upstream in the face of continued increases in salinity levels throughout the rivers, a process that may occur regardless of the new reservoir operation.
- Species collected by Bilkovic (2000) from the intake structure's estimated zone of influence included Alosa *aestivalis* (Blueback herring), *Alosa pseudoharengus* (alewife), *Alosa sapidissima* American shad), *Morone Americana* (White Perch), *Morone saxatilis* (Striped Bass) and *Perca flavescens* (Yellow Perch).
- entrainment of American shad eggs (2.5 mm to 3.8 mm) and striped bass eggs (2.4 mm to 3.9 mm) is unlikely due to their size relative to the screen slot width
- impingement will induce mortality due to the fragile nature of the eggs.
- Striped bass are at a reduced risk relative to American shad due to their predominance downstream of the proposed intake.
- some unknown proportion of the eggs of Alewife (0.8 mm to .27mm), blueback herring (0.87 mm to1.11 mm), and white perch (0.75 mm to 1.09 mm) are considered vulnerable to entrainment
- Yellow perch eggs are semi-buoyant and attach to vegetation or bottom material, making entrainment or impingement less likely.
- Since larval stages of American shad, perches and river herrings are weak swimmers with thin, thread-like and fragile bodies, their vulnerability to impingement and

entrainment during encounters with the intake structure is increased; there is little question that such encounters will result in mortality of these life stages.

- VIMS stated that great uncertainty exists surrounding the [screen exclusion] efficiency factor…There is an indication, however, that fish eggs and early larval stages are often free floating or have minimum swimming ability (Turnpenny, 1983). In the absence of clear guiding information VIMS assumed a conservative screen efficiency factor of zero.
- relatively large proportions of American shad and white perch eggs, and larvae of American shad, herring, white perch, and yellow perch were found within the intake's zone of influence during the 1997 – 1999 sampling period.
- daily estimates of spawning season average loss under a 75 mgd withdrawal scenario range from 255 striped bass eggs and 6,802 American shad larvae to 2,805 white perch eggs and 168,510 white perch larvae. Average daily estimated losses would range from 49 striped bass eggs and 1,315 American shad larvae to 542 white perch eggs and 32,578 white perch larvae under a 14.5 mgd withdrawal scenario.
- VIMS indicated that they could not estimate the probable losses to adult stocks of American shad, white perch, yellow perch, striped bass or river herring based on their analysis of impingement and/or entrainment of eggs and larvae by the intake structure; they indicate that small increases in daily mortality of eggs and larvae of stocks that are low in abundance could result in recruitment failure. VIMS states that the value of methods for projecting early life stage losses to adult life stages (e.g., equivalent adults modeling) to provide recommendations for management decisions is questionable.

8.0 ASA KWR Fisheries Impact Assessment Report

On April 2003 the RRWSG released a report entitled, “King William Reservoir: Potential Impacts of Water Withdrawals on Fish Populations of the Mattaponi River,” prepared by ASA Analysis & Communication, Inc.

Major conclusions presented in the ASA report were as follows:

- the proposed intake design, even at maximum pumping rates, will be sufficiently protective to ensure that biologically significant numbers of fish eggs, larvae, or older stages or larger macroinvertebrates will not be impinged.
- it is likely that the withdrawal of water from the Mattaponi River will result in the removal of a portion of the early life stages of some species of fish.
- only two year-round inhabitants, white perch and yellow perch, have planktonic (i.e. transported about by currents) early life stages and are abundant in the vicinity of the proposed intake; because of their potential involvement with the proposed intake, these two were selected for assessment.
- all four anadromous species (striped bass, American shad, alewife, and blueback herring) have planktonic early life stages and can be found in the vicinity of the proposed intake at Scotland Landing and were also selected for assessment.
- there is little likelihood of any significant entrainment of striped bass eggs or larvae at the proposed Mattaponi River intake
- the potential for entrainment of American shad eggs at the Mattaponi River intake appears minimal
- the annual fractional loss of American shad larvae under the mean withdrawal rate for April and May (14.1 mgd) would be less than 0.2 percent of the population.
- this average rate of loss would range from less than 1 to 6 equivalent adult American shad in each year.
- it is likely that some river herring eggs could pass through the intake screens; however, given that most spawning likely occurs well away from the proposed intake location, the potential for entrainment of river herring eggs is very limited.
- the annual fractional loss of river herring larvae under the mean withdrawal rate for April and May (14.1 mgd) would be less than 0.5 percent of the population.
- Assuming a period of entrainment vulnerability totaling eight weeks, this average rate of loss would equate to 7 to 24 equivalent adult river herring per year.
- the potential population level risk from entrainment of white perch eggs at the Mattaponi River intake is minimal

- the annual fractional loss of white perch larvae under the mean withdrawal rate for April and May (14.1 mgd) would be approximately 0.3 percent of the population;
- assuming a period of entrainment vulnerability totaling eight weeks, this rate of loss would range from 68 to 97 equivalent adult white perch per year
- the potential population level risk from entrainment of yellow perch eggs at the Mattaponi River intake is minimal
- the annual fractional loss of yellow perch larvae under the median withdrawal rate for April and May (14.1 mgd) would be less than 0.1 percent.
- there is no reason to expect that the relatively small changes in salinity distributions within the Mattaponi River expected from the water withdrawals for King William Reservoir will have any affect on habitat availability or spawning and nursery success of fish within the River.

Additional technical information was provided to VMRC by ASA in response to technical comments made by Commissioner Dr. Cynthia Jones on findings presented in the ASA report. Questions were raised by Dr. Jones concerning the validity of the adult loss projections when the population being modeled was not at equilibrium (equilibrium population is an assumption of the Equivalent Adults Model) and when the biological input data were not specific to the stock being modeled, and the level of uncertainty associated with the projections given the uncertainties in model input parameters. In a May 8, 2003 letter from Mr. William Dey of ASA to Dr. Cynthia Jones, VMRC, Mr. Dey addressed these issues by presenting results of a sensitivity analysis using a range of input values for wedgewire screen exclusion efficiency, fishing mortality, and net reproductive rate. The range of lost adults based on the most extreme values of each of those three model inputs was 0 to 50.

9.0 Other Fisheries Assessment Comments and Issues, and Panel Use of Prior Assessment Results

Many individuals and organizations submitted comments on the FEIS, participated in VDEQ permit proceedings, and presented testimony at the VMRC KWR permit hearing that related to fisheries issues. From reviews of submittals and testimony, it appears that the VIMS and ASA documents encompass all the relevant categories of Mattaponi River fisheries impact issues, and thus the details of these numerous hearing comments are not summarized here.

While the VIMS and ASA reports are in agreement on a number of elements of their impact assessments (e.g., identification of species potentially impacted), significant disagreements on some issues are also evident. While the Panel was aware of the positions of the different parties on a number of the most significant fisheries impact issues, our effort in preparing this report was directed at drawing our own conclusions and developing measures to eliminate or minimize fisheries impacts, and not on resolution of conflicting conclusions and opinions presented in prior assessments. However, where it appeared appropriate, some of the most significant points of disagreement are mentioned in some sections of the report, particularly where useful in examining conflicting technical positions.

APPENDIX C

METHODOLOGY FOR ESTABLISHING TEMPERATURE TRIGGER POINTS FOR PROTECTION OF EARLY LIFE STAGES OF FISH IN THE MATTAPONI RIVER:

HUDSON RIVER PROTOTYPE

1. Introduction - Purpose and Objective of Analysis

The purpose of this report is to provide a basis for developing biologically-based triggers to define a pumping hiatus for the proposed Mattaponi River intake for King William Reservoir. These triggers will be designed to provide the maximum practicable protection to the early life stages of American shad, and to provide a high degree of protection to other fish species of concern (river herring, striped bass, and white perch) that utilize the Mattaponi River as spawning and nursery habitat.

Unfortunately, site-specific data to develop technically sound triggers for the Mattaponi River are limited. In 1997 – 1999, sampling of the early life stages of fish in the Mattaponi River was conducted as part of a larger study evaluating the spawning and nursery habitat requirements of American shad in the Mattaponi and Pamunkey rivers (Bilkovic 2000). However, these data did not capture the full temporal occurrence of the key fish species in the river in any single year nor were the number of years covered sufficient to accurately capture the true year-to-year variability in temporal abundance patterns.

A broader review of studies on the temporal patterns in egg and larval fish abundance in tidal freshwaters waters of Chesapeake Bay also revealed only very limited data which we determined was insufficient for the purposes of developing temperature triggers for a pumping hiatus. For example, ichthyoplankton sampling in the Pamunkey River was conducted in 1989 and 1990 (Sismour 1994). However, intensive sampling necessary for this assessment was limited to a single year (1989) and the focus of this study was on river herring not American shad. Extensive multi-year ichthyoplankton sampling programs in the Potomac River in the 1980s targeted striped bass, and the catch of American shad eggs and larvae was too sparse to be of value for this analysis effort (Krainak et al, 1977). Further a field, ichthyoplankton sampling of the upper tidal Delaware River was conducted in 1998 (PSEG 2001). However, this sampling was also limited to a single year and the sampling location was well downstream of primary shad spawning and nursery grounds, so few shad eggs and larvae were collected. American shad scientists in the Chesapeake Bay watershed (R. St. Pierre, USFWS; M. Hendricks, Pennsylvania Fish and Boat Commission; D. Weinrich, Maryland Department of Natural Resources) were also contacted to determine if any other useful American shad early life stage data might be available. They indicated they were unaware of data sets other than those we had identified.

Owing to the lack of appropriate data from areas in or near the Mattaponi River, we decided to use an extensive fisheries dataset available for the Hudson River. The Hudson River estuary is located approximately 300 miles north of the Mattaponi River. The Hudson River dataset was found to contain a wealth of information on American shad and the other target species that was sufficient for a scientifically rigorous assessment. The tidal portion of the Hudson River is an estuary that extends more than 150 miles from its mouth at New York City north to the Green Island Dam at Troy. Tidal freshwaters of the estuary are of excellent quality and serve as a source of drinking water for several communities along its banks. The Hudson River estuary also contains a healthy and diverse fish community, including abundant populations of many of the same species that dominate the fish community of the Mattaponi River. Virtually all of the fish species of concern related to the proposed King William Reservoir water withdrawals are also abundant in the Hudson River estuary.

As a result of concerns over the potential effects of cooling water withdrawals by five existing steam-electric generating stations on anadromous and resident fish populations, the Hudson River estuary has been subject to intensive fisheries investigations since 1974. These studies have focused on the early life stages (e.g., eggs and larvae) of fish using the Hudson River as spawning and nursery habitat. The cumulative, almost 30-year dataset compiled as a result of these ongoing studies has yielded an information base on the spatial and temporal patterns of abundance of many anadromous fish species that is unmatched anywhere in the world.

The data collected in the Hudson River estuary provide excellent information on the spatial and temporal occurrence patterns for each of the primary species of concern for the King William Reservoir project. In addition, these studies targeted those life stages most vulnerable to power plant withdrawals (eggs and larvae), and so are directly relevant to an assessment of the proposed water withdrawal intake on the Mattaponi River. We believe that the Hudson River studies provide an invaluable dataset to illustrate how temperature triggers for pumping hiatus can be defined for the Mattaponi River.

We recognize, however, that the actual dates in which the eggs and larvae of the target species are found in the Hudson River will not be the same as the dates in the Mattaponi River. For example, it is reasonable to expect that American shad spawning occurs much earlier in the Mattaponi than in the more northern Hudson. Such a supposition is clearly supported by available data. It is widely recognized that water temperature is an important, and potentially predominant, cue for spawning in American shad and water temperature is an important determinant for subsequent larval development rates (Weiss-Glanz et al. 1986; Collette and Klein-MacPhee 2002). Hence, the abundance patterns of egg and larval fish in systems like the Hudson and Mattaponi should be strongly linked to patterns in water temperature. Therefore, the Hudson data will not be used to define absolute trigger dates for use in the Mattaponi, but rather to identify candidate water temperatures for triggers that can then be later refined with Mattaponi River monitoring data (see Appendix A).

In this document, we use data from the Hudson River estuary to determine possible temperature trigger points for pump shutdown and startup during the spring egg and larval season. The analysis contained herein consists of four discrete steps:

> Step 1. Compare temperature patterns in the Hudson River estuary with temperature patterns in the Mattaponi River to determine if the Hudson could serve as a reasonable surrogate.
>
> Step 2. Determine the relationship between water temperature and the abundance of American shad eggs and yolk-sac larvae in the Hudson and select appropriately protective temperature triggers.
>
> Step 3. Evaluate the timing (calendar dates) and duration (number of days) of a pumping hiatus associated with selected temperature triggers based on long-term term temperature records from the Hudson River estuary.

Step 4. Estimate the level of biological protection afforded by pumping hiatuses based on various combinations of temperature triggers for four target fish taxa (American shad, river herring, striped bass, and white perch) using the long-term fish monitoring database from the Hudson River estuary.

The results of each of these steps are described in the following sections. While the results presented in this document are largely derived from the Hudson River estuary, it is important to recognize that, prior to initial operation of the Mattaponi River intake, intensive multi-year sampling of the Mattaponi River will provide the necessary site-specific information that will be used, if necessary, to refine the temperature triggers in order to provide a specified level of protection. A detailed description of the proposed sampling plan for the Mattaponi River is provided in Appendix A. The Hudson River analysis presented herein quantitatively illustrates how the resulting Mattaponi data will be analyzed to identify temperature triggers in the Mattaponi that provide maximum practicable protection for early life stages of shad.

2. Brief Description of Hudson Studies

Routine fisheries investigations of the Hudson River estuary began in 1974 and have continued annually to the present time. While these investigations address a wide variety of life stages, particular emphasis has been on the ichthyoplankton (fish eggs and larvae) because these life stages are most vulnerable to the power plant cooling water withdrawals. The results of these studies have been summarized in a series of annual "Year-Class" reports, which provide the results of each year's sampling. Such "Year-Class" reports have been published annually since 1974. Examples of recent "Year-Class" reports include ASA (2000, 2001a, 2001b, 2002).

In these fisheries investigations, sampling of fish eggs, larvae and early juveniles consisted of a complete survey of the entire estuary on a weekly basis during periods of principal ichthyoplankton occurrence. Sampling was conducted using a stratified random design with approximately 200 ichthyoplankton samples being collected each week, although only about 110 have been analyzed per week in recent years. For each annual survey, the Hudson River estuary was divided into 13 geographic regions based on morphometry (Figure 1). Each of these regions was further divided into 3 strata consisting of a shoal stratum (areas of the estuary $\leq$ 20 deep), a bottom stratum (areas of the estuary > 20 feet deep and encompassing a water column up to 10 feet off the bottom), and a channel stratum (areas of the estuary > 20 feet deep and > 10 feet off the bottom. Sampling locations within each region and stratum were assigned randomly. In addition, sampling depths within the channel stratum were also assigned randomly. A minimum of three samples was collected within each combination of region and stratum.

Samples in the channel stratum were collected using a 1.0-m^2 Tucker trawl, while samples in the bottom stratum were collected using a 1.0 m^2 epibenthic sled. The shoals stratum was sampled by both gear. Both gears were equipped with 505-micron mesh nets and digital flowmeters to record volume sampled. All samples were collected for approximately 5 minutes duration at a tow speed of approximately 1 meter per second, yielding an average of 300 m^3 of water sampled. Samples collected were preserved in 10 percent Formalin and forwarded to the laboratory for processing.

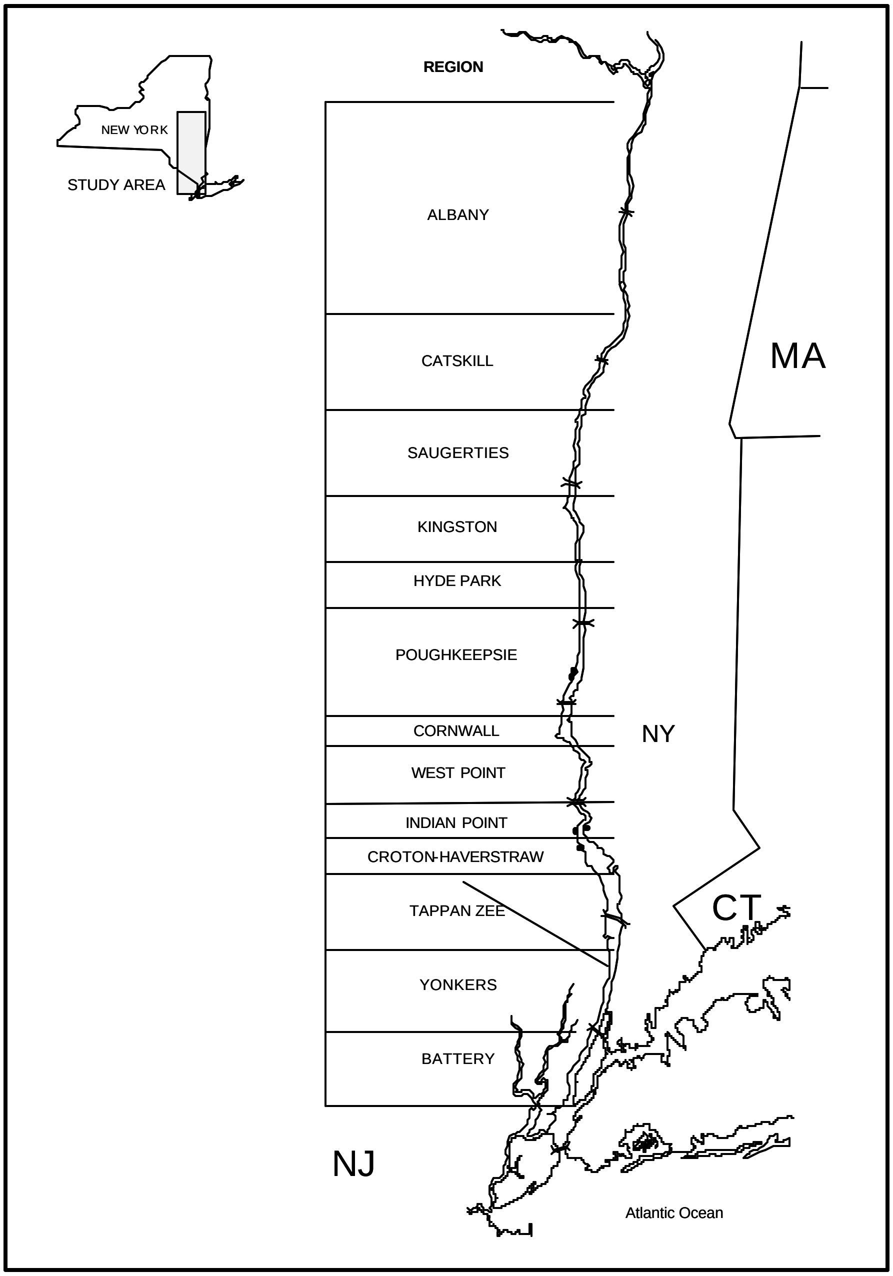

Figure 1 Geographic regions used in the ichthyoplankton surveys of the Hudson River estuary, 1974 – 2000.

In the laboratory, all fish eggs, larvae and early juveniles were removed from each sample selected for analysis, and identified to the lowest practical taxon (usually species, although alewife and blueback herring were collectively identified as river herring). Specimens were also assigned to one of four life stage categories: egg, yolk-sac larva, post yolk-sac larva, or juvenile. The transition from the yolk sac to the post yolk-sac larval stages occurred at the completion of a functional digestive system, while the transition from the larval to the juvenile stage occurred at the acquisition of a full complement of adult fin rays.

3. Step 1: Relationship Between Temperature Patterns in Hudson and Mattaponi Rivers

The first step in the analysis was to compare patterns of water temperature in the Hudson River estuary with those in the Mattaponi River. The focus of this comparison was on the spring spawning and larval nursery period. While it is reasonable to expect water temperatures in the Mattaponi River to increase earlier in the year than in the Hudson, we were interested in knowing if the rates of temperature rise are similar. If so, then it would be reasonable to expect that the periods of egg and larval occurrence would be of similar duration. Further, similar rates of increase in water temperature would increase our confidence on the transferability to the Mattaponi River of temperature triggers for a pumping hiatus developed using Hudson data.

Daily measurements of water temperature in the Hudson River have been collected since 1951 at the Poughkeepsie Water Works (PWW) intake located in the freshwater area of the estuary. Owing to the strong tidal currents and resulting water mixing in the Hudson, the PWW temperature records provide a reliable measure of water temperatures throughout freshwater areas of the estuary (Wells and Young 1992). In the Hudson, water temperatures increase in an almost linear fashion starting at 0 to 2 C in mid-March and rising to 22 to 24 C by late June or early July (Figure 2). While there is variability in the actual water temperatures in the Hudson from year to year, it appears that the same temperatures are reached within a two-week window in approximately 75 percent of the years. This year-to-year variation in water temperature appears to be a major determinant of observed temporal variation in the occurrence of the egg and larvae of many resident and anadromous fish species.

Unfortunately similar long-term records do not exist for tidal freshwater areas of the Mattaponi River[1]. Since 1995, the City of Newport News Waterworks has conducted some water temperature monitoring of the tidal Mattaponi River on a monthly basis at a station located approximately 0.5 miles upstream of Scotland Landing. These measurements were part of a larger monitoring of physical and chemical parameters of the Mattaponi River. While these measurements exhibit considerable variability from year to year, comparison to the Hudson data show that both rivers exhibit generally similar rates of increase during spring, with temperatures

[1] Long-term records exist for water temperature measured at the VIMS pier on the lower York River. However, this location is under the direct influence of Chesapeake Bay and is mesohaline. Hence, these records were not considered to be reliable measures of water temperature in the freshwater areas of the Mattaponi River.

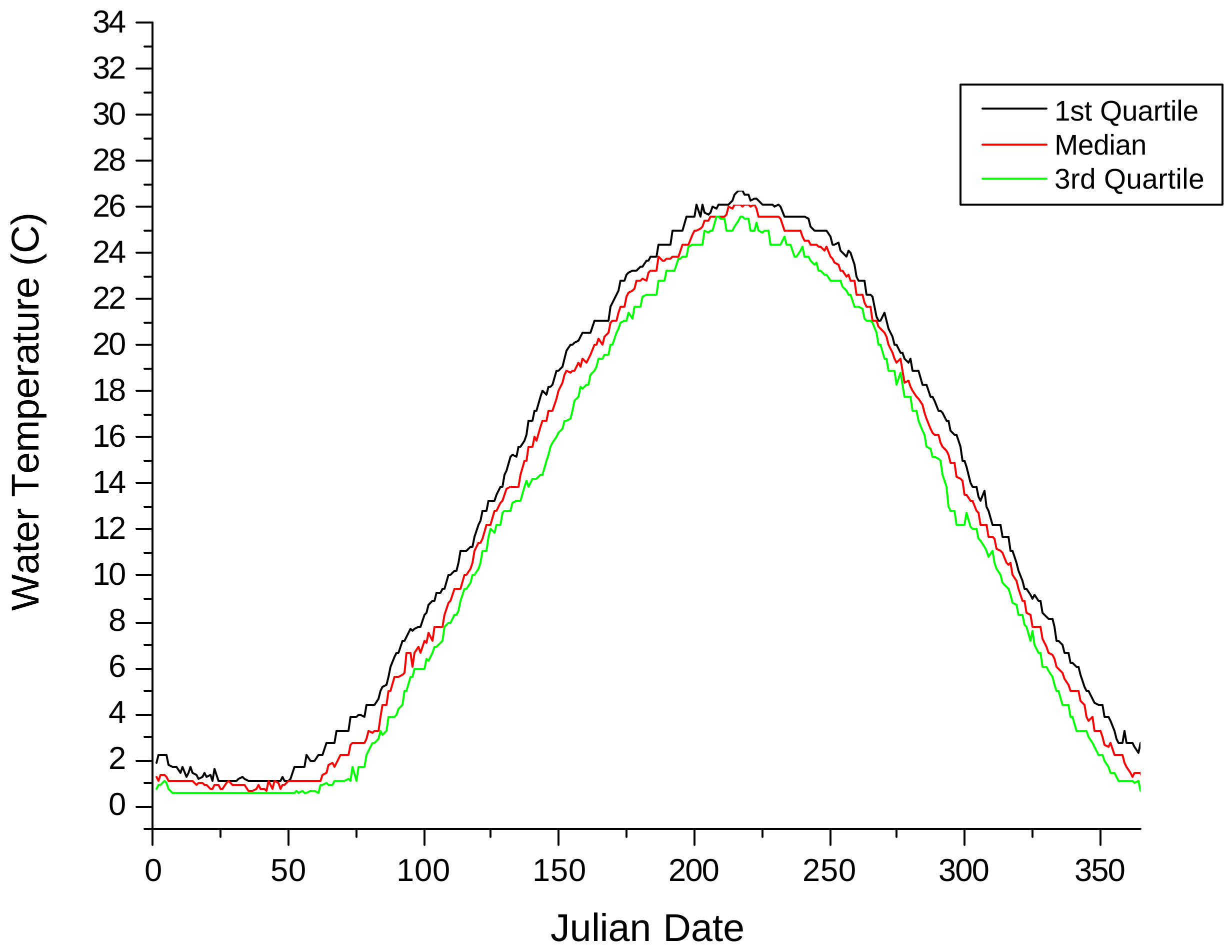

Figure 2 Overall seasonal pattern in water temperatures in the Hudson River estuary near Poughkeepsie, NY, 1974 – 2000.

in the Mattaponi River averaging 4 to 6 C warmer than temperatures in the Hudson at the same time (Figure 3). Water temperatures in the Mattaponi River reached the same temperatures as observed in the Hudson, but approximately one month earlier.

In addition to the grab-sample measurements of temperature in the Mattaponi just upstream of Scotland Landing, continuous monitoring of water temperature was recently initiated at Sweethall on the Pamunkey River on 1 March 2002 and at Walkerton on the Mattaponi River on 24 May 2003. This temperature monitoring provides daily minimum, maximum and mean water temperature records at each location. Unfortunately, temperature records for 2003 from the Hudson are not, as yet, available, so a direct comparison of recent data to the Hudson was limited to the 2002 data from the Pamunkey. Daily water temperatures in the Pamunkey and in the Hudson for spring 2002 showed remarkably similar patterns (Figure 4a). A regression of daily mean water temperatures in the Pamunkey versus the daily temperatures from the Hudson yielded a strong relationship ($R^2 = 0.94$), a slope of almost exactly unity (1.01), and a y-intercept of 6.7 (Figure 4b). This analysis demonstrates that water temperatures during spring in the Pamunkey and Hudson Rivers increase at the same rate with temperatures on the same date being just under 7 C warmer in the Pamunkey than in Hudson.

The final analysis was a comparison of water temperatures in the Pamunkey River to those in the Mattaponi River. This comparison was limited to the period of 24 May though 30 June 2003. As with the comparison between the Pamunkey and Hudson Rivers, the comparison of the May-June 2003 temperatures between the Pamunkey and Mattaponi showed a strong linear relationship ($R^2 = 0.95$), with a slope of almost exactly unity (1.05) and a y-intercept of -2.7 (Figure 5). These results demonstrate that water temperatures in the Mattaponi and Pamunkey Rivers are strongly correlated with each other, with temperatures in the Mattaponi River being slightly cooler. Combining the intercept in the Hudson-Pamunkey analysis (6.7) with the intercept in the Pamunkey-Mattaponi analysis (-2.7) yields an estimated difference between the Hudson and Mattaponi Rivers of approximately 4 C; a result almost identical with the Mattaponi being 4 to 6 C warmer based on the Hudson-Mattaponi temperature comparison of Figure 3, using the grab samples just upstream of Scotland Landing.

These analyses comparing water temperatures among the Hudson, Pamunkey, and Mattaponi Rivers provide strong evidence that rates of temperature increase in freshwater of the Hudson River estuary are similar to those in the Mattaponi River. This supports the assumption that the entrainable stages of American shad would have similar durations of occurrence in both the Hudson and Mattaponi Rivers. In addition, water temperatures on the same dates tend to be in the range of 4 to 6 C warmer in the Mattaponi than in the Hudson. This translates into the Mattaponi reaching the same temperatures as Hudson four to five weeks earlier.

4. Step 2: Relationship Between Temperature and Egg and Yolk-Sac Larval Occurrence for American Shad

Available ichthyoplankton data from the Hudson River estuary were used to define the relationship between water temperature and the abundance of potentially entrainable stages of American shad. Our analysis indicated that these stages were the egg and yolk sac larvae. Post yolk sac larvae are not considered vulnerable to entrainment for the following reasons. The

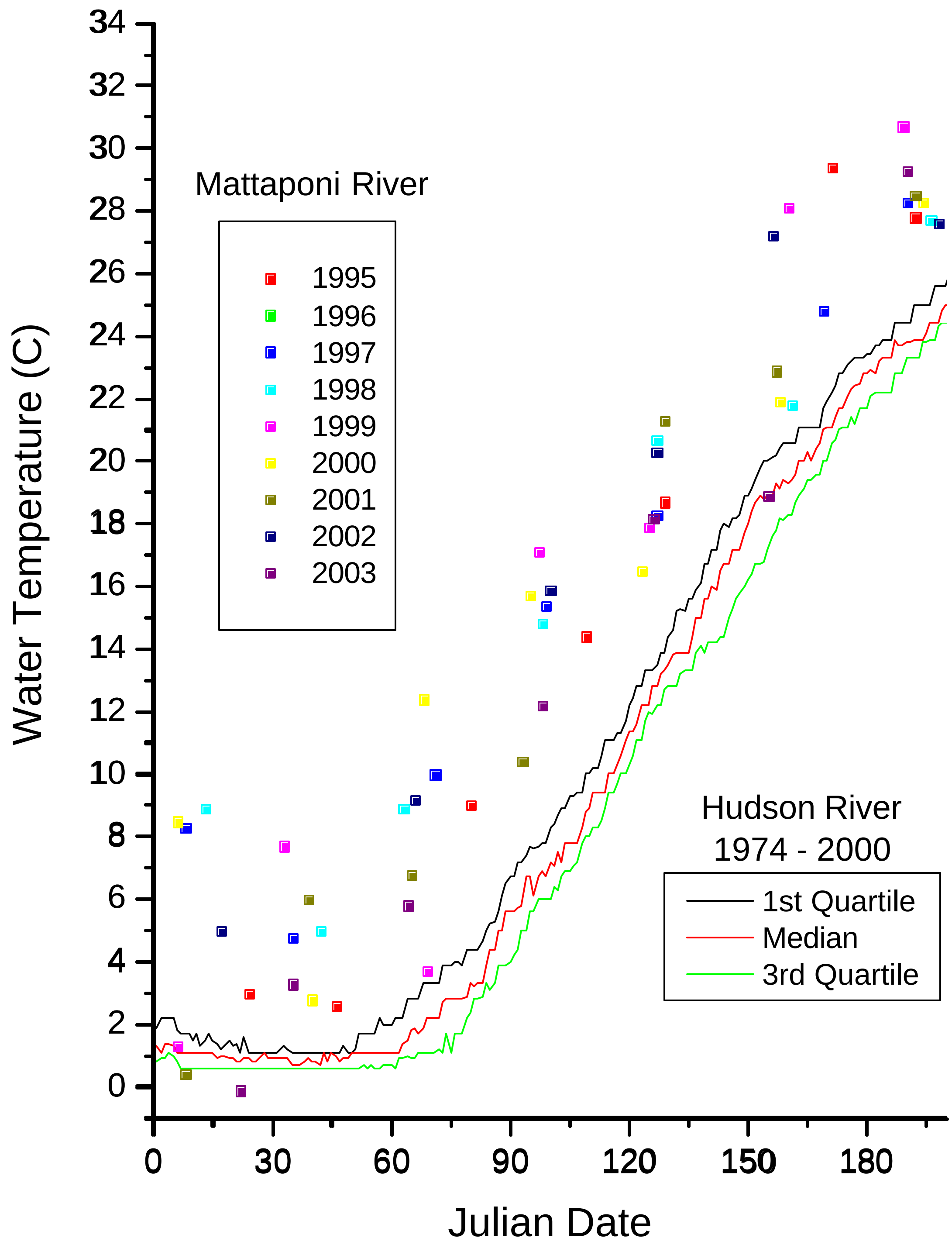

Figure 3 Comparison of spring water temperature measurements taken in the Mattaponi River using grab samples just upstream from Scotland Landing to overall patterns in the Hudson River estuary near Poughkeepsie, NY.

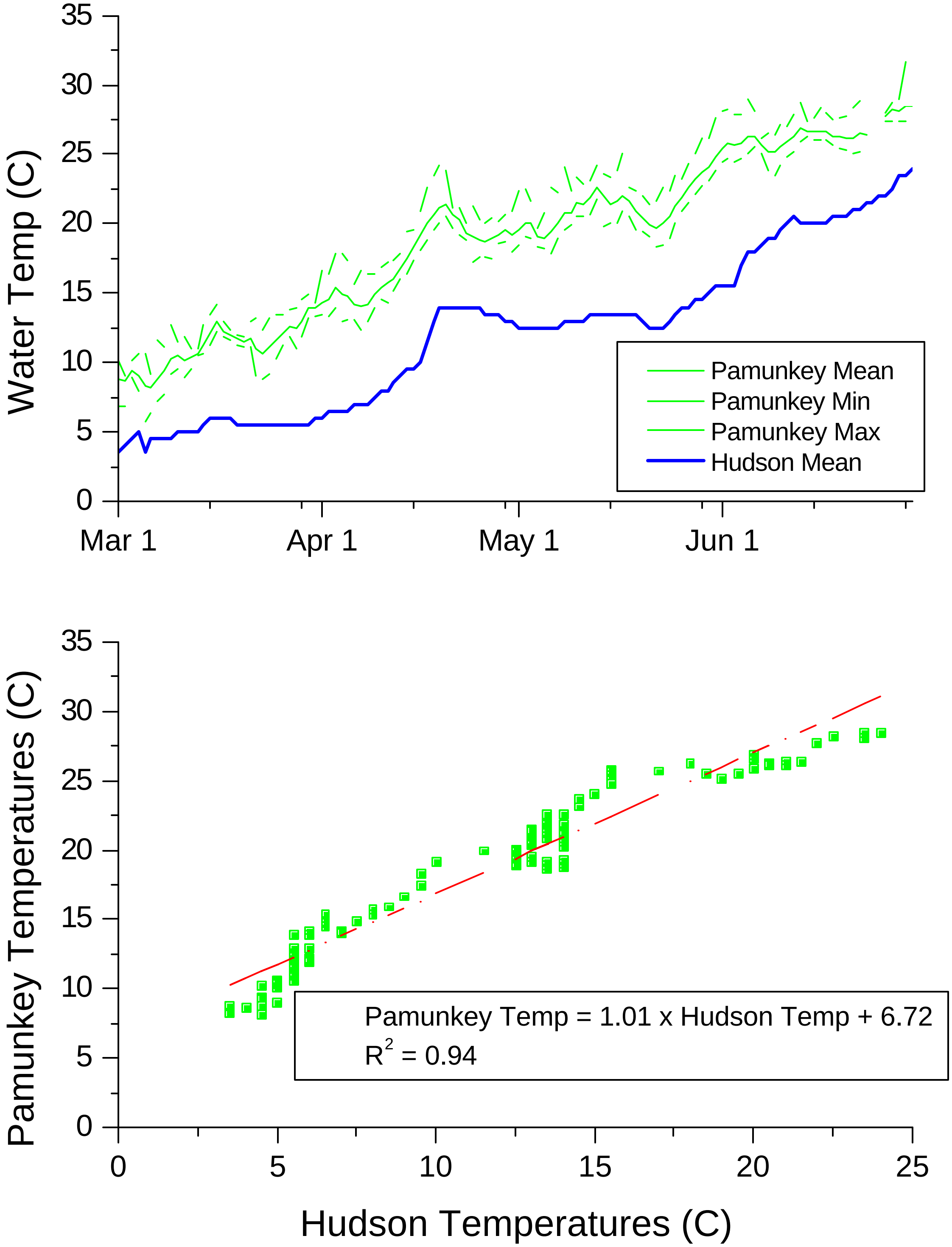

Figure 4 Comparison of daily water temperature measurements from the Pamunkey River near Sweethall, VA to daily water temperatures from the Hudson River estuary near Poughkeepsie, NY, March – June 2002.

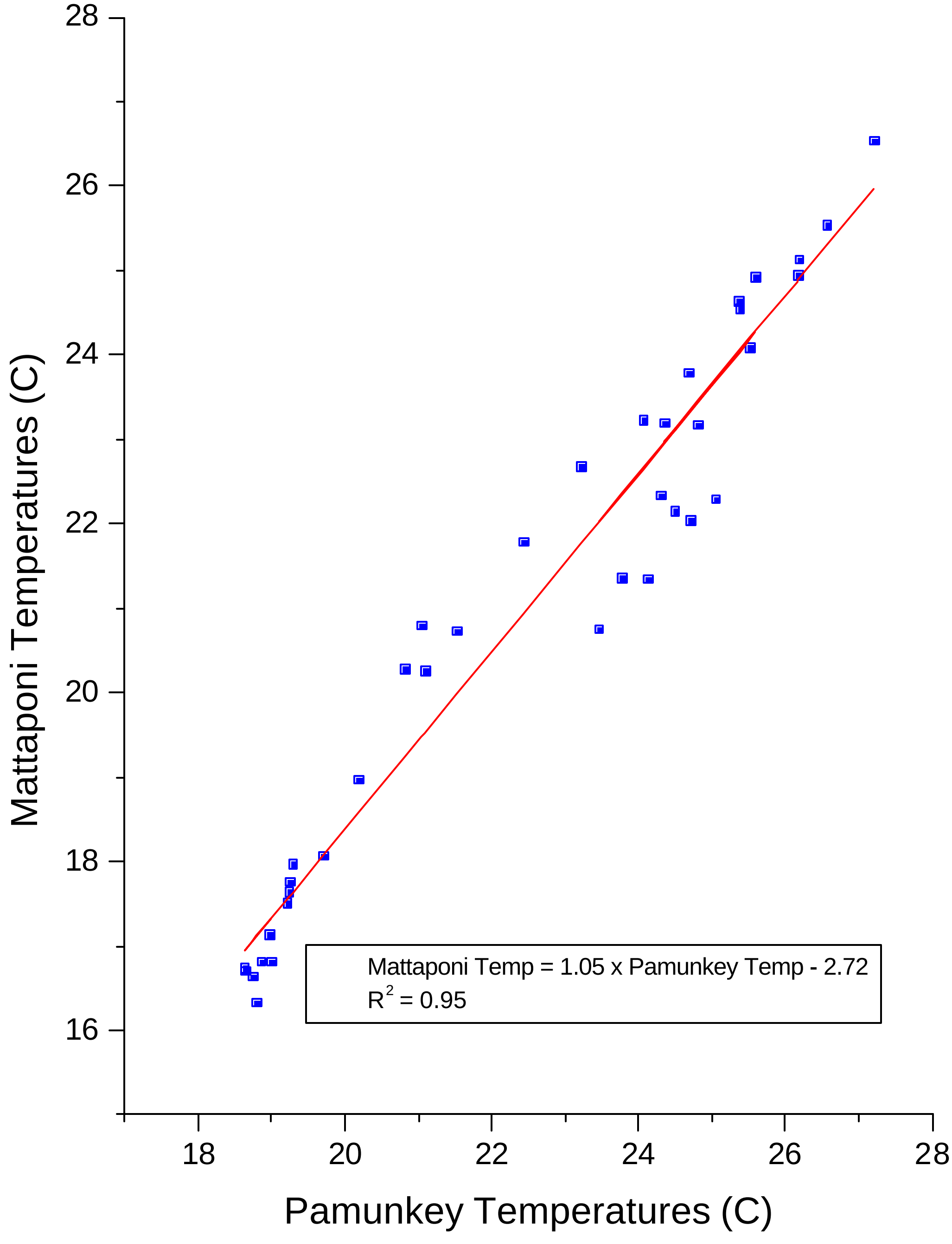

Figure 5 Comparison of daily water temperature measurements from the Mattaponi River near Walkerton, VA to daily water temperatures from the Pamunkey River near Sweethall, VA, May – June 2003.

transition between yolk-sac and post yolk-sac larval American shad occurs when the larvae are approximately 12 mm long (Weiss-Glanz et al. 1986). At 12-mm length, shad larvae are strong and active swimmers and appear to be too large to pass through the 1-mm slots of the proposed KWR Mattaponi River intake (see Appendix B). This contention is supported by independent analysis of wedgewire screen performance conducted by Gowan et al. (1999) and Langhei Ecology (1998). Hence for this analysis, we focused on the relationship between water temperature and the abundance of American shad eggs and yolk-sac larvae, the only two shad life stages potentially affected by the operation of the KWR intake.

Using data from the Hudson River mean densities of shad eggs and yolk-sac larvae were calculated for each sampling stratum during each sampling week of each year from 1974 through 2000. Next, these densities (i.e., number of individuals/m^3) were multiplied by the volume of water in each stratum to estimate the standing crop of eggs and yolk-sac larvae in each stratum (i.e., total number of individuals), and these stratum standing crop estimates were summed to calculate the total standing crop within the entire estuary in each sampling week of each year. Thereafter, the weekly standing crop estimates of each life stage were summed to calculate to total annual standing crop of that life stage in each year. Finally, each weekly standing crop estimate of shad eggs and yolk-sac larvae was divided by the total annual standing crop for that life stage to determine the fraction of each life stage that occurred during each week of a given year. A more detailed explanation of these calculations is provided in Attachment 1.

Plots of the cumulative fraction of total standing crop of American shad eggs and yolk-sac larvae versus mean weekly water temperature revealed a strong influence of temperature on when these life stages occurred in the river (Figure 6). American shad eggs were generally first collected in the Hudson when water temperatures were 10 to 12 C, and generally last collected when water temperatures were 17 to 20 C. These spawning temperatures are consistent with those of Weiss-Glanz et al. (1986), who reported spawning temperatures of 12 – 20 C throughout shad's natural geographic range, and those of Klauda et al. (1991), who reported most spawning in Chesapeake Bay rivers between 12 and 21 C. American shad yolk sac larvae were generally first collected in the Hudson when water temperatures were 12 to 15 C, and generally last collected when water temperatures were 17 to 22 C.

Based on these plots of cumulative fraction of standing crops versus temperature, it appears that a hiatus of pumping when water temperatures are between 10 and 22 C would provide a very high level of protection to the egg and yolk-sac larval stages of American shad in the Hudson River. These temperature triggers appear to encompass the range of spawning temperatures of shad in tributaries to the Chesapeake Bay, and is broader than the observed range of temperatures (12.4 to 20.5 C) over which American shad eggs and larvae were found in the Mattaponi River by Bilkovic (2000). The high level of protection provided by pumping shutdown based on these temperature triggers would be afforded to the eggs and yolk-sac larvae throughout the estuary, regardless of whether or not the eggs or larvae were within the hydraulic influence of the proposed water intake.

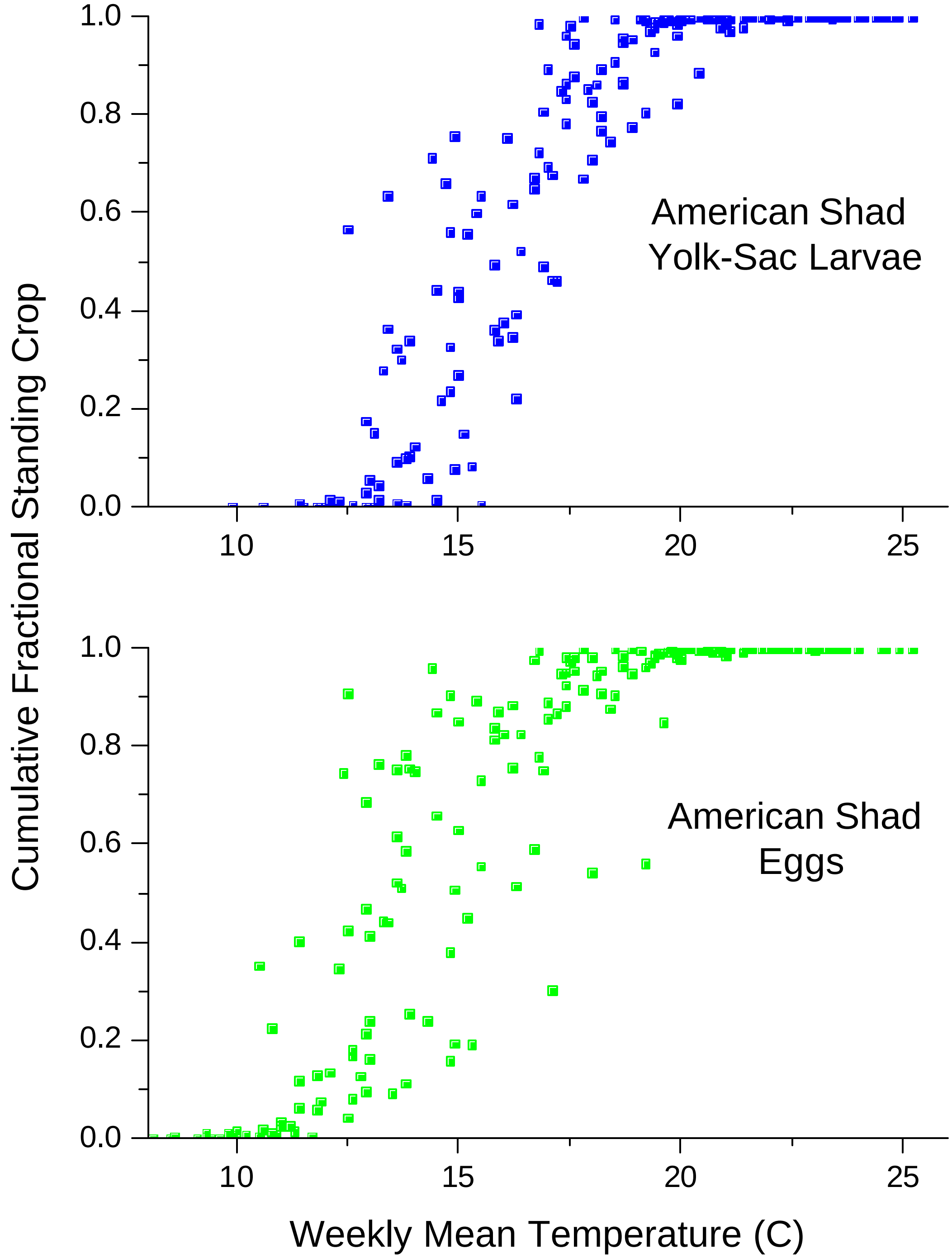

Figure 6 Relationship between the cumulative fractional standing crop of American shad eggs and yolk-sac larvae and weekly mean water temperatures in the Hudson River estuary, 1974 – 2000. Cumulative fractional standing crop is computed from weekly standing crop estimates by adding each week's standing crop to standing crops from previous weeks and dividing by the sum over all weekly standing crops.

5. Step 3: Timing and Duration of Pumping Hiatus

The available 52-year record (1951 – 2002) of daily water temperatures from the Hudson River estuary were then used to evaluate the timing and total duration of a hypothetical pumping hiatus based on 10 and 22 C temperature triggers. For this evaluation, we have assumed that pumps would be shut off on the first occurrence of 10 C water temperature at the selected monitoring location. These pumps would then be restarted when water temperatures first exceeded 22 C at that same monitoring location.

Based on the Hudson River temperature dataset and the 10 and 22 C temperature triggers, pumping would, depending on the year, be stopped in the Hudson beginning somewhere between early April and mid-May (Figure 7a). In most years, the pumping hiatus would start in the last 10 days of April. Pumping would resume again sometime between the beginning of June and mid-July, again depending on year (Figure 7b). In most years, pumping would begin again in the last 10 days of June. Overall duration of the hypothetical pumping hiatus in the Hudson ranged from 44 to 83 days, with durations from 50 to 70 days being most common (Figure 7c). It is important to remember that the actual dates are specific to the Hudson River estuary. In the Mattaponi River, the actual dates for the stopping and restart of pumping are likely to be approximately one month earlier. However, given that the rate of water temperature increases appear to be similar between the Hudson and Mattaponi Rivers, it is likely that the overall duration of the pumping hiatus in the Mattaponi River would be similar to the 50 to 70 days estimated for the Hudson.

In addition to evaluation of the frequency distribution of the pumping hiatus dates and durations, we considered whether there might have been any long-term trends that might affect the reliability of the application of the current study results to future years. To address this question, we plotted the start dates, stop dates, and overall durations of the pumping hiatus by year to see if there have been any long-term trends. Consistent with observations of generally warmer climatic conditions in recent times, predicted dates for both starting and stopping of the pumping hiatus in the Hudson River have been getting earlier over the past 3 decades (Figure 8). However, the overall duration of the pumping hiatus appeared to have no overall trend.

The results of this analysis suggest that while the actual timing of the pumping hiatus based on temperature triggers might be even earlier in future years, the actual duration of the hiatus would likely remain relatively constant.

6. Step 4: Level of Protection Afforded to Shad and Other Species

The final step in the evaluation of the proposed 10 and 22 C temperature triggers for the pumping hiatus was to use the Hudson River datasets on temperature and egg and larval abundance to estimate the degree of protection that would have been afforded to each of the species of concern in each year of record. As previously noted, post yolk-sac larval American shad were not considered susceptible to entrainment in the proposed fine-mesh, low-velocity water intake owing to their large size and strong swimming ability. Entrainment of the other three species is possible at least part way through their post yolk-sac larval stage. Hence, the post yolk-sac larvae life stage was included for river herring, striped bass, and white perch.

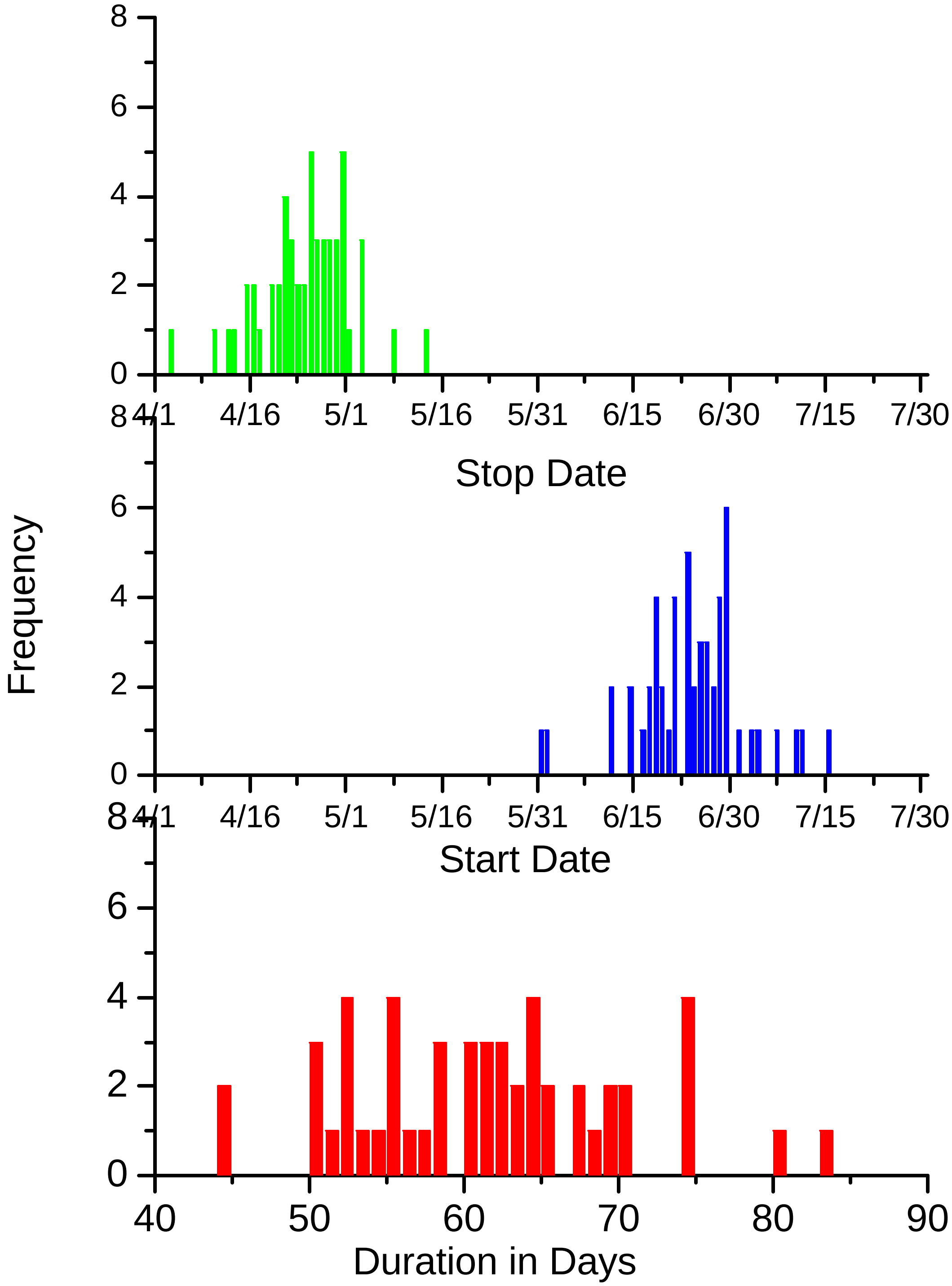

Figure 7 Frequency distributions of beginning dates, ending, dates, and total duration (in days) for when water temperatures first reach 10 C and first drop below 22 C over a 52-year period in the Hudson River estuary, 1951 – 2002.

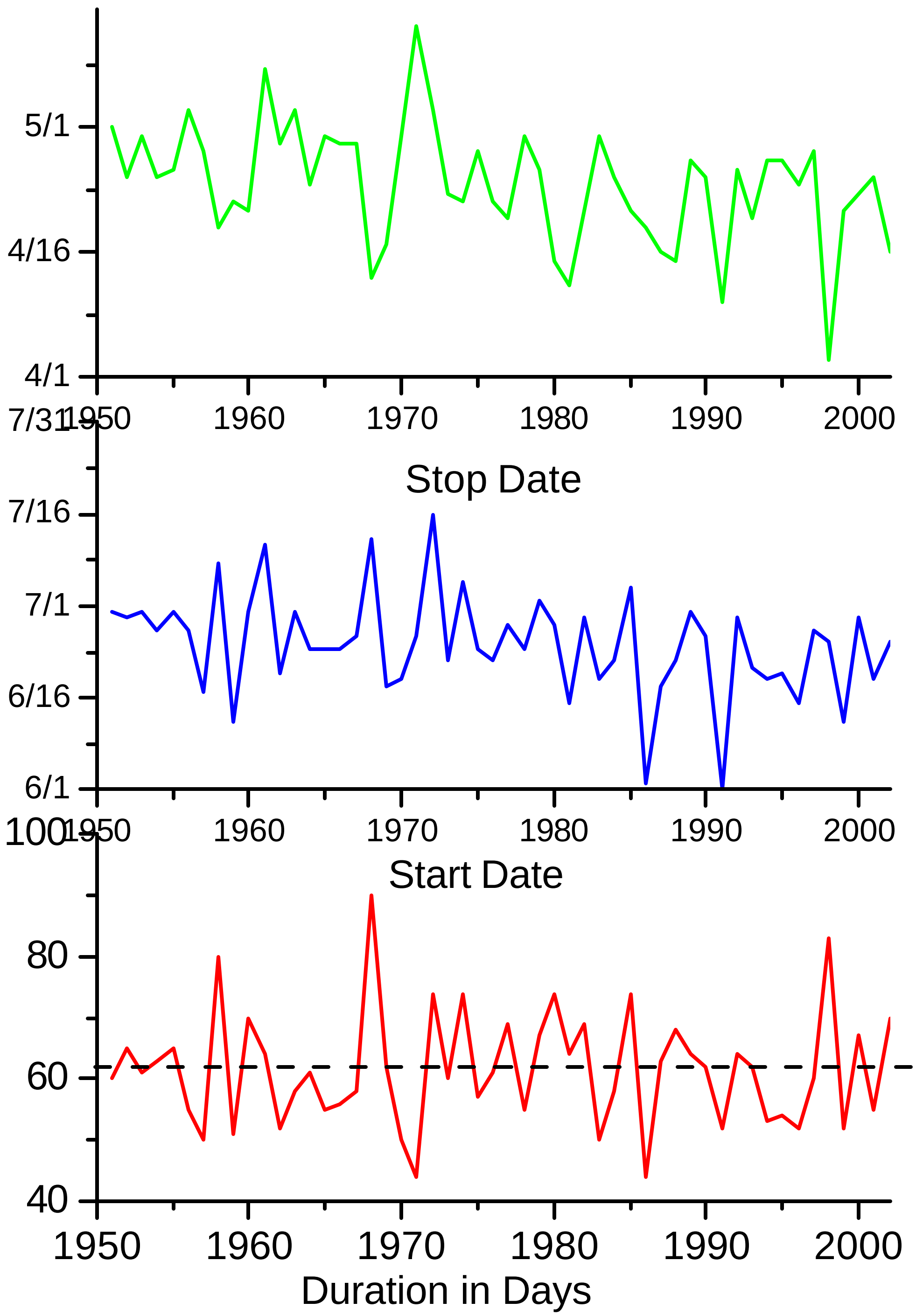

Figure 8 Long-term trends in the beginning dates, ending dates, and total durations of when water temperatures first reach 10 C and first drop below 22 C over a 52-year period in the Hudson River estuary, 1951 – 2002.

Unfortunately in several of the years (1981 through 1988 and 1991), the start of ichthyoplankton sampling in the Hudson River estuary was delayed until after water temperatures had already exceeded 10 C. Hence, it was impossible to determine the level of protection afforded by a pumping hiatus that began with 10 C, and these years were therefore dropped from the analysis. In addition to evaluating the proposed 10 and 22 C temperature triggers, the protection afforded by three other temperature triggers (10 – 23 C; 9 – 22 C, and 9 – 23 C) were also evaluated for the four fish species as part of a sensitivity analysis. The protection afforded the four species by these more conservative temperature triggers using data from the Hudson River estuary are provided in Attachment 2.

For American shad, the 10 and 22 C temperature triggers for a pumping hiatus encompassed 100 percent of the standing crop of yolk sac larvae and from 97 to 100 percent of the standing crop of eggs in the Hudson River across years (Table 1). For river herring, the proposed pumping hiatus included 98 to 100 percent of the eggs and yolk-sac larvae and from 75 to 100 percent of the post yolk-sac larvae across the years. For striped bass, the proposed pumping hiatus protected more than 99 percent of the eggs and yolk-sac larvae and from 88 to 100 percent of the post yolk-sac larvae. For white perch, the proposed pumping hiatus encompassed more than 98 percent of the eggs and yolk-sac larvae and from 73 to 100 percent of the post yolk-sac larvae.

As Table 1 shows, less than 98% protection for most species occurred in only a few years. For the life stages most susceptible to entrainment (eggs and yolk-sac larvae), this temperature-triggered pumping hiatus would protect 97 percent or more of the standing crop of eggs and yolk-sac larvae of all four species in every year. Protection of the post-yolk larval stages was also high, but more variable from year to year. Of the 18 years, protection of post-yolk sac larvae of striped bass exceeded 90% for 16 years and exceeded 85% for all 18 years. Protection of river herring post-yolk sac larvae exceeded 90% for 11 of the 20 years; exceeded 80% for 17 of the years, and the remaining year had a protection value of 75 %. Protection of white perch post yolk-sac larvae exceeded 90% for 14 of the years, 80% for 17 of the years, and the remaining year had a protection level of 73%.

7. Summary and Conclusions

The purpose of this analysis was to identify preliminary water temperature triggers for defining a pumping hiatus that would provide a high degree of protection from potential entrainment at the proposed Mattaponi River intake to the early life stages of American shad, river herring, striped bass and white perch. While data to define these triggers are presently lacking from the Mattaponi or adjacent rivers, our analysis demonstrated that extensive data available from the Hudson River estuary were both relevant and appropriate for defining temperature triggers that could, using future site-specific data, be later transferred to the Mattaponi River. Similar species of fish utilize the Mattaponi and Hudson Rivers as spawning and nursery habitat and the rates of temperature rise in the two rivers during the spring months are comparable.

The results of analysis using 27 years of available data on fish egg and larval abundances in the Hudson River estuary indicated that a pumping hiatus that begins when water temperatures first reach 10 C and continues until water temperatures first reach 22 C would provide a very high level of protection for each of the four fish species of concern. However, any individuals that

Table 1 – Estimates of the Percent of the Annual Standing Crop of Each Life Stage that Occurs Within the Period Defined by 10 and 22 C in the Hudson River Estuary, 1974 – 2000.

	American shad[2]		**River herring**			**Striped bass**			**White perch**		
Year[1]	**Egg**	**YSL**	**Egg**	**YSL**	**PYSL**	**Egg**	**YSL**	**PYSL**	**Egg**	**YSL**	**PYSL**
1974	100.00	100.00	100.00	100.00	98.81	100.00	100.00	99.29	100.00	100.00	98.61
1975	100.00	100.00	99.67	100.00	95.94	100.00	99.99	98.89	100.00	99.99	97.85
1976	97.12	100.00	98.20	98.57	74.95	100.00	99.94	88.73	99.85	99.90	80.61
1977	97.35	100.00	99.91	99.99	97.33	99.99	99.99	99.67	99.94	100.00	98.76
1978	99.12	100.00	99.99	100.00	98.63	100.00	99.99	96.08	100.00	100.00	99.53
1979	97.34	100.00	99.91	100.00	99.39	100.00	100.00	99.61	100.00	100.00	99.21
1980	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1989	98.89	100.00	99.47	100.00	98.50	100.00	100.00	99.45	99.98	100.00	98.59
1990	100.00	100.00	100.00	100.00	96.21	100.00	99.99	93.30	99.95	99.99	93.98
1992	100.00	100.00	99.98	99.50	96.22	100.00	100.00	99.56	100.00	100.00	98.20
1993	100.00	100.00	100.00	100.00	88.76	99.97	99.98	97.23	99.91	99.99	94.15
1994	99.92	100.00	99.99	99.99	87.28	99.98	99.91	95.09	99.56	99.96	91.15
1995	98.16	100.00	98.67	99.95	88.68	99.97	99.79	87.55	98.63	99.90	88.28
1996	100.00	100.00	100.00	99.91	81.56	99.95	99.98	95.51	99.98	99.95	86.23
1997	98.85	100.00	98.19	99.99	82.08	99.99	99.80	91.50	99.95	99.92	72.90
1998	100.00	100.00	100.00	100.00	99.99	100.00	100.00	99.82	100.00	100.00	99.60
1999	100.00	100.00	100.00	99.85	86.02	100.00	100.00	98.62	99.98	100.00	96.28
2000	99.89	100.00	99.91	100.00	99.84	100.00	100.00	99.99	100.00	100.00	99.86

[1] Years from 1981 through 1988 and 1991 not included since sampling was not initiated until after water temperatures had already reached 10 C.
[2] American shad post yolk-sac larvae (PYSL) not considered susceptible to entrainment at the KWR intake as a result of large size and strong swimming abilities.

occur outside of the pumping hiatus, while potentially susceptible to entrainment, would still be afforded a high degree of protection by the proposed 1-mm slot width screens with low ($\leq$ 0.25 fps) intake velocities and by an intake location with a hydraulic zone of influence that allows most eggs and larvae to pass the intake location without being entrained along with the water withdrawn (Appendix B). This combination of protective measures (pumping hiatus during the major period of occurrence, limited hydraulic zone of influence, low vulnerability to intake screen technology) will ensure that the intake will entrain few of the early life stages of any of the species evaluated.

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ATTACHMENT 1

METHODS USED TO CALCULATE CUMULATIVE FRACTIONAL STANDING CROPS FROM THE HUDSON RIVER ESTUARY DATA

The following describes how the cumulative fractional standing crops were calculated using data from the Hudson River estuary for each species, life stage, and year.

First a mean density (D_{jk}) was calculated for each region and stratum combination (j) and week (k) as follows:

$$D_{jk} = \frac{\sum_{i=1}^{n_{ijk}} \frac{C_{ijk}}{V_{ijk}}}{n_{jk}}$$

where:

C_{ijk}	=	Catch in the ith sample of the jth region and stratum combination in week k.
V_{ijk}	=	Volume of water sampled in the ith sample of the jth region and stratum combination in week k.
n_{jk}	=	Number of samples collected in the jth region and stratum combination (j) in week k.

Next, a total estuary-wide standing crop was calculated for each week (SC_k) as follows:

$$SC_k = \sum_{j=1}^{13} \left(D_{jk} \times V_j \right)$$

where:

V_j	=	Volume of the jth region and stratum combination.

Finally, the combined fractional standing crop for each week k ($CFSC_k$) was calculated as follows:

$$CFSC_k = \frac{\sum_{k=1}^{k} SC_k}{\sum_{k=1}^{m} SC_k}.$$

ATTACHMENT 2

ESTIMATES OF THE LEVEL OF PROTECTION AFFORDED BY ALTERNATE TEMPERATURE TRIGGERS BASED ON DATA FROM THE HUDSON RIVER ESTUARY DATA

Table 2-1 – Estimates of the Percent of the Annual Standing Crop of Each Life Stage of American Shad that Occurs Within the Period Defined by Alternate Temperature Triggers in the Hudson River Estuary, 1974 – 2000.

	9 - 22 C			10 - 23 C			9 - 23 C		
Year[1]	**Egg**	**YSL**	**PYSL**[3]	**Egg**	**YSL**	**PYSL**[3]	**Egg**	**YSL**	**PYSL**[3]
1974	100.00	100.00		100.00	100.00		100.00	100.00	
1975	100.00	100.00		100.00	100.00		100.00	100.00	
1976	100.00	100.00		97.12	100.00		100.00	100.00	
1977	100.00	100.00		97.35	100.00		100.00	100.00	
1978	100.00	100.00		99.12	100.00		100.00	100.00	
1979	99.95	100.00		97.34	100.00		99.95	100.00	
1980	100.00	100.00		-[2]	-[2]		-[2]	-[2]	
1989	100.00	100.00		98.89	100.00		100.00	100.00	
1990	100.00	100.00		100.00	100.00		100.00	100.00	
1992	100.00	100.00		100.00	100.00		100.00	100.00	
1993	100.00	100.00		100.00	100.00		100.00	100.00	
1994	99.93	100.00		99.99	100.00		100.00	100.00	
1995	99.95	100.00		98.16	100.00		99.95	100.00	
1996	100.00	100.00		100.00	100.00		100.00	100.00	
1997	99.95	100.00		98.85	100.00		99.95	100.00	
1998	100.00	100.00		100.00	100.00		100.00	100.00	
1999	100.00	100.00		100.00	100.00		100.00	100.00	
2000	100.00	100.00		99.89	100.00		100.00	100.00	

[1] Years from 1981 through 1988 and 1991 not included since sampling was not initiated until after water temperatures had already reached 10 C.
[2] No estimate for 1980 as sampling was discontinued before water temperatures had reached 23 C.
[3] American shad post yolk-sac larvae (PYSL) not considered susceptible to entrainment at the KWR intake as a result of large size and strong swimming abilities.

Table 2-2 – Estimates of the Percent of the Annual Standing Crop of Each Life Stage of River Herring that Occurs Within the Period Defined by Alternate Temperature Triggers in the Hudson River Estuary, 1974 – 2000.

	9 - 22 C			10 - 23 C			9 - 23 C		
Year[1]	**Egg**	**YSL**	**PYSL**	**Egg**	**YSL**	**PYSL**	**Egg**	**YSL**	**PYSL**
1974	100.00	100.00	98.81	100.00	100.00	98.81	100.00	100.00	98.81
1975	99.67	100.00	95.94	99.67	100.00	95.94	99.67	100.00	95.94
1976	99.97	99.64	74.95	99.97	99.64	74.95	99.97	99.64	74.95
1977	100.00	100.00	97.33	100.00	100.00	97.33	100.00	100.00	99.11
1978	100.00	100.00	98.63	100.00	100.00	98.63	100.00	100.00	98.63
1979	100.00	100.00	99.39	100.00	100.00	99.39	100.00	100.00	99.95
1980	100.00	100.00	100.00	-[2]	-[2]	-[2]	-[2]	-[2]	-[2]
1989	100.00	100.00	98.50	99.47	100.00	98.50	100.00	100.00	98.50
1990	100.00	100.00	96.21	100.00	100.00	99.93	100.00	100.00	99.93
1992	99.98	99.50	96.22	99.98	100.00	99.97	99.98	100.00	99.97
1993	100.00	100.00	88.76	100.00	100.00	94.82	100.00	100.00	94.82
1994	100.00	99.99	87.28	99.99	100.00	95.90	100.00	100.00	95.90
1995	99.82	99.95	88.68	98.67	99.95	88.68	99.82	99.95	88.68
1996	100.00	99.91	81.56	100.00	99.91	81.56	100.00	99.91	81.56
1997	99.83	99.99	82.08	98.19	99.99	82.08	99.83	99.99	82.08
1998	100.00	100.00	99.99	100.00	100.00	99.99	100.00	100.00	99.99
1999	100.00	99.85	86.02	100.00	100.00	96.21	100.00	100.00	96.21
2000	100.00	100.00	99.84	99.91	100.00	99.84	100.00	100.00	99.84

[1] Years from 1981 through 1988 and 1991 not included since sampling was not initiated until after water temperatures had already reached 10 C.
[2] No estimate for 1980 as sampling was discontinued before water temperatures had reached 23 C.

Table 2-3 – Estimates of the Percent of the Annual Standing Crop of Each Life Stage of Striped Bass that Occurs Within the Period Defined by Alternate Temperature Triggers in the Hudson River Estuary, 1974 – 2000.

	9 - 22 C			**10 - 23 C**			**9 - 23 C**		
Year[1]	**Egg**	**YSL**	**PYSL**	**Egg**	**YSL**	**PYSL**	**Egg**	**YSL**	**PYSL**
1974	100.00	100.00	99.29	100.00	100.00	99.29	100.00	100.00	99.29
1975	100.00	99.99	98.89	100.00	99.99	98.89	100.00	99.99	98.89
1976	100.00	99.94	88.73	100.00	99.94	88.73	100.00	99.94	88.73
1977	99.99	99.99	99.67	100.00	100.00	99.95	100.00	100.00	99.95
1978	100.00	99.99	96.08	100.00	99.99	96.08	100.00	99.99	96.08
1979	100.00	100.00	99.61	100.00	100.00	100.00	100.00	100.00	100.00
1980	100.00	100.00	100.00	-[2]	-[2]	-[2]	-[2]	-[2]	-[2]
1989	100.00	100.00	99.45	100.00	100.00	99.45	100.00	100.00	99.45
1990	100.00	99.99	93.30	100.00	100.00	99.61	100.00	100.00	99.61
1992	100.00	100.00	99.56	100.00	100.00	100.00	100.00	100.00	100.00
1993	99.97	99.98	97.23	100.00	100.00	99.20	100.00	100.00	99.20
1994	99.98	99.91	95.09	99.99	99.99	99.15	99.99	99.99	99.15
1995	99.97	99.79	87.55	99.97	99.79	87.55	99.97	99.79	87.55
1996	99.95	99.98	95.51	99.95	99.98	95.51	99.95	99.98	95.51
1997	99.99	99.80	91.50	99.99	99.80	91.50	99.99	99.80	91.50
1998	100.00	100.00	99.82	100.00	100.00	99.82	100.00	100.00	99.82
1999	100.00	100.00	98.62	100.00	100.00	99.75	100.00	100.00	99.75
2000	100.00	100.00	99.99	100.00	100.00	99.99	100.00	100.00	99.99

[1] Years from 1981 through 1988 and 1991 not included since sampling was not initiated until after water temperatures had already reached 10 C.
[2] No estimate for 1980 as sampling was continued after water temperatures had reached 23 C.

Table 2-4 – Estimates of the Percent of the Annual Standing Crop of Each Life Stage of White Perch that Occurs Within the Period Defined by Alternate Temperature Triggers in the Hudson River Estuary, 1974 – 2000.

	9 - 22 C			10 - 23 C			9 - 23 C		
Year[1]	**Egg**	**YSL**	**PYSL**	**Egg**	**YSL**	**PYSL**	**Egg**	**YSL**	**PYSL**
1974	100.00	100.00	98.61	100.00	100.00	98.61	100.00	100.00	98.61
1975	100.00	99.99	97.85	100.00	99.99	97.85	100.00	99.99	97.85
1976	99.85	99.90	80.61	99.85	99.90	80.61	99.85	99.90	80.61
1977	100.00	100.00	98.76	99.94	100.00	99.63	100.00	100.00	99.63
1978	100.00	100.00	99.53	100.00	100.00	99.53	100.00	100.00	99.53
1979	100.00	100.00	99.21	100.00	100.00	99.99	100.00	100.00	99.99
1980	100.00	100.00	100.00	-[2]	-[2]	-[2]	-[2]	-[2]	-[2]
1989	99.99	100.00	98.59	99.98	100.00	98.59	99.99	100.00	98.59
1990	99.95	99.99	93.98	99.95	100.00	99.85	99.95	100.00	99.85
1992	100.00	100.00	98.20	100.00	100.00	99.99	100.00	100.00	99.99
1993	99.91	99.99	94.15	100.00	100.00	98.22	100.00	100.00	98.22
1994	99.56	99.96	91.15	100.00	100.00	98.60	100.00	100.00	98.60
1995	99.97	99.90	88.28	98.63	99.90	88.28	99.97	99.90	88.28
1996	99.98	99.95	86.23	99.98	99.95	86.23	99.98	99.95	86.23
1997	99.97	99.92	72.90	99.95	99.92	72.90	99.97	99.92	72.90
1998	100.00	100.00	99.60	100.00	100.00	99.60	100.00	100.00	99.60
1999	100.00	100.00	96.28	99.98	100.00	99.18	100.00	100.00	99.18
2000	100.00	100.00	99.86	100.00	100.00	99.86	100.00	100.00	99.86

[1] Years from 1981 through 1988 and 1991 not included since sampling was not initiated until after water temperatures had already reached 10 C.
[2] No estimate for 1980 as sampling was continued after water temperatures had reached 23 C.

APPENDIX D

KWR PRE-OPERATIONAL ICTHYOPLANKTON SURVEY AND ENTRAINMENT MONITORING PROGRAMS

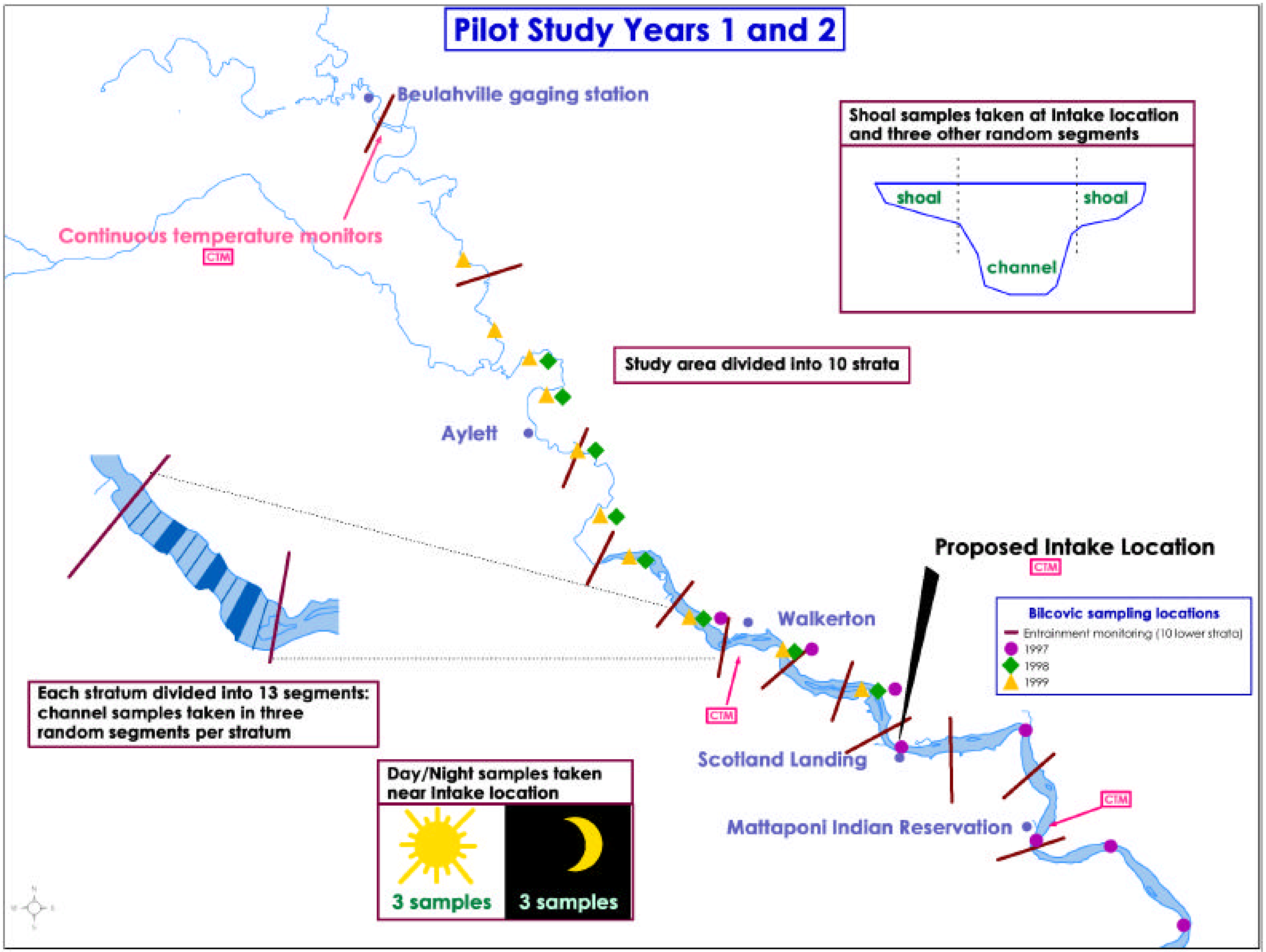
INTRODUCTION

The preoperational monitoring program described here was developed by the King William Reservoir Fisheries Panel to establish the scope of a survey that would provide sufficient data to develop temperature triggers for a pumping hiatus that would achieve the protection goals specified. The entrainment program was designed so as to provide sufficient data to estimate entrainment rates and proportional loss estimates under circumstances when water withdrawal would be occurring when American shad early life stages are present. Both study designs also served as a basis for estimating program costs, information requested by the RRWSG. The Panel considers these to be preliminary designs, and acknowledges that they will be subject to review, comment and revision in accordance with terms of the KWR VDEQ Water Protection Permit. In addition, the Panel anticipates that the study designs will be refined over time, based on each year's study findings.

Pre-operational Ichthyoplankton Survey

- Annual spawning season surveys will be conducted for a minimum of 8 years and until initiation of water withdrawal; continuous temperature monitors will be placed at 4 locations: Beulaville gauging station, Walkerton Bridge, the proposed intake location, and at river km 80 (below Mattaponi Indian Reservation)

- Years 1 and 2: Pilot Study (Figure 1)
  - -- Sampling in years 1 and 2 will be temporally and geographically intensive in order to provide information needed to refine and make more efficient the survey design for later years of sampling.
  - -- The pilot survey region will extend from km 80, 5 km below the Mattaponi Indian Reservation, to km 139, Beulaville, an approximately 60 km reach; the locations at which ichthyoplankton samples were taken by Dr. Donna Bilkovic in her thesis studies in 1997, 1998 and 1999 are shown in Figure 1; the pilot survey region encompasses all portions of the Mattaponi River in which American shad early life stages were taken in Dr. Bilkovic's studies.
  - -- This study reach will be divided into 10 geographical strata; the reach from Beulaville to Aylett will be broken into two strata, and the remaining study reach will be divided into 8 additional strata of equal length
  - -- Within a stratum, 13 consecutive, equal length segments will be defined;
  - -- Samples will be collected in a starting segment, selected at random from among the first 3 segments, and at the next two 5th sequential segments



Pilot Study Years 1 and 2
Beulahville gaging station
Shoal samples taken at intake location and three other random segments
shoal
shoal
channel
Continuous temperature monitors
CTM
Study area divided into 10 strata
Aylett
Proposed Intake Location
CTM
Walkerton
Bilcovic sampling locations
Entrainment monitoring (10 lower strata)
1997
1998
1999
CTM
Each stratum divided into 13 segments: channel samples taken in three random segments per stratum
Scotland Landing
Day/Night samples taken near intake location
3 samples
3 samples
CTM
Mattaponi Indian Reservation

Figure 1.

- -- In those river segments where water depth and bottom topography permit, one stepped bongo net haul will be made in the channel (i.e., 3 samples will be taken in each of the 10 strata); in those strata and segments in which boat access and use of bongo nets may not be feasible, alternative sampling methods may be used (e.g., push nets, stationary nets, ichthyoplankton seine nets), as appropriate to local conditions; this design will yield a total of 30 channel samples per sampling event.
- -- In order to confirm that densities estimated from channel samples are representative of ichthyoplankton densities within a river cross section, samples will be taken in the shoals on either side of the channel within the strata segment nearest to the intake location and at three other segments randomly selected from among the segments at which samples are to be taken in each sampling event; where feasible, sampling will be as conducted in the channel; if not feasible, alternative sampling methods will be employed, as appropriate to local conditions; 8 shoal samples will be taken during each sampling event.
- -- For logistical reasons, sampling will be conducted during daylight hours; but to confirm that daylight samples are representative, an additional set of channel samples will be taken at night within the river strata in which the intake will be located, yielding 3 night samples per sampling event
- -- Total number of samples per sampling event will be 41
- -- Sampling will be conducted twice per week during the first two weeks of the spawning season (starting when water temperature reaches 8 ºC) and during the last two weeks of the proposed pumping shutdown period (starting when water temperatures reach 20 ºC but continuing until temperatures reach 24 ºC); sampling will be conducted weekly during the intervening period (Figure 2)
- -- Projecting a total 10 week sampling period, during which twice-weekly sampling will occur for 4 weeks, and weekly sampling for 6 weeks, results in a total of 14 sampling events; with 41 samples per event, total number of samples per year will be 574 during the two years of pilot study
- -- All ichthyoplankton taken in samples will be identified to the lowest taxonomic level feasible and life stage (egg, yolk-sac, post-yolk-sac and juveniles) and length frequency data will be collected.

- Years 3 to 8+: Extended Survey
  - -- Weekly sampling throughout, with start and end temperature triggers for sampling refined based on pilot survey results (anticipate a 10-week sampling period) (Figure 2)

KWR PRE-OPERATIONAL ICHTHYOPLANKTON SURVEY TIMELINE

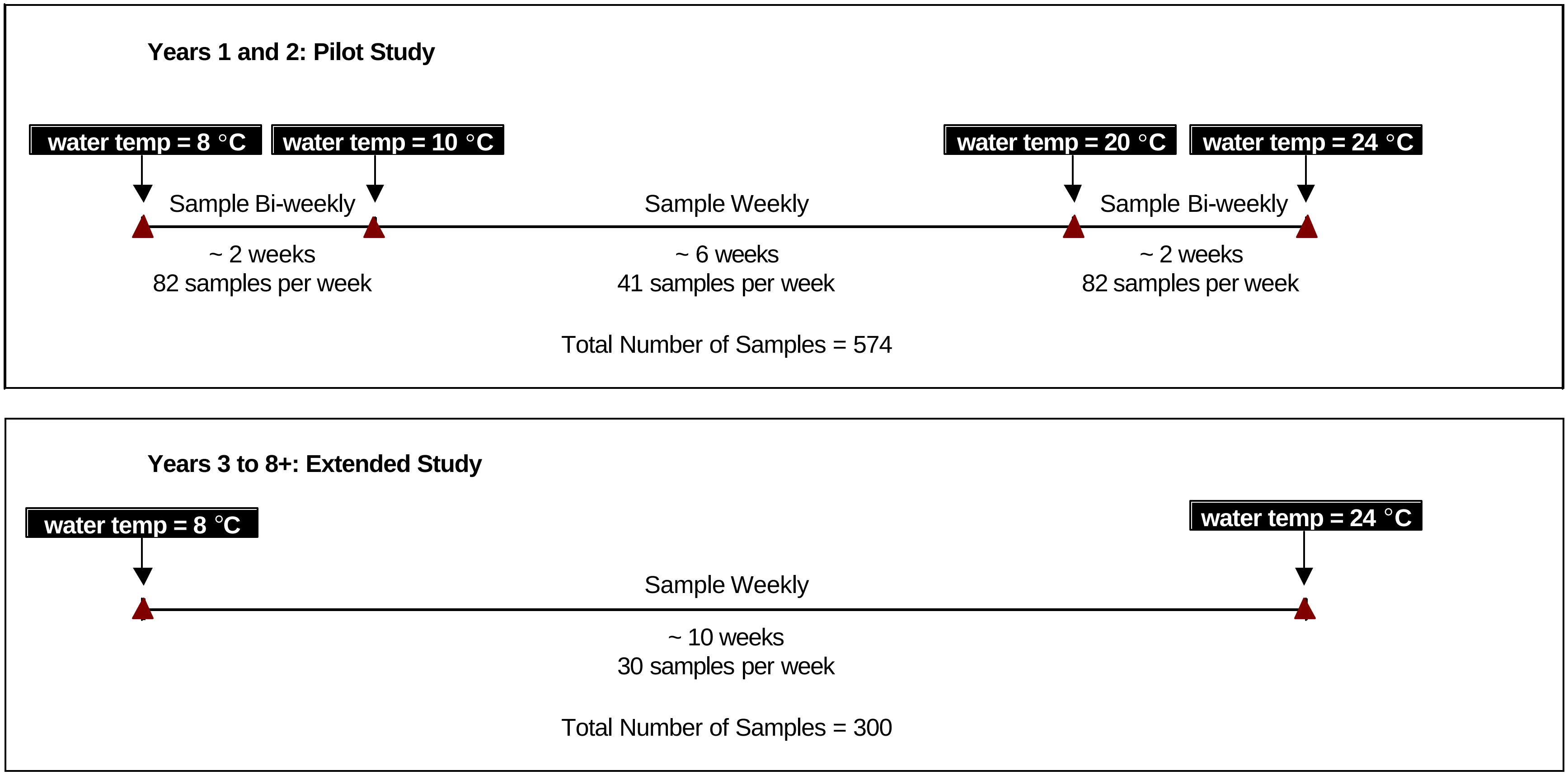


Figure 2.

- -- Upstream and downstream study boundaries will be refined based on results of the pilot survey results, with the expectation that the upstream boundary will be in the vicinity of Aylett (Figure 1)
- -- The number of strata will remain at 10 (with three channel samples per strata), but the boundaries of the strata will be redefined, based on river bathymetry and features, and on ichthyoplankton distributions found in the pilot surveys
- -- The revised strata will be of approximately equal volume, to ensure that densities estimated for each will have equal weight in estimating total river ichthyoplankton standing stock and proportion of total standing stock occurring in each strata
- -- Assuming that no significant shoal/channel or day/night differences are found in the pilot surveys, only stepped oblique channel samples will be collected (in those segments where such gear can be used; otherwise alternative sampling methods will be used), yielding 30 samples per sampling event; if significant differences are found, the study design will be revised to address those differences, but within the total number of samples defined here (e.g., 30 per event, and a total of 300 per year)

- Data Analysis and Development of Mattaponi-Specific Temperature Triggers; Although Hudson River data on temperature and American shad egg and larval occurrence have guided our analyses of likely relationships on the Mattaponi River, actual Mattaponi River data will be used to select the operational triggers for the pumping hiatus. The following steps will be used in this selection.
  - -- Step 1. - Ichthyoplankton density data from Mattaponi River field samples will be extrapolated to strata-specific standing stock values (numbers of individuals in each stratum) using river strata volumes; standing crop estimates in each strata will allow calculation of: (a) the percentage of total standing stock within each stratum on each sampling date, and (b) the percentage of seasonal standing stock on any individual sampling date. The method for estimating standing stock for the two pilot study years will take into account the changing sampling frequency at the beginning and end of the sampling period.
  - -- Step 2. - Continuous temperature data from the four monitoring stations will be examined to determine the optimal means of synthesizing the temperature data for establishing temperature trigger values for the pumping hiatus. Temperature data from each station and from all stations combined will be analyzed to determine the trigger values that provide the highest probability for accurate prediction of the first occurrence of American shad eggs and the last occurrence of American shad yolk-sac-larvae. Examples of the types of temperature data analyses that may be required include: alternative methods for developing location-specific or river-wide daily averages from the

continuous monitoring data; correlation analyses of data from the four temperature monitoring stations to evaluate the spatial variation in temperature and the consistency among locations; and analysis of short-term temperature trends as forecasters of the time a trigger value would be expected to be attained. The temperature trigger values would be those that accurately and consistently occur over the expected 8 years of pre-operational monitoring data concurrent with: (1) the first occurrence of American shad eggs anywhere within the region of the river being sampled and (2) the last occurrence of American shad yolk-sac larvae anywhere in the sampled area.

-- Step 3. - By combining the results of steps 1 and 2, temperature triggers will be established that ensure absolute protection of a certain percentage of American shad eggs and yolk-sac larvae. The level of protection afforded by the temperature triggers will be evaluated by applying the temperature triggers to each of the eight years of standing crop estimates by strata and date. Selection criteria for the final trigger values (synthesized from the four continuous monitoring data sets) will be that a minimum of 97% of the total standing stock of American shad eggs and yolk-sac larvae over the entire spawning season would occur between the upper and lower temperature triggers in at least 7 of the 8 years of sampling, and no less than 95% of the total standing stock of American shad eggs and yolk-sac larvae over the entire spawning season would occur between the upper and lower temperature triggers in any single year. The RRWSG has committed to a pumping hiatus between the temperatures of 10 ºC and 22 ºC in all years, even if the preoperational monitoring data show that a smaller temperature range would provide the targeted level of protection.

- Exploratory Hatch Date Study

  -- Information on hatch dates of American shad juveniles that contribute to yearclasses in each year will be taken into account in establishing the temperature triggers for the pumping hiatus. Hatch date will provide validation of the temperature triggers, since hatch dates for all juveniles would be expected to fall within the temperature triggers established in Step 3, above.

  -- An American shad juvenile survey is being conducted in the Mattaponi River by VIMS and is expected to continue, in order for Virginia to meet ASMFC shad management program requirements; thus, juvenile shad should be available for future analyses.

  -- The City of Newport News will provide funding to VIMS or another qualified organization (up to a total of $50K annually) for reading of juvenile otoliths in order to establish hatch dates of juveniles comprising year class production in each of the first four study years.

-- Methods employed will be those generally accepted by the research community for work of this nature, and as used in prior VIMS studies (e.g. Aiken thesis work). However, validation of the use of otoliths to estimate juvenile ages and quality control in reading of juvenile otoliths will be of great importance, because of the intent to use resultant data for temperature trigger verification. Thus, a rigorous quality assurance plan for the hatch date study will be essential. Such a plan would be expected to include hatch date validation and use of multiple readers and blind repeat readings for a subset of otoliths to ensure a high degree of precision in the results of the quality assurance readings.

-- Results of the hatch date analysis will be provided to the City of Newport News on a timely basis for incorporation into their analysis and reports; use of the data for theses, dissertations or open-literature publications will not be precluded, with proper acknowledgment.

KWR Entrainment Ichthyoplankton Survey

- Entrainment sampling can be conducted only when pumping is occurring and will be conducted only when early life stages are anticipated to be present

- Years of Normal Operation – No sampling will be conducted in years when spawning season pumping shutdowns are implemented in accordance with temperature triggers established based on the 8+ years of Mattaponi River preoperational ichthyoplankton sampling

- Drought-emergency years:

  -- During drought-emergency years when pumping occurs during the normal non-pumping times, screening entrainment sampling, consisting of two samples taken in the vicinity of the intake screens weekly, beginning March 1, will be collected; these samples will be processed as quickly as possible for American shad eggs, and when any American shad eggs are found in a screening survey sample, entrainment sampling will be initiated and conducted until the temperature trigger for pumping initiation is reached.

  -- Entrainment sampling will consist of two repeated samples taken simultaneously in the river (adjacent to the intake screens) and within the intake pipe at some point behind the intake screens, every 6 hours over a 24-hour period (Figure 3; note that the figure shows the upper boundary of the sampling area for the pilot pre-operational surveys; the upper boundary for the

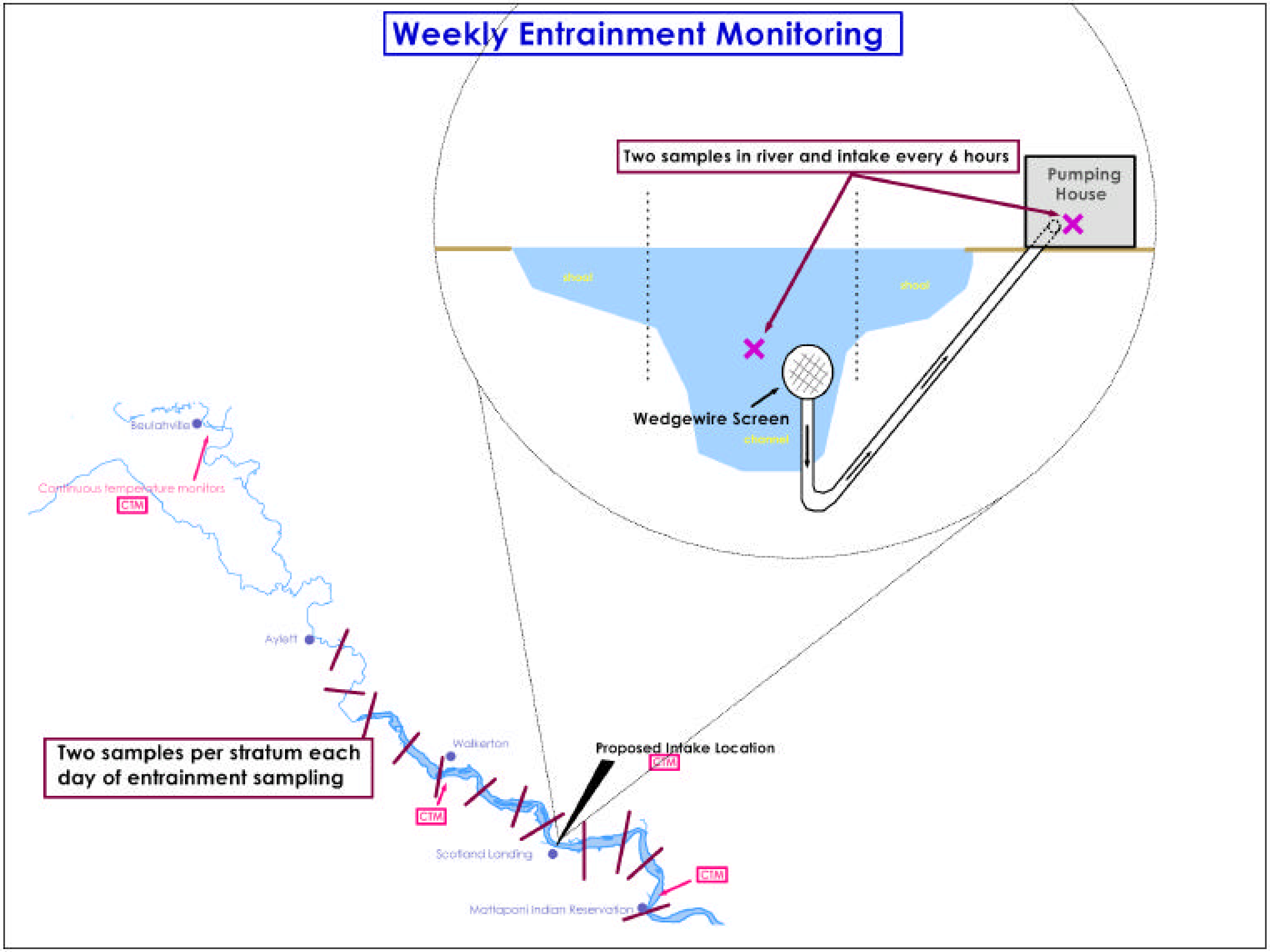

Weekly Entrainment Monitoring
Two samples in river and intake every 6 hours
Pumping House
Wedgewire Screen
Beulahville
Continuous temperature monitors
CTM
Aylett
Walkerton
Two samples per stratum each day of entrainment sampling
Proposed Intake Location
CTM
CTM
Scotland Landing
CTM
Mattaponi Indian Reservation

Figure 3.

survey area when entrainment sampling is to be conducted is likely to be much further downstream).

-- Two channel samples per pre-operational strata (9 strata, since intake strata is part of entrainment sampling) will be collected weekly whenever entrainment sampling is occurring, yielding 18 samples per sampling event)

-- With weekly sampling and assuming a total 8 weeks of sampling over the course of the spawning period, a total of 144 in-river samples and 48 entrainment samples are anticipated, for total of 192 samples per year (Figure 4)

-- Estimates will be made of the numbers of eggs and yolk-sac larvae that pass into the piping (and lost to the river) during the drought-emergency pumping for all periods when entrainment sampling is conducted.

KWR ICHTHYOPLANKTON ENTRAINMENT SURVEY

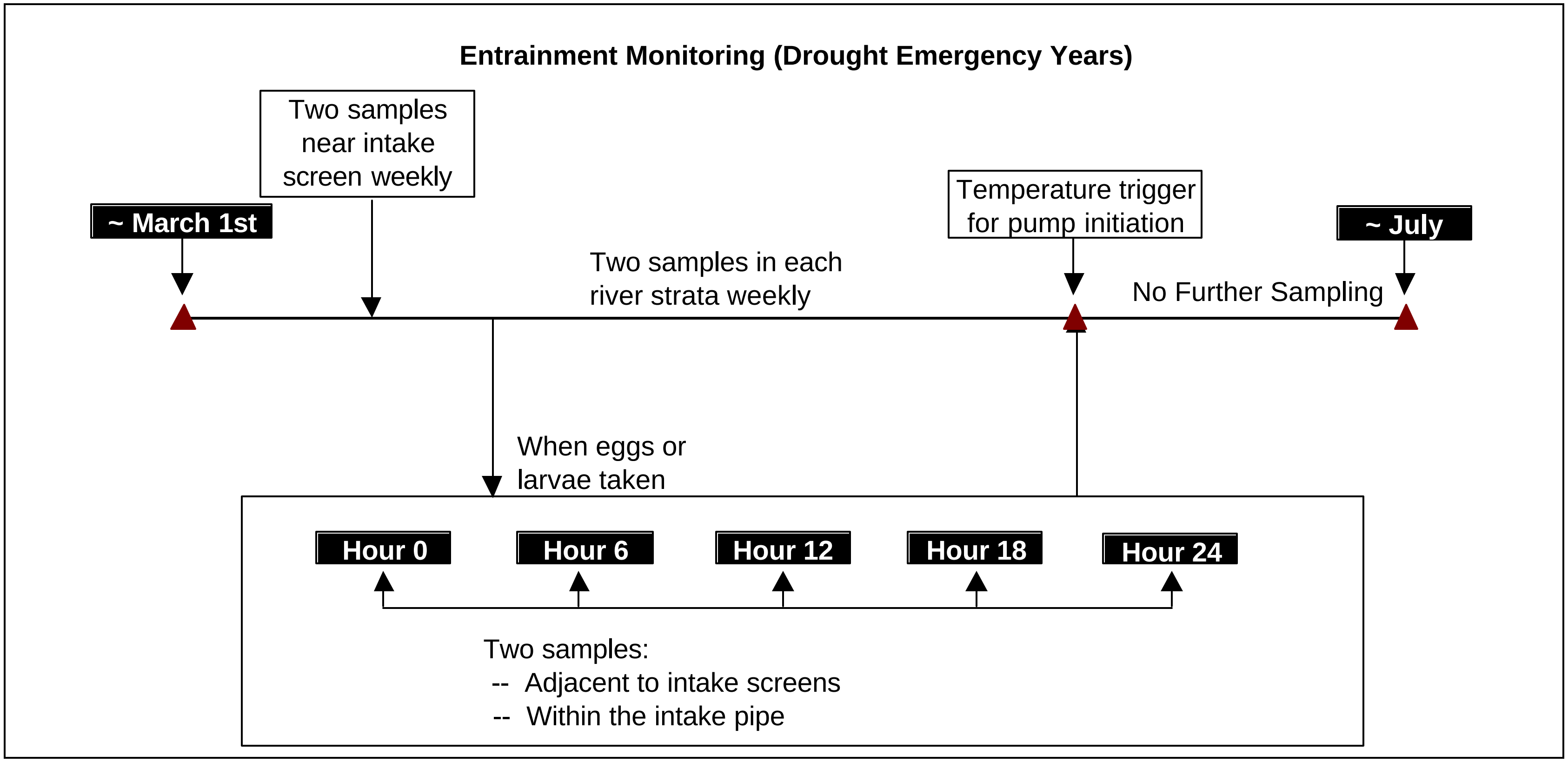


Figure 4

APPENDIX E

ALDEN LABORATORY WEDGEWIRE SCREEN EFFECTIVENESS REPORT

FISH PROTECTION CAPABILITY ASSESSMENT OF THE CYLINDRICAL WEDGEWIRE SCREEN DESIGN PROPOSED FOR THE KING WILLIAM RESERVOIR MATTAPONI RIVER INTAKE

Prepared for

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February, 2004

FISH PROTECTION CAPABILITY ASSESSMENT OF THE CYLINDRICAL WEDGEWIRE SCREEN DESIGN PROPOSED FOR THE KING WILLIAM RESERVOIR MATTAPONI RIVER INTAKE

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1 INTRODUCTION

An intake for a municipal water supply (King William Reservoir, King William County, Virginia) has been proposed for construction in the Mattaponi River at Scotland Landing. The intake structure incorporates six cylindrical wedgewire "T-screens" designed to minimize the impingement and entrainment of fish eggs and larvae. The T-screens proposed for the KWR intake are horizontal cylinders of fine-mesh screening held in mid water-column (as further described below). Stakeholders have raised concerns regarding the magnitude of potential losses to local fish populations caused by the operation of the proposed intake. To address these concerns, a thorough understanding of the fish protection capabilities of wedgewire screens is needed with respect to biological, hydraulic, engineering, and operational considerations.

Cylindrical wedgewire screens were initially developed and evaluated as a technology for fish protection at electric power plant cooling water intakes following the passage of the Clean Water Act (CWA) amendments in 1972. Initial studies conducted in the nineteen seventies and early eighties assessed the engineering feasibility of the cylindrical screen design and its effectiveness at protecting fish. The engineering studies demonstrated that cylindrical screens could effectively withdraw power plant cooling water depending on environmental conditions and site-specific engineering criteria. Also, early biological studies provided data indicating wedgewire screens were capable of substantially reducing entrainment of fish eggs and larvae and, consequently, should be considered as means to minimize adverse environmental impacts (AEI) at cooling water intakes.

Based on the results of previous studies and the performance of existing installations, cylindrical wedgewire screens are one of several technologies considered by the U.S. Environmental Protection Agency (EPA) as having potential to meet current performance standards for minimizing impingement mortality and entrainment of fishes (EPA 2002). The performance standards are part of EPA's rule-making for implementing Section 316(b) of the Clean Water Act (CWA), which requires that the location, design, construction, and capacity of a cooling water intake structure (CWIS) reflect the "best technology available" (BTA) for minimizing AEI (EPA 2004). Adverse environmental impacts from CWISs may occur from entrainment of aquatic organisms into the cooling water system and from the impingement (entrapment) of larger life stages on water intake screens. Cylindrical wedgewire screens were cited by the EPA as one of four technologies on which their impingement standards were based (80-95% reduction in impingement mortality from baseline), and one of three technologies for the establishment of entrainment standards (60-90% entrainment reduction from baseline). The final rule, signed into law by the EPA in February 2004, allows existing facilities located on freshwater rivers or streams to meet the impingement mortality and entrainment reduction standards by installing cylindrical wedgewire screens. Under this option, there must be sufficient ambient cross currents to facilitate removal of debris, through-slot velocities must be less than 0.5 ft/s, and screen slot size should be appropriate for the size of organisms targeted for protection. Currently, cylindrical wedgewire screens are the only technology approved by the EPA for meeting the performance standards of the new rule.

The Virginia Department of Game and Inland Fisheries has established design criteria for fish screens at water intakes based on a review of relevant literature (Gowan et al. 1999). For wedgewire screens, these criteria include a maximum slot size of 1 mm, through-slot velocities of 0.25 ft/s or less, sweeping velocities equal to or greater than slot velocities, and position of a screen face parallel to ambient flow. The design proposed for the KWR intake screens meets all of these criteria, except during a small portion of the tidal cycle when channel velocities will drop below the maximum through-slot velocity. The 0.25 ft/s slot velocity criteria recommended by Gowan et al. (1999) is the most conservative through-screen velocity criteria established by any state or federal agency. The EPA based their performance standards for reducing impingement mortality on a through-screen velocity of 0.5 ft/s and federal and state agencies on the west coast have established a maximum approach velocity criteria of 0.33 ft/s at a distance of three inches from a screen face (through-slot velocities corresponding to this approach velocity will be higher) (CDFG 1993; NMFS 1995; WDFW 1995). However, the EPA and west coast agency criteria are for juvenile fishes (e.g., > 25 mm in length). The Virginia screen criteria were developed with consideration for the swimming capabilities of larval fishes.

The City of Newport News specifically selected cylindrical wedgewire screens, in conjunction with the proposed design and operational criteria, for the purpose of minimizing the impact of the King William Reservoir intake on Mattaponi River fish populations. To assess the fish protection capabilities of the selected design, Alden Research Laboratory, Inc. (Alden) has reviewed the results of laboratory and field studies for relevant information on the biological and hydraulic performance of cylindrical wedgewire screens. The goal of this effort was to develop a thorough understanding of wedgewire screen design and operation with respect to fish protection capabilities. This information is then used to evaluate the effectiveness of the proposed intake screen design in minimizing fish entrainment and impingement. In addition to the review of wedgewire screen studies, Alden develop an understanding of the likely hydraulic zone of influence (HZI) of the proposed intake in the Mattaponi River and how it would influence risks of fish eggs and larvae to entrainment. Near-field flow conditions (i.e., within several feet of the screens) were also evaluated using available laboratory and numerical data. When considered together, the biological effectiveness data from the literature and far and near-field hydraulic characterizations provide a solid basis for assessing the overall effectiveness of the proposed screen design in minimizing entrainment and impingement of Mattaponi River fishes. Finally, the potential for fish eggs and larvae to be injured or killed during passage across cylindrical screens was assessed using data from studies that have examined the effects of mechanical and hydraulic stressors on ichthyoplankton.

The findings of this report were considered by the King William Reservoir Fisheries Panel in the impact assessment and development of mitigation measures for the proposed intake.

2 CYLINCRICAL WEDGEWIRE SCREEN DESIGN AND OPERATION

2.1 Cylindrical Wedgewire Screen Concept and Design

Cylindrical wedgewire screens have a "V," or wedge-shaped, cross-section wire welded to a framing system that forms a slotted screening element (Figure 1). Screening elements can be deployed as single units or as T-screens (Figure 1). The T-screen has been the most common configuration used for cooling water intake applications of wedgewire screens. However, single units are commonly installed at pump intakes for other types of water withdrawals (e.g., irrigation diversions) as means to prevent juvenile fish entrainment. Cylindrical screens have been considered for application at many types of water intakes because of effective debris management and/or their ability to minimize or eliminate fish entrainment and impingement. The primary mechanisms for minimizing debris loading and fish impacts are: (1) very low approach velocities and (2) sweeping flows that facilitate the movement of debris and organisms past a screen.

For the purposes of our assessment, and to be consistent with other literature and agency criteria, we have defined through-slot velocity as the calculated flow velocity between a screen's wire bars. Estimated slot velocities across a screens surface are dependent on a screen's percent open area (porosity) and withdrawal flow rate. Slot velocities will decrease with greater porosity and increase with greater flow withdrawal. We consider approach velocity to be the velocity component perpendicular to the screen face and sweeping velocity (also referred to as channel or ambient velocity) as the component parallel to the screen. All established agency velocity criteria recommend that sweeping velocities be equal to or greater than approach (or through-slot) velocities to facilitate the movement of fish past screens (CDFG 1993; NMFS 1995; Gowan et al. 1999; WDFW 2000).

Cook (1978) demonstrated how flow fields associated with cylindrical wedgewire screens generally result in successful debris management and reductions in fish entrainment and impingement. Specifically, a cylindrical screen enclosing an intake pipe will create near-uniform through-slot velocities across a screen's surface and approach velocities that decrease at a rate corresponding to the square of the distance from the point of withdrawal. In the analysis of screen design by Cook (1978), uniform flow distribution and very low approach velocities were considered necessary for minimizing the entrapment of debris and aquatic biota. These conditions are achieved by considering the relationships between screen length and diameter, length of pipe within the screen, and flow velocity (Figure 2). Based on these relationships, Cook (1978) presented two velocity coefficients for assessing screen performance. The uniformity coefficient was defined as the ratio of maximum through-slot velocity to minimum velocity (V_{max}/V_{min}) and the performance coefficient was the ratio of maximum to average slot velocity (V_{max}/V_{avg}). Screen performance is maximized when these coefficients are equal to one, resulting in optimum conditions for preventing debris build-up and entrainment and impingement of aquatic organisms.

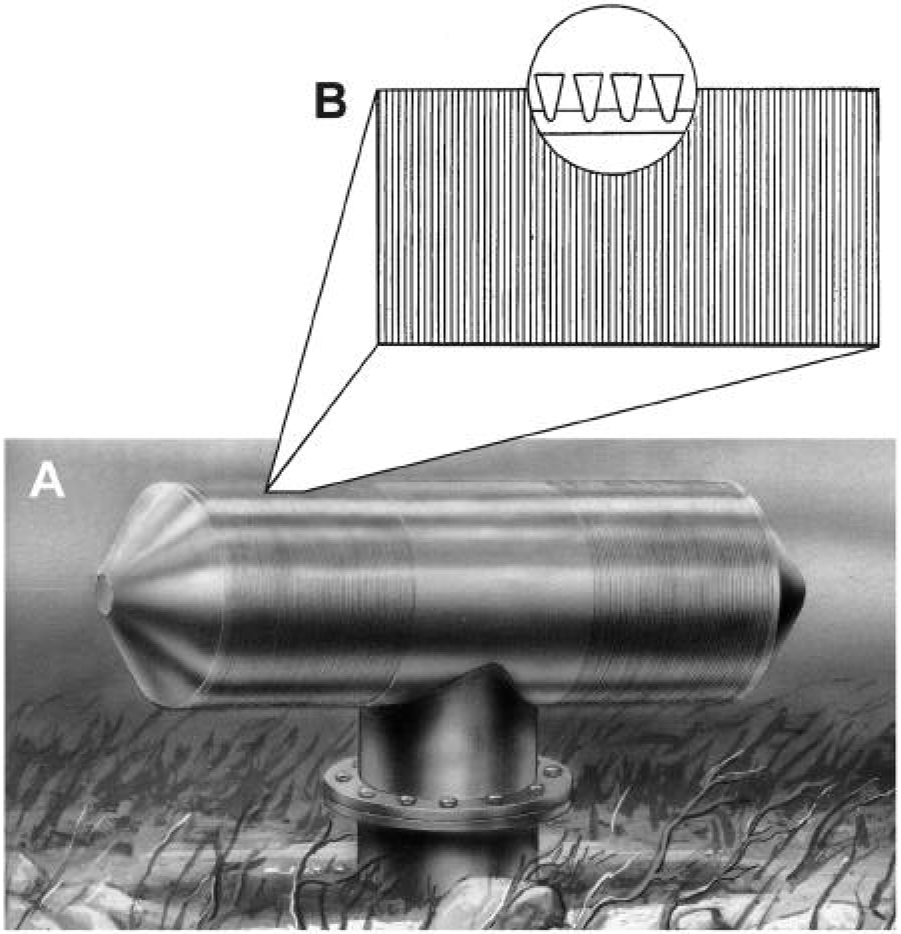

Figure 1. Depiction of a cylindrical wedgewire screen installation (A) and close-up view of slotted wedgewire screen elements (B) (EPRI [2003], modified from Hanson et al. [1978] and EPRI [1999]).

The screen performance analysis presented above was conducted for screens located in waters with no ambient cross flows (i.e., sweeping velocities). Cook (1978) suggested when cylindrical screens are placed perpendicular to approaching flow with velocities of 1 ft/s or less they will appear "invisible" when the percent open area is 40% (this is the approximate open area of 1-mm slot screens with 1.5-mm wire bars, which is the design selected for the KWR intake). However, screens oriented perpendicular to approaching flow have stagnant areas on the upstream face and eddies on the downstream side. Impacts from large debris items also may be a concern. Consequently, Cook (1978) proposed that a T-screen oriented parallel to the flow would improve performance by providing tangential velocities approximately equal to ambient currents with no stagnation points along the length of each screen section (Figure 3). When considering the results of the hydraulic analysis, Cook (1978) cited biological effectiveness data from Hanson et al. (1978) to conclude the probability of larvae and eggs contacting a screen would be lower for the parallel orientation and that the ability of larvae to avoid entrapment increased with distance from the screen due to rapid reductions in approach velocities.

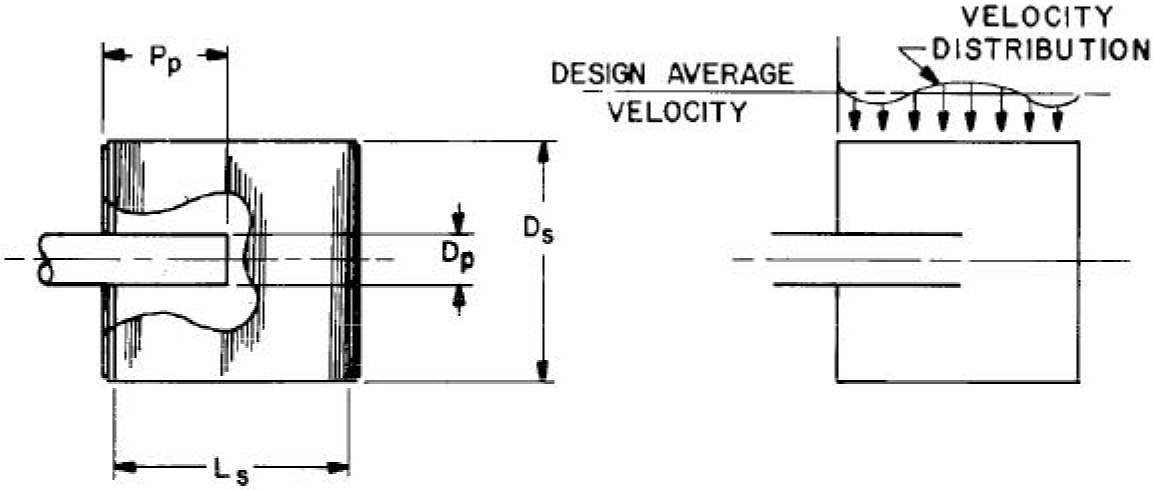

Figure 2. Cylindrical screen design parameters that need to be considered for establishing near-uniform velocity distributions across the surface of a screen (Cook 1978). Design parameters include intake pipe length extending into screen (P_p), pipe diameter (D_p), screen length (L_s), and screen diameter (D_s).

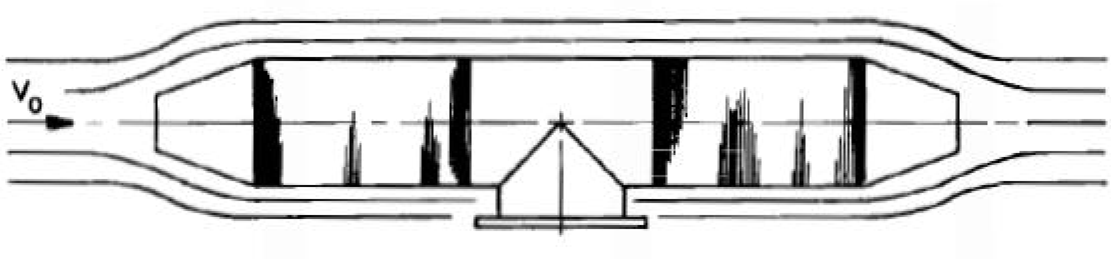

Figure 3. Flow streams approaching and passing a cylindrical wedgewire T-screen oriented parallel to the flow (Cook 1978).

Screen design parameters proposed for the KWR intake meet or exceed important criteria identified by Cook (1978) for effectively minimizing debris loading and entrapment of aquatic organisms. The KWR screens will have a small slot size (1 mm) to physically exclude most ichthyoplantkon, they will be oriented parallel to ambient flow, and they will have a maximum through-slot velocity considerably less than 0.5 ft/s. Also, today's screen manufacturers have advanced the design of cylindrical screens to create even greater flow distribution uniformity, further improving screen performance under a wide range of operating conditions.

2.2 King William Reservoir Intake Screen Design

The proposed King William Reservoir (KWR) will be maintained with water withdrawn from an intake structure located on the Mattaponi River at Scotland Landing. The design of the KWR intake screens considered in our assessment was based on descriptions and information presented in ASA (2003). Design parameters that are considered pertinent to our assessment of fish protection capabilities are summarized below.

The design for the KWR intake structure includes the use of twelve cylindrical wedgewire screens oriented parallel to river discharge and tidal flows. The twelve screens will comprise six T-screens (i.e., two screens per T) positioned in a single line. Each screen section (i.e., one-half of each T-screen) will be 84 inches in diameter and 84 inches wide. Screen slots will be 1 mm wide with an estimated maximum slot velocity of 0.25 ft/s at the maximum design intake withdrawal rate of 75 mgd. Slot velocities are expected to be less than 0.1 ft/s for 75% of the time the intake will be operating based seasonal withdrawal rates estimated from safe yield modeling and minimum instream flow requirements (Figure 4; King William Reservoir Joint Permit Application). Tidal velocities will range from 0 ft/s at slack tide to about 3 ft/s during the ebb tide; maximum velocities during flood tide will approach 2.5 ft/s (Figure 5; Basco 1996).

As described by Cook (1978), approach velocities (i.e., velocity vector perpendicular to the screen face) will dissipate rapidly with distance from a screen. This means that even at the maximum through-slot velocity expected to occur when the KWR intake is operating at pumping capacity, the approach velocities will be considerably less. For the estimated average monthly withdrawal rate (15 mgd), approach velocities will effectively be 0.05 ft/s or less at any distance from the surface of the KWR screens (Figure 6). Additionally, sweeping velocities created by river discharge and tidal flow will be much greater than approach velocities during a large portion of the tidal cycle. This hydraulic condition (i.e., high sweeping velocities relative to approach velocities) is the primary mechanism by which entrainment and impingement of ichthyoplankton is minimized or eliminated at wedgewire screen facilities.

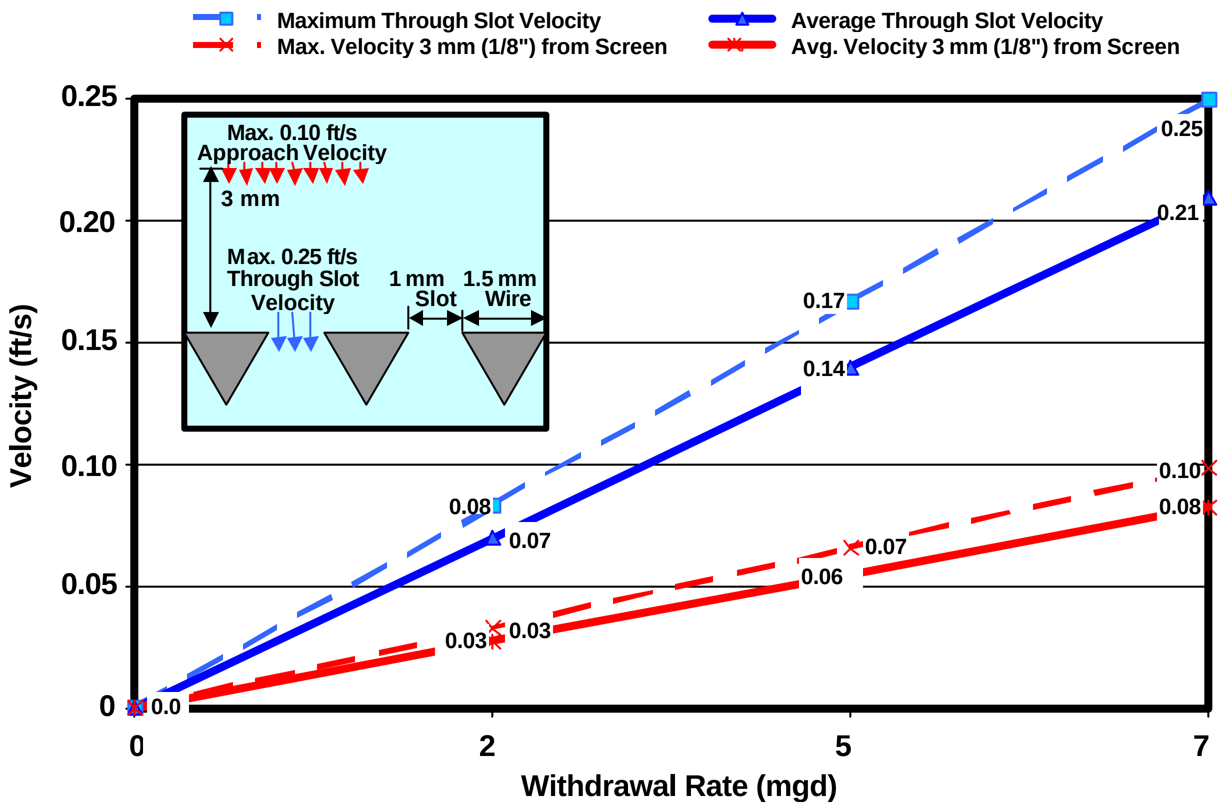

Figure 4. Estimated through-slot and screen approach velocities for the expected operating range (i.e., withdrawal flow rates) of the proposed KWR intake screens (graphic provided by Malcolm Pirnie, Inc.).

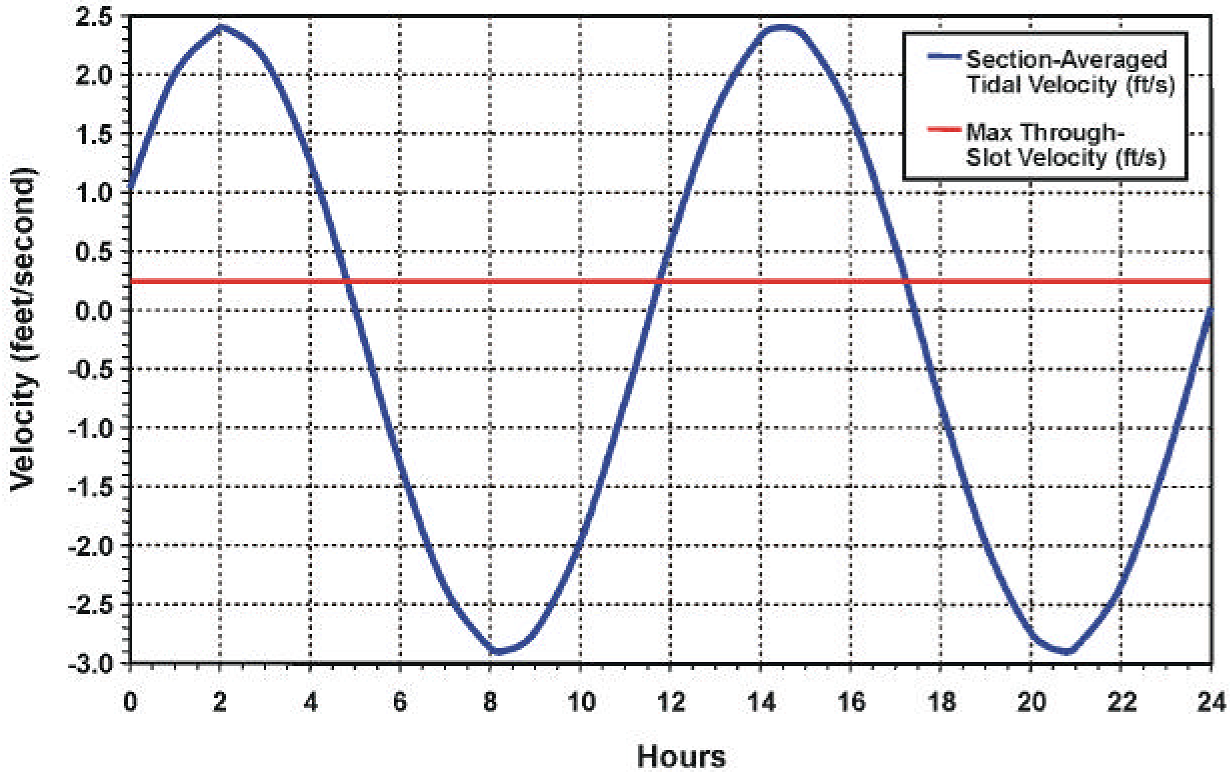

Figure 5. Estimated tidal velocities for the Mattaponi River at Scotland Landing (modified from Basco 1996).

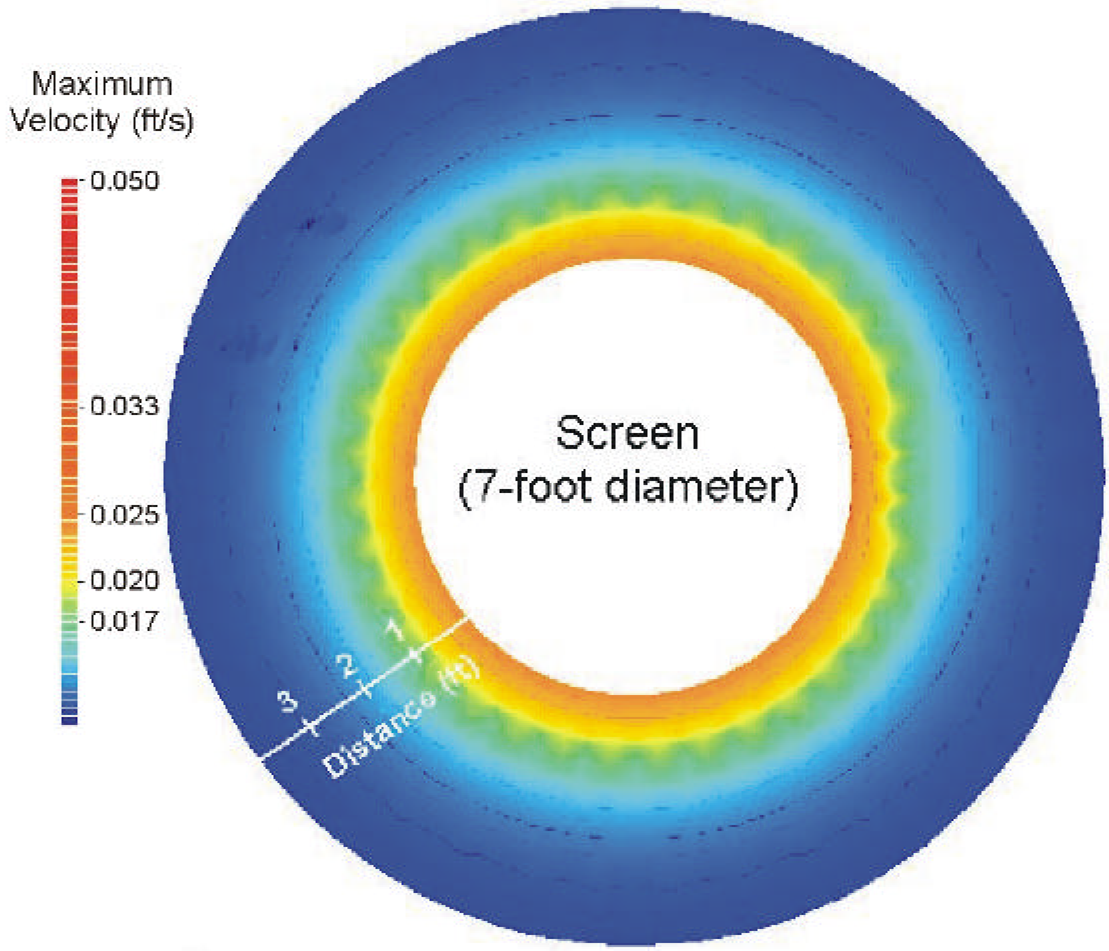

Figure 6. Predicted cross-sectional velocity profile for the proposed KWR intake screens operating at a flow rate of 15 mgd (estimated average monthly withdrawal rate based on minimum instream flow requirements and safe yield modeling; graphic provided by Malcolm Pirnie, Inc.).

3 BIOLOGICAL EFFECTIVENESS OF CYLINDRICAL WEDGEWIRE SCREENS

The ability of cylindrical screens to minimize entrainment and impingement of aquatic organisms is mainly dependent on near-field hydraulic conditions (i.e., within several feet of the screen surface) and the sizes and swimming abilities of fish. Specifically, research on cylindrical wedgewire screens has demonstrated that the following conditions, alone or in combination, are important for reducing entrainment and impingement of fish eggs and larvae to negligible levels: (1) a sufficiently small slot size to physically block passage of the smallest lifestages to be protected; (2) a low through-slot velocity to provide protection for passive or weakly swimming organisms; and (3) ambient currents (i.e., “sweeping” velocity) to carry organisms and debris away from screens. When all of these conditions are met, cylindrical wedgewire screens should be capable of protecting a wide range of species and life stages. However, the relative importance of each of these parameters in maximizing exclusion efficiency may vary with changes in other parameters. For example, small slot widths (= 1 mm) and low through-slot velocities (= 0.5 ft/s) may be overly protective at sites where ambient currents are of sufficient magnitude to carry larvae and eggs past a screen or where abundances of ichthyoplankton are low.

Wedgewire screen design and operational criteria that are considered optimal for protecting aquatic organisms have been developed from engineering and biological studies conducted nationwide over the last 30 years. Engineering studies have verified the presence of hydraulic conditions that facilitate the movement of debris and ichthyoplankton past cylindrical screens when they are placed in areas with ambient currents (Cook 1978; EPRI 2003). As discussed in more detail below, biological studies have successfully demonstrated the high efficiency of these screens in reducing entrainment and impingement under a range of hydraulic conditions for a variety of species and life stages. Using available information, wedgewire screens can be designed to achieve a balance between engineering and biological concerns by selecting a slot velocity and slot width that meet operational requirements for water withdrawal and that are protective of species and life stages of interest. For example, the lowest possible slot velocity and smallest slot size attainable may not be any more protective than less conservative designs if other conditions (e.g., fish size and swimming ability and ambient flow velocities past the screens) contribute to very low entrainment and impingement rates.

Using available data and information from past studies, as well as in accordance with regulatory agency recommendations (Gowan et al. 1999; EPA 2002), the proposed KWR intake screens have been specifically designed to provide fish larvae and eggs a high degree of protection from entrainment and impingement. The maximum through-slot velocity of the screens will be 0.25 ft/s at the maximum intake pumping rate of 75 mgd. However, maximum through-slot velocities are expected to be less than 0.10 ft/s for 75% of the time the intake will be operating because water withdrawal will not always occur at the maximum design flow rate (based on an average monthly withdrawal rate of about 15 mgd calculated from safe yield modeling; ASA 2003). Additionally, ambient current velocities at the proposed location for the intake will range from 0.0 ft/s during slack tides to 2.5-3.0 ft/s at peak tidal flows. With the exception of slack tide periods, the natural river currents will likely provide sufficient sweeping velocities (i.e., equal to or greater than through-slot velocities) for carrying ichthyoplankton past the screens (Hanson et al. 1978; Heuer and Tomljanovich 1978; EPRI 2003). Swimming capabilities of larval fish also will reduce the likelihood of entrainment and impingement, particularly for fish greater than 10 mm in length (Hanson et al. 1978; Weisberg et al. 1984; EPRI 2003).

To support the conclusion that the screen design proposed for the KWR intake is highly protective of ichthyoplankton, a detailed review of wedgewire screen biological evaluations is presented below. This review of past research focuses on entrainment and resulting estimates of exclusion efficiency because several studies have demonstrated impingement of fish larvae does not occur, or is negligible, when wedgewire screens are operated with low slot velocities (0.5 ft/s) (Browne et al. 1981; EA Science and Technology 1986; EPRI 2003). Fish eggs may also experience low impingement rates, particularly in the presence sweeping flows and low slot velocities (Hanson et al. 1978; EPRI 2003).

3.1 Review of Wedgewire Screen Biological Evaluations

There have been a variety of studies that have examined the ability of wedgewire screens to protect ichthyoplankton at water intakes (Table 1). Most of these studies were conducted during the late nineteen seventies and early eighties. Evaluations of biological effectiveness generally have focused on a slot width of 1 mm and a through-slot velocity of 0.5 ft/s (twice the proposed King William Reservoir intake slot velocity). Extensive exclusion efficiency data are available for relatively few species, however, with the most comprehensive data being reported for striped bass, yellow perch, and bay anchovy. American shad, the primary species of interest for the KWR intake installation, have not been evaluated with cylindrical wedgewire screens. Other clupeids have been investigated, but the existing data for species in this family of fishes are limited. Also, only one study has evaluated a through-slot velocity as low as 0.25 ft/s, which is the maximum design slot velocity for the KWR intake screens (this research was conducted with flat panel screens, not cylindrical). Despite the lack of information specific to the proposed KWR intake design, the available data provide strong evidence that the KWR screens will be highly protective of ichthyoplankton in the Mattaponi River. This evidence comes primarily from evaluations of screens that have less protective through-slot velocities than those proposed for the KWR screens, yet results from these studies indicate that cylindrical wedgewire screens are an effective method for minimizing impacts of water intakes on aquatic organisms (EPRI 1999; Gowan et al. 1999; EPA 2002).

The first step in designing biologically protective wedgewire screening systems for intakes is to select a sufficiently small slot width to physically exclude a large portion of the organisms that will potentially be exposed to an intake and that also meets engineering criteria for the operation of an intake. Physical exclusion is based on the body width and depth of larvae and the diameter of eggs relative to slot size. Larvae and eggs larger than the slot width of a screen generally will not be entrained. However, if impingement occurs, it is possible that some ichthyoplankton larger than the space between bars could be squeezed through a slot by intake flows. The influence of organism size on entrainment rates with respect to screen slot width has been demonstrated in several studies. Weisburg et al. (1987) determined that exclusion of bay anchovy and round goby larvae from cylindrical wedgewire screens with varying slot widths was generally dependent on fish length. During their study, larvae less than 5 mm were not effectively excluded by any of the slot sizes evaluated (1, 2, and 3 mm), whereas more than 47%

Table 1. Summary of wedgewire screen studies with respect to intake design parameters proposed for the King William Reservoir intake.

Reference	Study Type	1-mm Slot Width	0.25 ft/s Slot Velocity	Striped Bass	Clupeid	Fresh-water Species	Estuarine Species	Lifestage
Browne (1979), Browne et al. (1981)	field	X					X	E/L
EA Science & Tech (1986)	field			X		X	X	E/L
Ehrler and Raifsnider (1999)	field	X		X	X		X	E/L
EPRI (2003)	lab	X		X		X		E/L
Hanson et al. (1978; 1979; 1981)	lab	X		X		X	X	E/L
Heuer and Tomljanovich (1978, 1979)	lab	X	X	X		X		L
Lifton (1979)	field	X						E/L
Otto et al. (1981)	field	X			X	X		E/L
Veneziale (1992)	field				X	X	X	E/L
Weisberg et al. (1984, 1987)	field	X					X	E/L
Zeitown et al. (1981)	field				X	X		E/L

of fish between 5-10 mm and 90% or more of fish longer than 10 mm were excluded by a 1-mm slot screen. Other studies have also demonstrated that fish longer than about 5 mm can be effectively excluded by screens with 1-mm slot widths (Hanson et al. 1978; Hanson 1981; Heuer and Tomljanovich 1978; Otto 1981; EPRI 2003).

The conclusions drawn by Weisberg et al. (1987) regarding relationships between fish length and entrainment are limited to a narrow range of slot velocities that were tested. During their study, through-slot velocity was maintained between about 0.45 and 0.65 ft/s. Ambient channel velocities were not reported, but testing was conducted in a canal leading to a cooling water intake where velocities likely were about 0.5 to 1.0 ft/s or greater. Other studies have shown that larvae less than 10 mm can be protected from entrainment with 1-mm slot screens when sweeping flows (i.e., ambient currents) are relatively high in comparison to through-slot velocity (Hanson et al. 1978; EPRI 2003). The EPRI (2003) study demonstrated that 35 and 83% of fish less than 10 mm in length tested with a 1-mm screen could be excluded when channel velocities were two times greater than a slot velocity of 0.5 ft/s (Table 2). Impingement rates for these test conditions were less than 5% for the four species tested (Table 3). Because the maximum slot velocity of the KWR intake will not exceed 0.25 ft/s, and channel velocities will be greater than 0.5 ft/s for about 85% of each tidal cycle (Basco 1996), it is likely that exclusion efficiencies at the KWR intake will be considerably higher than those reported by Weisberg et al. (1987) and EPRI (2003).

Table 2. Mean percent entrainment (SD in parentheses) of fish larvae released upstream of a 1-mm slot screen operated with a through-slot velocity of 0.5 ft/s (EPRI 2003). Average lengths of striped bass, winter flounder, and common carp were between 6.0 and 6.5 mm. White sucker larvae averaged 13.9 mm in length.

Slot Velocity (m/s)	Channel Velocity (m/s)	Striped Bass	Winter Flounder	Common Carp	White Sucker	Combined Species Mean
0.15	0.08	41.4 (10.3)	84.6 (5.9)	94.0 (7.8)	12.4 (12.4)	59.7 (36.0)
	0.15	27.0 (5.4)	72.4 (13.1)	81.9 (6.9)	8.3 (5.5)	54.8 (31.7)
	0.30	16.7 (3.5)	61.3 (3.8)	64.5 (5.5)	5.8 (2.3)	39.3 (27.6)

Table 3. Mean percent impingement (SD in parentheses) of fish larvae released upstream of a 1-mm slot screen operated with a through-slot velocity of 0.5 ft/s (EPRI 2003). Average lengths of striped bass, winter flounder, and common carp were between 6.0 and 6.5 mm. White sucker larvae averaged 13.9 mm in length.

Slot Velocity (m/s)	Channel Velocity (m/s)	Striped Bass	Winter Flounder	Common Carp	White Sucker	Combined Species Mean
0.15	0.08	0.0 (0.0)	1.1 (1.7)	5.2 (3.0)	10.8 (4.2)	4.7 (5.1)
	0.15	0.0 (0.0)	2.4 (1.1)	6.0 (3.7)	2.7 (3.1)	3.1 (3.2)
	0.30	0.0 (0.0)	1.3 (1.3)	4.8 (3.0)	4.0 (1.4)	2.8 (2.6)

Predictive models (i.e., regression equations) based on the entrainment data reported by Weisberg et al. (1987) were developed by Langhei Ecology (1998) as a means to estimate exclusion efficiencies using fish length and slot size. Their analysis was conducted to assess potential entrainment of *Alosa* species through 1 and 2-mm slot wedgewire screens at a proposed intake. For a 1-mm screen, Langhei Ecology (1998) estimated exclusion efficiencies would be between about 20 and 70% for American shad 5 to 10 mm in length, greater than 70% for fish larger than 10 mm, and 100% exclusion occurring for fish larger than 13 mm. These predictions are very similar to exclusion efficiencies estimated from tests with live fish (EPRI 2003; 100-entrainment percentages reported in Table 2). The Langhei Ecology (1998) predictive models are useful for estimating exclusion efficiencies of 1-mm slot screens that will be operated with similar channel and through-slot velocities as those experienced during the tests reported by Weisberg et al. (1987) (through-slot velocities were between 0.45 to 0.65 ft/s). However, for sites where channel velocities are higher and slot velocities are lower, an analysis using these data would underestimate exclusion rates. Such would be the case for the KWR intake, for which exclusion rates likely will be considerably higher due to the much lower slot velocity and higher channel velocities experienced during most portions of the Mattaponi River tidal cycle at the proposed intake site.

In addition to physical exclusion, the size of fish larvae can influence behavioral avoidance of screens if swimming strength is sufficient for avoiding intake flows that can lead to impingement or entrainment. Differences in exclusion rates observed between smaller and larger sized larval groups evaluated in past studies likely have been the result of differences in both fish sizes and swimming abilities. Visual observations and estimated entrainment rates of fish that are physically capable of passing through slots have demonstrated that swimming ability contributes to effective exclusion, even for smaller larvae (< 10 mm) (Hanson et al. 1978; Zeitoun et al. 1981; Otto et al. 1981). Hanson et al. (1978) and Hanson (1981) showed that the percentage of striped bass larvae capable of swimming away from an operating screen, thus avoiding entrainment and impingement, in the absence of sweeping flows increased with fish size (i.e., larger fish were stronger swimmers).

The ability of larvae to actively avoid entrainment and impingement will be dependent on slot and channel velocities relative to swimming speed. That is, swimming speed must exceed screen approach velocities (which are less than through-slot velocity) or channel velocities need to be high enough to sweep organisms along a screen. Data presented by Gowan et al. (1999) indicate larvae that are about 10 mm in length can maintain swimming speeds of about 1 to 4 body lengths per second (0.03 to 0.13 ft/s) for a minimum of an hour, depending on species and water temperature. For the estimated average monthly withdrawal rate of 15 mgd, approach velocities calculated for the KWR screens are less than 0.05 ft/s at distances greater than 6 inches from the screen face (Figure 6). Therefore, larvae that are beyond this distance from the screens likely will be able to swim away from the KWR intake screens, even at slack tide. Avoidance should be even greater when ebb and flood tides create velocities capable of sweeping fish past the screens. This assessment indicates that fish larvae exposed to the KWR screens will be able to actively avoid entrainment (and be carried downstream in the presence of sweeping flows) and that this ability will be increase as fish grow (i.e., greater swimming speeds will result in greater screen avoidance).

As previously mentioned, through-slot velocity and sweeping velocity have considerable influence on impingement and entrainment of fish exposed to wedgewire screens. Impingement and entrainment have been positively correlated with slot velocity and inversely related to sweeping velocity (Hanson et al. 1978; Heuer and Tomljanovich 1978; EPRI 2003). Available data suggest that the ratio of ambient velocity to slot velocity should be maximized for effective exclusion of aquatic organisms (Hanson et al. 1978; EPRI 2003). However, even at a ratio of 1 (i.e., channel velocity is equal to slot velocity), high rates of screen exclusion can occur, depending on species and fish size (Hanson et al. 1978; Hanson 1981; EPRI 2003). The maximum slot velocity for the KWR intake will result in channel-to-slot velocity ratios ranging from 0 (slack tide) to 12 (maximum tidal flow), with a ratio of 2 or greater occurring during about 85% of the tidal cycle. Most previous studies have evaluated channel-to-slot velocity ratios between 1 and 2, often with relatively high exclusion rates (Hanson et al. 1978; Heuer and Tomljanovich 1978; EPRI 2003). The results of studies that have evaluated multiple channel and slot velocities indicate wedgewire screens should be protective (e.g., > 80%) for most species and life stages when channel velocities are equal to or greater than through-slot velocities.

Results from the one study that evaluated a 0.25 ft/s slot velocity demonstrated that larvae of several species of freshwater fish 7-14 mm in length can be excluded from a 1-mm slot screen at rates typically exceeding 80%, and often greater than 90% (Heuer and Tomljanovich 1979). The estimates of exclusion from this study were based on the ability of released larvae to safely pass a 20 ft length of wedgewire screen, which is about 6 ft longer than the total length of screen on each KWR T-screen (i.e., the KWR T-screens are designed to be 24 ft long with two 7-ft screen lengths). Average sweeping velocities tested by Heuer and Tomljanovich (1979) at the upstream end of the test screen section were about 2 ft/s, decreasing to about 1 ft/s at the downstream end. In general, statistical comparisons showed that screen exclusion was significantly greater at a slot velocity of 0.25 ft/s than at a velocity 0.50 ft/s. The results of this study support the conclusion that exclusion efficiencies of larvae greater than about 8 mm in length will likely exceed 80% at the KWR intake when sweeping flows are at least 1 ft/s and the slot velocity is 0.25 ft/s (i.e., at the maximum design pumping rate of 75 mgd). When the pumping rate is 33 mgd or less, which is expected to occur about 75% of the time the screens are operating, slot velocities at the KWR intake will be 0.10 ft/s or less. At these low slot velocities, exclusion rates are likely to exceed 90% for all larvae exposed to the KWR screens, particularly when channel velocities will be greater than the slot velocity.

Several field studies have been conducted with cylindrical wedgewire T-screens installed parallel to ambient currents (Otto et al. 1981; EA Science and Technology 1986; Ehrler and Raifsnider 1999). Tests conducted by Otto et al. (1981) and Ehrler and Raifsnider (1999) were performed with 1-mm slot screens operated at slot velocities of 0.4 and 0.5 ft/s, respectively. EA Science and Technology (1986) reported the results of entrainment and impingement sampling conducted with 0.5-mm slot screens operated at a design slot velocity of 0.5 ft/s. During each of these studies, species and life stage occurrences and abundances in the vicinity of the intakes were determined with concurrent sampling (either towed or fixed net sampling). However, data reported for EA Science and Technology (1986) focused on species composition, abundance, and length (or diameter for eggs) and not any type of measure of exclusion efficiency.

The two field studies conducted with the 1-mm slot T-screens (i.e., same slot width as proposed for KWR screens) demonstrated that entrainment densities of ichthyoplankton were less than the densities of the same species collected during river samples. Based on river densities and expected entrainment rates proportional to flow withdrawn through an open intake, Ehrler and Raifsnider (1999) concluded that two wedgewire intake screens installed at the Logan Generating Plant were effective in reducing entrainment rates of striped bass eggs and larvae to insignificant levels. Otto et al. (1981) reported that clupeid larvae comprised about 7% of the total larvae entrained and about 45% of larvae captured during river sampling. Additionally, the length range of entrained clupeid larvae was 3 to 8 mm, whereas river sampling collected specimens as large as 15 mm. Based on these results, and those for other species collected, Otto et al. (1981) suggested that physical exclusion was only important for eggs because larvae appeared to be capable of detecting and reacting to the flow fields surrounding the test screen. It was further suggested that, based on the size of fish entrained, larvae longer than about 6 to 8 mm had sufficient swimming capabilities to completely avoid entrainment despite being able to fit through the 1 mm slots. These conclusions are important to the assessment of the KWR screens because striped bass and clupeid larvae are of primary concern in the Mattaponi River and the proposed screens have the same slot width as the screen evaluated by Ehrler and Raifsnider (1999) and Otto et al. (1981), but only half the slot velocity. The results of both studies suggest the proposed design for the KWR intake will be highly protective for several species of concern. The study by Otto et al. (1981) also provides additional evidence that fish greater than 10 mm in length will have exclusion efficiencies at or near 100%.

Although several studies have demonstrated the efficacy of cylindrical wedgewire screens in reducing entrainment and impingement of aquatic organisms, it is important to recognize potential weaknesses in the data collected and differences in experimental design that may influence how the results of past studies effect the analysis of impacts of the proposed KWR intake. Most evaluations of cylindrical screens have been conducted with only one screen section (i.e., only half of a T-screen) and with test screens oriented perpendicular to the flow. Manufacturers currently recommend T-screens be positioned parallel with any prevailing currents to facilitate debris removal and bypassing of aquatic organisms. Results from a laboratory study that evaluated striped bass entrainment and impingement with perpendicular and parallel screen orientations support this recommendation, particularly for fish larvae tested with 1 and 2-mm slot widths (EPRI 2003). With respect to species-specific exclusion rates, American shad have not been evaluated with wedgewire screens. However, results from tests with bay anchovy support the conclusion that low rates of entrainment and impingement can be achieved for very fragile species with this technology (Weisberg et al. 1987). Testing with striped bass and yellow perch has demonstrated that these species can also be effectively protected with wedgewire screens (Hanson 1981). Because the results from previous studies have led to the conclusion that a slot width of 1 mm and a through-slot velocity of 0.5 ft/s are sufficient for protecting ichthyoplankton, the screen design criteria selected for the KWR intake should be highly protective of aquatic organisms.

The study reported by EPRI (2003) provides data that may be the most relevant to the KWR intake screens due to the design and operational parameters that were evaluated. The design and results of this study are discussed in more detail below.

3.2 EPRI Cylindrical Wedgewire Screen Laboratory Study

An evaluation of ichthyoplankton entrainment and impingement rates associated with cylindrical wedgewire screens was recently conducted to develop a better understanding of the factors that influence biological effectiveness of this technology and to provide information that would be useful in designing future applications for cooling water intakes (EPRI 2003; Amaral et al. in press). This study was funded by EPRI and the EPA in response to the new rules being developed by the EPA for implementing Section 316(b) of the CWA. Cylindrical wedgewire screens are considered by the EPA to be one of only three existing fish protection technologies with relatively high potential for reducing entrainment mortality at cooling water intakes, and one of four technologies for effectively reducing impingement rates. Of all the previous studies conducted with cylindrical wedgewire screens, the EPRI laboratory study provides data that are probably the most relevant to the KWR intake. The EPRI study evaluated 1-mm T-screens oriented parallel to approaching flow under similar, but less protective, hydraulic conditions using several species that occur in the Mattaponi River. When reviewing these data, it is important to remember that through-slot velocities proposed for the KWR intake are substantially less than the lowest slot velocity (0.5 ft/s) evaluated during the EPRI study. Lower slot velocities were not selected for evaluation by EPRI and the EPA because the test velocities that were selected, 0.5 and 1.0 ft/s, were considered to have good potential for protecting most species and life stages at water intakes based on past research. Slower through-slot velocities would even be more protective.

The EPRI study was conducted in a laboratory flume with flowing water. Screen design and operation parameters selected for testing included three slot widths (0.5, 1.0, and 2.0 mm), two through-slot velocities (0.5 and 1.0 ft/s), and three channel velocities (0.25, 0.5, and 1.0 ft/s). Eight fish species were chosen for the study based on their occurrence at a large number of cooling water intakes with different types of source water (e.g., river, estuary, lake, and coastal). Due to availability constraints and the logistics of testing a large number of parameters and species, not all species were evaluated with every set of test conditions (i.e., all possible combinations of slot width, slot velocity, and channel velocity). Also, only eggs or only larvae were evaluated during testing with some species, and an artificial egg (gelatinous bead) was used to evaluate entrainment and impingement of striped bass eggs.

The biological effectiveness of the test screens was determined by estimating entrainment and impingement percentages for a known number of organisms released about 2 ft upstream of the nose of a test screen. This release location resulted in all organisms passing within several inches of the screen surface. Because intake velocities decrease rapidly with distance from the screen surface, the estimated entrainment and impingement rates from this study are considered to represent minimum exclusion rates. That is, organisms passing by a wedgewire screen at greater distances likely would be excluded at considerably higher rates than was observed during the flume tests. In fact, velocity measurements and computer modeling of flow fields surrounding the test screens indicate larvae and eggs located more than 6 to 12 inches from the screen surface would not be subject to entrainment or impingement in the presence of sweeping flows equal to or greater than 0.5 ft/s and with slot velocities as high as 0.75 ft/s (see next section for more detailed discussion of the effects of near-field flow conditions). Entrained fish were collected in a plankton net prior to flow passing through the intake pump. Impinged fish were counted using underwater cameras that were manually moved along the screen surface after a test. Three to five trials were conducted for each set of test conditions evaluated and approximately 75 to 100 organisms were released per trial. A mean percent entrained and impinged for each set of test conditions was calculated from the replicate trial estimates.

Several patterns associated with entrainment and impingement rates are evident from the results of the EPRI study, and are pertinent to the biological effectiveness of the KWR intake screens. For 1-mm slot screens operated with a slot velocity of 0.5 ft/s (twice that proposed for the KWR screens), impingement rates of larvae were generally about 5% or less, even when the approaching channel velocity was 50% lower than the slot velocity (i.e., 0.25 ft/s versus 0.5) (Table 3). Consequently, the low slot velocities that will be experienced by larvae at the KWR intake (0.25 ft/s maximum and 0.10 ft/s for 75% of the time the intake will be operating) probably will result in larval impingement rates of 1 to 2% or lower. Exclusion rates (i.e., 100-entrainment rate) of four species evaluated with the 1-mm slot screens decreased with increasing channel velocity (Figure 7). Entrainment varied considerably among species, but was less than 30% for striped bass and white sucker larvae when the channel velocity was equal to or greater than the slot velocity (Table 2). Entrainment rates of winter flounder and common carp were considerably higher, exceeding 60% for tests at all channel velocities. Based on these data and the lower slot velocities of the KWR screens, entrainment rates for larvae passing within several feet of the intake screens probably will be between 30 to 50% for fish less than 10 mm (i.e., based on striped bass, winter flounder, and common carp data in Table 2) and less than 10% for fish greater than 10 mm (based on white sucker data). Complete exclusion of larvae in the near-field of the KWR intake (i.e., within several feet of the screen surface) likely will occur for fish greater than about 12 mm in length. These conclusions are also supported by the results of other studies (Hanson et al. 1978; Weisberg et al. 1987) and a review of available data (Gowan and Garman 1999).

For the purposes of this report, a more in-depth statistical analysis of exclusion rates from the EPRI study was conducted to develop estimates of exclusion efficiencies that would likely be experienced by fish larvae exposed to the KWR intake screens. For this analysis, a multiple regression was conducted with data from tests with all species evaluated with the 1-mm slot screen at slot velocities of 0.5 and 1.0 ft/s. The dependent variable for the regression analysis was the proportion of fish excluded by the screen, and the independent variables were channel-to-slot-velocity ratio and fish length. An arcsine transformation was used for the dependent variable (proportion excluded) to approximate a normal distribution (Zar 1984). Using the channel-to-slot velocity ratio instead of the individual velocity variables provides a standardized parameter that can represent a wide range of velocity conditions (e.g., a ratio of 2 can represent a channel and slot velocity combination of 0.50 and 0.25 ft/s, respectively, or a combination of 0.2 and 0.1 ft/s). However, it is important to remember that the data reported by EPRI (2003) represent velocity ratios established with slot velocities of 0.5 and 1.0 ft/s and not 0.25 ft/s (i.e., maximum design slot velocity for the KWR intake screens). This represents a potential weakness in extrapolating the regression results to the KWR intake, but also suggests that the results are conservative because they are generated from tests with less protective slot velocities. Additionally, the EPRI study did not include tests with larvae between about 9.0 and 13.5 mm in length. This is the approximate length range for which complete or near complete exclusion has been reported in the literature. The absence of this data likely result in conservative predictions for KWR intake screen exclusion rates because larvae of some species that are greater than 8 mm probably have sufficient swimming capabilities to avoid entrainment at slot velocities of 0.5 ft/s or less (Otto et al. 1981; Hanson et al. 1978; Hanson 1981; Weisberg et al. 1987).

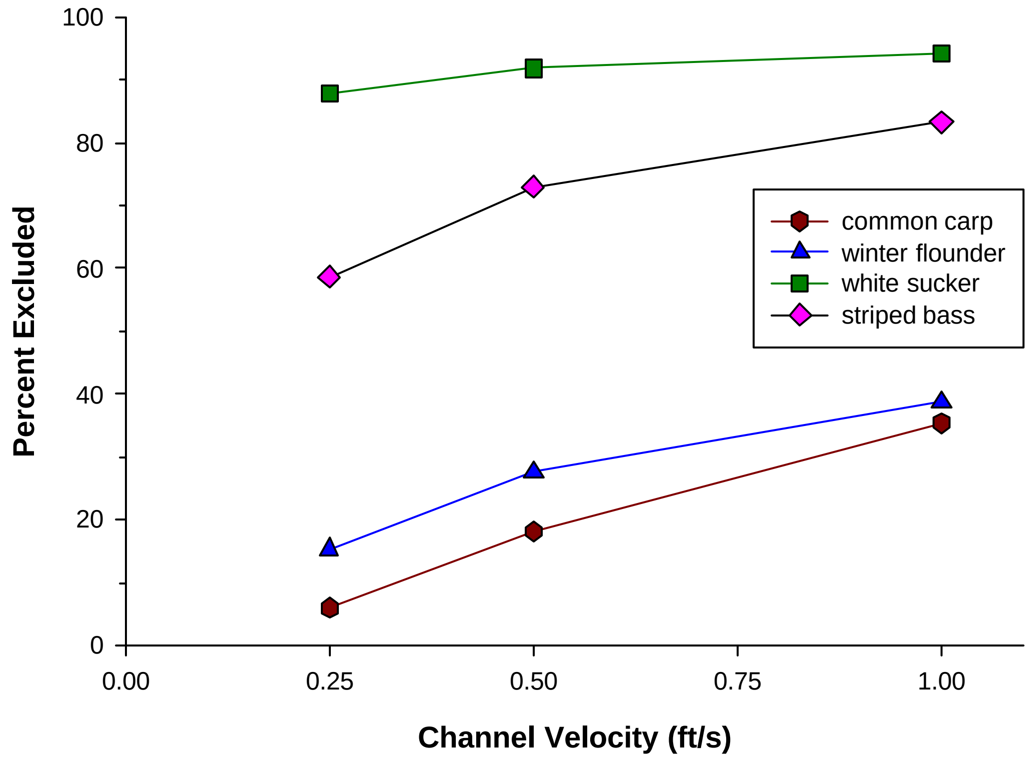

Figure 7. Mean percent larval exclusion by channel velocity for tests with a 1-mm slot screen and a through-slot velocity of 0.5 ft/s (EPRI 2003).

The results of the multiple regression were statistically significant for the relationship between proportion excluded and the two independent variables ($P < 0.05$; Table 4). The constant and the independent variable coefficients were also statistically significant ($P < 0.05$; Table 4). The multiple regression equation was used to predict exclusion efficiencies based on fish size (Figure 8) and channel velocity (Figure 9) for slot velocities of 0.10 and 0.25 ft/s (i.e., most common operational velocity and maximum for the KWR screens). At a slot velocity of 0.10 ft/s or less, complete exclusion should occur for larvae 12 mm or greater when channel velocities reach 0.25 ft/s (i.e., greater than 90% of complete tidal cycle). Complete exclusion of larvae greater than 5mm is predicted to occur at 0.10 ft/s slot velocity when channel velocities are 0.5 ft/s or greater (i.e., approximately 85% of tidal cycle). At the maximum slot velocity of 0.25 ft/s, 100% percent exclusion of larvae more than 5mm is likely when channel velocities reach 1.0-1.5 ft/s (larvae 5-12 mm) and 0.5-0.75 ft/s (larvae >12 mm). Complete or near complete exclusion has been reported in the literature for fish between 8 and 12 mm in length, even at channel velocities less than 0.5 ft/s. This suggests that exclusion predictions generated from the EPRI (2003) data are conservative (larvae between about 9.0 and 13.5 mm were not tested during the EPRI study).

Table 4. Multiple regression results for relationship between entrainment exclusion (dependent variable) and fish length and channel-to-slot velocity ratio (independent variables) using data from tests with a 1-mm slot screen and through-slot velocities of 0.5 and 1.0 ft/s (EPRI 2003).

N: 106
r: 0.765
r^2: 0.585
SE of estimate: 20.286

Variable	Coefficient	SE	t	*P*(2 tail)
constant	-11.376	4.524	-2.514	0.013
Length	4.748	0.421	11.272	0.000
Vel ratio	11.644	2.309	-5.043	0.000

Analysis of Variance

Source	Sum-of-Squares	df	Mean-square	*F*-ratio	p
regression	27213.007	2	13606.504	72.471	0.000
residual	19338.475	103	187.752		

In contrast to larvae, surrogate striped bass eggs and live white sucker eggs (> 2 mm in diameter) evaluated during the EPRI study were more susceptible to impingement than entrainment because their diameters were greater than the slot widths evaluated. Alewife eggs, which were less than 1 mm in diameter, were more susceptible to entrainment than to impingement. Striped bass and white sucker eggs were impinged at high rates when the channel velocity was less than the slot velocity (Table 5; Figure 10). However, at channel velocities equal to or less than the slot velocity, impingement rates dropped drastically and entrainment was 0% with the exception of one series of tests with white sucker (Table 6; Figure 10). Because slot velocities for the KWR screens will be 0.25 ft/s or less and channel velocities will be equal to or greater than this value more than 90% of a complete tidal cycle, the impingement rates for the eggs of most species at the proposed KWR intake (i.e., those with egg diameters greater than the 1-mm slot size) likely will be less than 5%. For eggs with diameters less than 1 mm (e.g., river herring), the closest analog is the entrainment estimates for alewife eggs tested with 0.5 and 2.0-mm slot screens (Table 6). The results of tests with this species indicate impingement of eggs less 1 mm in diameter probably will not occur at the KWR intake and entrainment rates will likely be less than 10% when channel velocities are equal to or greater than the through-slot velocity.

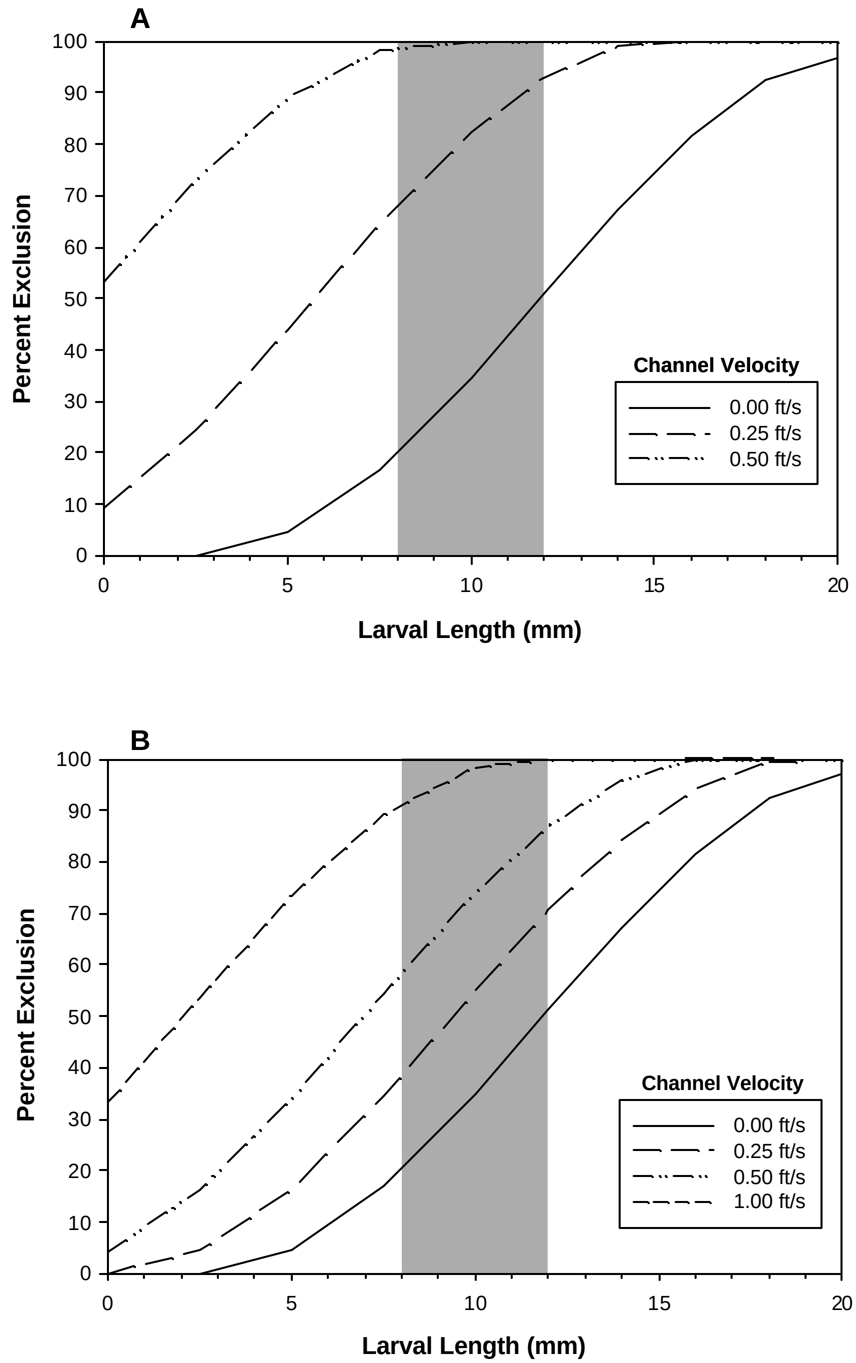

Figure 8. Screen exclusion rates by larval length for a 1-mm slot screen with a through-slot velocity of 0.10 ft/s (A) and 0.25 ft/s (B) and varying channel velocities. Exclusion rates were generated from a multiple regression analysis of entrainment data from EPRI (2003). Independent variables included ratio of channel-to-slot velocity and fish length. Shaded areas indicate length range for which complete or near-complete exclusion has been reported in the literature (i.e., estimates generated from the EPRI data are likely conservative).

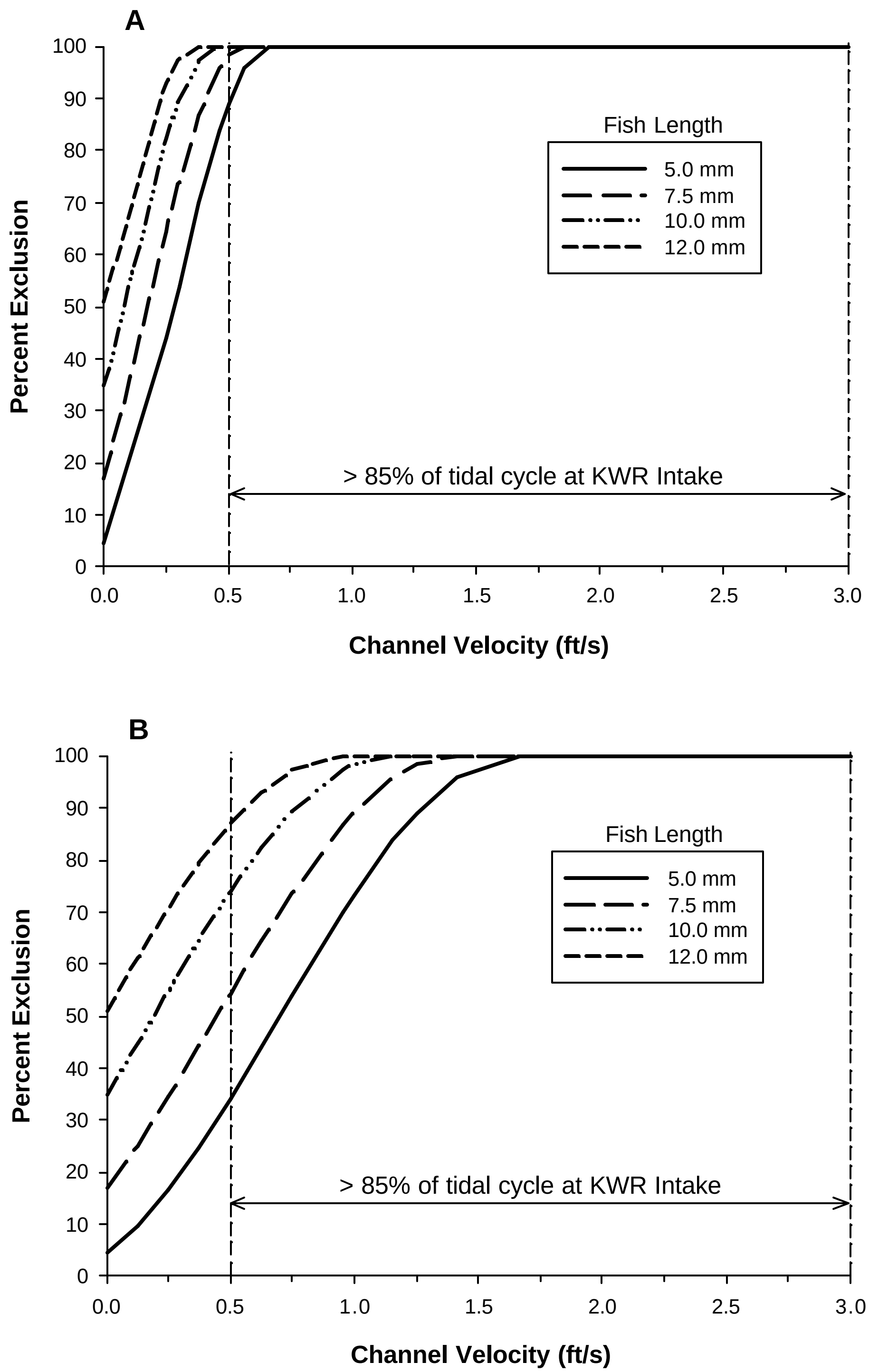

Figure 9. Screen exclusions rates by channel velocity for a 1-mm slot screen with through-slot velocities of 0.10 (A) and 0.25 ft/s (B). Exclusion rates were generated from a multiple regression analysis of entrainment data from EPRI (2003). Independent variables included ratio of channel-to-slot velocity and fish length.

Table 5. Mean percent impingement of fish eggs evaluated during EPRI-EPA wedgewire screen evaluation (EPRI 2003). Mean egg diameters were 4.5 mm for of striped bass surrogate eggs, 3.2 mm for white sucker eggs, and 0.7 for alewife eggs.

Slot Size (mm)	Slot Velocity (m/s)	Channel Velocity (m/s)	Mean Percent Impingement and Entrainment (SD in parentheses)					
			Striped Bass		White Sucker		Alewife	
			Imp	Ent	Imp	Ent	Imp	Ent
0.5	0.15	0.08	13.0 (10.6)	0.0(0.0)	0.5 (0.7)	0.0 (0.0)	--	--
		0.15	0.7 (1.2)	0.0(0.0)	1.1 (1.1)	0.0 (0.0)	--	--
		0.30	0.0 (0.0)	0.0(0.0)	0.0 (0.0)	0.0 (0.0)	--	--
	0.30	0.08	97.3 (2.3)	0.0(0.0)	59.8 (25.0)	0.3 (0.6)	0.0 (0.0)	19.7 (8.6)
		0.15	21.3 (16.7)	0.0(0.0)	4.8 (2.8)	0.0 (0.0)	0.0 (0.0)	10.1 (15.2)
		0.30	0.0 (0.0)	0.0(0.0)	0.5 (1.2)	0.0 (0.0)	0.0 (0.0)	–
1.0	0.15	0.08	91.0 (14.7)	0.0(0.0)	--	--	--	–
		0.15	0.3 (0.6)	0.0(0.0)	--	--	--	--
		0.30	0.0 (0.0)	0.0(0.0)	--	--	--	--
	0.30	0.08	98.7 (1.2)	0.0(0.0)	--	--	--	--
		0.15	88.7 (3.5)	0.0(0.0)	--	--	--	--
		0.30	0.0 (0.0)	0.0(0.0)	--	--	--	--
2.0	0.15	0.08	93.7 (4.9)	0.0(0.0)	--	--	--	--
		0.15	4.7 (3.2)	0.0(0.0)	--	--	--	--
		0.30	0.0 (0.0)	0.0(0.0)	--	--	--	--
	0.30	0.08	--	--	--	--	--	52.8 (31.6)
		0.15	--	--	--	--	--	29.5 (40.1)
		0.30	--	--	--	--	--	26.4 (11.3)

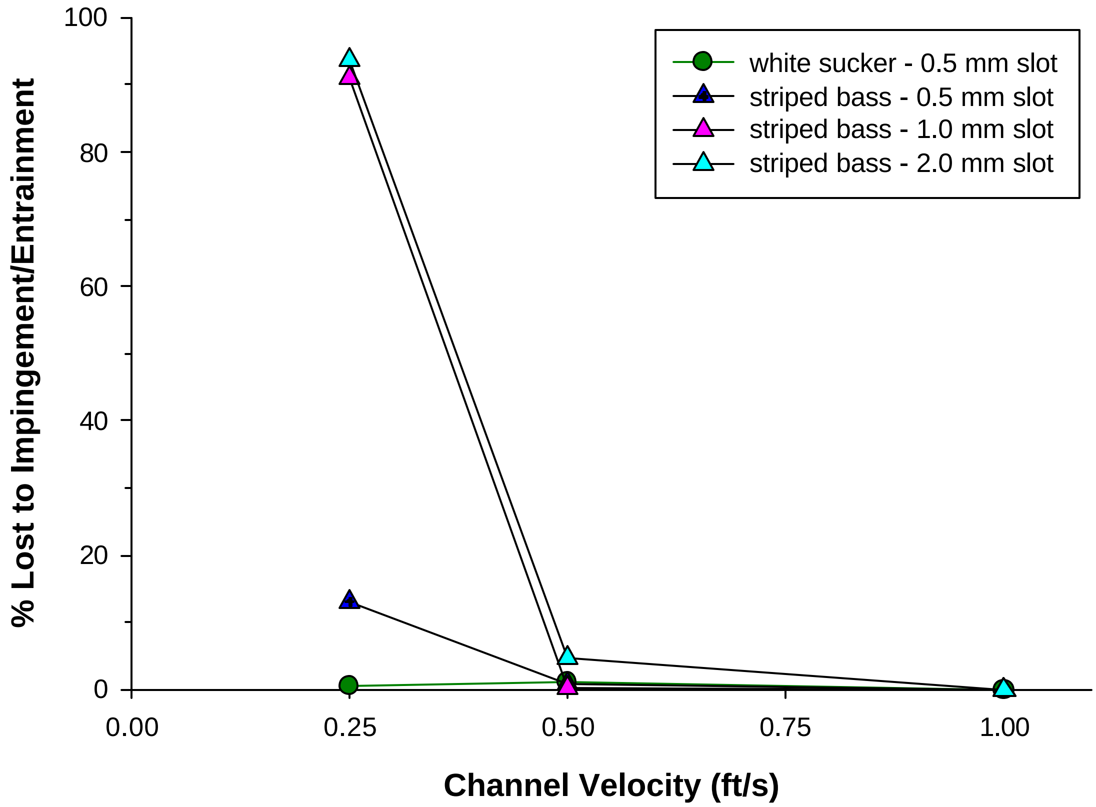

Figure 10. Mean percent of eggs impinged by channel velocity during tests with a 1-mm slot screen and a through-slot velocity of 0.5 ft/s (EPRI 2003). Percent lost represents impingement for surrogate striped bass and live white sucker eggs (i.e., entrainment was typically 0% due to their large size) and it represents entrainment for live alewife eggs, which were too small to become impinged

The results of the EPRI laboratory study provide a strong basis for estimating exclusion efficiencies of eggs and larvae that will be susceptible to entrainment and impingement at the proposed KWR intake. Larval impingement was negligible (generally < 5%) for all conditions evaluated during the EPRI study, and impingement of eggs was generally 0% when channel velocities were equal to or greater than slot velocities. Based on these observations and the expected channel and slot velocities that larvae and eggs will experience at the KWR intake, impingement rates of ichthyoplankton likely will be less than 5% and, consequently, should result in the loss of very few fish. Entrainment rates (or exclusion efficiency) will vary with species, size, slot velocity, and channel velocity. The analysis of data from the EPRI study indicates that high rates of exclusion (> 90%) should occur for fish larvae greater than 12 mm in length during 85% or more of the tidal cycle at the intake site when slot velocities are 0.25 ft/s or less. Smaller larvae (5-12 mm) should be excluded at rates in excess of 90% when channel velocities exceed 0.5 ft/s and the slot velocity is 0.10 ft/s or less. These estimates of exclusion are for eggs and larvae passing very close to the screen surface (i.e., within inches) and would increase with distance away from the screens. Exclusion rates for all ichthyoplankton within a screen's hydraulic zone of influence (i.e., within several feet of a screen's surface) may be very high for all stages of a tidal cycle, including during slack periods.

3.3 Biological Effectiveness Conclusions

The primary conclusions from the fish protection capability assessment of cylindrical wedgewire screens and the proposed screen design for the KWR intake include the following:

- The results from biological evaluations have demonstrated that cylindrical wedgewire screens are viable technology for effectively protecting ichthyoplankton at water intakes. In addition to the literature, this conclusion is supported by established screen design criteria for water intakes developed independently by the U.S. EPA for cooling water intakes and by the Virginia Department of Game and Inland Fish. Cylindrical wedgewire screens are the only EPA-approved technology that can be used to meet the new national performance standards for reducing impingement mortality and entrainment at existing cooling water intakes located on freshwater rivers.

- Several studies have reported complete or near complete exclusion of larvae between 8 and 12 mm in length. Differences in the minimum length at which complete exclusion was observed are likely due to species-specific swimming capabilities and the hydraulic conditions that were tested (i.e., slot and sweeping velocities).

- High rates of exclusion have been demonstrated during several studies for screens with through-slot velocities of 0.5 ft/s. This slot velocity is twice the maximum design velocity of the KWR screens. Consequently, exclusion rates of larvae at the KWR intake should exceed most previously reported estimates for 1-mm slot screens, particularly when sweeping flows (i.e., channel velocities) are equal to or greater than slot velocities. Tidal channel velocities are expected to be equal to or exceed the maximum design velocity of 0.25 ft/s for more than 90% of the duration of each tidal cycle. These hydraulic conditions should also contribute to very low rates of egg entrainment and impingement (both should be less than 5 to 10% when channel velocities are equal to or exceed slot velocities).

- Results from the one study that evaluated a 0.25 ft/s slot velocity found that exclusion rates were significantly greater for larvae tested with this velocity than for a slot velocity of 0.5 ft/s. Data reported by this study for tests with a 1-mm slot screen were conducted with freshwater fish larvae ranging in length from about 5 to 14 mm. Eighty to 100% exclusion occurred over a screen length of 20 ft for fish longer than 7 mm and with sweeping flows ranging from 2 to 1 ft/s from the upstream to downstream end of the screen. Similar hydraulic conditions are expected to be present at the KWR intake as was tested during this study, indicating that most larvae exposed to the KWR screens will also be excluded at rates exceeding 80% for a large portion of each tidal cycle.

4 ASSESSMENT OF HYDRAULIC ZONE OF INFLUENCE

The natural hydraulic patterns of a water body, and their relationships to intake withdrawals, are important factors for assessing the risk of fish populations to water intake structures. For an organism to be to become impinged or entrained it must enter the hydraulic zone of influence (HZI) of an intake structure. Thus, while the general proximity of a primary spawning or nursery area to an intake structure can be an important influence on the likelihood of a fish population being at risk to entrainment and impingement, hydraulic conditions approaching and surrounding intake screens will determine actual susceptibility to loss. The EPA acknowledges the importance of the HZI in its proposed CWA Section 316(b) implementation rules, defining the HZI as "that portion of the source water body hydraulically affected by the [intake structure's] withdrawal of water." For the purposes of our assessment, the HZI is defined as the zone, or volumetric area, of water from which flow is withdrawn.

In rivers, the HZI begins at an upstream point where the entire discharge flow has a relatively low probability of entering an intake. As river's flow approaches an intake, the HZI decreases in size and the probability of water within the HZI entering an intake increases, whereas flow outside the HZI has a negligible probability of being withdrawn. It is generally assumed that passive particles within a river experience the same probabilities of being withdrawn by an intake as does river flow (EPRI, in press). However, organisms traveling within the HZI of an intake may still have a high probability of avoiding entrainment or impingement due to favorable hydraulic conditions that develop in the near vicinity of an intake(e.g., low slot velocity, relatively high sweeping velocities that result in eggs and larvae being carried past cylindrical screens). Effective guidance can occur even when ichthyoplankton are within close proximity to a screen's surface (< 1 inch). This is particularly true with cylindrical wedgewire screens (EPRI 2003), which are specifically designed to create optimum hydraulic conditions for debris management and protection of aquatic organisms. Sections 2 and 3 should be reviewed for detailed discussions of screen design and ichthyoplankton exclusion efficiencies.

In separate assessments of fish population impacts, the Virginia Institute of Marine Science (VIMS) and ASA Analysis and Communications, Inc. (ASA) prepared independent estimates of average daily ichthyoplankton losses resulting from the operation of the proposed KWR intake structure located at Scotland Landing. Both studies required estimates of screen exclusion efficiency (defined as the percentage of organisms in the withdrawal flow that escape entrainment) and an assumption of uniform larval and egg distributions within the vicinity of the intake screens. Since the VIMS and ASA analyses were performed, two relevant research studies sponsored by the Electric Power Research Institute (EPRI) have been completed (EPRI 2003; EPRI in press). The first study examined impingement and entrainment rates for early life stages or several species (EPRI 2003) and the second study used computer numerical modeling to define the HZI of six cooling water intakes located in various types of water bodies (EPRI in press). Both EPRI studies provide valuable information that can be used to assess the risk of ichthyoplankton to entrainment at the KWR intake.

The VIMS analysis of the impact of the intake structure at Scotland Landing states that:

> "For the Mattaponi River, tidal excursion values in the vicinity of Scotland Landing are estimated to be approximately 2.5 nautical miles. We can reasonably assume that the eggs and early larval stages dispersed within the water column are generally subject to the effects of water withdrawal throughout multiple tide cycles within the limits of tidal excursion. Thus, the intake structure's [hydraulic] zone of influence is taken to be a section of river stretching from 2.5 nautical miles upriver of Scotland Landing to 2.5 nautical miles downriver of Scotland Landing. Eggs and larval densities from this area of the Mattaponi River were used to assess potential impacts (Mann 2003)."

Characterizing the zone of influence of a water intake by equating it to an estimate of tidal excursion is reasonable when considering the total hydraulic effect of the withdrawal on the overall flow of a river. However, an intake will withdraw water preferentially from different portions of a water body according to its design and location within a water body. Passive particles that are outside the portion of a river from which an intake is withdrawing water will have a negligible probability of encountering an intake.

To characterize the HZI of the KWR intake and how it may affect the risk of ichthyoplankton to entrainment and impingement, we reviewed the results of cooling water intake HZI analyses presented in EPRI (in press) and cylindrical screen flow field data from the laboratory study reported by EPRI (2003). The HZI analyses describe far-field flow conditions of water intakes and can be used to develop estimates of an organism's risk to entrainment based on location relative to an intake and the calculated HZI. The laboratory data describe the near-field flow conditions (i.e., within several feet of screen surface) that facilitate movement of debris and organisms past cylindrical screens. Following the review of the EPRI reports, we characterized near and far-field HZIs for the KWR intake using hand calculations. The results of these analyses were used to generate estimates of entrainment risks for larvae and eggs approaching the KWR intake. Entrainment risk, as discussed in the context of an HZI analysis, only indicates the probability that a passive particle (e.g., fish egg) will be drawn towards an intake with the flow that is being withdrawn. Entrainment risk is not equivalent to screen exclusion efficiency, which was discussed in detail in Section 3. The information and data presented in this section provide a reasonable approach to determining the percent of ichthyoplankton that may be exposed to the KWR screens as the organisms move past the intake.

4.1 HZI Characteristics of Cooling Water intake Flow Withdrawals

4.1.1 General HZI Assessment of Water Intakes

Water movements in the area of tidal excursions (often on a scale of miles) are important for understanding the vulnerability of drifting organisms to entrainment at a water intake. These water movements can be simulated on a computer (i.e., modeled) to estimate the sources and numbers of organism susceptible to being withdrawn. Although modeling has not been conducted for the KWR intake, there are general lessons and useful information that can be garnered from modeling studies that have been done for cooling water intakes.

EPRI (in press) discusses the application of computational modeling techniques that can be used for characterizing the HZI of an intake. Using the methods described, six case studies of site-specific HZIs were performed. The case studies involved cooling water intakes located on a variety of water body types. Three of the HZI case studies were considered to have some relevance to the KWR intake because they were conducted for sites located on rivers. These sites included the Tanners Creek (Ohio River), Browns Ferry Power Plant (Tennessee River reservoir), and Connecticut Yankee (Connecticut River; tidal reach) power plants. Although these plants have distinct differences in design and location compared to the KWR intake (e.g., much larger rivers, greater water flow withdrawals, and shoreline intakes), the underlying characteristics of the estimated HZIs demonstrate certain principles that are applicable to any water intake. Mainly, water is only withdrawn from a relatively small portion of a source water body and this zone decreases considerably in size as flow approaches and enters an intake. Consequently, only those organisms present in an intake's HZI will bare an appreciable risk to entrainment and impingement, whereas all organisms outside of the HZI will pass safely downstream. Therefore, it is necessary to consider the location of an intake relative to expected fish distributions in order to fully assess potential impacts (Paller et al. 1995). To further explore the importance of intake HZIs, more details of the EPRI case studies that are considered most relevant to the KWR intake are presented below.

The Browns Ferry intake is located on a shoreline of the Wheeler Reservoir, which is impounded by Wheeler Dam on the Tennessee River. Flow through the reservoir is continuous and dependent on inflow and discharge at the dam. The numerical model of the Browns Ferry intake demonstrated that cooling water is withdrawn from a relatively small region along the side of the reservoir leading to the plant (Figure 11). The stream-line characterization of the Browns Ferry intake flow provides a good representation of the decreasing size of an HZI as water moves closer to an intake. This will also occur at the KWR intake, except the location and screen design will allow flow to pass all around the intake screens, potentially producing a narrower HZI with respect to distance from the intake. That is, because water is withdrawn from a 360^o radius, the HZI will not extend as far from the screens as it would for a shoreline intake at the same location.

The EPRI analysis of the Tanners Creek intake provided similar information to what was generated for the Browns Ferry Plant. However, a different computational approach was used for the Tanners Creek analysis because it did not involve an assessment of the station's heated discharge, which was a consideration in the model selection for the Browns Ferry intake. The Tanners Creek Plant has a shoreline cooling water intake located on the Ohio River. The HZI analysis for this site was conducted at two river discharge rates and one intake flow rate (about 1,027 mgd). Because an intake's HZI is more pronounced at lower flows (i.e., intake flow is a greater proportion of river discharge), the focus of our assessment was on the results of the model analysis conducted at the lower river discharge, of which the intake flow rate was about 3%.

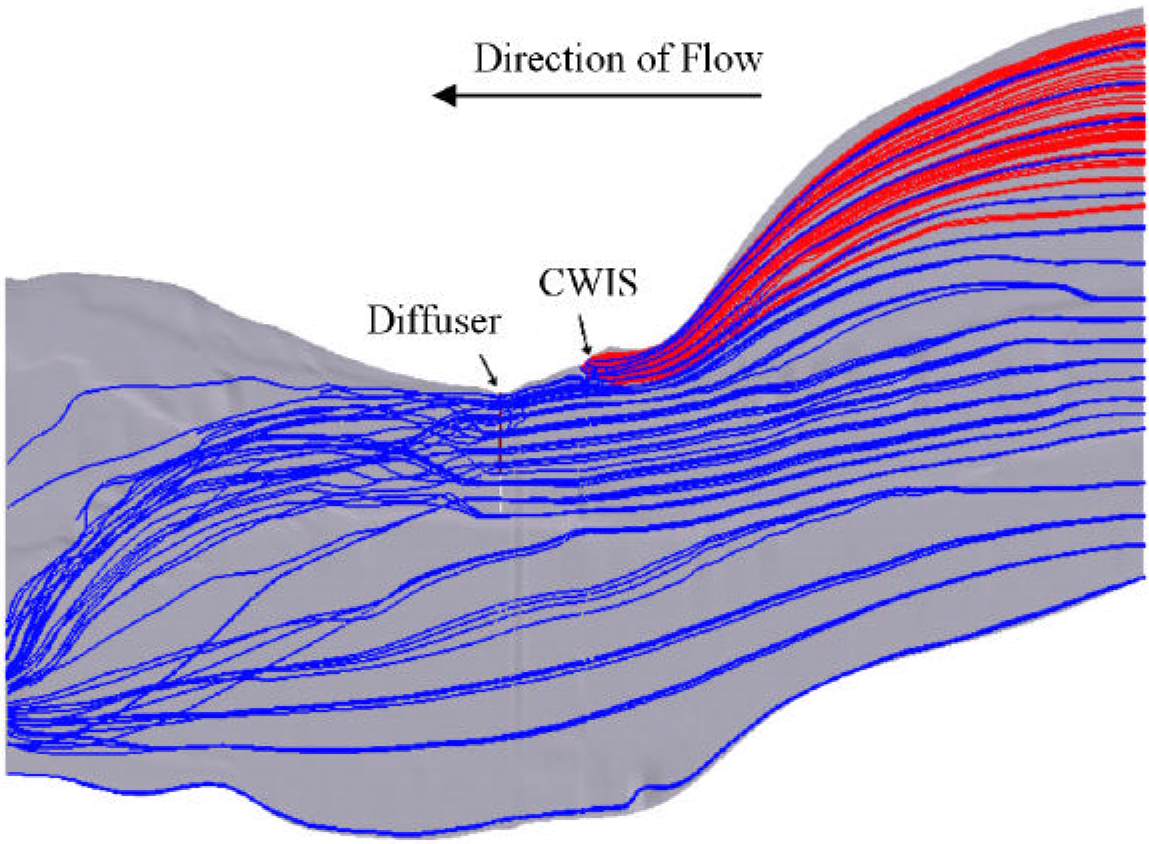

Figure 11. Numerical model results depicting the HZI of the Browns Ferry cooling water intake structure (CWIS). Blue streamlines represent river flow passing by intake and red streamlines represent portion of river discharge withdrawn by the plant's intake.

For the Tanners Creek HZI evaluation, a stochastic computational model was used to simulate the random aspects of passive particles moving downstream in the Ohio River from release points upstream of the intake. Data collected with this model included the downstream movements of 5000 particles released from 560 points upstream of the intake. Using this approach, a probability of entrainment was calculated for particles released from the same location based on the numbers that entered the intake and the numbers that passed downstream.

Entrainment probability contour maps generated from the Tanners Creek analysis demonstrate that the HZI is very small relative to the entire width of the river and that entrainment probabilities are low, even for particles passing downstream close to the shoreline on which the intake is located (Figures 12 and 13). Differences in entrainment probabilities occurred between particles released near the surface and at the river bottom. This was most likely due to the intake configuration, which withdraws water from several distinct depth locations. The Tanners creek analysis also demonstrates that entrainment probabilities decrease with increases in river discharge. This is due to a smaller proportion of river flow being withdrawn. For any given pumping rate, entrainment probabilities for the KWR intake will also vary with river discharge, being lowest during periods of peak tidal flow and greatest at slack tide (seasonal differences in river discharge will also have the same effect). Thus, the size of the HZI will decrease with increases in flow and increase at lower river discharges (e.g., slack tide).

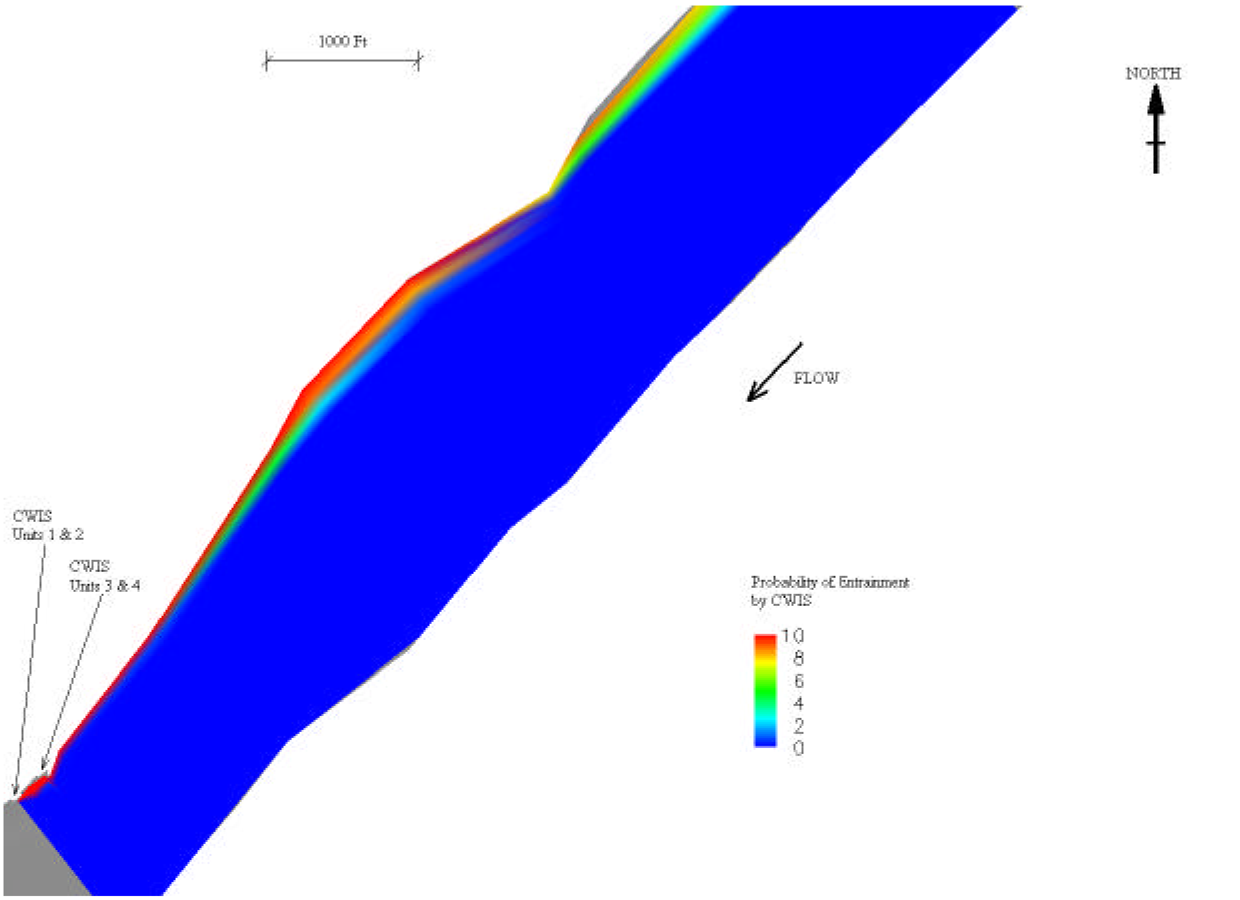

Figure 12. Numerical model results depicting the probability of entrainment for passive particles moving downstream at the water surface as they encounter the Tanners Creek cooling water intake structure (CWIS).

The EPRI case study of the Connecticut Yankee Nuclear Power Plant provides data for the HZI of an intake located within the tidal reach of a large river. The Connecticut Yankee cooling water intake is located on eastern shore of the Connecticut River about 16 miles upstream from Long Island Sound. The study area extends about two miles upstream from the CWIS and about three miles downstream. These distances are the approximate range of the tidal excursion in the vicinity of the plant. Simulation conditions used in the Connecticut Yankee HZI numerical model included a river discharge of 9,700 mgd and an intake withdrawal rate of 585 mgd (6% of river discharge). To calculate the HZI of the Connecticut Yankee CWIS, specified concentrations of passive organisms were released into the modeled flow from different locations one to two miles upstream of the power plant. An advection/dispersion algorithm was used to calculate the movement of the "numerical surrogate particles" past the CWIS during several successive tidal cycles. The concentration of surrogate organisms entering the intake was recorded during these simulations. The percentage of particles entrained by the CWIS was calculated using this information and the total number released at the beginning of the simulations.

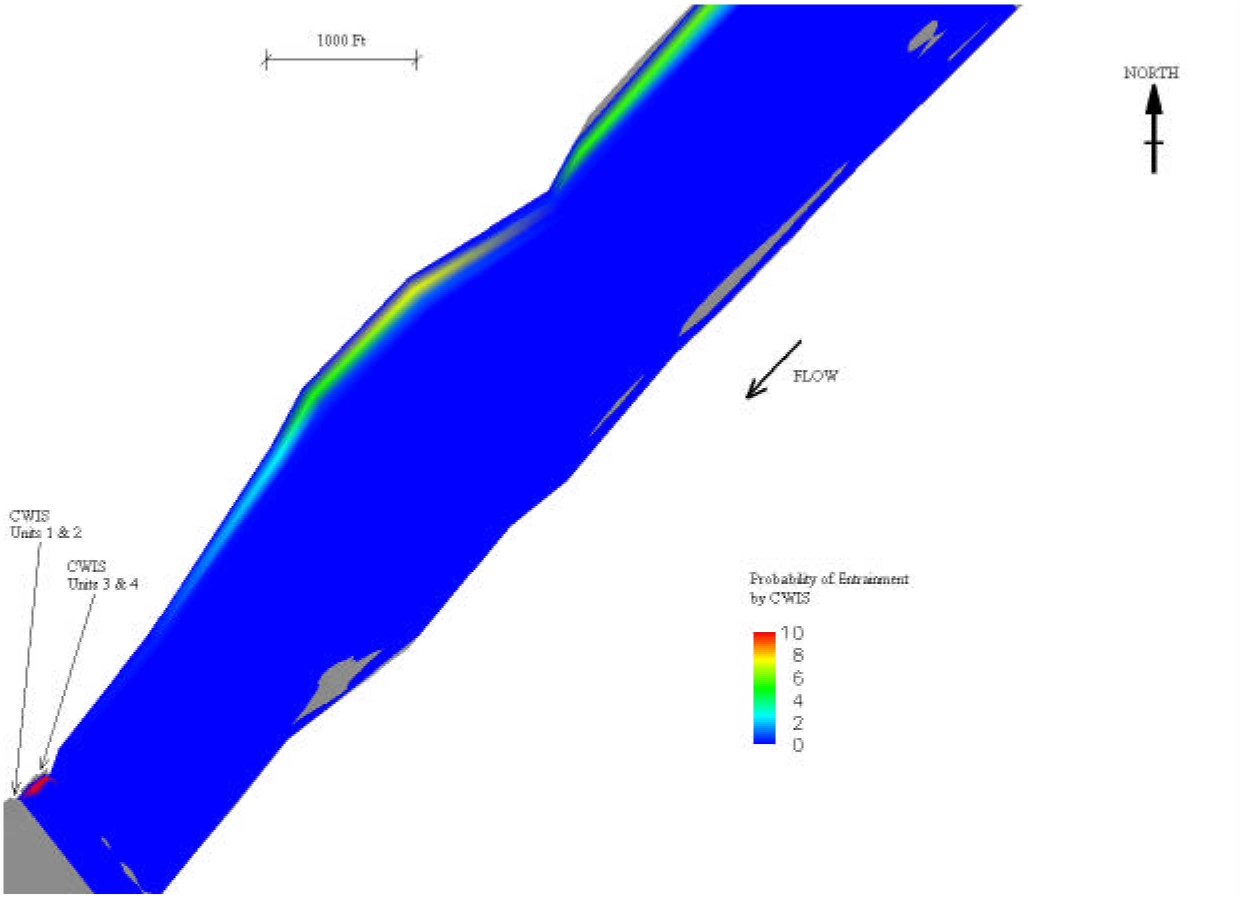

Figure 13. Numerical model results depicting the probability of entrainment for passive particles moving downstream at near the river bottom as they encounter the Tanners Creek cooling water intake structure (CWIS).

Entrainment probabilities estimated for two locations upstream of the Connecticut Yankee intake demonstrated that the risk to entrainment varied with depth and location across the width of the river (Figure 14). These entrainment probabilities were calculated from particles released at 19 different cross-sectional locations. Entrainment probabilities increased with proximity to the intake along the side of the river that the intake was located and decreased on the opposite side. Similar to the other HZI case studies, the increase in entrainment risk along the shoreline leading to the Connecticut Yankee intake and corresponding decreases across the river width towards the

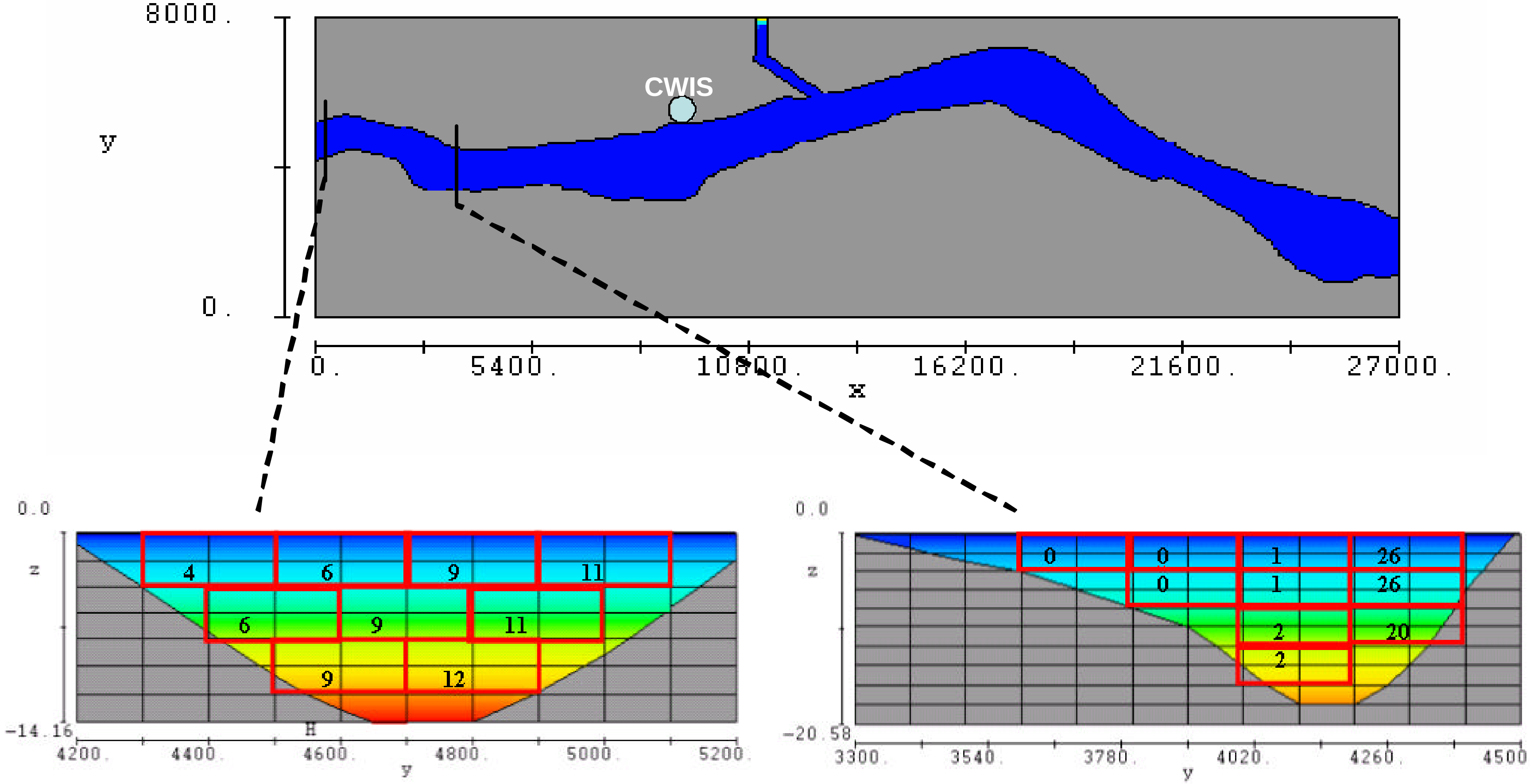

Figure 14. Probability of entrainment (%) for neutrally buoyant particles released upstream of the Connecticut Yankee cooling water intake. The x, y, and z coordinates represent length, width, and depth, respectively.

opposite shore represent a decrease in the HZI of withdrawn water. Entrainment probabilities outside of the HZI drop to zero and the zone in which there is no risk to entrainment expands considerably as river flow approaches the intake. Entrainment probabilities also decrease with depth because the Connecticut Yankee intake withdraws water from near the surface. At the cross-section furthest from the intake, the differences in entrainment risk between water withdrawn from the surface and water withdrawn from bottom is minimal and the HZI is wider at this location.

In contrast to the KWR intake, the Connecticut Yankee power plant has a shoreline water intake. However, as with the other case studies, the same principles associated with HZI size and entrainment risk will hold true for the KWR cylindrical screens and may even be enhanced for better fish protection due to the mid-river and mid-depth location and screen design. Cylindrical screens positioned parallel to ambient currents river are designed to allow fish and eggs to continue downstream in the presences of sufficient sweeping flows, even when organisms are within the HZI and in close proximity to a screen's surface (see Section 3).

The results of the cooling water intake HZI modeling studies provide valuable information for assessing ichthyoplankton risk to entrainment (i.e., probability of encountering an intake). However, because HZI analyses typically rely on the assumption of uniform particle distributions and neutral buoyancy, passive organisms that are not uniformly distributed in a body of water will have entrainment risks that do not correspond to the percentage of water removed by an intake or the volumetric area of the withdrawn flow as it approaches an intake. Ichthyoplankton abundance sampling in the vicinity of water intakes has demonstrated that entrainment rate predictions based on proportion of flow withdrawn may be invalid depending on intake design and location (Paller et al. 1995). Additionally, for some intakes, a certain portion of passive organisms within the HZI will pass by an intake in the presence of ambient river currents. The KWR intake will be located near mid-channel and will withdraw water from the approximate middle of the water column. Thus, the results of the cooling water intake HZI studies indicate that the entrainment of organisms in the Mattaponi River should be mainly from the center of channel and about mid-depth. Eggs and larvae that are located close to the river banks or near the bottom and surface should be outside the HZI of the KWR intake and, therefore, would not be at risk to entrainment. The following section provides more specific information on the KWR intake HZI and probable levels of entrainment risk for organisms approaching the screens.

4.1.2 HZI Analysis of KWR Intake

We developed estimates of the HZI of the KWR intake using hand calculations to define the region of the Mattaponi River in which ichthyoplankton will be affected by intake flows and to provide site-specific probabilities for passive particles encountering the screens. Upstream and downstream limits of an intake HZI can be estimated by applying arguments of continuity and mixing zone concepts (see Fischer et al. [1979], pp. 104 to 120, for a thorough discussion of the methods used to estimate the limits of an HZI). Using this approach, the upstream limit of the

HZI is defined to be the distance required for "complete mixing" of a centerline discharge as defined by Fischer et al. (1979):

$$L = 0.1\, u\, W^2/\varepsilon_t \qquad (1)$$

where: L = Complete Mixing Length
u = Average Velocity
W= Width of Channel
ε_t = Transverse Mixing Coefficient

The mixing length, L, corresponds to the distance required for materials released from a point discharge in the center of a channel to mix uniformly throughout the channel. For this problem, the mixing length can be thought of as the distance "upstream" of the intake beyond which a uniform chance of entrainment for passive organisms in a river exists.

The results of the calculations depend on the choice of the transverse mixing coefficient, ε_t and represent the portion of organisms that may encounter the intake screens during a single pass by the intake. The value of this coefficient depends on the shape of the river in the vicinity of the proposed intake structure and can be uniquely identified only by the results of field-testing performed at the site. However, the value of transverse mixing coefficient can be estimated from the results of experimental measurements of transverse mixing in open channels with curves and irregular sides (Fischer et al. 1979). In our evaluation, the transverse mixing coefficient proposed by Jackman and Yotsukra (1977) for the Potomac River was used to support the calculations. The shape of the Potomac River in the location where this study was carried out was described to be, "gently meandering with up to 60 degree bends."

Our analysis of the KWR intake HZI involved calculating L for three different channel velocities (0.25, 1.5, and 3.0 ft/s) representing approximate average and maximum tidal discharge flow rates. The width of the channel, W, was equal to 450 ft (the approximate width of the channel at the proposed intake site). Between the upstream limit of the HZI and the intake structure the width of the HZI was assumed to decrease linearly (Figures 15 through 17). The chance of encountering the screen was calculated to be the percentage ratio between the intake flow rate and the flow rate carried by the portion of the river within the HZI. The HZI of the KWR intake screens was estimated for three intake flow rates (monthly average, highest seasonal upper quartile, and maximum design capacity). Estimates of the HZI dimensions for ebb and flood tidal flows are similar, but the HZI will be greater during flood tide due to less flow and slightly lower velocities.

The distance upstream from the intake at which complete mixing occurs (i.e., particles located across the entire width and depth of the river have a some small probability of encountering the intake screens) becomes shorter as channel velocities decrease. The upstream limit of the HZI is similar to the distance associated with the tidal excursion (i.e., about 2.5 miles) at the proposed location of the intake for the highest channel velocity evaluated, but is considerable less at the mid and low channel velocities (Figures 15 through 17). As expected, the probability of passive particles encountering the intake increases as flow withdrawal rates increase and decrease with increases in tidal velocities. The estimated HZIs for the different flow conditions demonstrate

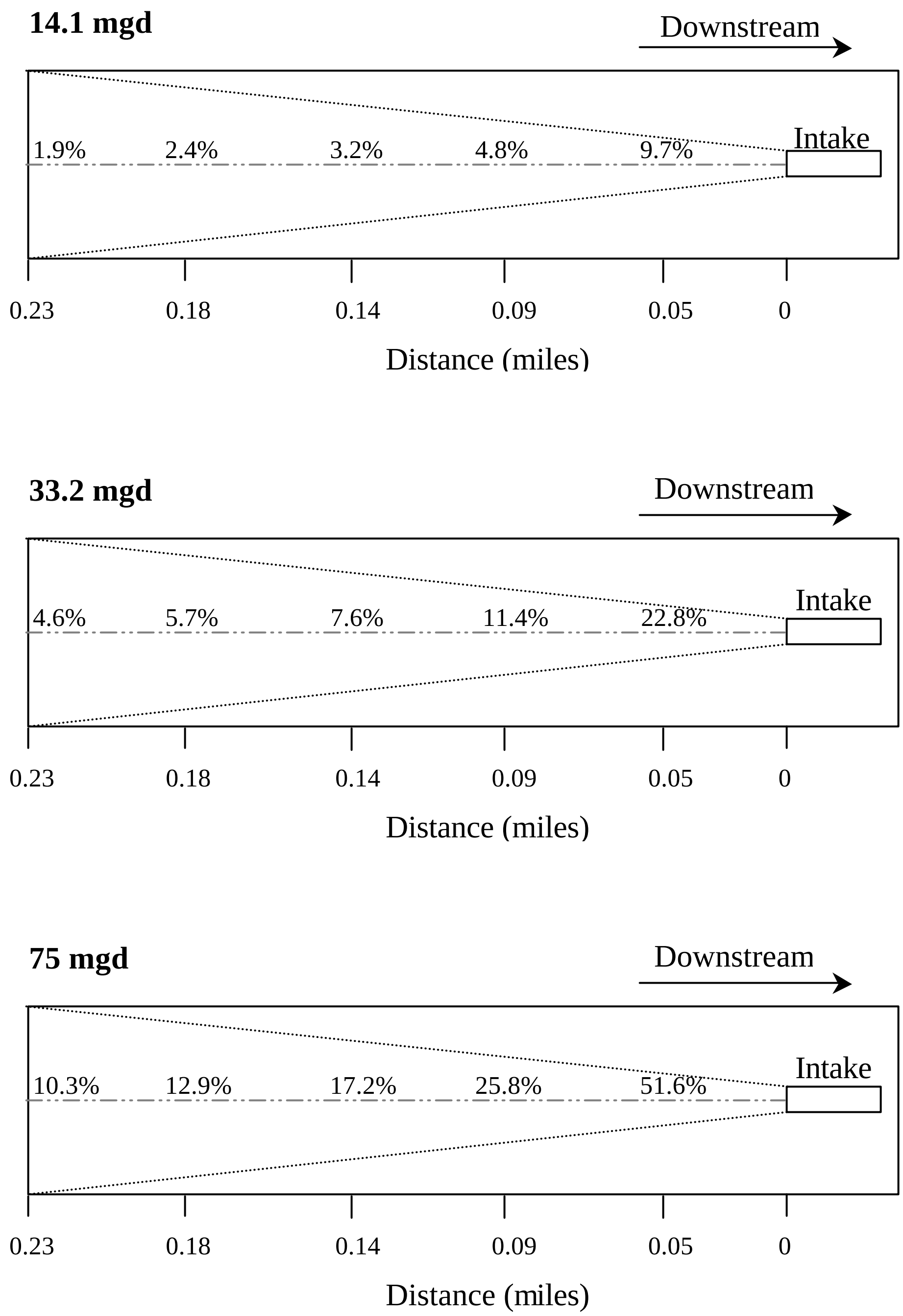

Figure 15. Estimated HZI of the KWR intake at three withdrawal rates and a low ebb tide flow rate. Channel velocity at the screens is approximately 0.25 ft/s. Percentages indicate the probability that passive particles within the HZI will encounter the screens when at the corresponding distances upstream.

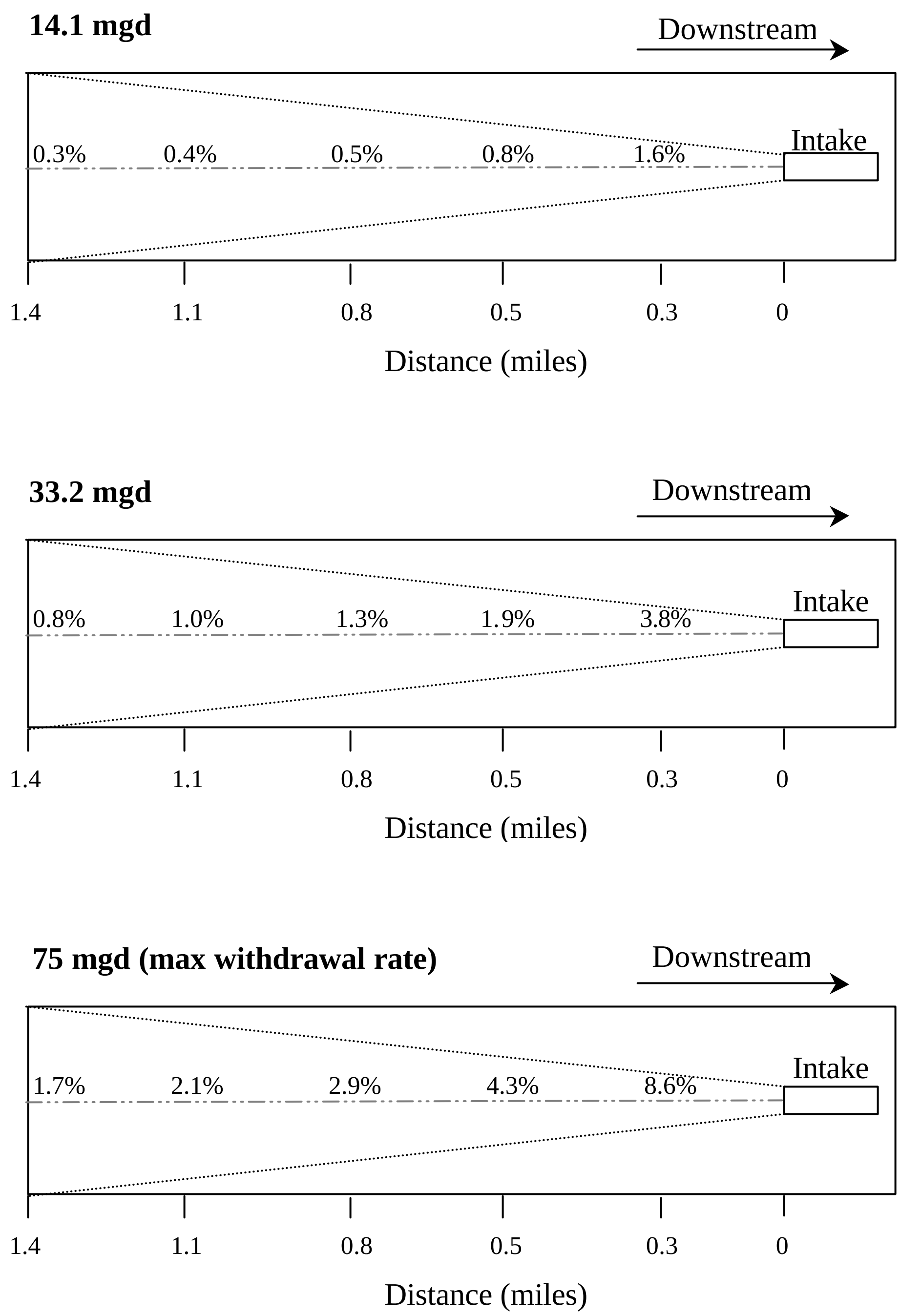

Figure 16. Estimated HZI of the KWR intake at three withdrawal rates and average ebb tidal flow. Channel velocity at the screens is approximately 1.5 ft/s. Percentages indicate the probability that passive particles within the HZI will encounter the screens when at the corresponding distances upstream.

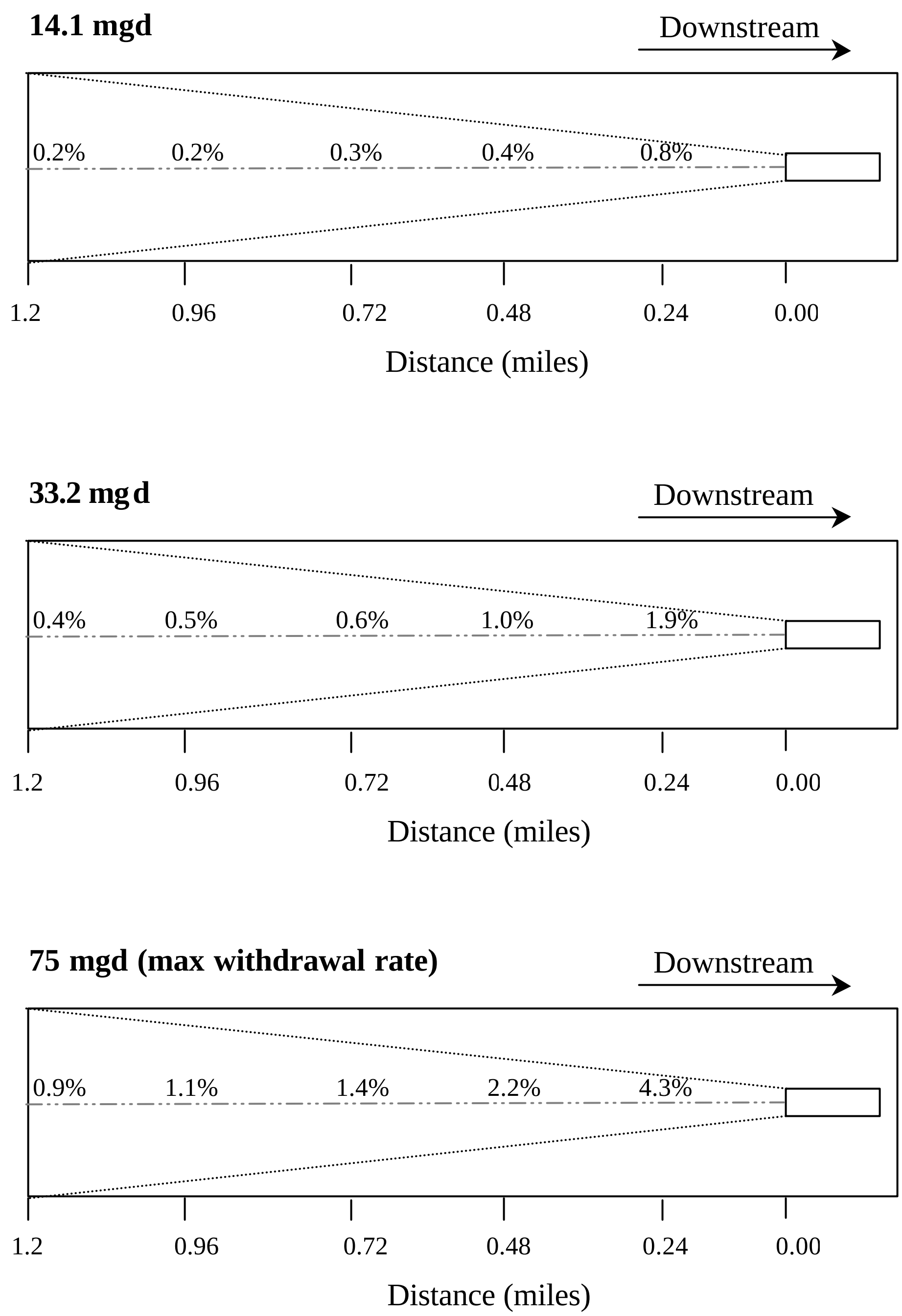

Figure 17. Estimated HZI of the KWR intake at three withdrawal rates and peak ebb tidal flow. Channel velocity at the screens is approximately 3.0 ft/s. Percentages indicate the probability that passive particles within the HZI will encounter the screens when at the corresponding distances upstream.

that passive organisms located in a large portion of the river (i.e., towards the shorelines and near the river surface and bottom) at the intake site likely will not be at risk to entrainment during a large portion of the tidal cycle. that passive organisms located in a large portion of the river (i.e., towards the shorelines and near the river surface and bottom) at the intake site likely will not be at risk to entrainment during a large portion of the tidal cycle.

The results of HZI analysis for the KWR intake indicate that:

- The probability of encountering the KWR intake for passive organisms that originate at the upstream and downstream limits of the HZI is small (about 10% or less).

- The width and upstream extent of the HZI are small (i.e., narrow and short) before the likelihood of encountering the screens is calculated to exceed 5% (within 0.5 miles of intake for withdrawal rates of 33.2 and 75 mgd).

- For most flow conditions, the probability of encountering the intake screens is negligible for organisms located near the river bottom and surface (i.e., outside the HZI at the screens) and towards the shorelines is negligible at the location of the intake.

Even when organisms are within the an intake's HZI at the location of the withdrawal, entrainment of fish eggs and larvae may occur at rates as low as 0 to 10%, depending on the ratio of sweeping- to-slot velocity and organism size.

4.2 Near-Field Flow Conditions of Cylindrical Wedgewire Screens

4.2.1 General Characterization of Cylindrical Wedgewire Screen Near-Field Flows

Results of laboratory studies and computer modeling reported by EPRI (2003) indicate that cylindrical wedgewire screens (i.e., T-screens) withdraw water from a well-defined region based on their design and operation. EPRI (2003) reported velocity measurements and numerical modeling results for a cylindrical wedgewire screen with 2-mm wide slots, a slot velocity of 0.75 ft/s, and a channel velocity of 0.25 ft/s. Flume velocity measurements were recorded in a vertical plane aligned with the centerline of a 12-inch diameter cylindrical T-screen installed in a flow tank. These measurements were used to validate the results of the numerical modeling of flow into the intake screen.

The flow vectors (i.e., magnitude and direction) estimated from the laboratory measurements and numerical modeling indicate that water approaching a T-screen is more likely to enter the intake if it comes from a location close to the centerline of the structure (Figures 18 and 19). The volumetric area of the withdrawn water can be envisioned as a stream-tube (i.e., a bundle of streamlines) extending upstream from the intake structure (Figure 19). Flow patterns within several feet of the screen surface suggest that, for the flow velocities tested, passive particles beyond 1 to 2 ft would safely pass downstream and not be subjected to entrainment or impingement. The distance at which passive organisms will not be drawn towards the KWR screens may be less because the proposed slot velocity is much lower than that evaluated during the EPRI study and channel velocities will be considerably faster for a large portion of the tidal cycle. Consequently, the near-field zone in which fish eggs and larvae may be drawn towards the KWR screens could potentially be less than 1 ft from surface of the screens. However, organisms within this near-field zone may still be carried downstream of the screens at relatively high rates by ambient currents (i.e., sweeping velocities) which will be equal to or higher than slot velocities during a large portion of each tidal cycle (see Section 3 for discussions of the effects of sweeping flows on screen exclusion rates).

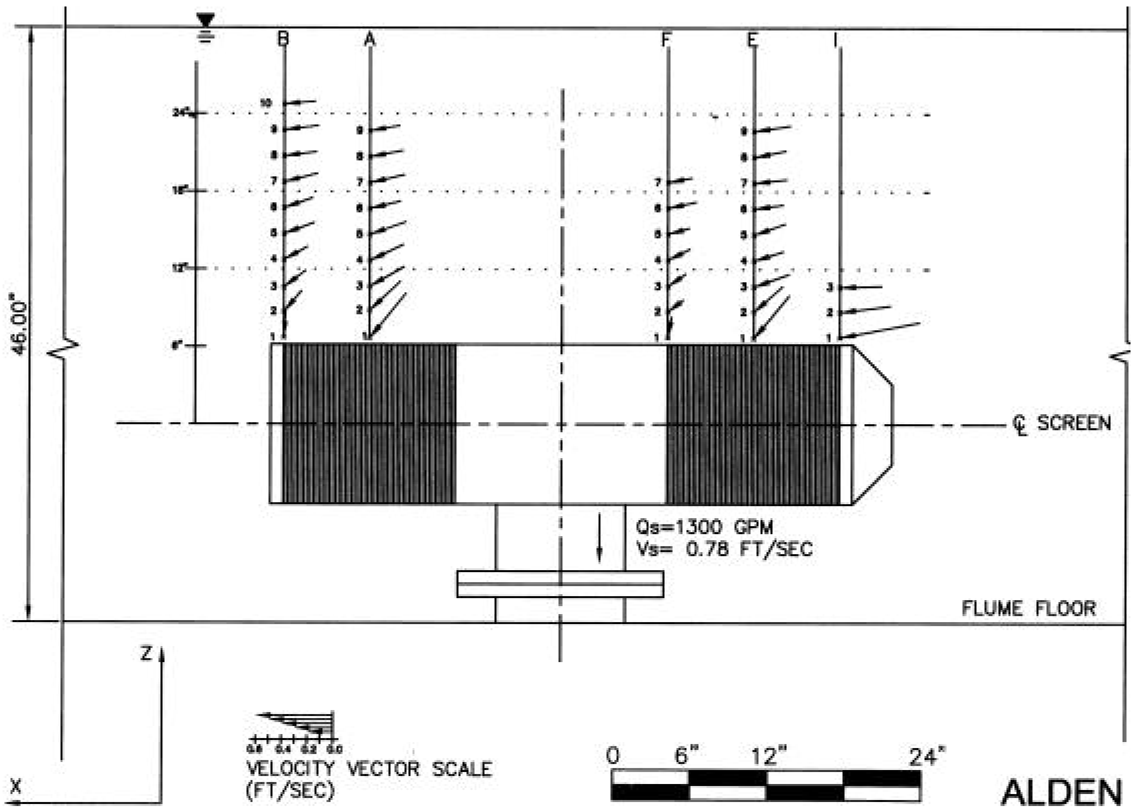

Figure 18. Wedgewire screen (2-mm slot) flow direction and magnitude measured with an acoustic Doppler velocimeter (EPRI 2003). Flume velocity was set at 0.25 ft/s and through-slot velocity at 0.78 ft/s.

The results of the EPRI (2003) flow field evaluation demonstrate that water entering an intake approaches from a narrow region directly upstream of the structure. This is also supported by the intake screen HZI assessment (Section 4.1), which showed that the zone of influence shrinks considerably as water approaches an intake. The computed and measured velocities reported by EPRI (2003) show that velocities induced by a cylindrical screen are markedly lower with increasing distance away from the intake. The rapid dissipation of approach velocities perpendicular to a cylindrical wedgewire screen has been identified in previous studies and is considered a mechanism by which cylindrical wedgewire screens provide effective fish protection (Cook 1978). Aquatic organisms within the near-field zone of influence will be at greater risk to entrainment or impingement than those outside of it, but the velocity vectors and flow streamlines presented in EPRI (2003) support the conclusion that eggs and larvae in close proximity to the screen can effectively pass downstream under certain hydraulic conditions (i.e., low slot velocity and equal or higher sweeping velocities; see Section 3 for more detailed information on screen exclusion efficiency). Additionally, the flow conditions at the KWR screens will be more favorable than those evaluated in the EPRI (2003) study with respect to fish protection (and debris management).

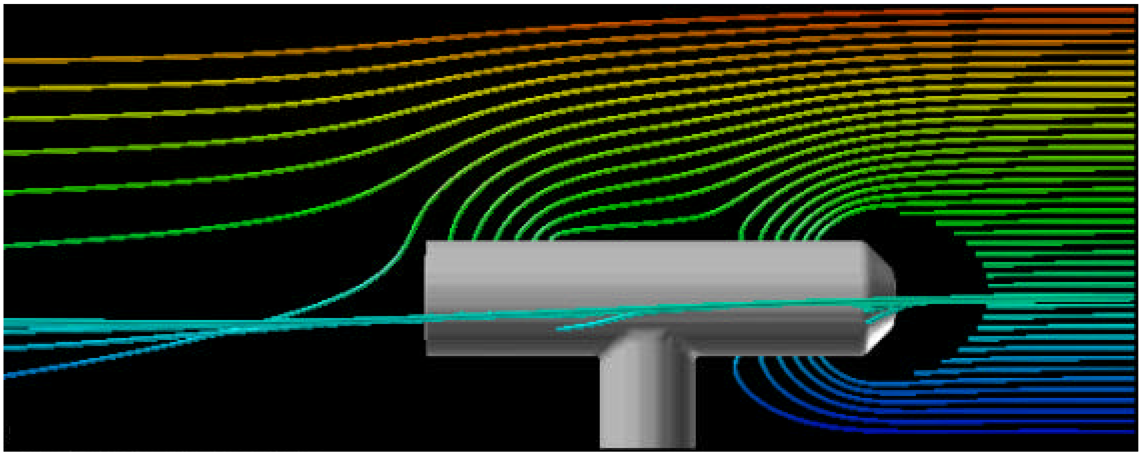

Figure 19. Flow streamlines for a cylindrical wedgewire screen (2-mm slot) generated from a numerical model (EPRI 2003). Flow conditions for the model included a 0.25 ft/s channel velocity and 0.78 ft/s slot velocity.

4.2.2 Near-Field Hydraulic Analysis of KWR Intake

The results of laboratory testing reported by EPRI (2003) indicate that the hydraulic influence of a cylindrical wedgewire screen is felt at a certain radial distance away from a screen (Figure 19) and that this distance (i.e., zone of influence) is dependent on slot and sweeping velocities (which are based on screen porosity, withdrawal rate, and river discharge). To assess the near-field zone of influence surrounding the KWR screens, we calculated the diameter of the "stream-tube" entering a screen located at the proposed intake site. The stream tube diameter, or zone of influence, was calculated for several different operating conditions and approach velocities. The objective of this analysis was to estimate the percentage of the river cross-section that is affected by the intake flows in the vicinity of the intake structure. The results of the near-field hydraulic analysis provide a measure of the cross-sectional area from which water is withdrawn by the KWR intake screens

For T-screens aligned parallel to ambient currents, the estimated dimensions of the flow field entering the KWR intake were based on the continuity of the approaching river flow. The diameter of this flow field, or stream-tube, was calculated according to the following equation (EPRI 2003):

$$D = 2*\text{Sqrt}[(Q/V)/\pi] \tag{2}$$

where: D = Diameter of Stream-tube
Q = Withdrawal Flow Rate
V = Approach Flow Velocity

The percent of the river cross-section occupied by flow that enters the intake, at the location of the intake can be calculated as follows:

$$\% = [(Q/V)/(d \text{ x } W)] \text{ x } 100 \tag{3}$$

where: Q = Withdrawal Flow Rate
V = Approach Flow Velocity
d = Average River Depth
W = Width of River (450 ft at intake location)

The average river depth (10 ft) was calculated from bathymetry data presented in Basco (1996). Since the proposed withdrawal structure for the KWR intake involves a row of T-screens aligned parallel to ambient flow direction, Equations 1 and 2 can be used to estimate the size of the near-field HZI at the river cross-section that contains the withdrawal structure.

The diameter of the near-field zone of influence surrounding KWR screens was calculated for three withdrawal rates (14.1, 33.2, and 75 mgd) and a range of channel velocities (0.1 to 3.0 ft/s) that occur throughout each tidal cycle at the location of the intake (Table 6). As expected, the diameter of the near-field zone of influence increases as approach velocity decreases and withdrawal rate increases. The percentage of the cross-sectional area at the intake location that this zone occupies ranges from less than 1% at the highest tidal velocity to about 25% at a tidal velocity of 0.1 ft/s and a pumping rate of 75 mgd (Table 7). The nominal percentage of the river cross-section that is affected by withdrawal flows at the location of the intake over the course of a tidal cycle ranges from 1.0% at a withdrawal rate of 14.1 mgd to 5.2% at a withdrawal rate of 75 mgd (Table 8).

Table 6. Diameter (ft) of the KWR intake near-field zone of influence by withdrawal flow rate and river velocity. The zone of influence is estimated for the area immediately upstream of an intake screen.

Intake Flow (mgd)	Mattaponi River Velocity (ft/s) at Intake Location							
	0.1	0.2	0.5	1.0	1.5	2.0	2.5	3.0
14.1	16.7	11.8	7.5	5.3	4.3	3.7	3.3	3.0
33.2	25.6	18.1	11.4	8.1	6.6	5.7	5.1	4.7
75.0	38.4	27.2	17.2	12.2	9.9	8.6	7.7	7.0

The results of the near-field hydraulic analysis of the KWR intake screens support the following conclusions:

- The diameter of the near-field zone of influence is slightly larger than the diameter of the screening structure for most operating conditions (i.e., range of tidal velocities). The diameter of the zone is greater at lower channel velocities and higher withdrawal rates.

- At an intake withdrawal rate of 14.1 mgd (slightly less than the average monthly withdrawal rate based on safe-yield modeling), the near-field zone of influence will not extend to the surface or bottom of the river. At higher withdrawal rates (33.2 and 75 mgd), the zone of influence will only extend to the river surface and bottom when channel velocities are 0.2 ft/s or less (i.e., within about a 1 hour period surrounding slack tide).

- The nominal percentage of the river cross-section at the proposed KWR intake site that will be occupied by the near-field zone of influence over the course of a complete tidal cycle is 5.2% at the maximum pumping rate of 75 mgd and less than 2.5% at pumping rates of 33.2 mgd or less.

Table 7. Percent of river cross-section within the HZI of the KWR intake for a range of tidal velocities. Tidal velocities less than 0.5 ft/s are expected to occur for about 15% of each complete tidal cycle.

Intake Flow (mgd)	Mattaponi River Velocity (ft/s) at Intake Location							
	0.1	0.2	0.5	1.0	1.5	2.0	2.5	3.0
14.1	4.8	2.4	1.0	0.5	0.3	0.2	0.2	0.2
33.2	11.4	5.7	2.3	1.1	0.8	0.6	0.5	0.4
75.0	25.8	12.9	5.2	2.6	1.7	1.3	1.0	0.9

Table 8. Nominal percent of river cross-section occupied by the near-field zone of influence of the KWR cylindrical wedgewire screens over the course of a complete tidal cycle.

KWR Intake Flow Rate (mgd)	Percent of Cross-Section Occupied
14.1	1.0%
33.2	2.3%
75.0	5.2%

4.3 HZI Assessment Summary

Case study evaluations of cooling water intakes using computational techniques have shown that far-field HZIs comprise a relatively small volume of water approaching an intake. The size of an HZI for a riverine intake will depend the amount of water withdrawn relative to the total river discharge. However, regardless of flow conditions, HZIs decrease in size with increasing proximity to an intake (this also equates to a smaller proportion of total ichthyoplankton being in the HZI) and the percentage of passive particles within an HZI that will encounter intake screens increases. The results of the far and near-field analyses of the KWR screens suggest that the length of the HZI for this site will extend about 2.5 miles in either direction and has a diameter that varies between 3 and 40 ft directly upstream of the intake, depending on tidal velocity and withdrawal flow rate. Although the calculated HZI extends approximately 2.5 miles upstream and downstream of the proposed intake, the probability that passive organisms originating at the upstream and downstream limits will encounter the intake screens is small (typically 10% or less; Figures 15-17). The results of the HZI analysis also suggest that the majority of water entering the intakes will come from the center of the river, rather than from the sides or from near the bottom of the river. At the site of the proposed intake, the nominal percentage of river cross-section occupied by the HZI is calculated to be about 5% or less over a range of withdrawal flow rates (14.1 to 74 mgd). Consequently, assuming uniform distributions of ichthyoplankton, only 5% of fish eggs and larvae present in the vicinity of the intake site would occur within the HZI of the KWR intake as flow encountered the screens. Exclusion efficiencies for ichthyoplankton that encounter the screens should exceed 80% given relatively high channel-to-slot velocity ratios that are expected to occur during greater than 85% of each tidal cycle (see Section 3 for more details on exclusion efficiencies).

5 POTENTIAL INJURY AND MORTALITY OF FISH LARVAE AND EGGS DUE TO SCREEN CONTACT

Despite a limited HZI for the KWR intake and reasonable assurance that the combination of narrow slots, low slot velocities, and adequate sweeping flows minimizes entrainment and impingement, concerns remain that fish eggs and larvae passing along a screen's surface may be susceptible to injury or mortality from contact abrasion or other potential stressors (e.g., hydraulic shear). Whereas rates of entrainment and impingement at wedgewire screen intakes can be quantified experimentally with relative ease, the indirect effects on organisms that only contact a screen are more difficult to quantify. Differentiating the effects of screen contact from handling effects of collecting specimens for analysis requires a carefully executed experimental design. However, a limited number of studies directly related to impingement mortality of eggs and larvae at wedgewire screen intakes have been conducted. In addition, while not directly applicable, studies of impingement-induced mortality associated with other types of fish exclusion technologies can provide further insight into the magnitude of potential indirect effects.

To fully understand potential effects of contact with the KWR intake screens, it is important to recognize the specific stressors that may be acting upon eggs and larvae. In addition to the direct effects of impingement, other stressors include the hydraulic effects of shear and turbulence. Contact abrasion may also act as a stressor upon larvae and eggs interacting with the intake structure. Although the effects of shear, turbulence, and contact abrasion have not been studied directly as they relate to wedgewire screens or other exclusion devices, they have been examined in laboratory tests for other applications. Stressors that were considered relevant to the assessment of the proposed KWR intake with respect to fish contact with wedgewire screens include the following:

- <u>Impingement</u>
  When an organism is held a against a screen surface by intake flow it is classified as impingement. Varying degrees of impingement can occur, ranging from momentary contact and immobilization to terminal impingement resulting in mortality. The effects of impingement can be described by a subset of other stressors. Impinged organisms experience flow variations and associated shear and turbulence and are held in contact with a foreign object.

- <u>Shear and turbulence</u>
  Shear forces occur at the interface between two bodies of water moving at different velocities. Under these conditions, a fish is exposed to differential forces across its body (Killgore et al. 2001) which can cause rotation and deformation and lead to mortality (Morgan et al. 1976). Turbulence reflects a fluctuation in velocity magnitude and direction. Because shear forces are present in turbulent flow, it is often difficult to differentiate between the effects of shear and turbulence. In general, the physical effects of shear and turbulence on an organism are probably similar.

- Contact abrasion
  As approach flows carry eggs and larvae downstream, some may come into contact with an intake screen. Given sufficient sweeping velocities and low intake velocities, these organisms may slide or bounce along a screen before progressing downstream. This action could potentially result in contact abrasion that may lead to injury.

A review of the following study types was conducted to determine the potential for the various stressors to injure larvae and eggs exposed to cylindrical wedgewire screens:

- Wedgewire screen impingement studies (both cylindrical and flat panel)
- Fine-mesh screen and aquatic filter barrier (AFB) impingement survival studies
- Laboratory shear and turbulence evaluations
- Cooling water intake entrainment survival studies
- Turbine/propeller damage evaluations

Data from these studies were examined to determine if the stressors evaluated and any estimates of injury and mortality were applicable to cylindrical wedgewire screen applications, or if they could provide insight to the extent of injury, if any, that might be expected at the KWR intake.

5.1 Impingement

In a laboratory study, Hanson et al. (1978) examined the effectiveness of wedgewire screens for reducing entrainment and impingement of striped bass larvae and eggs. Although they subsequently expanded their study to include an *in situ* evaluation with 19 additional species, the majority of these organisms were well past the larval stage and the results are therefore not applicable here. The components of the study most relevant to this discussion focused on identifying the ability of larval striped bass to avoid entrainment or prolonged impingement upon contacting the screens and quantifying potential egg mortality rates associated with impingement. The ability of larvae to avoid entrainment and recover from impingements of varying durations demonstrate that early life stages of fish can swim close to and contact a wedgewire screen without suffering any apparent injuries or mortality.

Larval studies were conducted in a 9.1 by 4.6-m oval flume into which test screens were placed. A 5-hp pump was used to induce flow through a cylindrical Johnson wedgewire screen with slot widths of 1 mm. Intake velocities ranged from 0.5 to 2.0 ft/s. These experiments were conducted in the absence of any channel velocity (i.e. static conditions). Test fish were acquired from an onsite hatchery and were 8 to 17 mm in length when tested. Surviving fish were used for subsequent tests, however, testing was discontinued once surviving larvae reached 33 days of age (up to 17 mm in length). After acclimating to the flume water, the larvae were released to interact with the screen and their swimming ability and behavior were noted.

Avoidance behavior was observed in all trials, however, most entrainment occurred within 1 minute of initial exposure to the test screen. As fish grew, their ability to avoid impingement and entrainment increased. A total of 93 impingements, 75 escapes, and 16 entrainments occurred (Table 9). Larvae that were impinged for longer durations typically entered the screen tail-first and were held there by their opercula. The authors speculated that the ensuing damage was probably fatal. However, many fish that became impinged were able to eventually escape Table 9). These tests demonstrated the ability of larvae greater than 8 mm in length to actively avoid entrainment and recover from impingement at intake velocities between 0.5 to 2.0 ft/s and without any sweeping flows. With a maximum slot velocity of only 0.25 ft/s and tidal flow velocities reaching 2.5 to 3.0 ft/s, these data indicate impingement of larvae greater than 8 mm on the KWR screens probably will be rare and that fish of this size should also be able to avoid entrainment as well.

Table 9. Escapes of striped bass larvae following impingement on 1-mm slot wedgewire screen with no approach velocity (Hanson et al. 1978).

N	TL (mm)	Age (days)	Intake Velocity (ft/s)	Impingement Occurrences	Escapes	% Escaped
1	8.0-10.0	10-14	0.5	3	3	100
10	9.8-10.9	18	0.5	3	0	0
10	8.6-11.2	18	1.0	10	7	70
10	8.3-12.4	19	1.0	11	4	36
2	13.0-15.4	19-23	0.5	6	4	67
7	10.3-10.9	24	0.5	3	3	100
7	8.3-12.1	26	0.5	0	--	--
11	8.4-13.6	29	0.5	1	0	0
11	9.8-14.5	30	1.0	20	20	100
11	12.5-16.1	30	1.5	24	22	92
10	13.0-17.0	32	2.0	4	4	100
10	13.0-17.0	32	1.5	8	8	100

Experiments to estimate egg mortality caused by impingement were conducted in a smaller 3.0 by 1.5 m oval flume using a 30.5 by 30.5 mm flat panel screen with a slot width of 0.5 mm oriented perpendicular to the approaching flow. Tests were performed with several developmental stages of eggs to identify differences in susceptibility to impingement mortality associated with egg development. Upon initiation of a trial, eggs were released about 1.2 m upstream of the test screen into water flowing at 0.5 ft/s and remained impinged for predetermined periods of time. Trials were conducted for durations of 30, 60, and 120 seconds, after which time the impinged eggs were collected and placed in a jar partially filled with an antiseptic solution. For comparative purposes, control groups were also held in flume water for the same predetermined period of time and then placed in jars. Eggs were periodically monitored for mortality until 60 minutes after termination of the trial. The mortality rates for the control and treatment groups were then compared.

Mortality attributable to impingement ranged from 0% to 11.9%. However, the mean impingement mortality for several trials ranged only from 0% to 2.0% and the overall mean mortality for all egg developmental stages was 1.4% (Table 10). Most mortality took place within the first 30 minutes after impingement. Mortality was highest in the earliest stage of development (late-gastrula), which may indicate a higher degree of fragility. The low rates of mortality that were observed suggest that fish eggs can contact wedgewire screens without suffering high rates of injury and mortality. These tests also indicate that shear associated with sweeping flows and intake velocities probably is not detrimental to fish eggs for the conditions tested (i.e., intake velocity and channel velocities of 0.5 ft/s).

Table 10. Summary of striped bass egg mortality (%) one hour following impingement on a 0.5-mm slot wedgewire screen at an approach velocity of 0.5 ft/s and a slot velocity of 0.5 ft/s (Hanson et al. 1978). Test groups were impinged for durations of 30, 60, and 120 seconds. Control groups were held in flume water.

	30 seconds	60 seconds	120 seconds	Total
Late gastrula – early embryo (1.8-3.2 mm)				
Test	6.6	5.2	4.3	5.5
Control	4.6	3.4	3.7	3.9
Difference	*2.0*	*1.8*	*0.6*	*1.6*
Tailbud – free (2.1-2.4 mm)				
Test	1.1	0.0	0.0	0.5
Control	0.0	0.0	0.0	0.0
Difference	*1.1*	*0.0*	*0.0*	*0.5*
Fully developed embryo (2.0-2.7 mm)				
Test	0.7	0.8	0.0	0.5
Control	0.3	0.0	0.0	0.1
Difference	*0.4*	*0.8*	*0.0*	*0.4*
Total (1.8-3.2 mm)				
Test	4.5	3.7	2.9	3.7
Control	2.5	2.4	2.0	2.3
Difference	*2.0*	*1.3*	*0.9*	*1.4*

In one of the few studies that have evaluated exposure of early life stages of American shad to fish protection technologies, Radle (2001) estimated mortality of eggs impinged on the Gunderboom Marine Life Exclusion System (or aquatic filter barrier – AFB). Although the screening material and hydraulic conditions associated with this exclusion technology differ from that of wedgewire screens, the concerns regarding American shad at the proposed King William intake screens and a lack information on impingement mortality eggs of this species suggest that this study is worth considering because the eggs were exposed to impingement and contact with a potentially abrasive surface. The material comprising an AFB consists of course fabric with a pore size of 20 microns. This material, all though soft, is generally rougher than the smooth metal bars that comprise wedgewire screens.

The experimental apparatus used by Radle (2001) consisted of several 14-cm diameter hatching jars that were part of a shad culture facility. Control jars contained a steel mesh near the bottom, onto which incubating eggs are placed. Treatment jars were created by overlaying the steel mesh with one of two types of AFB material (standard pore size or perforated with –mm holes to allow for greater flow rates). After each jar was filled with water, flow was provided at a velocity of

0.1 ft/s and 100 live shad eggs were introduced. The eggs remained impinged for predetermined periods of time, ranging from one to four hours. At the end of a trial, flow to the jars was shutoff and the AFB material was removed, leaving the eggs in the jars to continue incubation. Following a 24-hour post-impingement period, the eggs were removed from both treatment and control jars and examined to determine the number of mortalities.

Only 7 of the 1200 eggs used in the study (control and treatment combined) had died after 24 hours. Survival rates in all jars were 99% or higher (Table 11). During a large portion of the time the intake is operating, the slot velocities through the KWR screens are expected to be equal to or less than 0.1 ft/s, which is the velocity that was evaluated during the AFB study. The high impingement survival rates observed by Radle (2001) indicate that American shad eggs that come into contact with or become impinged on the KWR screens likely will not suffer injuries that would lead to high rates of mortality That is, prolonged static contact with a relatively rough material did not appear to affect survival of American shad eggs. Therefore, impingement or contact with smoother materials, such as wedgewire screens, probably would also result in very low mortality rates, particularly at low slot velocities similar to those evaluated during the AFB study.

Table 11. Survival of one day-old American shad eggs following impingement of varying duration on two types of AFB fabric at 0.01 ft/s. Control groups were held on steel mesh according to standard shad hatchery conditions.

Jar Number	Fabric Type	Hours Impinged (#)	Live Recoveries (#)	Dead Recoveries (#)	Survival (%)
10	Lovett	1	100	0	100
11	Lovett	1	99	1	99
12	Lovett	2	100	0	100
13	Lovett	2	100	0	100
14	Lovett	4	99	0	100
15	Lovett	4	100	0	100
24	Perforated	1	99	1	99
25	Perforated	1	98	1	99
22	Perforated	2	100	0	100
23	Perforated	2	100	0	100
20	Control	0	99	0	100
21	Control	0	99	0	100

In another evaluation of impingement effects, laboratory testing was conducted by ESEERCO (1981) to evaluate mortality of several species of larval fish exposed to fine-mesh screens. Impingement on 350 and 500 micron mesh screens was evaluated by introducing larvae into a flume upstream of the test screens. Tests were performed at several approach velocities ranging from 0.5 to 2.0 ft/s and for impingement durations ranging from 2 to 16 minutes. At the end of each test, larvae were removed from the screens and held for up to 96 hours to observe post-impingement mortality. The species evaluated included striped bass, winter flounder, and alewife. Prolarvae and postlarvae were tested for each species.

Mean impingement mortality rates for each species and larval stage evaluated in the ESEERCO study are provided in Tables 12 through 18. Control mortalities are provided where available. Impingement mortality was nearly always greatest at the highest approach velocity. At 0.5 ft/s, mean impingement mortality was typically greatest for striped bass (43.91 to 91.8%). However, control mortality for striped bass prolarvae was also high (56.5%), suggesting a large portion of treatment fish mortalities were due to handling and/or holding fish. Impingement mortality for winter flounder at 0.5 ft/s ranged from 7.3% (prolarvae) to 72.2% (postlarvae after eight minutes of impingement). Similar to striped bass, control mortality for postlarval flounder was relatively high (33.8%), demonstrating that handling-related injury was contributing to the observed mortality rates of fish exposed to the screens. Prolarval alewife impingement mortality at 0.5 ft/s was 4 to 5%. Mortality of postlarval alewife was much higher (76 to 83%). However, control mortality was also higher (43.3%). These tests show that larval fishes are capable of surviving screen contact and impingement when approach velocities perpendicular to the screens are between 0.5 and 2.0 ft/s. Because through-slot velocities at the proposed King William Reservoir screens will be 0.25 ft/s or less and approach velocities perpendicular to the screens will dissipate rapidly, impingement mortality rates should be considerably less than those reported by ESEERCO (1981) for fine-mesh screens.

Table 12. Mortality of striped bass prolarvae (5.4-6.4 mm) 96 hours after impingement for different durations. Mean control mortality was 56.5%.

Velocity	Two minutes		Four minutes		Eight minutes		Sixteen minutes	
(ft/s)	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
0.5	72.4	11.0	51.2	24.2	91.8	9.0	84.6	18.6
1.0	63.4	4.9	62.9	6.9	90.7	8.3	96.0	6.9
1.5	70.7	20.5	92.0	8.0	98.7	2.3	100.0	0.0
2.0	97.3	4.6	100.0	0.0	100.0	0.0	100.0	0.0

Table 13. Mortality of striped bass postlarvae (6.5-17.1 mm) 96 hours after impingement for different durations. Mean control mortality was 8.1%.

Velocity	Two minutes		Four minutes		Sixteen minutes	
(ft/s)	Mean	95% CI	Mean	95% CI	Mean	95% CI
0.5	--	--	--	--	43.91	6.63
1.0	--	--	--	--	58.91	7.68
1.5	--	--	--	--	97.6	9.88
3.0	18.35	7.46	49.13	14.9	--	--

Table 14. Mortality of winter flounder prolarvae 96 hours after impingement. Mean control mortality was 4.1%.

Velocity (ft/s)	Mean (%)	95% Confidence Interval
0.5	7.3	3.6 to 13.7
1.0	10.7	5.6 to 19.8
1.5	16.5	8.8 to 30.2
2.0	35.6	19.5 to 64.1

Table 15. Mortality of winter flounder early postlarvae 96 hours after impingement. Mean control mortality was 42.5% (33.8% St. Dev.).

Velocity	Two minutes		Eight minutes		Sixteen minutes	
(ft/s)	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
0.5	64.9	28.4	72.0	24.0	66.8	18.4
1.0	93.1	13.1	100.0	100.0	100.0	0.0
1.5	93.1	13.9	97.7	2.7	--	--
2.0	100.0	0.0	100.0	0.0	--	--

Table 16. Mortality of winter flounder late postlarvae 96 hours after impingement. Mean control mortality was 8.3%.

Velocity	Two minutes		Eight minutes		Sixteen minutes	
(ft/s)	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
0.5	54.0	19.8	62.0	31.1	28.0	33.9
1.0	22.0	19.8	36.0	28.3	--	--
1.5	34.0	14.1	31.4	4.8	--	--
2.0	16.4	0.5	59.1	6.9	--	--

Table 17. Mortality of alewife prolarvae 48 hours after impingement. Mean control mortality was 0.0%.

Velocity	Two minutes		Eight minutes	
(ft/s)	Mean	St. Dev.	Mean	St. Dev.
0.5	5.1	3.8	4.1	4.1
1.0	11.8	14.4	18.9	14.1
1.5	10.5	10.5	44.1	7.4
2.0	28.2	6.9	69.7	6.6

Table 18. Mortality of alewife postlarvae after impingement. Mean control mortality was 43.3% (36.2% St. Dev.).

Velocity	Two minutes		Eight minutes	
(ft/s)	Mean	St. Dev.	Mean	St. Dev.
0.5	76.3	25.8	82.7	24.1
1.0	84.0	20.2	92.8	12.3
1.5	92.5	8.6	96.7	5.3
2.0	90.5	12.1	98.6	4.3

Impingement survival studies conducted with various screening technologies provide data that indicate mortality rates of fish eggs impinged on wedgewire screens and aquatic filter barriers are low (typically less than 5%) and that larvae can survive, and often avoid, impingement on wedgewire and fine-mesh screens with approach velocities considerably greater than those proposed for the KWR screens. These results demonstrate that physical contact with screening devices generally does not result in high rates of mortality for eggs and larvae. The studies discussed above typically evaluated early life stages of fish in the absence of any type of sweeping flow. That is, all flow was being withdrawn by the test devices resulting in flow velocities perpendicular to the screening surfaces. This resulted in test organisms striking the screening materials at the speed of the approaching flow and led to greater impingement rates than would be expected in the presence of ambient cross flows. With the exception of slack tide periods, tidal velocities at the KWR intake will prevent ichthyoplankton from striking the screens in this manner, thereby reducing the probability of impingement-related injury and mortality. If eggs and larvae in the Mattaponi River contact the intake screens, they will most likely glance the screens as they move downstream (eggs may roll along the screen surface and the frequency and magnitude of impact for larvae probably will be dependent on swimming ability). This glancing or rolling contact may be less damaging than direct impacts, particularly when it does not result in impingement.

5.2 Shear and Turbulence

Shear and turbulence may occur along the surface of wedgewire screens due to the natural movements of river flows and interactions between sweeping and intake velocities (i.e., varying magnitudes and flow directions). Shear and turbulent forces associated with the operation of wedgewire screens could potentially damage ichthyoplankton if they reach magnitudes that have been shown to cause injury. However, as discussed below, it is unlikely that such hydraulic conditions will exist in the vicinity of the proposed KWR screens, primarily due to low slot velocities (0.25 ft/s or less).

Morgan et al. (1976) reported the results of a laboratory study during which they attempted to separate the effects of shear on fish eggs and larvae from that of other potential stressors. The experimental apparatus used in this study consisted of two concentric plexiglass cylinders (20.3 and 30.5 cm diameter) permanently fixed to a plexiglass base. To replicate shear forces, a third rotating cylinder (25.4 cm diameter) was placed between the other two cylinders, thereby creating two chambers. The middle cylinder was then driven by a pulley system and motor such that upon spinning it induced shear fields in the inner and outer chambers. To identify the effects these shear fields had on early lifestages of fish, white perch and striped bass larvae and fertilized eggs were introduced into the sample chamber. The organisms were then subjected to exposures lasting from 1 to 20 minutes. The apparatus was operated at an rpm that varied by trial, yielding shear levels of 76 to 404 dynes/cm^2 (this is a standard unit of measurement for shear). Control tests were conducted by placing eggs and larvae in an identical apparatus for the duration of the trial but not activating the motor. Mortality consisted of disruption of the yolk-protein material or total disintegration for eggs and lack of mobility or acute tissue destruction for larvae.

Based on the mortality rates seen at various shear levels and durations of exposure, regression models were created for eggs and larvae of each species. Thus, given an observed level of shear in the environment, the resulting mortality could be predicted for a known exposure duration. Additional regression equations were developed with which LS_{50} (amount of shear required to kill 50% of eggs or larvae within a given time interval) could be estimated. For example, at 1 minute of exposure one would expect 50% mortality of: striped bass eggs at 542 dynes/cm^2, striped bass larvae at 785 dynes/cm^2, white perch eggs at 425 dynes/cm^2, and white perch larvae at 415 dynes/cm^2 (Table 19).

Table 19. Estimated LS_{50} values at shear exposures of various durations for striped bass and yellow perch eggs and larvae (Morgan et al. 1976).

Species and Stage	Exposure (min)	LS_{50} (Dynes/cm^2)
striped bass eggs	1	542
	2	255
	4	190
striped bass larvae	1	785
	2	510
	4	300
white perch eggs	1	425
	2	415
	5	175
	10	165
	20	120
white perch larvae	1	415
	2	340
	4	125

For the study by Morgan et al. (1976) to provide useful information relevant to contact mortality of eggs and larvae at wedgewire screens, the ambient shear levels must be determined. In an unpublished analysis, Ekholm (2001) provides the shear levels a fish egg would experience while resting on a Johnson Passive Intake Screen during normal operation. At intake velocities of 0.35 ft/s, 0.45 ft/s, and 0.50 ft/s, expected shear levels would be 11.38 dynes/cm^2, 18.80 dynes/cm^2, and 23.22 dynes/cm^2. These shear levels are higher than those that would be experienced with the KWR intake screens, but they also do not account for the effects of sweeping velocities. Ekholm (2001) goes further by applying the regression equations of Morgan et al. (1976) for striped bass and white perch eggs and larvae mortality. The resulting estimates show that shear-induced mortality could range from 0.02% to 25.18% depending on species, life stage, and duration of exposure (Table 20). As expected, the highest mortality would occur over the longest duration of exposure (4 minutes). Other trends suggest that shear induced mortality is consistently higher for eggs than for larvae of the same species, and higher for white perch larvae than striped bass larvae. However, it is important to note that these mortality predictions would act upon only those fish that actually become impinged, and only if they remain impinged for one minute or more. Except during slack tide periods, the hydraulic conditions of the KWR screens (i.e., low slot velocities and sufficient sweeping flows for carrying organisms past the screens) should result in very low impingement rates (< 5%; see Section 3).

Table 20. Projected egg and larvae mortality rates due to shear forces at a wedgewire screen based on regression equations from Morgan et al. (1976) and calculations from Ekholm (2001).

Species and Stage	Time (minutes)	Velocity Minimum (%)	Velocity Average (%)	Velocity Maximum (%)
striped bass eggs	1	3.06	4.40	5.12
	2	2.19	3.64	4.5
	4	3.58	5.73	6.97
striped bass larvae	1	0.01	0.02	0.03
	2	0.27	0.55	0.73
	4	0.06	0.17	0.27
white perch eggs	1	0.4	0.78	1.03
	2	0.68	1.23	1.59
	5	4.78	7.34	8.78
	10	4.9	7.59	9.11
	20	11.63	15.9	18.12
white perch larvae	1	0.12	0.28	0.40
	2	0.24	0.53	0.74
	4	18.9	23.13	25.18

In an assessment of the effects of hydro turbine passage on ichthyoplankton, Cada (1990) reviewed several studies that examined injury and mortality of fish eggs and larvae exposed to varying levels of shear and turbulence. Because the studies reviewed were conducted at water velocities greater than about 6 ft/s, the turbulence and shear forces fish experienced were likely much greater than those that would be experienced by fish at the KWR intake. In a study by Kedl and Coutant (1976), in which several species of larval fish were passed through a 12-m long 2.2-cm diameter condenser tube at velocities of 5.8 m/s, less than 5% mortality was observed in all cases. O'Connor and Poje (1979) subjected larval striped bass to velocities up to 3.0 m/s by passing them through a condenser tube. Neither yolk-sac larvae nor 16-day old post-yolk-sac larvae experienced mortality rates that were significantly different from those of control fish. Using a power-plant simulator, Cada et al. (1981) exposed larvae of several species to velocities of 2.4 m/s through 3.2-cm diameter pipes. However, these fish were simultaneously exposed to moderate pressure changes (56-146 kPa) which would not exist at a wedgewire screen intake. Although common carp larvae experienced high mortality (84%), mortality rates of all other species tested (mosquitofish, bluegill, channel catfish, and largemouth bass) were not significantly different from control groups, and were typically less than 2%.

Cada (1990) also discusses the possible synergistic effects of flow-induced stressors with other thermal or chemical stressors often present at power plants. However, these effects are not relevant to fish exposed to cylindrical wedgewire screens. Based on the review of numerous studies and data describing stressors associated with turbine passage, Cada (1990) concluded that ichthyoplankton would not be subjected to high rates of injury and mortality while passing through turbines. Unlike larvae and eggs encountering wedgewire screens, fish passing through turbines are exposed to physical contact with moving parts and rough surfaces (i.e., mechanical stressors). Additionally, hydraulic conditions throughout a turbine system are much more severe than those surrounding a cylindrical screen. Consequently, the conclusion that ichthyoplankton are not negatively impacted by passage through turbines supports the conclusion that injury and mortality of organisms passing over wedgewire screens is probably very low.

In another study that examined damage caused by high rates of shear, Killgore et al. (2001) evaluated survival of early life stages of fish after entrainment through a scale-model towboat propeller in a circulating water channel. Shovelnose sturgeon *(scaphirhynchus platorynchus)* larvae, lake sturgeon *(Acipenser fulvescens)* larvae, paddlefish *(Polyodon spathula)* eggs and larvae, and blue sucker *(Cycleptus elongates)* larvae were injected 38 cm upstream of the 46 cm-diameter propeller. They were then collected in downstream nets and observed for immediate and delayed mortality (up to 180 minutes after entrainment). The propeller was operated at several different speeds to achieve shear stresses of 634, 1613, 3058, and 4743 dynes/cm^2. Mortalities observed under these conditions were then compared to control mortality without the propeller activated. At shear forces of 4743 dynes/cm^2, observed mortality was as high as 86.0% and was significantly greater than control mortality for most species. However, mortality rates were not significantly different from the control mortality at shear stresses below 1613 dynes/cm^2. Because shear stresses at the surface of wedgewire screens are estimated to be about 23 dynes/cm^2 or less, these results suggest that mortality from shear at the proposed KWR intake would be very low or unlikely to occur.

The results of studies that have examined the effects of shear and turbulence on early life stages of fish have shown shear rates considerably higher than those that will occur at the surface of the KWR screens are needed to cause significant injury and mortality to fish eggs and larvae. The low through-slot velocities (0.25 ft/s maximum) of the KWR screens should result in shear rates of about 12 dynes/cm^2 or less. This low rate of shear, combined with potentially low rates of impingement, suggests mortality rates associated with this stressor will be negligible. Additionally, because wedgewire screens are designed to have uniform velocity distributions, larvae and eggs passing by the screens (i.e., avoiding impingement) should not be exposed to larger variations in shear levels regardless of sweeping velocities. Finally, despite a much harsher environment with respect to mechanical and hydraulic stressors, a review of available literature describing the effects of several stressors on eggs and larvae indicated that damage to ichthyoplankton passing through turbines was inconsequential. This provides strong support for the conclusion that organisms passing over the KWR screens will be subject to very low rates of injury and mortality.

5.3 Contact Abrasion

We did not find any studies that directly quantified the frequency of contact abrasion or evaluated subsequent injury and mortality following egg or larval contact with an intake structure. As mentioned above, contact is a component of impingement and it is therefore difficult to differentiate between the effects of contact and impingement. However, because all impinged fish necessarily contact the intake structure, and because additional stressors act upon impinged fish, injury and mortality induced by contact abrasion alone is expected to be less than that observed for fully impinged fish. In fact, we see that, depending on the species and life stage, impingement survival can be relatively high.

Eggs and larvae transported by tidal or fluvial currents can be expected to make contact with both natural and foreign submerged structures. Because intake velocities may be comparable to ambient velocities, any resulting contact abrasion would likely be similar to that observed under natural conditions. Although injury or mortality associated with contact abrasion may occur, there is no evidence to suggest that it would significantly increase mortality rates.

5.4 Summary of Potential Injury Mechanisms

We reviewed the results of studies that assessed a wide range of stressors to identify information that would help determine potential effects of impingement, shear and turbulence, and contact abrasion on the survival of fish eggs and larvae exposed to wedgewire screens. Most of the information reviewed discussed impingement rates and mortality and the ability of larvae to escape impingement. Several studies have also evaluated the effects of shear and turbulence on ichthyoplankton. However, no information or data directly related to contact abrasion was found. Most of the species evaluated for impingement mortality were estuarine and included striped bass, yellow perch, and winter flounder. With the exception of tests conducted by Radle (2001), there was little information pertinent to American shad, a primary species of concern at the proposed KWR intake. Several studies demonstrated that impingement typically results in low rates of ichthyoplankton mortality, depending on hydraulic conditions and duration of exposure, and even relatively small larvae (< 10 mm in length) have the ability to escape after becoming impinged on wedgewire screens. With respect to hydraulic stressors, some studies have shown that relatively high magnitudes of shear can be lethal for eggs and larvae. However, shear rates along the surface of wedgewire screens typically are much lower than those identified in past studies as damaging to fish. Conclusions regarding the passage of ichthyoplankton through hydro turbines also provide evidence that mortality rates of eggs and larvae exposed to wedgewire screens will be minimal.

6 CONCLUSIONS

The following are conclusions regarding the fish protection capabilities of the cylindrical wedgewire screens proposed for the KWR intake. These conclusions are based on a review of wedgewire screen studies (Section 3), analysis of the probable HZI of the intake at both near and far fields (Section 4), and a review of literature examining the injury and mortality of larvae and eggs exposed to various hydraulic and physical stressors (Section 5).

- Available data from wedgewire screen evaluations demonstrate that, when appropriately designed, cylindrical wedgewire screens are capable of effectively reducing entrainment and impingement of aquatic organisms under a variety of operating conditions. Specifically, a screen slot size of 1 mm and slot velocities of 0.5 ft/s or less have been cited by several studies as being sufficient for effectively protecting ichthyoplankton from entrainment and impingement at water intakes. The maximum design slot velocity for the KWR intake screens is 0.25 ft/s, which is half the 0.5 ft/s velocity that has been evaluated during most studies and that has been concluded to be sufficient for effectively protecting ichthyoplankton.

- Important parameters for minimizing entrainment and impingement that have been identified during biological evaluations of wedgewire screens include small slot width (2 mm or less), low slot velocity (0.5 ft/s or less), and channel velocities equal to or greater than expected slot velocities. The proposed design and operational parameters for the KWR intake screens meet these criteria, indicating the screens will provide a high level of protection for Mattaponi River fishes.

- The proposed maximum and primary operational slot velocities for the KWR intake (0.25 and < 0.10 ft/s, respectively) meet or exceed through-screen velocity criteria established by the Virginia Department of Game and Inland Fisheries and the U.S. Environmental Protection Agency for protecting fish at water intakes.

- Fish greater than 5 mm in length have the ability to actively avoid entrainment at low slot velocities (0.5 ft/s or less). As fish grow, this ability increases, resulting in complete or near complete screen exclusion when most fish species attain lengths between 8 and 12 mm.

- Impingement rates of fish larvae and eggs exposed to the KWR intake screens likely will be less than 5% for organisms that pass within a few feet of the screens.

- Entrainment rates will vary with species, size, and slot and channel velocities. However, 90% exclusion for larvae longer than 5 mm is likely for 85% of each tidal cycle when the screens are operated at slot velocities of 0.10 ft/s or less (i.e., 75% of the time that the screens are operational). At the maximum slot velocity of 0.25 ft/s, exclusion rates are likely to be 40% or greater for larvae between 5 and 10 mm in length, 75 to 100% for fish between 10 and 12 mm, and 90 to 100% for fish longer than 12 mm.

- Entrainment of eggs with diameters greater than 2 mm will be highly unlikely at the KWR intake. Entrainment of smaller eggs (<2 mm) should be less than 10% when channel velocities are equal to or more than the slot velocity.

- The near-field zone of influence of the KWR intake screens will only encompass a relatively small cross-sectional area approaching the screens. The effective area of the HZI will decrease with proximity to the intake and will increase with decreasing tidal velocities.

- The diameter of the near-field zone of influence will range from 3 to 40 ft depending on tidal velocities and pumping rate (the largest diameters of this zone will occur around slack tide and at the maximum pumping rate). Based on this range of diameters, the cross-sectional area at the intake location that the near-field zone will occupy will range from less than 1% to about 26%.

- At the maximum pumping rate of 75 mgd, the HZI of the KWR intake will comprise a relatively small proportion (< 5%) of the total cross-sectional area of the Mattaponi River at the location of the screens during a large portion of the tidal cycle (i.e., when tidal velocities exceed 0.5 ft/s). The HZI will be considerably smaller at pumping rates of 33 mgd and less, which will occur approximately 75% of the time the intake is operating. Assuming uniform ichthyoplankton distributions, the proportion of available eggs and larvae that encounter the screens will be directly proportional to the HZI cross-sectional area at the location of the intake. Actual entrainment and impingement rates of ichthyoplankton exposed to the screens will be dependent on local hydraulic conditions (i.e., slot and sweeping velocities) and larval size and swimming capabilities, but likely will exceed 80% during a large portion of the time the intake is in operation.

- Based on a review of several types of studies that have evaluated damage to ichthyoplankton exposed to various stressors, larvae and eggs that contact wedgewire screens probably do not suffer high rates of injury and mortality. Conditions that minimize the potential for contact-related injuries include low slot velocities, sweeping flows that approach and pass parallel to the screens, and the smoothness of the wire metal that comprises wedgewire screens. Also, studies of fine- mesh screens and aquatic filter barriers have shown that eggs and larvae of various species are capable of surviving impingement at relatively high rates over a wide range of intake velocities.

From these conclusions, it is apparent that only a small portion of eggs and larvae within the river will occur within the HZI of the KWR intake for the majority of time that the pumps are operating. Additionally, for a large portion of each tidal cycle (>85%), ichthyoplankton that will be at risk to entrainment and impingement (i.e., those within the HZI that will encounter the intake screens) likely will experience exclusion rates in excess of 75%. Consequently, impacts to Mattaponi River fishes resulting from the operation of the KWR intake (i.e., potential entrainment and impingement losses) should be insignificant. For American shad, and several other species, this low level of impact will be almost completely avoided by a shut down of pumping operations during periods when eggs and larvae are expected to be present in the vicinity of the proposed intake. Even without the pumping hiatus, very low and inconsequential rates of entrainment and impingement of fish eggs and larvae are likely to occur at the KWR intake. This conclusion is strongly supported by available data from wedgewire screen biological evaluations and Alden's HZI analysis.

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GENERAL CAPABILITIES

Alden Research Laboratory (Alden), located in Holden, Massachusetts, was founded in 1894 as a self-supporting research department of Worcester Polytechnic Institute (WPI), and in 1986 incorporated as a private company. Alden has performed applied research and provided testing services to industry and government since its early beginning, making it probably the oldest continuing hydraulic laboratory in the world. A national and international reputation has been earned in precision flow metering, fish passage and protection, machinery performance testing, and hydraulic structures. Both physical and computational modeling are used, including state of the art CFD, as most appropriate. Consulting services are provided in analyzing and solving flow related problems, and field measurements are made for evaluating turbine and pump performance. Developmental and calibration testing of flow meters to an uncertainty of better than 0.25% is conducted in Alden's various flow loops using the gravimetric method traceable to NIST.

Over fifty full-time people with varying training and expertise comprise the total Alden staff. Of the professional staff, a number have Ph.D. degrees and most have Master's degrees with specialization in different areas of hydraulics, fluid mechanics, and fisheries biology. The professional staff is involved in national and international society activities and many staff members have a variety of industrial experience. Testing and data reduction are handled by experienced engineering and biological assistants, and every Alden study is conducted by a team supervised by a full-time professional staff member. Service functions within Alden which support the technical activities include instrumentation, skilled crafts, heavy construction, purchasing, graphic arts, clerical, and accounting. The scope of Alden=s capabilities in areas relating to chemistry, materials, and life or earth sciences is enhanced by a continuing working relationship with faculty from various WPI departments.

Alden uses about thirty acres of extensive facilities to conduct testing and hydraulic modeling. Approximately twenty buildings equipped with flow supplies and control offices are available for hydraulic models or other experiments. Biological evaluations of fish passage and protection technologies are supported by state-of-the-art fish culture facilities that have been used to maintain over 30 species of fish for testing purposes. Fully equipped and staffed carpentry, machine, and instrumentation shops provide rapid and efficient model construction services. Extensive equipment is available for the construction and alteration of models and test facilities from wood, plastic, metals or combinations thereof required for the conduct of experimental research in the laboratory or field. An instrumentation department provides a variety of measuring and processing devices appropriate to a modern flow engineering laboratory, including a laser doppler anemometer (LDA), hot-wire and hot-film anemometers, swirl meters, various types of velocity probes, temperature sensors, and pressure transducers, all with appropriate readouts and computerized data acquisition. Alden has a graphics and photography section with experienced staff and all necessary equipment, including high speed and time lapse video, and computerized data displays. In addition to fixed facilities providing air and water flow, an inventory of movable flow related equipment, such as pumps, valves, metering devices, etc., is maintained and available.

FISH PROTECTION AT WATER INTAKES

Alden Research Laboratory, Inc. (Alden) has a team of engineers and scientists that is widely recognized for developing effective fish protection systems and upstream and downstream fish passage facilities, as well as for the resolution of environmental issues associated with project licensing. The team provides extensive experience and capabilities in the development, design, evaluation and construction of fish protection and passage facilities at a variety of water intakes. Team members are recognized in the industry and within regulatory agencies as leaders in the development of innovative technologies and have been instrumental in resolving difficult issues related to 316(b) requirements of the Clean Water Act and the hydroelectric licensing process. In addition to conducting numerous laboratory and field evaluations of existing and developing technologies, Alden's team has authored several authoritative documents on the subjects of fish entrainment and impingement, turbine passage survival, and intake protective measures.

The need for fish protection or passage facilities is often one of the most contentious issues associated with water resource projects. Alden's expertise allows our team to use the best available data to evaluate the cost and potential biological effectiveness of alternative fish protection measures. Biological and engineering evaluations of alternative technologies have been performed for application at many cooling water intakes, conventional hydro sites, pumped storage projects, and irrigation diversions situated in river, lake, and marine environments. Having extensive capabilities for performing hydraulic model studies and laboratory and field biological evaluations has allowed Alden to participate in the development of state-of-the-art fish protection facilities that are in use throughout the United States. Various types of fish screens have been developed and evaluated by Alden, including coarse- and fine-mesh modified traveling screens (Ristroph-type collection screens with fish lifting buckets), fixed and traveling fish diversion screens, cylindrical wedgewire screens, and rotary drum screens. In addition, Alden staff have conducted extensive research on the effectiveness of behavioral barriers for preventing fish entrainment and/or impingement, including strobe lights, sound deterrent systems, air bubble curtains, hanging chains, and water jet barriers. Alden also has been active in a U.S. Department of Energy program that was initiated to develop and evaluate alternative turbine runners designed to reduce injury and mortality of fish.

Alden is dedicated to maintaining a leadership role in continued development of fish protection and passage technologies and to keeping abreast of all ongoing research efforts. The fisheries team has compiled four comprehensive reviews on fish passage and protection technologies for the Electric Power Research Institute (EPRI). The first report, published in 1986, has become a standard reference that describes the advantages and limitations of all applicable technologies, with an emphasis on hydroelectric applications. The next two reviews, published in 1994 and 1998, are updates of the 1986 report and summarize recent developments in the use of technologies such as strobe lights, sound projectors, and high velocity fish screens. In 1999, Alden prepared a comprehensive review of state-of-the-art fish protection technologies for use at cooling water intakes to satisfy requirements of Section 316(b) of the Clean Water Act. In 2000, Alden prepared an EPRI report entitled "Procedural Guideline for Evaluating Alternative Fish Protection Technologies to Meet Section 316(b) Requirements of the Clean Water Act."

Our team has also compiled several reviews pertaining to fish entrainment and turbine passage survival. Documents prepared for EPRI include a review of entrainment and turbine passage survival studies published in 1992, a guideline on methodologies used in entrainment and passage survival studies published in 1997, and a database of entrainment and survival studies published in 1997. Alden staff also co-authored a review of entrainment studies and protective measures that was published by FERC in 1995. As a result of these efforts, the Alden staff has compiled entrainment and passage survival data from hundreds of recent studies. Our staff is well positioned to select the most appropriate data sets for estimating entrainment rates and turbine passage survival without conducting costly, site-specific studies.

In addition to monitoring and assessing the status of fish protection and passage technologies, Alden has and continues to perform engineering and biological evaluations of existing and developing technologies. These studies have been conducted for industry groups and resource and regulatory agencies. Technologies such as cylindrical wedgewire screens, angled bar racks and louvers, barrier nets, aquatic filter barriers, traveling screens, and behavioral deterrents have been evaluated in various laboratory and field studies for potential widespread and site-specific applications. The scope of many of these studies have included engineering performance, computational fluid dynamics modeling, and biological assessments. Because Alden was initially established as a hydraulic modeling laboratory, extensive laboratory facilities are available for testing any technology under a wide range of operating conditions. Additionally, Alden scientists maintain several fish culture systems that have been used for holding over 30 species of fish (freshwater, estuarine, marine) for testing purposes. Evaluations of fish protection technologies have been conducted with eggs, larvae, juveniles, and adults.

Alden's team of engineers and scientist understands the importance of involving resource and regulatory agencies in the process of designing fish passage structures, and are able to obtain rapid and meaningful agency interaction and response to permitting issues. Long-standing working relationships have been established with the Environmental Protection Agency, the Federal Energy Regulatory Commission, the U.S. Fish & Wildlife Service, the National Marine Fisheries Service, and many regional, state and local agencies that are based on a history of successful interaction and mutual respect.

APPENDIX F

KWR SAFE YIELD MODELING TECHNICAL MEMORANDUM

February 18, 2004

To: King William Reservoir Fisheries Panel

From: Ron Harris, P.G., Chief of Water Resources, Newport News Waterworks

Paul Peterson, Project Manager, Malcolm Pirnie, Inc.

Re: King William Reservoir Project
Mattaponi River Withdrawal Operations

The purpose of this memorandum is to provide the King William Reservoir (KWR) Fisheries Panel with information on how KWR water supply benefits were estimated and how associated Mattaponi River withdrawal operations would vary over time and in response to a proposed American shad spawning season pumping hiatus. This memorandum is organized into four sections as follows:

- Project Water Supply Benefits
- Temporal Variation in River Withdrawals
- Pumping Hiatus Effect on Post-Shad Spawning Withdrawals
- Frequency of Spawning Season Withdrawals Under Drought Emergencies

1.0 PROJECT WATER SUPPLY BENEFITS

Safe yield analysis of the KWR Project provides a measure of the dependable water supply benefit from the project. Malcolm Pirnie developed a raw water supply system model using the STELLA graphical programming language to accomplish this analysis. This model was originally developed in early 1998 to allow simulation of conditions stipulated by the Virginia Department of Environmental Quality's (VDEQ) December 22, 1997 Virginia Water Protection Permit. Assumptions and results from the STELLA safe yield modeling analysis were fully documented in Malcolm Pirnie's October 2000 "Evaluation of Safe Yield Benefits from King William Reservoir Project".

Additional safe yield analysis was performed by Camp Dresser & McKee (CDM) using their FORTRAN model of the Newport News Waterworks raw water supply system. The original version of this FORTRAN model was developed in 1989 and was used to evaluate safe yield for many of the alternatives presented in the U.S. Army Corps of Engineers' (USACE) January 1997 Final Environmental Impact Statement (FEIS) for the Regional Raw Water Study Group (RRWSG). An updated version of the FORTRAN model (SYMODELWIN) was used to develop an independent estimate of safe yield benefits from the KWR Project.

Existing Newport News Raw Water Supply System

The City of Newport News Waterworks operates a regional water supply system serving the cities of Newport News, Hampton, Poquoson, and portions of York County and James City County. The raw water supply system consists of a raw water intake on the Chickahominy River, three western storage reservoirs, two terminal reservoirs, a raw water transmission system, and a brackish groundwater supply. **Figure 1** summarizes pertinent characteristics of each reservoir in the existing Newport News system.

King William Reservoir Project

The KWR Project would require Mattaponi River withdrawal and transmission facilities, a new reservoir on Cohoke Creek in King William County, KWR withdrawal facilities, and a transmission main from KWR to Diascund Creek Reservoir, that includes a crossing of the Pamunkey River. A 75 mgd raw water intake structure and pumping station would be located on the Mattaponi River at Scotland Landing, in King William County. The new reservoir would store 12.2 billion gallons and cover 1,526 acres at a normal pool elevation of 96 feet msl. **Figure 2** summarizes key features of the proposed project.

Mattaponi River Minimum Instream Flow Rules

For safe yield modeling purposes, Mattaponi River withdrawals were simulated in accordance with the minimum instream flow (MIF) conditions stipulated in the VDEQ's December 22, 1997 Virginia Water Protection Permit. The basic permitted MIF condition is a "modified 80 percent monthly exceedance" rule. No Mattaponi River withdrawals are permitted when gaged freshwater flows drop below these permitted levels. Withdrawals are only permitted at more lenient 40/20 Tennant levels if mandatory use restrictions have been imposed. The STELLA model simulates imposition of use restrictions at monthly "conservation triggers" stipulated in the VDEQ permit which correspond to percentages of available system storage remaining. **Figure 3** portrays the Mattaponi River MIF levels as compared to average and median measures of freshwater flow contribution at the proposed intake site.

The modified 80 percent monthly exceedance levels range from 434 mgd in March to 114 mgd in August through October, and are higher than the 40/20 Tennant levels during every month of the year. The modified 80 percent monthly exceedance flows are based on monthly flow rates which have a probability of being exceeded 80 percent of the time during the period of record and are then increased by: (1) setting a minimum flow rate threshold of 108.5 mgd (lowest median monthly streamflow value (September)) and (2) reserving an additional allowance for other projected consumptive use in the Mattaponi River Basin.

The 40/20 Tennant levels provide that withdrawals may not be made from the Mattaponi River during the months of December through May when freshwater flows are below 197.6 mgd (about 40 percent of mean annual flow) or during the months of June through November when freshwater flows are less than 98.8 mgd (about 20 percent of mean annual flow). The estimated average freshwater flow of the Mattaponi River at Scotland Landing is 487 mgd based on Mattaponi River (Beulahville) streamflow records for Water Years 1942 through 2001.

Figure 1

EXISTING NEWPORT NEWS WATERWORKS RESERVOIRS

Reservoir	Drainage Area (square miles)	Normal Pool Elevation (feet msl)	Storage Capacity (BG)	Surface Area (acres)
Chickahominy	301	3	0.35	1,095
Little Creek	4.6	60	7.40	917
Diascund Creek	44.6	26	3.49	1,110
Skiffes Creek	6.25	13	0.23	94
Lee Hall	14.6	19.5	0.88	493
Harwood's Mill	8.6	20	0.85	265
Totals				
With Chickahominy	**379.7**		**13.19**	**3,974**
Without Chickahominy	**78.7**		**12.84**	**2,879**

Figure 2

Project Features

1 75 MGD Mattaponi R. Pump Station

2 1½-mile Mattaponi R. Pipeline

3 1,526-acre, 12.2 BG KW Reservoir

4 11.7-mile Pipeline to Diascund Reservoir

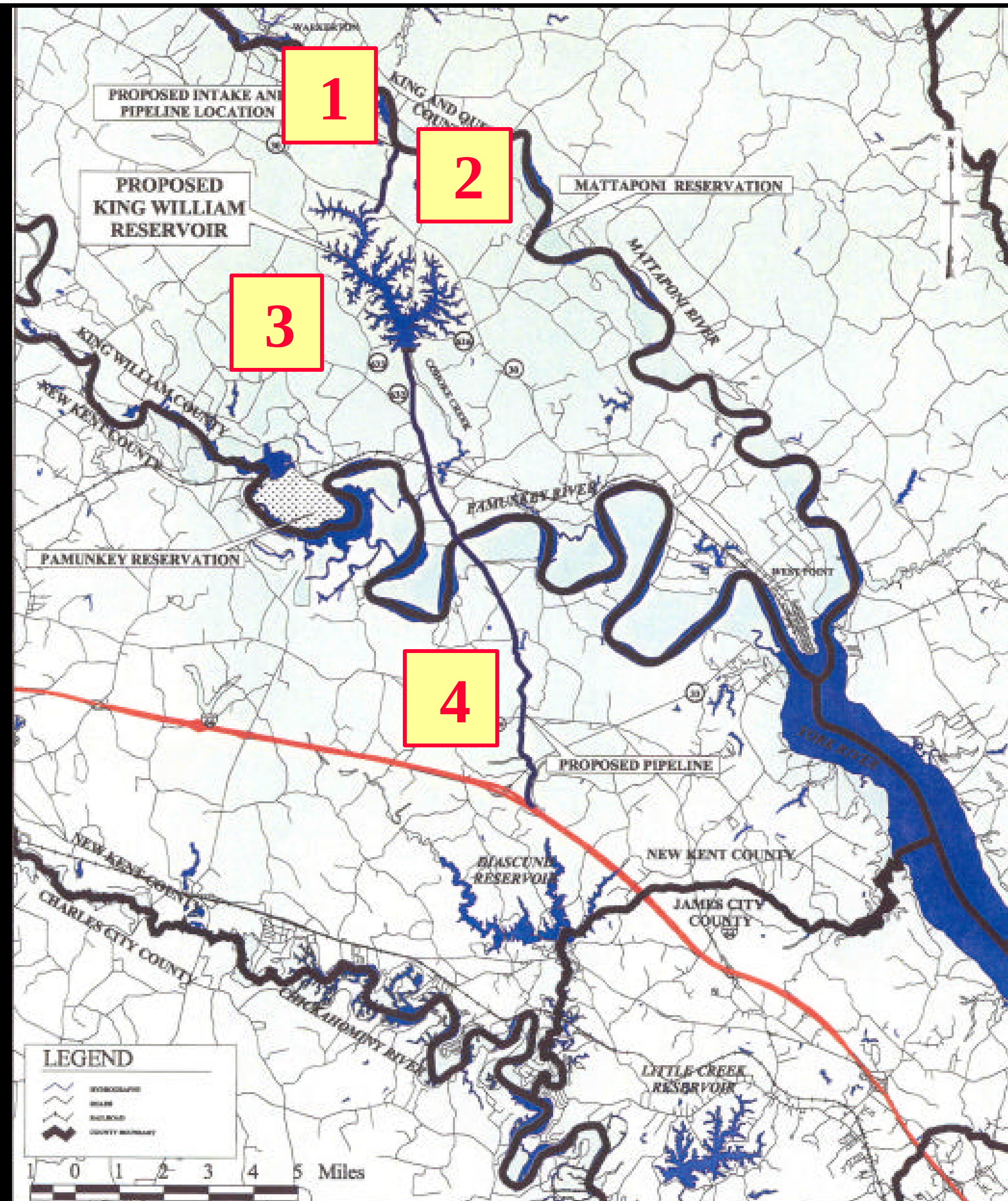
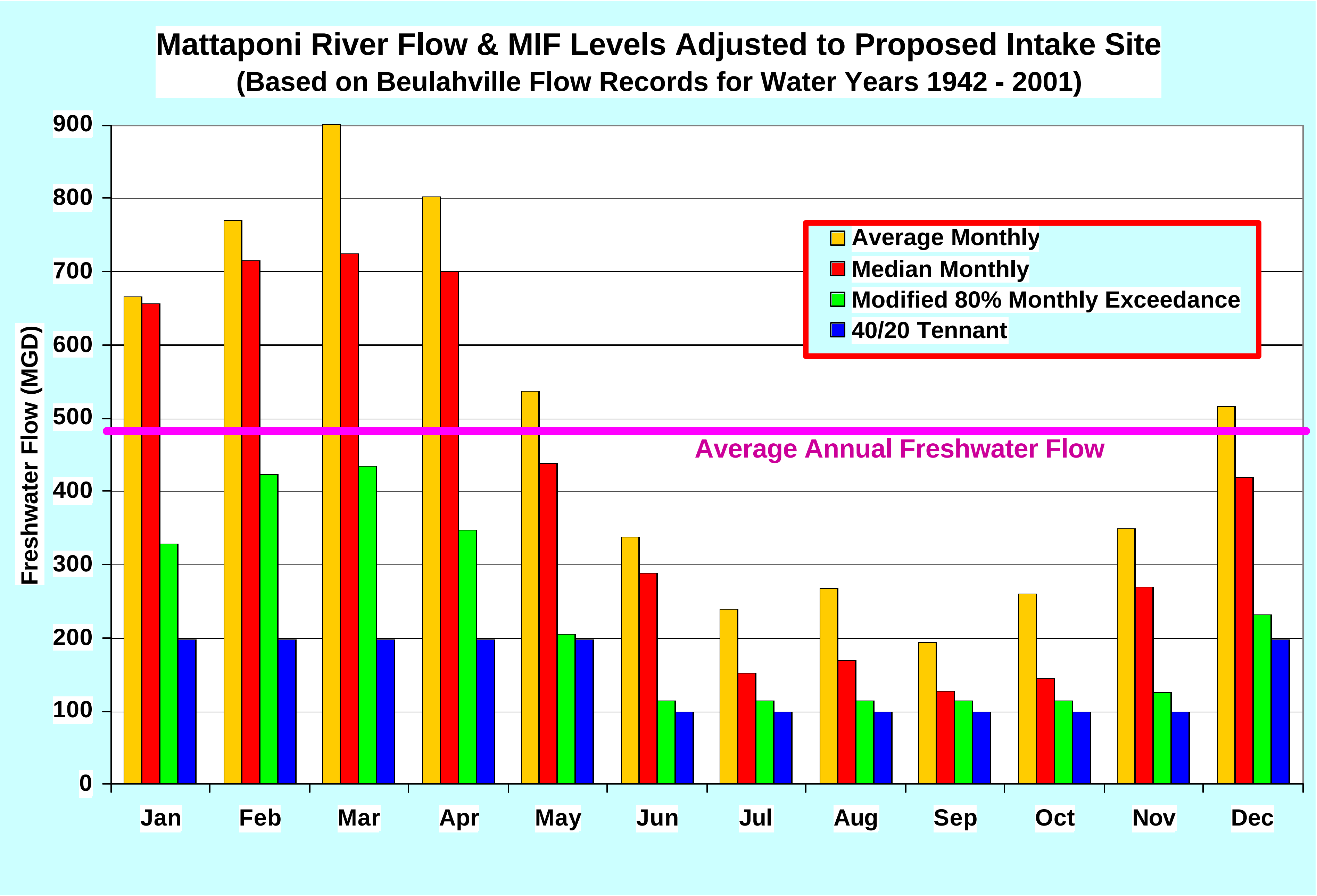


Figure 3


Mattaponi River Flow & MIF Levels Adjusted to Proposed Intake Site
(Based on Beulahville Flow Records for Water Years 1942 - 2001)
Freshwater Flow (MGD)
900
800
700
600
500
400
300
200
100
0
Average Monthly
Median Monthly
Modified 80% Monthly Exceedance
40/20 Tennant
Average Annual Freshwater Flow
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

It is important to note that these Mattaponi River rules are far more restrictive than the 10 cfs instream flow requirement for the Chickahmony River intake, which is currently the largest source of raw water supply for the entire RRWSG service area.

King William Reservoir Transfer Restriction

Another restriction of the VDEQ permit is that transfer rates from KWR to the existing Newport News system must not exceed 26.5 mgd on a 36-month running average basis. Therefore, the STELLA model simulates maximum allowable Chickahominy River withdrawals in order to minimize required withdrawals from KWR and the Mattaponi River. This is consistent with the intent of the VDEQ permit to minimize transfers of water from the Mattaponi River basin to the RRWSG service area on the Lower Peninsula.

In further explanation of this KWR transfer restriction, Dr. Ellen Gilinsky of VDEQ made an oral presentation to VMRC Commission members at their May 14, 2003 meeting. In her remarks she stated that: "… *The permit directs Newport News to exhaust other water sources first before withdrawing from the Mattaponi by limiting inner basin transfer in any given year to a certain amount, so this will be the source of last resort, not first resort."*

Safe Yield Results

A basic, yet critical measure of the water supply benefit of a reservoir system is its "safe yield". Safe yield is the theoretical maximum rate at which a water supply system could provide water continuously through the most severe drought of record without totally depleting the source of supply (i.e., available reservoir storage). This method assumes that during a drought identical to the worst drought of record, continuous operation of the water system at the "safe yield" rate would nearly exhaust the water supply during the drought.

In developing and testing the STELLA model, one of the model validation steps involved comparing estimated raw water safe yield for the existing Newport News Waterworks system with that derived from a previous model of the system developed by CDM. The safe yield estimates generated using the CDM models differ from the STELLA model result by 1 percent or less. Both the 56.6 mgd (STELLA) and 56.0 mgd (FORTRAN) baseline raw water safe yield estimates were used for this analysis to calculate incremental safe yield benefits from the KWR Project.

Using the STELLA model, total raw water safe yield benefits to the RRWSG were estimated for the combined KWR Project and existing Newport News system. These benefits are in addition to the 4 mgd of combined raw water withdrawals simulated for King William County (3 mgd) and New Kent County (1 mgd). Incremental treated water safe yield benefits to the RRWSG from the KWR Project were calculated as shown below. Treated water supply benefits were computed to allow direct comparison with long-term water demand and deficit forecasts.

0.95 x [Total Expanded System Raw Water Safe Yield - 56.6 mgd]

Where:

- The multiplier 0.95 accounts for raw water transmission losses, existing Newport News reservoir seepage losses, and treatment losses estimated at 5 percent of raw water safe yield benefits. These losses are not accounted for in the STELLA or FORTRAN models.

- 56.6 mgd is the estimated raw water safe yield of the existing Newport News system as determined using the STELLA model. This estimate excludes supply benefits from Newport News' recently implemented brackish groundwater system. A substitute value of 56.0 mgd is used in calculations involving results from CDM's FORTRAN model.

The resulting estimated KWR Project treated water safe yield benefit to the RRWSG is **18.8 mgd** based on a total expanded system raw water safe yield of 76.4 mgd. CDM used its updated FORTRAN model to simulate safe yield for a scenario comparable to the STELLA model scenario. The simulated total expanded system raw water safe yield was 77.6 mgd. Based on CDM's 56.0 mgd raw water safe yield estimate for the existing system, this results in an estimated KWR Project treated benefit to the RRWSG of **20.5 mgd**. Both models predict that the critical drought period occurs during the mid-1950s.

For modeling purposes, a constant 3 mgd withdrawal for King William County was simulated out of KWR, and a constant 1 mgd withdrawal for New Kent County was simulated out of the existing Newport News Waterworks reservoir system. Adding these host jurisdiction allowances to the net RRWSG benefits from the KWR Project results in an estimated total raw water safe yield benefit of between **23.8 and 25.6 mgd** as illustrated in the following table.

Raw Water Safe Yield Benefit Category	**STELLA Model (mgd)**	**FORTRAN Model (mgd)**
NN Surface Water System w/ KWR (1, 2)	76.4	77.6
NN Surface Water System w/o KWR (1, 2)	56.6	56.0
Net KWR Benefit to RRWSG	19.8	21.6
Net KWR Benefit to RRWSG and Host Communities	**23.8**	**25.6**

Notes: (1) Benefits are in addition to host allowances for King William and New Kent counties.
(2) The Newport News brackish groundwater supply is not included in these figures.

2.0 TEMPORAL VARIATION IN RIVER WITHDRAWALS

Using output from the safe yield analysis described in Section 1.0, analysis of simulated Mattaponi River withdrawals was conducted and compared to the fluctuating KWR storage over simulated historical periods. A 58-year simulation period was considered spanning October 1929 through September 1987. Daily York River Basin streamflow records used to simulate freshwater flow rates at Scotland Landing were from the Beulahville gage on the Mattaponi River and Doswell gage on the North Anna River.

Under 2040 to 2050 population conditions, when RRWSG water demands are projected to require full use of KWR safe yield, the average simulated Mattaponi River withdrawal was 14.5 mgd. **In prior years, when projected demands would be less, Mattaponi River withdrawals would also be less, since the full safe yield capacity of KWR would not yet be needed.**

The simulated Mattaponi River withdrawals vary for each month of the historical record as shown in **Figure 4**. This variation occurs due to fluctuating need for River withdrawals as KWR storage levels vary over the simulated historical record. In addition, the magnitude of Mattaponi River flow available for withdrawal constantly changes since it is a function of daily flow in the River, and the applicable monthly MIF level from the VDEQ permit. In order to more clearly show these withdrawal trends, 12-month running averages were computed and are shown in **Figure 5**.

The highest sustained Mattaponi River withdrawals coincide with reservoir storage recovery following the major droughts of the early 1930s, early 1940s, mid-1950s, 1960s, and 1980-81. During these reservoir storage recovery periods, 12-month running average Mattaponi withdrawals peaked at between 35 and 42 mgd. Individual average monthly withdrawals during these periods only infrequently reached the maximum 75 mgd withdrawal rate. In fact, over the entire 58-year simulation period (696 months), the average monthly withdrawal rate was 75 mgd during only 13 months, or less than 2 percent of the simulated months. Average monthly withdrawals exceeding 50 mgd occurred during 61 months, or less than 9 percent of the simulated months.

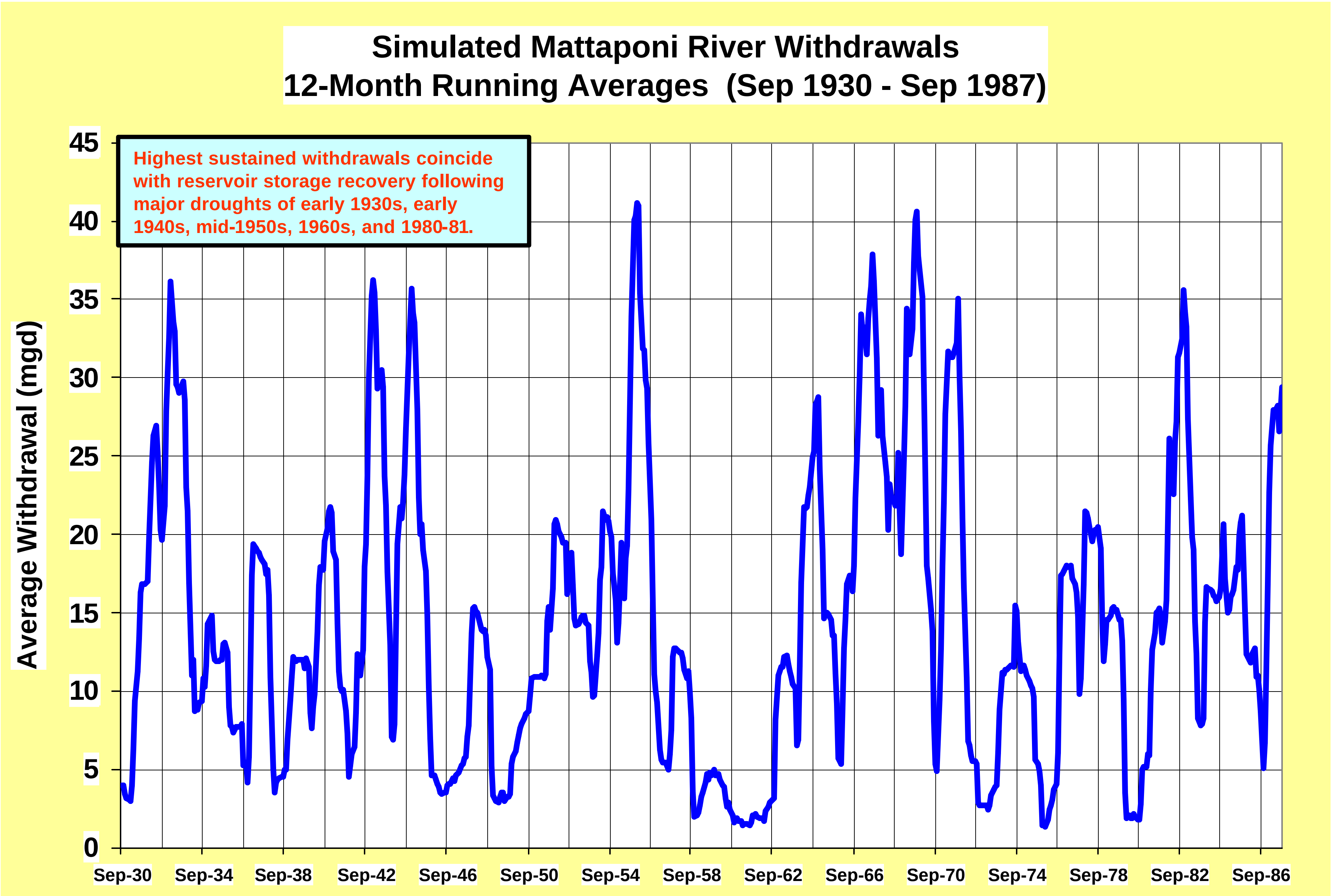
In order to show how Mattaponi River withdrawals vary year-to-year, individual average monthly withdrawal rates during the 1950s are shown in **Figure 6** which includes the critical drought period of the mid-1950s. Low withdrawals are typical since KWR storage is not substantially depleted in normal years. However, exceptions occur after periods such as the severe mid-1950s drought when higher withdrawals are needed to refill storage.

Figure 4

Simulated Monthly Mattaponi River Withdrawals from October 1929 to September 1987 (MGD)

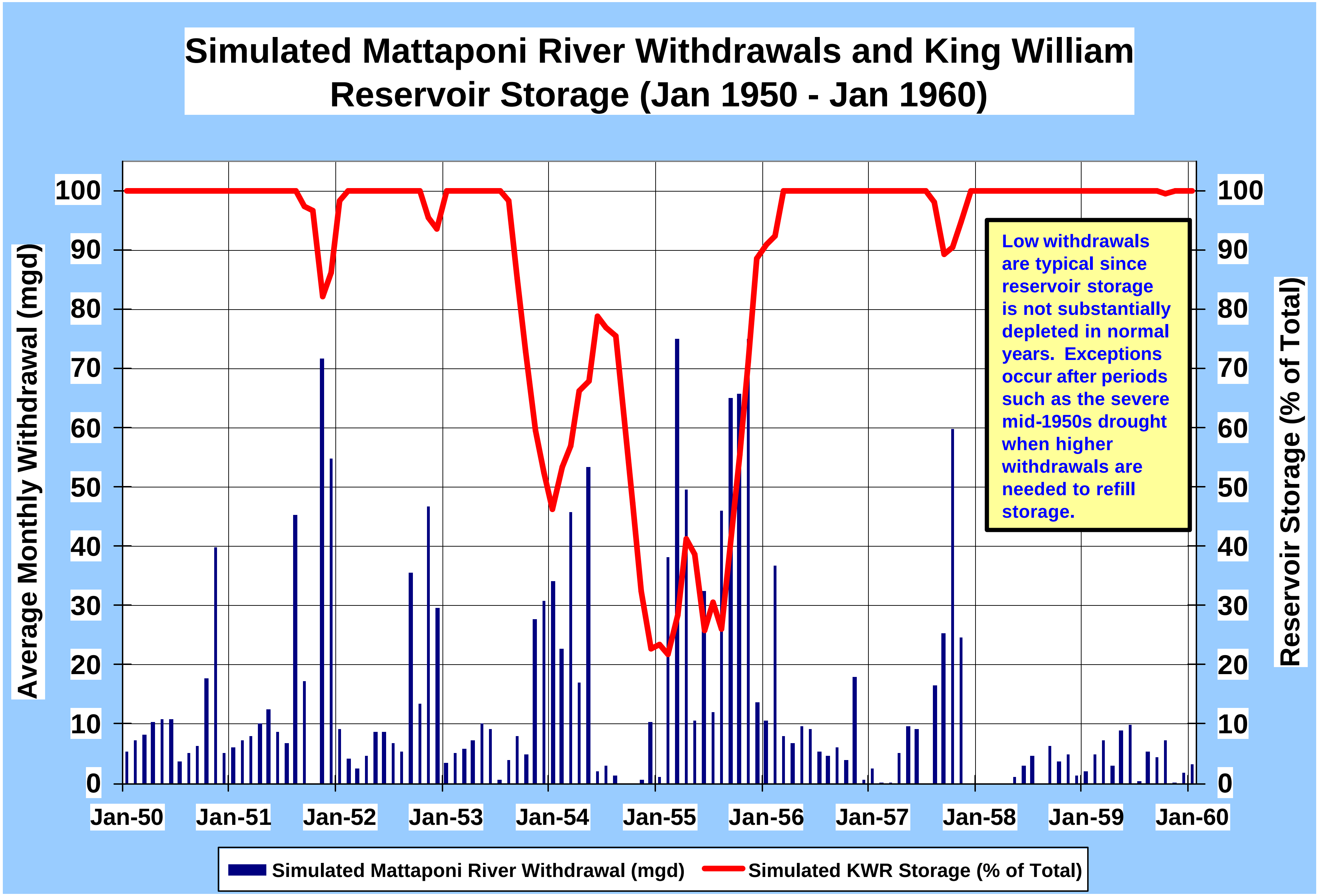
Oct-29	0.0	Aug-34	4.0	Jun-39	8.0	Apr-44	75.0	Feb-49	0.9	Dec-53	30.8	Oct-58	3.6	Aug-63	0.0	Jun-68	65.5	Apr-73	2.9	Feb-78	3.5	Dec-82	2.5
Nov-29	6.3	Sep-34	23.7	Jul-39	5.1	May-44	37.1	Mar-49	2.9	Jan-54	34.2	Nov-58	4.8	Sep-63	0.0	Jul-68	2.9	May-73	7.2	Mar-78	0.0	Jan-83	3.9
Dec-29	3.2	Oct-34	5.3	Aug-39	4.0	Jun-44	0.0	Apr-49	5.4	Feb-54	22.7	Dec-58	1.4	Oct-63	0.0	Aug-68	18.2	Jun-73	7.6	Apr-78	1.2	Feb-83	3.1
Jan-30	3.6	Nov-34	22.2	Sep-39	0.0	Jul-44	19.2	May-49	6.8	Mar-54	45.8	Jan-59	2.1	Nov-63	21.8	Sep-68	0.0	Jul-73	6.8	May-78	0.0	Mar-83	1.8
Feb-30	2.7	Dec-34	44.7	Oct-39	7.3	Aug-44	19.8	Jun-49	7.3	Apr-54	17.0	Feb-59	4.9	Dec-63	37.6	Oct-68	0.0	Aug-73	4.7	Jun-78	6.2	Apr-83	0.1
Mar-30	7.9	Jan-35	13.7	Nov-39	19.7	Sep-44	36.5	Jul-49	0.0	May-54	53.4	Mar-59	7.2	Jan-64	69.3	Nov-68	40.2	Sep-73	7.1	Jul-78	5.8	May-83	6.5
Apr-30	6.5	Feb-35	1.6	Dec-39	0.0	Oct-44	69.8	Aug-49	3.2	Jun-54	2.0	Apr-59	2.9	Feb-64	68.4	Dec-68	14.2	Oct-73	29.0	Aug-78	0.4	Jun-83	7.6
May-30	4.4	Mar-35	4.3	Jan-40	7.9	Nov-44	43.2	Sep-49	5.7	Jul-54	2.9	May-59	9.0	Mar-64	67.9	Jan-69	25.2	Nov-73	33.8	Sep-78	7.5	Jul-83	7.6
Jun-30	8.0	Apr-35	0.5	Feb-40	35.3	Dec-44	29.4	Oct-49	6.1	Aug-54	1.3	Jun-59	9.8	Apr-64	5.8	Feb-69	73.2	Dec-73	27.8	Oct-78	0.0	Aug-83	0.0
Jul-30	6.0	May-35	9.0	Mar-40	14.8	Jan-45	2.6	Nov-49	26.2	Sep-54	0.0	Jul-59	0.4	May-64	10.1	Mar-69	75.0	Jan-74	0.0	Nov-78	16.5	Sep-83	0.0
Aug-30	0.0	Jun-35	8.0	Apr-40	63.8	Feb-45	5.6	Dec-49	4.6	Oct-54	0.0	Aug-59	5.4	Jun-64	9.1	Apr-69	75.0	Feb-74	4.2	Dec-78	45.6	Oct-83	18.4
Sep-30	0.0	Jul-35	6.5	May-40	46.3	Mar-45	8.2	Jan-50	5.3	Nov-54	0.7	Sep-59	4.3	Jul-64	6.5	May-69	19.2	Mar-74	6.0	Jan-79	70.3	Nov-83	48.1
Oct-30	0.0	Aug-35	4.0	Jun-40	21.7	Apr-45	8.3	Feb-50	7.3	Dec-54	10.3	Oct-59	7.3	Aug-64	23.1	Jun-69	34.8	Apr-74	4.3	Feb-79	22.5	Dec-83	75.0
Nov-30	0.0	Sep-35	36.5	Jul-40	3.7	May-45	8.3	Mar-50	8.2	Jan-55	1.0	Nov-59	0.2	Sep-64	4.2	Jul-69	22.4	May-74	9.0	Mar-79	0.0	Jan-84	31.3
Dec-30	0.0	Oct-35	5.6	Aug-40	2.9	Jun-45	8.0	Apr-50	10.4	Feb-55	38.2	Dec-59	1.8	Oct-64	36.1	Aug-69	69.3	Jun-74	7.6	Apr-79	3.6	Feb-84	2.4
Jan-31	2.4	Nov-35	14.5	Sep-40	22.0	Jul-45	0.0	May-50	10.8	Mar-55	75.0	Jan-60	3.2	Nov-64	23.8	Sep-69	32.6	Jul-74	5.8	May-79	5.8	Mar-84	0.0
Feb-31	1.4	Dec-35	3.6	Oct-40	17.4	Aug-45	2.9	Jun-50	10.9	Apr-55	49.5	Feb-60	0.2	Dec-64	41.3	Oct-69	6.1	Aug-74	51.4	Jun-79	5.9	Apr-84	0.0
Mar-31	20.0	Jan-36	0.0	Nov-40	33.2	Sep-45	0.7	Jul-50	3.7	May-55	10.5	Mar-60	3.2	Jan-65	4.4	Nov-69	6.2	Sep-74	2.8	Jul-79	3.0	May-84	3.0
Apr-31	34.7	Feb-36	0.0	Dec-40	2.9	Oct-45	5.7	Aug-50	5.0	Jun-55	32.5	Apr-60	1.5	Feb-65	5.9	Dec-69	3.2	Oct-74	6.1	Aug-79	1.8	Jun-84	6.2
May-31	41.0	Mar-36	0.0	Jan-41	3.2	Nov-45	4.8	Sep-50	6.4	Jul-55	12.1	May-60	0.4	Mar-65	6.1	Jan-70	4.6	Nov-74	11.1	Sep-79	0.0	Jul-84	4.0
Jun-31	30.2	Apr-36	4.3	Feb-41	6.1	Dec-45	0.0	Oct-50	17.6	Aug-55	46.0	Jun-60	3.4	Apr-65	8.6	Feb-70	5.2	Dec-74	31.8	Oct-79	0.0	Aug-84	4.0
Jul-31	31.0	May-36	9.4	Mar-41	8.0	Jan-46	2.5	Nov-50	39.7	Sep-55	65.0	Jul-60	3.7	May-65	11.1	Mar-70	7.2	Jan-75	0.0	Nov-79	0.0	Sep-84	6.3
Aug-31	34.2	Jun-36	8.0	Apr-41	5.8	Feb-46	3.1	Dec-50	5.0	Oct-55	65.8	Aug-60	0.0	Jun-65	8.4	Apr-70	6.4	Feb-75	1.3	Dec-79	0.0	Oct-84	43.5
Sep-31	7.7	Jul-36	6.5	May-41	8.1	Mar-46	4.3	Jan-51	6.0	Nov-55	75.0	Sep-60	0.0	Jul-65	2.3	May-70	9.7	Mar-75	0.0	Jan-80	0.0	Nov-84	72.1
Oct-31	0.0	Aug-36	6.0	Jun-41	10.4	Apr-46	6.5	Feb-51	7.3	Dec-55	13.7	Oct-60	1.8	Aug-65	10.3	Jun-70	10.2	Apr-75	0.8	Feb-80	2.8	Dec-84	33.5
Nov-31	0.0	Sep-36	5.0	Jul-41	0.1	May-46	3.7	Mar-51	7.9	Jan-56	10.6	Nov-60	3.4	Sep-65	4.2	Jul-70	6.5	May-75	5.8	Mar-80	1.5	Jan-85	5.3
Dec-31	1.9	Oct-36	7.6	Aug-41	4.3	Jun-46	7.6	Apr-51	10.0	Feb-56	36.7	Dec-60	2.1	Oct-65	7.6	Aug-70	0.0	Jun-75	4.8	Apr-80	2.2	Feb-85	4.5
Jan-32	36.1	Nov-36	0.0	Sep-41	5.3	Jul-46	0.1	May-51	12.5	Mar-56	7.9	Jan-61	1.0	Nov-65	0.0	Sep-70	0.0	Jul-75	0.0	May-80	5.4	Mar-85	9.3
Feb-32	29.5	Dec-36	22.7	Oct-41	0.0	Aug-46	3.6	Jun-51	8.7	Apr-56	6.9	Feb-61	0.0	Dec-65	0.0	Oct-70	0.3	Aug-75	2.5	Jun-80	8.7	Apr-85	2.3
Mar-32	49.5	Jan-37	66.1	Nov-41	0.0	Sep-46	6.4	Jul-51	6.8	May-56	9.7	Mar-61	0.0	Jan-66	0.0	Nov-70	61.3	Sep-75	0.0	Jul-80	1.3	May-85	6.3
Apr-32	55.1	Feb-37	73.4	Dec-41	11.6	Oct-46	6.1	Aug-51	45.1	Jun-56	9.1	Apr-61	2.6	Feb-66	48.0	Dec-70	42.7	Oct-75	0.0	Aug-80	0.0	Jun-85	23.4
May-32	49.9	Mar-37	24.0	Jan-42	12.1	Nov-46	5.1	Sep-51	17.2	Jul-56	5.4	May-61	0.0	Mar-66	51.8	Jan-71	66.3	Nov-75	0.9	Sep-80	0.0	Jul-85	2.6
Jun-32	9.3	Apr-37	0.0	Feb-42	11.2	Dec-46	3.9	Oct-51	0.0	Aug-56	4.7	Jun-61	3.4	Apr-66	31.2	Feb-71	64.3	Dec-75	1.0	Oct-80	11.9	Aug-85	29.7
Jul-32	6.1	May-37	7.2	Mar-42	33.9	Jan-47	1.0	Nov-51	71.6	Sep-56	6.0	Jul-61	2.3	May-66	37.9	Mar-71	75.0	Jan-76	0.0	Nov-80	26.0	Sep-85	16.8
Aug-32	0.0	Jun-37	7.3	Apr-42	61.0	Feb-47	6.6	Dec-51	64.8	Oct-56	3.9	Aug-61	2.6	Jun-66	16.7	Apr-71	63.8	Feb-76	0.0	Dec-80	2.4	Oct-85	49.7
Sep-32	0.0	Jul-37	3.3	May-42	0.0	Mar-47	5.7	Jan-52	9.3	Nov-56	17.9	Sep-61	6.0	Jul-66	0.0	May-71	7.6	Mar-76	5.7	Jan-81	0.0	Nov-85	0.0
Oct-32	26.6	Aug-37	3.6	Jun-42	2.3	Apr-47	7.9	Feb-52	4.2	Dec-56	0.7	Oct-61	1.4	Aug-66	0.0	Jun-71	7.6	Apr-76	8.3	Feb-81	12.9	Dec-85	0.0
Nov-32	72.5	Sep-37	2.1	Jul-42	19.8	May-47	9.4	Mar-52	2.5	Jan-57	2.5	Nov-61	4.4	Sep-66	23.8	Jul-71	6.5	May-76	9.0	Mar-81	0.0	Jan-86	2.5
Dec-32	31.3	Oct-37	0.0	Aug-42	68.2	Jun-47	8.0	Apr-52	4.7	Feb-57	0.2	Dec-61	0.0	Oct-66	69.2	Aug-71	3.6	Jun-76	9.1	Apr-81	62.5	Feb-86	2.0
Jan-33	63.5	Nov-37	3.0	Sep-42	22.5	Jul-47	4.7	May-52	8.7	Mar-57	0.1	Jan-62	0.0	Nov-66	69.0	Sep-71	7.5	Jul-76	7.6	May-81	35.8	Mar-86	7.2
Feb-33	71.9	Dec-37	3.2	Oct-42	52.1	Aug-47	4.3	Jun-52	8.7	Apr-57	5.0	Feb-62	0.2	Dec-66	36.3	Oct-71	34.0	Aug-76	6.9	Jun-81	21.8	Apr-86	9.0
Mar-33	18.2	Jan-38	3.2	Nov-42	75.0	Sep-47	22.5	Jul-52	6.8	May-57	9.7	Mar-62	0.0	Jan-67	46.0	Nov-71	2.0	Sep-76	24.2	Jul-81	17.1	May-86	10.8
Apr-33	47.5	Feb-38	3.8	Dec-42	75.0	Oct-47	14.7	Aug-52	5.4	Jun-57	9.1	Apr-62	0.0	Feb-67	34.6	Dec-71	0.7	Oct-76	75.0	Aug-81	0.6	Jun-86	1.3
May-33	7.6	Mar-38	6.1	Jan-43	23.7	Nov-47	75.0	Sep-52	36.5	Jul-57	0.0	May-62	7.9	Mar-67	54.7	Jan-72	1.0	Nov-76	61.5	Sep-81	2.0	Jul-86	3.9
Jun-33	8.0	Apr-38	7.6	Feb-43	1.3	Dec-47	23.4	Oct-52	13.4	Aug-57	16.4	Jun-62	6.9	Apr-67	11.2	Feb-72	0.0	Dec-76	2.5	Oct-81	6.8	Aug-86	19.4
Jul-33	1.6	May-38	9.4	Mar-43	5.4	Jan-48	2.6	Nov-52	46.7	Sep-57	26.3	Jul-62	4.7	May-67	64.8	Mar-72	6.0	Jan-77	2.5	Nov-81	6.2	Sep-86	0.0
Aug-33	2.9	Jun-38	8.0	Apr-43	6.9	Feb-48	2.8	Dec-52	29.7	Oct-57	59.7	Aug-62	4.3	Jun-67	30.3	Apr-72	6.1	Feb-77	4.5	Dec-81	19.2	Oct-86	4.8
Sep-33	6.0	Jul-38	4.4	May-43	8.7	Mar-48	4.6	Jan-53	3.6	Nov-57	24.5	Sep-62	6.4	Jul-67	11.1	May-72	4.0	Mar-77	4.6	Jan-82	16.1	Nov-86	20.0
Oct-33	12.1	Aug-38	4.0	Jun-43	8.0	Apr-48	0.1	Feb-53	5.2	Dec-57	0.0	Oct-62	3.1	Aug-67	23.2	Jun-72	0.2	Apr-77	7.6	Feb-82	73.4	Dec-86	58.2
Nov-33	5.7	Sep-38	7.1	Jul-43	6.1	May-48	4.0	Mar-53	5.7	Jan-58	0.0	Nov-62	65.0	Sep-67	3.0	Jul-72	2.3	May-77	10.1	Mar-82	63.0	Jan-87	65.1
Dec-33	12.3	Oct-38	0.0	Aug-43	0.0	Jun-48	7.6	Apr-53	7.2	Feb-58	0.0	Dec-62	33.7	Oct-67	0.0	Aug-72	2.9	Jun-77	0.0	Apr-82	28.8	Feb-87	72.1
Jan-34	9.7	Nov-38	26.0	Sep-43	0.0	Jul-48	5.8	May-53	10.1	Mar-58	0.0	Jan-63	2.5	Nov-67	0.0	Sep-72	6.0	Jul-77	2.6	May-82	16.6	Mar-87	43.5
Feb-34	0.0	Dec-38	34.2	Oct-43	2.3	Aug-48	0.0	Jun-53	9.1	Apr-58	0.0	Feb-63	4.5	Dec-67	59.0	Oct-72	3.9	Aug-77	0.0	Jun-82	62.1	Apr-87	36.3
Mar-34	31.0	Jan-39	20.0	Nov-43	17.5	Sep-48	6.0	Jul-53	0.6	May-58	1.2	Mar-63	0.0	Jan-68	58.4	Nov-72	0.6	Sep-77	6.3	Jul-82	32.7	May-87	6.8
Apr-34	7.7	Feb-39	19.5	Dec-43	4.8	Oct-48	4.3	Aug-53	3.9	Jun-58	3.1	Apr-63	7.2	Feb-68	0.0	Dec-72	0.0	Oct-77	15.6	Aug-82	49.7	Jun-87	5.9
May-34	9.4	Mar-39	4.3	Jan-44	21.8	Nov-48	2.3	Sep-53	8.0	Jul-58	4.7	May-63	9.0	Mar-68	34.0	Jan-73	1.0	Nov-77	73.6	Sep-82	4.8	Jul-87	6.1
Jun-34	8.0	Apr-39	6.6	Feb-44	13.1	Dec-48	0.0	Oct-53	4.8	Aug-58	0.0	Jun-63	0.0	Apr-68	0.0	Feb-73	0.2	Dec-77	75.0	Oct-82	18.1	Aug-87	0.3
Jul-34	6.1	May-39	9.7	Mar-44	75.0	Jan-49	0.0	Nov-53	27.7	Sep-58	6.4	Jul-63	0.0	May-68	24.2	Mar-73	5.4	Jan-78	57.4	Nov-82	43.0	Sep-87	33.2

Figure 5



Simulated Mattaponi River Withdrawals
12-Month Running Averages (Sep 1930 - Sep 1987)
Highest sustained withdrawals coincide with reservoir storage recovery following major droughts of early 1930s, early 1940s, mid-1950s, 1960s, and 1980-81.
Average Withdrawal (mgd)
45
40
35
30
25
20
15
10
5
0
Sep-30
Sep-34
Sep-38
Sep-42
Sep-46
Sep-50
Sep-54
Sep-58
Sep-62
Sep-66
Sep-70
Sep-74
Sep-78
Sep-82
Sep-86

Figure 6


Simulated Mattaponi River Withdrawals and King William Reservoir Storage (Jan 1950 - Jan 1960)
Average Monthly Withdrawal (mgd)
Reservoir Storage (% of Total)
0
10
20
30
40
50
60
70
80
90
100
Jan-50
Jan-51
Jan-52
Jan-53
Jan-54
Jan-55
Jan-56
Jan-57
Jan-58
Jan-59
Jan-60
Low withdrawals are typical since reservoir storage is not substantially depleted in normal years. Exceptions occur after periods such as the severe mid-1950s drought when higher withdrawals are needed to refill storage.
Simulated Mattaponi River Withdrawal (mgd)
Simulated KWR Storage (% of Total)

3.0 PUMPING HIATUS EFFECT ON POST-SHAD SPAWNING WITHDRAWALS

The KWR Fisheries Panel is developing recommended protocols for a Mattaponi River pumping hiatus during the American shad spawning season which occurs each Spring. An evaluation was made to determine whether the pumping hiatus would result in greater withdrawals in post-shad spawning months to make up for the pumping hiatus.

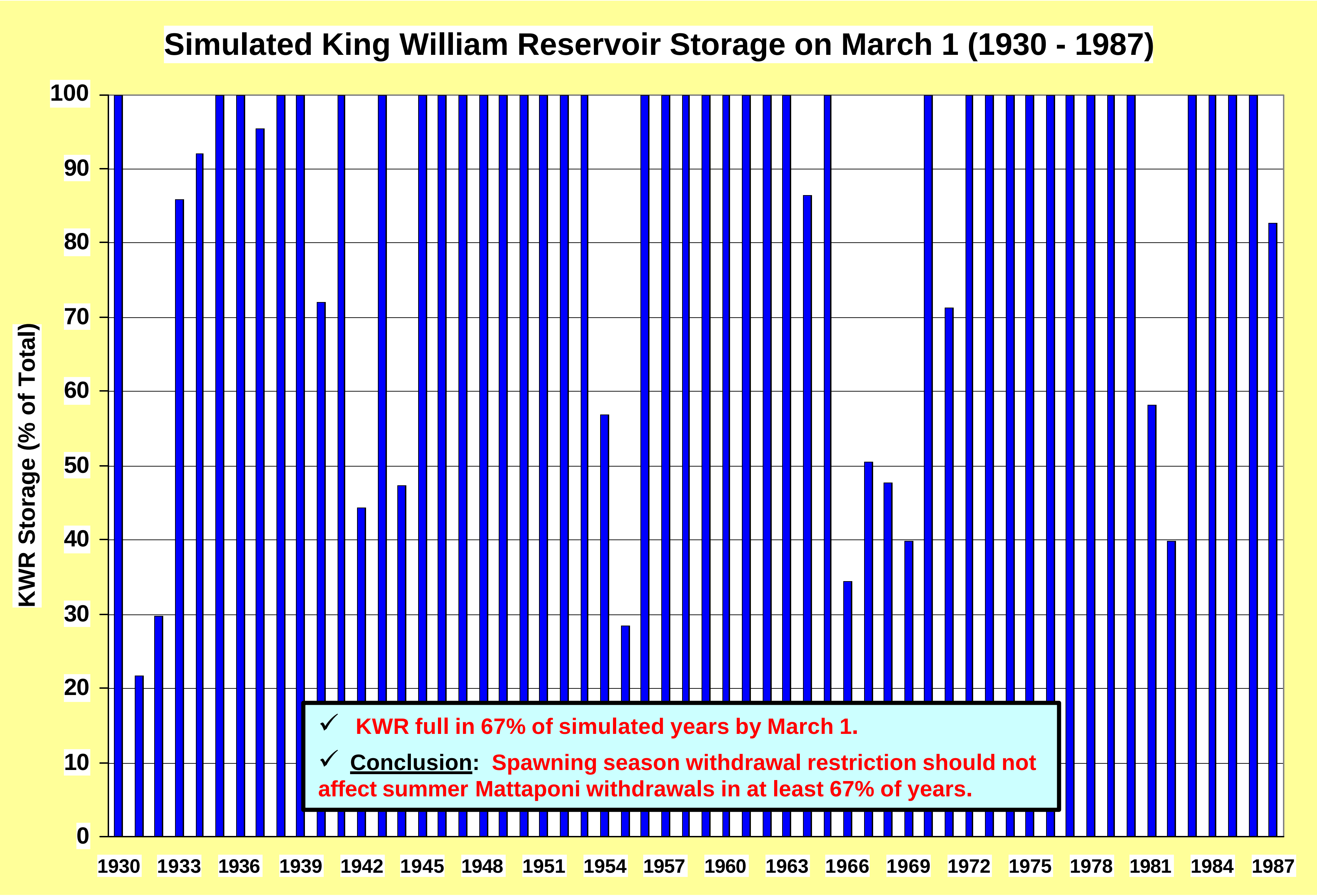
In order to evaluate this question, a reservoir storage analysis was first conducted to see how frequently simulated KWR storage was full by March 1 (i.e., approximating the time of year when the pumping hiatus for the American shad spawning season could occur). As shown in **Figure 7**, under projected 2040 to 2050 RRWSG water demand conditions, KWR was full in 67 percent of simulated years by March 1. In those years, there would be much less need for any Mattaponi River withdrawals during the Spring since KWR would start the Spring full and natural inflows to KWR through basin runoff from 9 square miles of contributing watershed would normally be highest. In such years, it is unlikely that substantial KWR drawdown would occur during the pumping hiatus that would require significantly higher summer River withdrawals. In other words, the pumping hiatus is expected to have little effect on Mattaponi River withdrawals during summer months (i.e., post-shad spawning period) in at least two-thirds of years.

The next step in this analysis was to consider the effect of a pumping hiatus during drought periods when KWR would not have been full by March 1. Significant drought periods were evaluated including the early 1930s, mid-1950s, mid- to late-1960s and early 1980s. As shown in **Figures 8 through 11**, although KWR is not full by March 1 in several years of these drought periods, maximum allowable summer Mattaponi River withdrawals are already simulated. In other words, even without the pumping hiatus, maximum summer withdrawals are already made and, in nearly all cases, there is no room to expand these withdrawals since the MIF levels in the VDEQ permit preclude any possible expansion of the withdrawal volumes. Evidence for this conclusion is clearly seen when simulated Mattaponi River withdrawals, despite substantial KWR storage drawdown, are consistently less than 75 mgd.

The VDEQ likewise recognized that MIF levels in the VDEQ permit would preclude expansion of summer withdrawals. In an oral presentation made by Dr. Ellen Gilinsky of VDEQ to VMRC Commission members at their May 14, 2003 meeting she stated that: "… *there's a set amount that can be withdrawn in the summer months. So regardless of the moratorium you're considering on withdrawal, you can't make up the difference in the summer months. It's going to affect the yield of the project. But you will not be able to take more water than our permit allows in the summer months, so that will protect that withdrawal."*

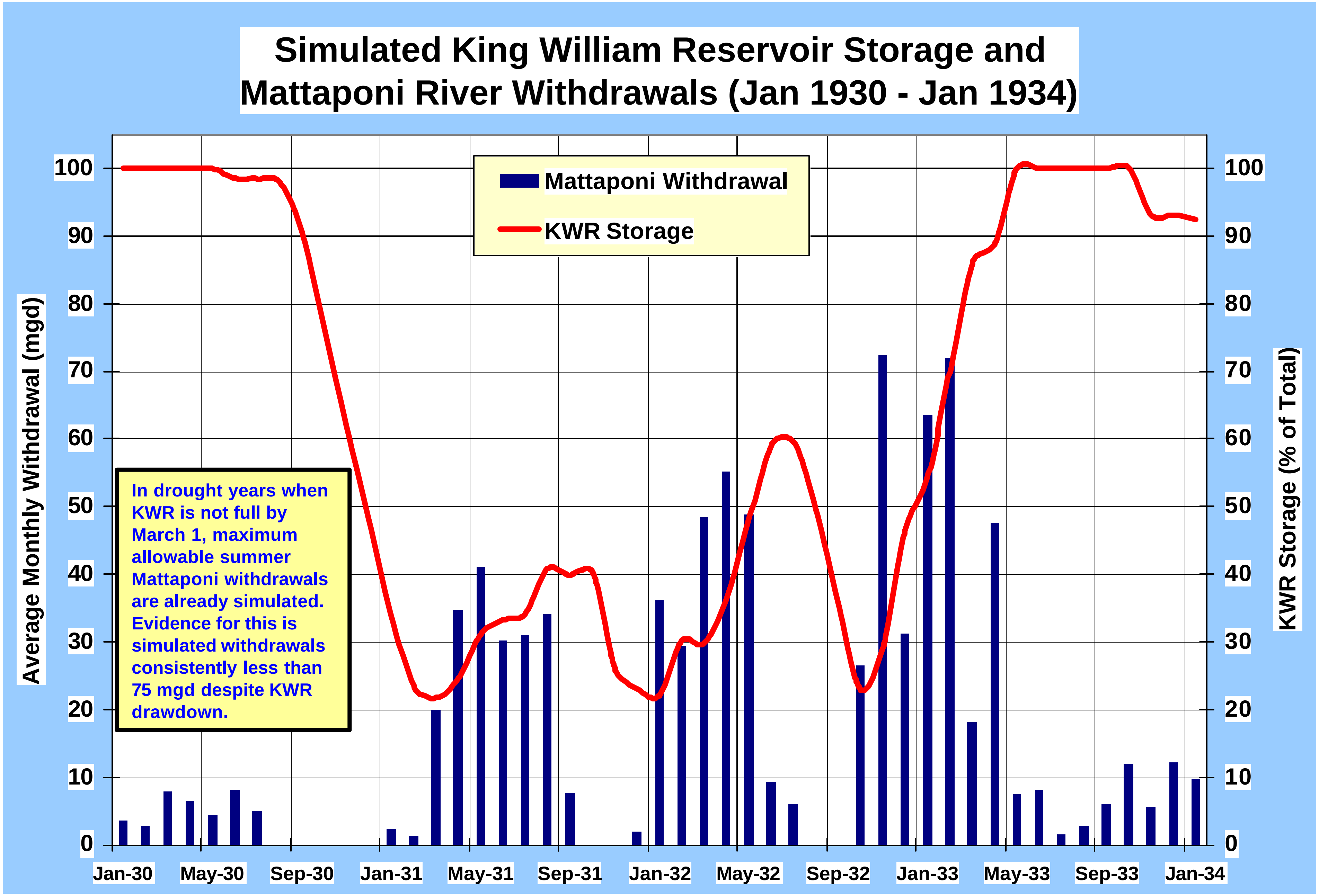
Virginia Marine Resources Commission (VMRC) staff also recognized this fact based on the oral statement made by Mr. Tony Watkinson of VMRC's staff to VMRC Commission members at their May 14, 2003 meeting. Mr. Watkinson stated: "… *it was also understood that withdrawals during the remainder of the year outside the spawning window would be controlled by DEQ withdrawal limits. The City would be required to meet these limits regardless of a time-of-year restriction for operating of the intake during the spawning period.*"

Figure 7



Simulated King William Reservoir Storage on March 1 (1930 - 1987)
KWR Storage (% of Total)
100
90
80
70
60
50
40
30
20
10
0
1930
1933
1936
1939
1942
1945
1948
1951
1954
1957
1960
1963
1966
1969
1972
1975
1978
1981
1984
1987
✓ KWR full in 67% of simulated years by March 1.
✓ Conclusion: Spawning season withdrawal restriction should not affect summer Mattaponi withdrawals in at least 67% of years.

Figure 8



Simulated King William Reservoir Storage and
Mattaponi River Withdrawals (Jan 1930 - Jan 1934)
Mattaponi Withdrawal
KWR Storage
In drought years when KWR is not full by March 1, maximum allowable summer Mattaponi withdrawals are already simulated. Evidence for this is simulated withdrawals consistently less than 75 mgd despite KWR drawdown.
Average Monthly Withdrawal (mgd)
KWR Storage (% of Total)
0
10
20
30
40
50
60
70
80
90
100
Jan-30
May-30
Sep-30
Jan-31
May-31
Sep-31
Jan-32
May-32
Sep-32
Jan-33
May-33
Sep-33
Jan-34

Figure 9

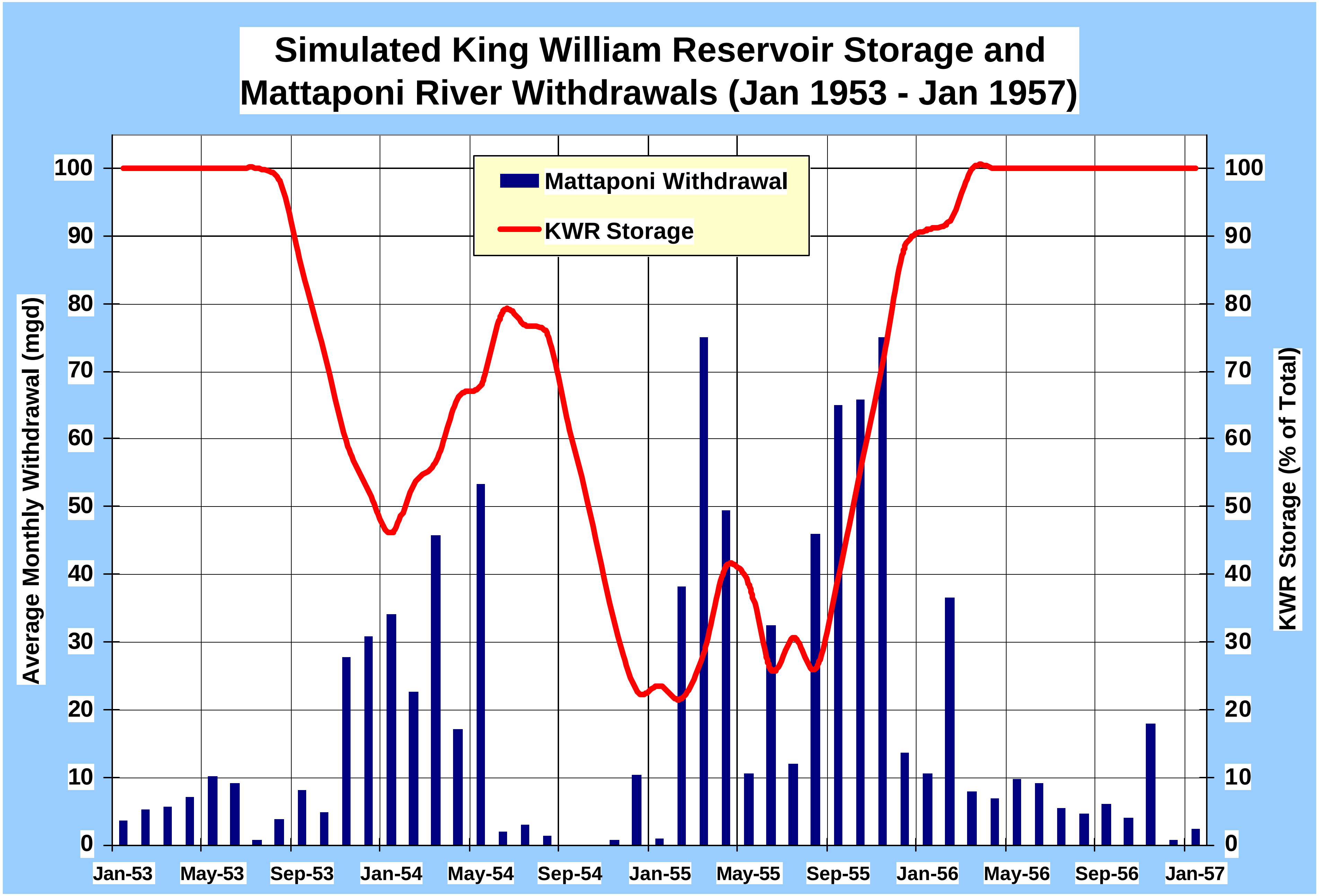

Simulated King William Reservoir Storage and
Mattaponi River Withdrawals (Jan 1953 - Jan 1957)
Mattaponi Withdrawal
KWR Storage
Average Monthly Withdrawal (mgd)
KWR Storage (% of Total)
0
10
20
30
40
50
60
70
80
90
100
Jan-53
May-53
Sep-53
Jan-54
May-54
Sep-54
Jan-55
May-55
Sep-55
Jan-56
May-56
Sep-56
Jan-57

Figure 10

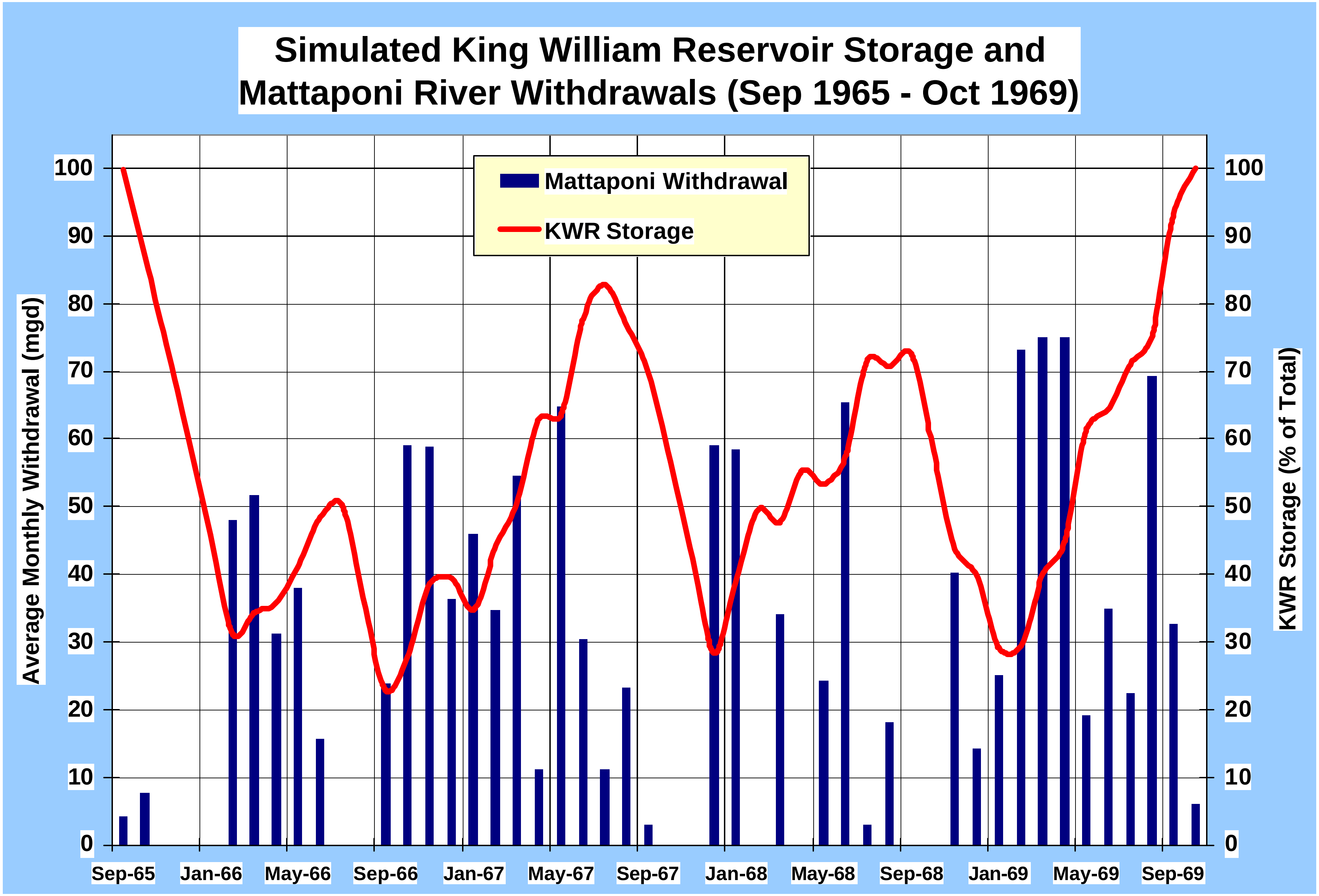
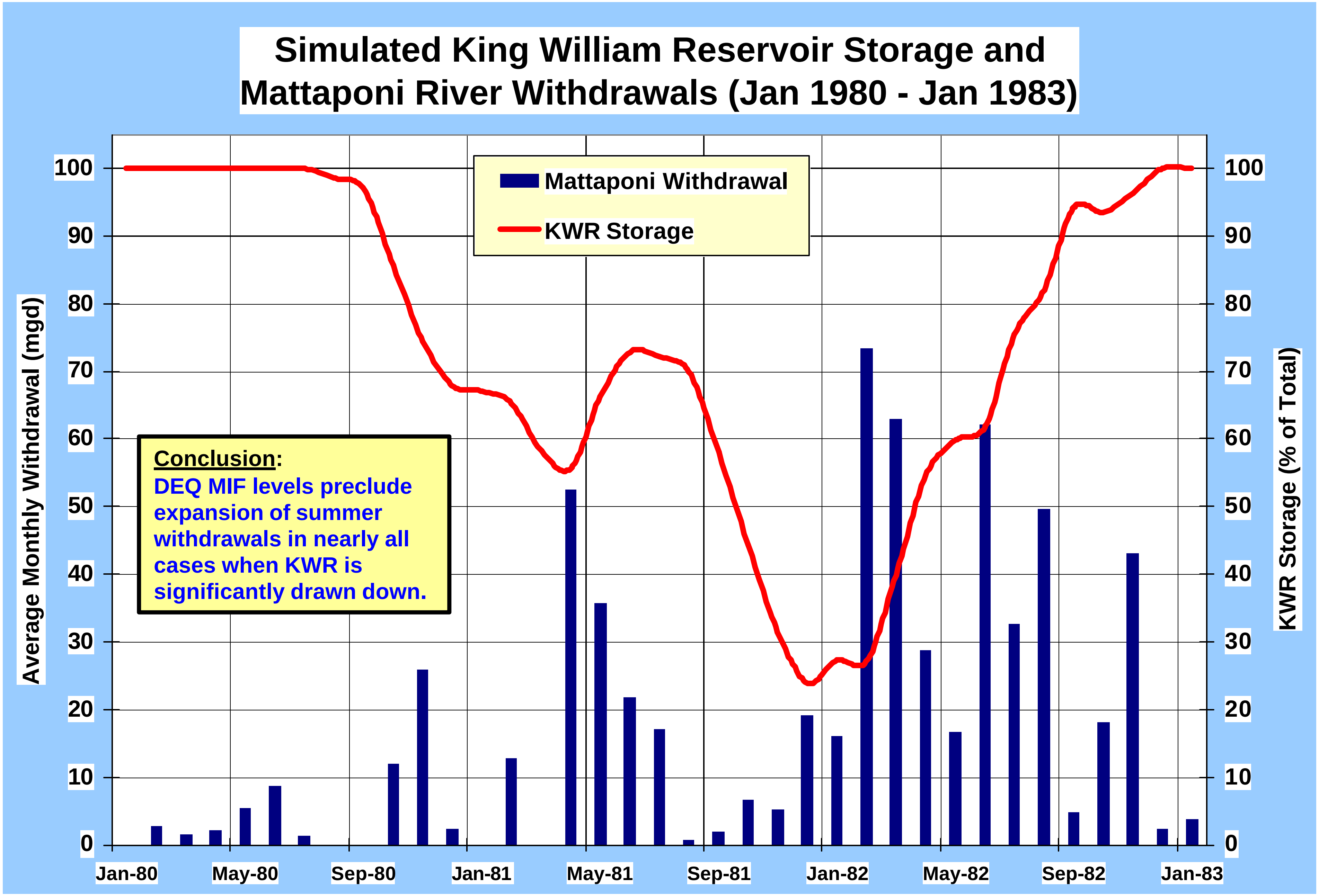

Simulated King William Reservoir Storage and
Mattaponi River Withdrawals (Sep 1965 - Oct 1969)
Mattaponi Withdrawal
KWR Storage
Average Monthly Withdrawal (mgd)
KWR Storage (% of Total)
0
10
20
30
40
50
60
70
80
90
100
Sep-65
Jan-66
May-66
Sep-66
Jan-67
May-67
Sep-67
Jan-68
May-68
Sep-68
Jan-69
May-69
Sep-69

Figure 11



Simulated King William Reservoir Storage and
Mattaponi River Withdrawals (Jan 1980 - Jan 1983)
Mattaponi Withdrawal
KWR Storage
Conclusion:
DEQ MIF levels preclude expansion of summer withdrawals in nearly all cases when KWR is significantly drawn down.
Average Monthly Withdrawal (mgd)
KWR Storage (% of Total)
0
10
20
30
40
50
60
70
80
90
100
Jan-80
May-80
Sep-80
Jan-81
May-81
Sep-81
Jan-82
May-82
Sep-82
Jan-83

We agree with the above conclusions of VDEQ and VMRC staff since our analysis has shown that in the months following the spawning season pumping hiatus there is not sufficient flow in the Mattaponi River to allow expanded Mattaponi withdrawals during dry years. Owing to the additional pumping restrictions in the VDEQ permit, the pumping hiatus simply means less water to the system (i.e., reduced yield) not a shift toward more intense summertime withdrawals.

4.0 FREQUENCY OF SPAWNING SEASON WITHDRAWALS UNDER DROUGHT EMERGENCIES

In order to protect public health and welfare, the normal pumping hiatus during the American shad spawning season would be lifted if a severe water supply emergency exists. However, during such periods the intake would continue to be operated in full compliance with the Mattaponi River MIF levels, the KWR transfer rate restriction, and all other conditions required by the VDEQ permit.

The spawning season pumping hiatus would remain in place for the duration of the operating life of the Mattaponi River intake facilities. Only during such rare times when a water supply emergency has been declared would the intake be operated during any portion of the spawning season. It is assumed that the declaration of such an emergency would be made by the Governor of Virginia or his appointee. The declaration of a water supply emergency would not necessarily mean that Mattaponi River withdrawals would be made, only that they could be made as long as the operation of the intake continued in accordance with the monitoring and operating conditions outlined in the VDEQ permit. Water quality conditions would also be considered prior to initiating any Mattaponi River withdrawals.

Mattaponi River withdrawals during the normal pumping hiatus would be expected to occur only rarely. In fact, VMRC staff stated in their May 14, 2003 Addendum to their Habitat Management Division Evaluation that: "… *it seems clear that there is only a minimal likelihood that withdrawals would be required during any spawning season restriction as a result of a drought emergency declared by the Governor. Furthermore, any withdrawals would again be controlled by the DEQ restrictions*." This same statement was made by Mr. Tony Watkinson of VMRC's staff in his oral presentation to VMRC Commission members at their May 14, 2003 meeting.

As further confirmation of VMRC's statement, an analysis was conducted by the RRWSG to address the expected frequency that the spawning period pumping hiatus might be lifted due to a State-declared drought emergency. CDM's updated model of the Newport News Waterworks raw water supply system (i.e., SYMODELWIN) was used for this analysis since it includes a longer period of record (1928-2002) than the STELLA model. Safe yield analysis simulations were run to determine the approximate probability for severe drought conditions occurring coincident with the American shad spawning period. The analyses were run using a water demand value of 75 mgd that corresponds to predicted usage in the 2040-2050 timeframe. **Prior to demand reaching this level, the probability of reservoir levels reaching critical trigger levels in the Spring would be lower than those presented.**

As shown in **Figure 12**, three extended or multi-year drought periods were identified in which simulated reservoir levels dropped below mandatory drought action trigger levels in the VDEQ permit. As shown in **Figures 13 through 15**, these three drought periods were next evaluated to determine if the reservoir levels coincided with the American shad spawning period identified approximately as March-May. Out of the 74-year (1928-2002) historical period, only the Spring months of 1931 and 1955 were within drought periods capable of depleting reservoir levels to VDEQ drought action trigger levels. Our conclusion from this analysis is that the expected probability that the pumping hiatus might be lifted due to a State-declared drought emergency would be on the order of 3 percent or less (2 years out of a 74-year record represents only 2.7 percent of the years).

Figure 12

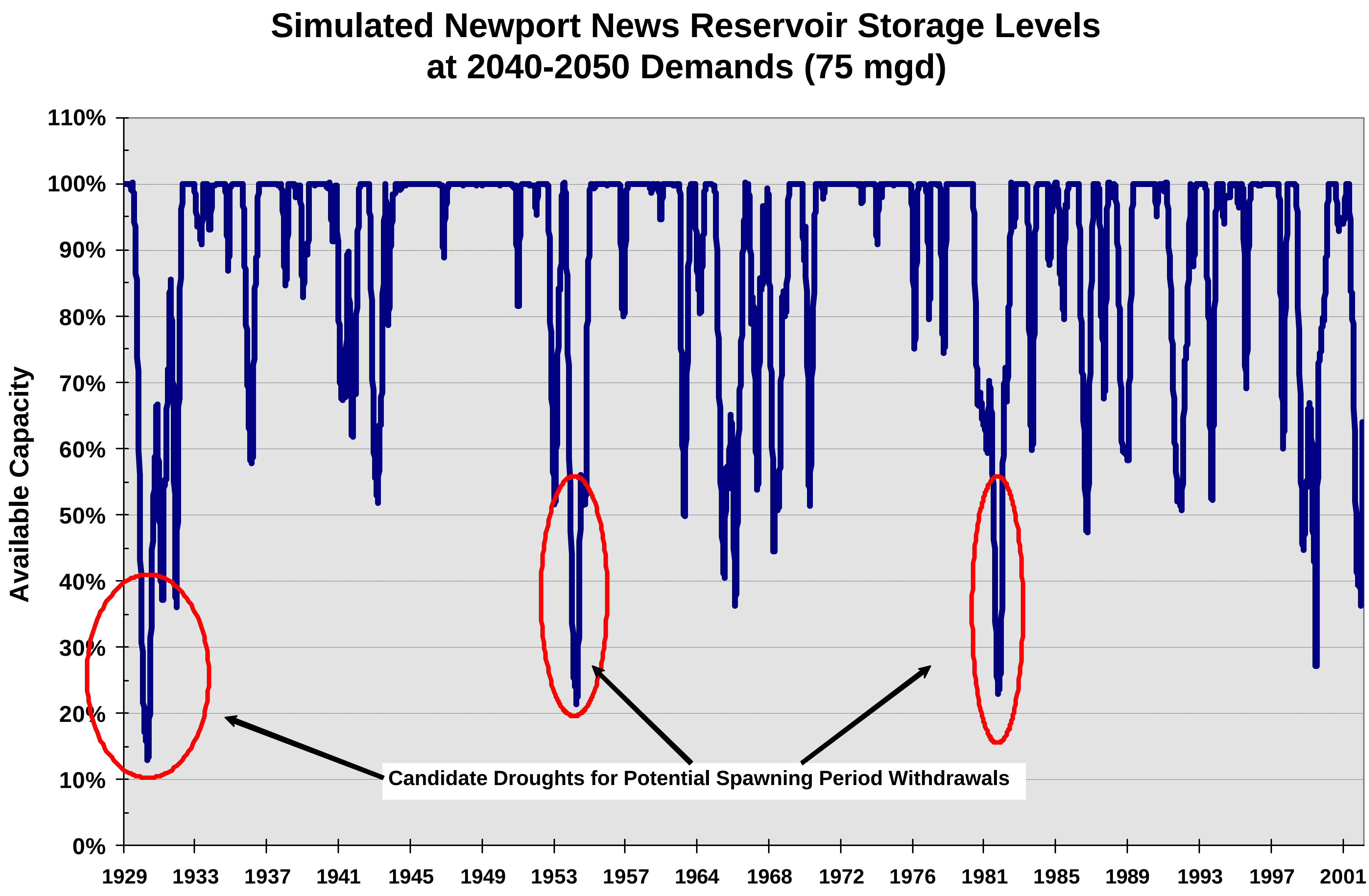

Simulated Newport News Reservoir Storage Levels
at 2040-2050 Demands (75 mgd)
Available Capacity
110%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1929
1933
1937
1941
1945
1949
1953
1957
1964
1968
1972
1976
1981
1985
1989
1993
1997
2001
Candidate Droughts for Potential Spawning Period Withdrawals

Figure 13

Simulated Newport News Reservoir Storage Levels at 2040-2050 Demands (75 mgd) - 1930 to 1933

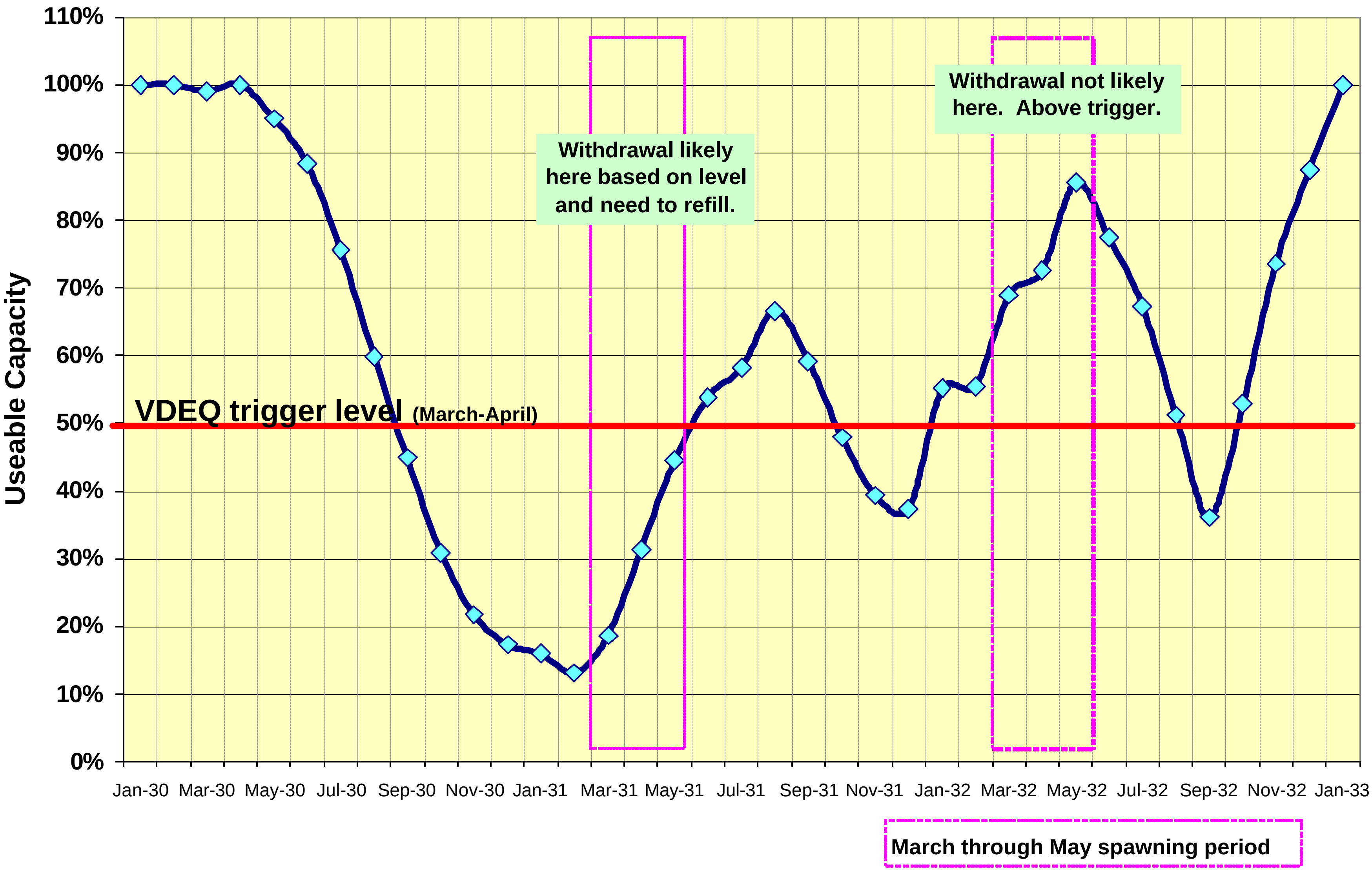


Figure 14

Simulated Newport News Reservoir Storage Levels at 2040-2050 Demands (75 mgd) - 1953 to 1955

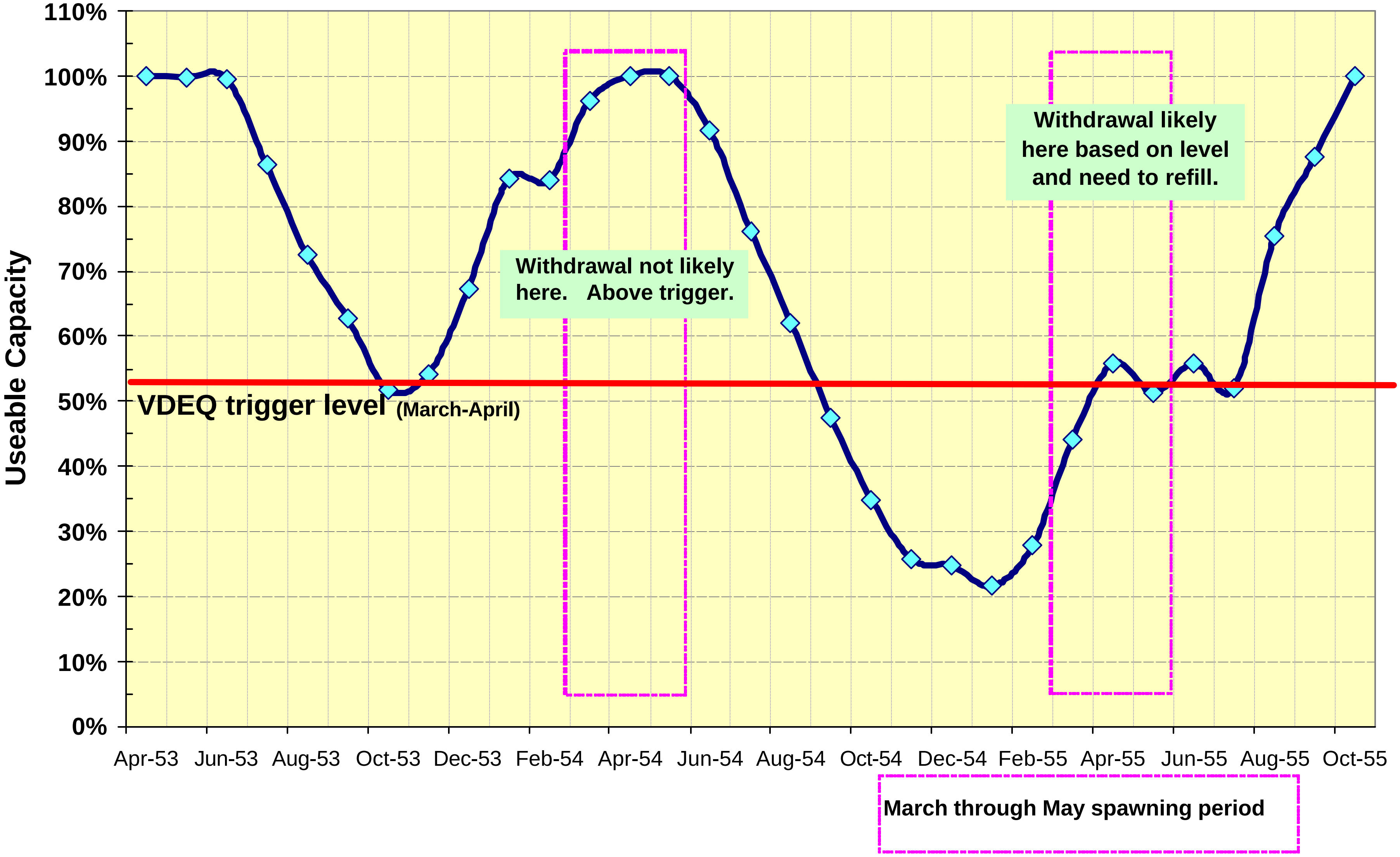
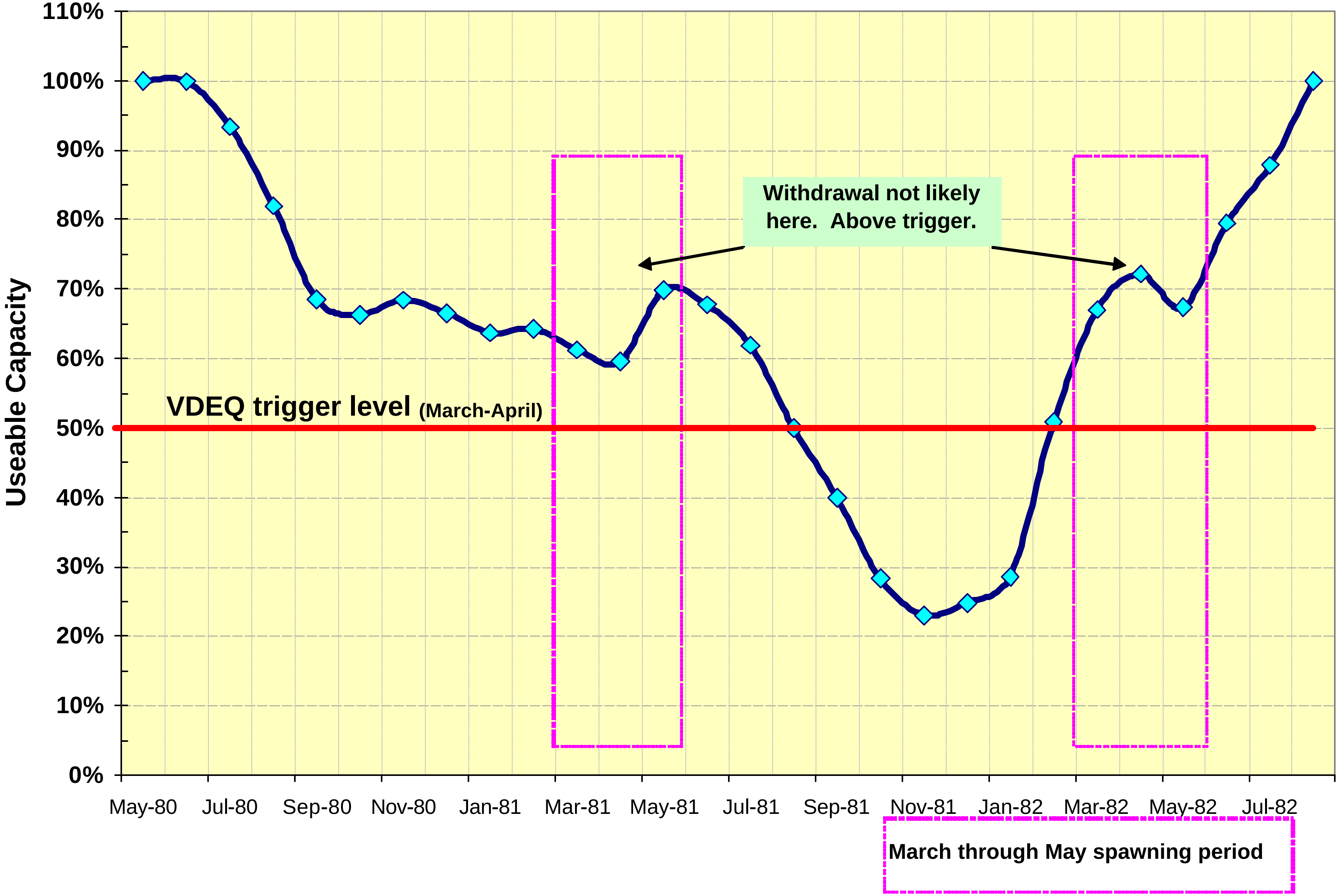


Figure 15

Simulated Newport News Reservoir Storage Levels at 2040-2050 Demands (75 mgd) - 1980 to 1982



The latest published studies on climate change in the Mid-Atlantic Region from Penn State University predict that it will be somewhat warmer and perhaps wetter in the Region. Human activities that release heat-trapping gases into the atmosphere are also expected to continue to accelerate the observed warming trend. Such predictions do not allow us to look at individual extreme or threshold level events such as severe drought periods. However, if these general predictions for wetter conditions mean that future droughts will be less severe, then this suggests that the probability of State-declared drought emergencies and associated relaxation of the pumping hiatus may be even lower than estimated above using historical climate and streamflow records from the past century. It would therefore seem reasonable and appropriate to use the climate and streamflow histories from the 20th Century to make water use predictions for the 21st Century. This is especially true since the 20th Century record contains at least three different, multi-year drought events.

3114-017-420

APPENDIX G

KWR TECHNICAL MEMORANDUM 2

Waterworks

MALCOLM PIRNIE

March 26, 2004

To: King William Reservoir Fisheries Panel

From: Ron Harris, P.G., Chief of Water Resources, Newport News Waterworks

Paul Peterson, Project Manager, Malcolm Pirnie, Inc.

Re: King William Reservoir Project
Mattaponi River Withdrawal Facilities

As the King William Reservoir (KWR) Fisheries Panel continues to work toward concluding your assessments, findings and recommendations we wanted to ensure that each of you had all of the operating details, assumptions, background project details, and construction data relating to the proposed withdrawal facilities on the Mattaponi River. Some or most of this information has been provided in various formats as you studied these issues over the past several months.

This memorandum is organized into six sections and an attachment containing project drawings as follows:

- 1.0 Project Background and Summary Description
- 2.0 Mattaponi River Withdrawal Rules and Expected Rates
- 3.0 Mattaponi River Intake Design
- 4.0 Mattaponi River Intake Construction and Operation
- 5.0 Mattaponi River Pump Station Design
- 6.0 Mattaponi River Tidal Wetlands and Water Quality
- Attachment: Updated Mapping and Preliminary Engineering Drawings

We thought it would be helpful to consolidate these materials at this time to assist you in preparation of your final report. These materials should also be useful to the Fisheries Panel as we formally restart our permitting process with the Virginia Marine Resources Commission (VMRC) on April 1, 2004. During this phase of the project we expect to continue our deliberations, consultations, and negotiations with the VMRC (and their resources agencies).

Again, thank you for your insights and deliberations. Please contact either of us if you have any questions regarding this information.

1.0 PROJECT BACKGROUND AND SUMMARY DESCRIPTION

In September 1988, the Regional Raw Water Study Group (RRWSG) commissioned Malcolm Pirnie to prepare a Regional Raw Water Supply Plan "To provide a dependable, long-term public water supply for the Lower Virginia Peninsula, in a manner which is not contrary to the overall public interest." The RRWSG evaluated 35 raw water supply alternatives in order to fulfill the basic project purpose defined above. This evaluation was carried out under the provisions of the Section 404(b)(1) Guidelines of the Federal Clean Water Act. The Section 404(b)(1) Guidelines are the substantive criteria used in evaluating impacts resulting from, and selecting sites for, the discharge of dredged or fill material into waters of the United States (including wetlands).

The alternatives evaluation process resulted in a decision by the RRWSG in December 1996 to submit a Joint Permit Application (JPA) for the KWR Project with dam site KWR-IV. Since December 1996, significant changes have been made to certain aspects of the Project, resulting in two previous revisions of the JPA. Following the issuance of a Virginia Water Protection Permit (VWPP) by the Virginia Department of Environmental Quality (VDEQ) in December 2002 for the Project, additional changes and refinements have been made to the project concept. In particular, the conceptual design of the Mattaponi River Pump Station's intake system has been refined and additional detail developed as a result of a new, detailed bathymetric survey of the river bottom at the pump station site.

The KWR Project as currently proposed includes (see also **Figure 1**):

- A 75 mgd raw water intake in the Mattaponi River, utilizing an array of twelve submerged wedge wire screens with 1 mm slots, designed for a maximum through slot velocity of 0.25 feet per second (fps).

- The 75 mgd capacity Mattaponi River Pumping Station, located completely on uplands adjacent to the intake screen array.

- Approximately 1.5 miles of 54-inch diameter, 75 mgd capacity, raw water pipeline from the Mattaponi River Pump Station to the King William Reservoir.

- The 12.2 billion gallon (BG) King William Reservoir covering approximately 1,526 acres on Cohoke Creek, impounded by a 1,700-foot long dam located approximately 1,000 feet downstream of County Route 626.

- The 50 mgd capacity King William Reservoir Pump Station, located just downstream of the dam site.

- Approximately 11.7-miles of 42-inch and 48-inch diameter, 50 mgd capacity, raw water pipeline from the King William Reservoir Pump Station to an outfall adjacent to Beaverdam Creek in the Diascund Creek Reservoir basin, including trenchless directional drill crossings of Cohoke Creek and the Pamunkey River.

- A Wetland Mitigation Plan to compensate for affected non-tidal wetlands within the project area.

Figure 1

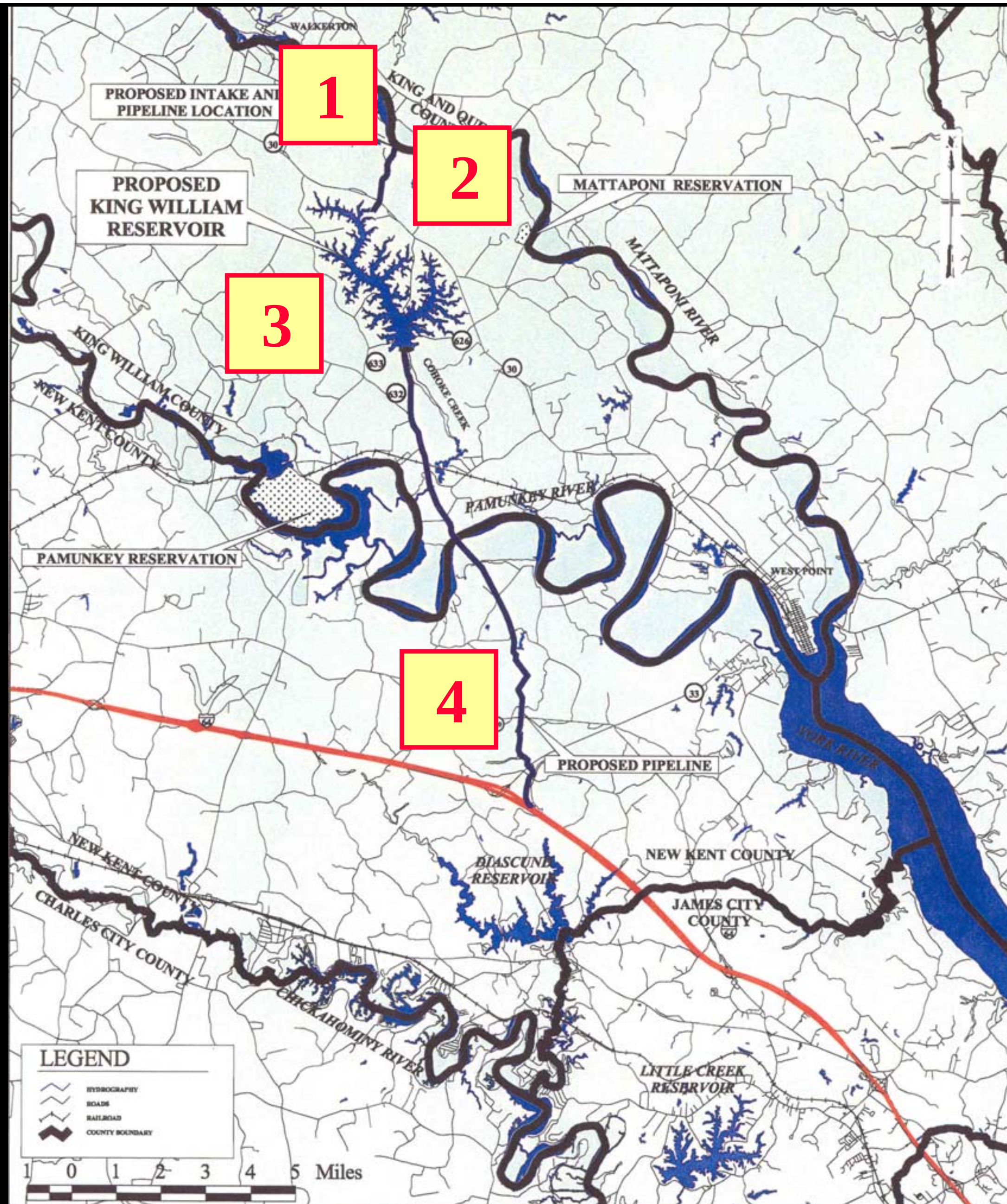
Project Features

1 **75 MGD Mattaponi R. Pump Station**

2 **1½-mile Mattaponi R. Pipeline**

3 **1,526-acre, 12.2 BG KW Reservoir**

4 **11.7-mile Pipeline to Diascund Reservoir**



- A Fisheries Mitigation Plan being prepared by the Fisheries Panel.

- An Ecological Monitoring Plan to document physical and biological conditions in the Mattaponi River system prior to and following the start of operations of the water supply intake. This plan will be finalized upon completion of the assessment currently being prepared by the Fisheries Panel. It is subject to approval by VDEQ as a condition of the City's VWPP.

The remainder of this memorandum deals exclusively with the proposed Mattaponi River withdrawal facilities.

2.0 MATTAPONI RIVER WITHDRAWAL RULES AND EXPECTED RATES

Minimum Instream Flow Requirements

The King William Reservoir will operate as an off-stream raw water storage reservoir. Because of the reservoirs' small drainage area (8.92 sq. miles), the yield from this project will come primarily from the water withdrawn from the Mattaponi River. Water withdrawals from the Mattaponi River will be restricted by a minimum instream flow requirement (MIF). River withdrawals must be made in accordance with the MIF conditions stipulated in the December 2002 VWPP issued by VDEQ. The basic permitted MIF condition is a "modified 80 percent monthly exceedance" rule. The VWPP allows withdrawals at alternate 40/20 Tennant levels only if mandatory use restrictions have been imposed.

The modified 80 percent monthly exceedance levels range from 434 mgd in March to 114 mgd in August through October, and are higher than the 40/20 Tennant levels during every month of the year. The modified 80 percent monthly exceedance flows are based on monthly flow rates which have a probability of being exceeded 80 percent of the time during the period of record and are then increased by: (1) setting a minimum flow rate threshold of 108.5 mgd (lowest median monthly streamflow value (September)) and (2) reserving an additional allowance for other projected consumptive use in the Mattaponi River Basin.

The 40/20 Tennant levels provide that withdrawals may not be made from the Mattaponi River during the months of December through May when freshwater flows are below 197.6 mgd (about 40 percent of mean annual flow) or during the months of June through November when freshwater flows are less than 98.8 mgd (about 20 percent of mean annual flow). The estimated average freshwater flow of the Mattaponi River at Scotland Landing is 487 mgd based on Mattaponi River (Beulahville) streamflow records for Water Years 1942 through 2001.

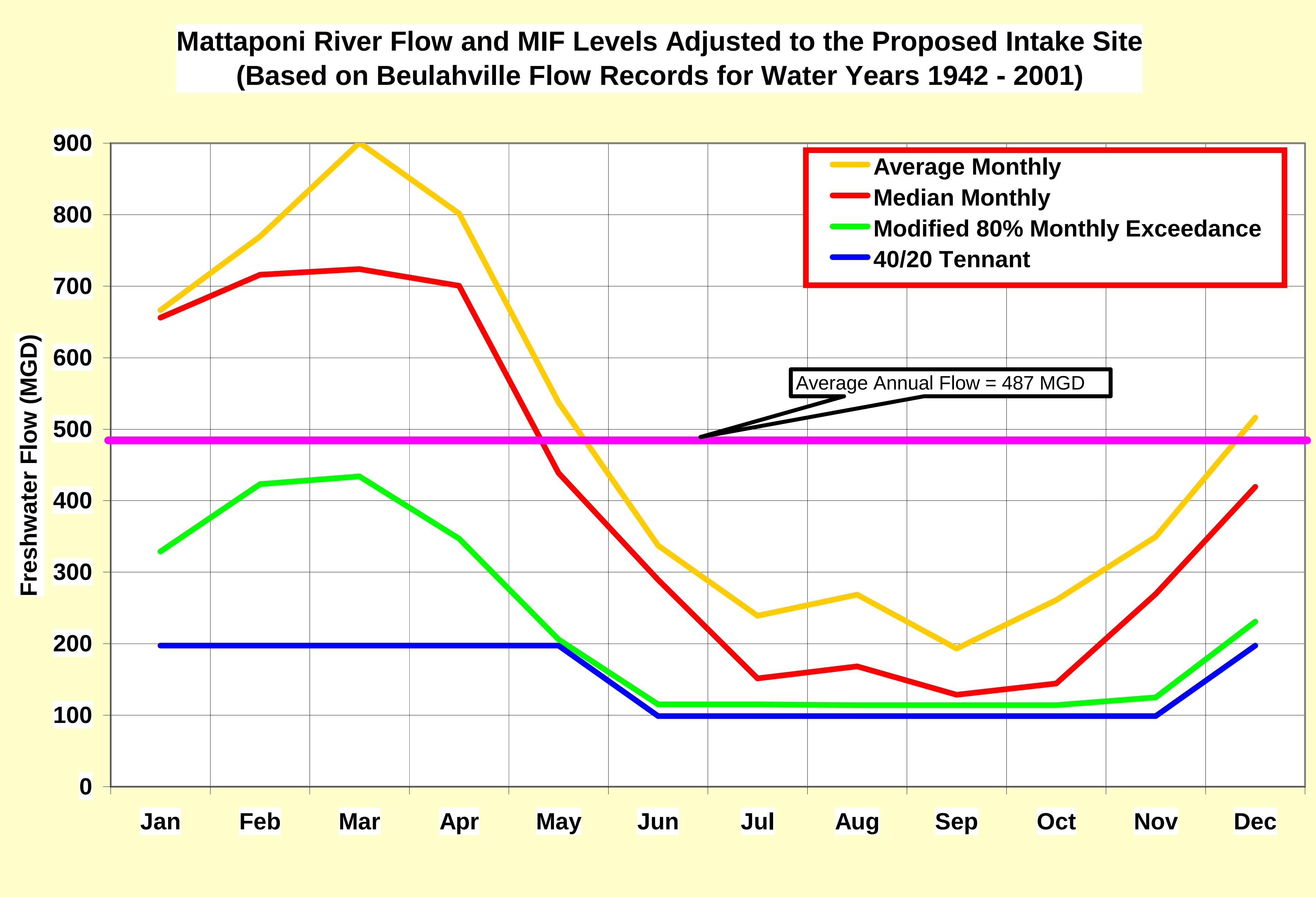
Figure 2 illustrates the monthly average river flows at the intake site, based on 59 years of flow records and the monthly MIFs below which withdrawals cannot occur. Withdrawals would be made only from the increment of flow that is in excess of the MIF. Withdrawals would not be allowed to reduce the actual flows to below the MIF values. Initial reservoir filling must also be conducted subject to these VWPP conditions. Consequently, the duration of initial filling will depend, in large part, on climatic conditions occurring at that time.

The Mattaponi River intake is designed for a maximum pumping capacity of 75 mgd. However, actual operation will be regulated under the VWPP minimum instream flow requirements for the Mattaponi River at Scotland Landing, so actual allowable pumping rates on any given day may be less than 75 mgd. That is, pumping at the Mattaponi River intake shall not be allowed to reduce the actual freshwater flow to the River downstream of the intake to less than the permitted minimum instream flows. The net effect of these strict measures is that this intake will operate primarily during periods of moderate to high river flow.

Expected Future Withdrawal Rates

To estimate the magnitude of expected water withdrawals from the river, safe yield modeling of the proposed project was conducted using hydrologic data from the period October 1929 to September 1987 and anticipated 2040 to 2050 water demand conditions, together with the

Figure 2


Mattaponi River Flow and MIF Levels Adjusted to the Proposed Intake Site
(Based on Beulahville Flow Records for Water Years 1942 - 2001)
900
800
700
600
500
400
300
200
100
0
Freshwater Flow (MGD)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Average Monthly
Median Monthly
Modified 80% Monthly Exceedance
40/20 Tennant
Average Annual Flow = 487 MGD

VWPP permitted MIF requirements for the Mattaponi River. The results of this modeling show that the monthly average withdrawal of water from the Mattaponi River will average only 14.5 mgd, which is less than 20 percent of the intake design capacity. On a seasonal basis, summary statistics of the anticipated withdrawals based on the safe yield modeling are as follows:

Season	Average	Median	Upper Quartile
Winter	16.2 mgd	5.2 mgd	22.5 mgd
Spring	13.2 mgd	8.0 mgd	10.4 mgd
Summer	9.1 mgd	4.7 mgd	7.5 mgd
Fall	19.6 mgd	7.3 mgd	33.2 mgd

Note: These statistics do not take into account effects of a possible spawning season pumping hiatus.

From these statistics, it can be seen that average Mattaponi River withdrawals will be highest in fall and winter, and lowest in summer. The fact that the median (50th percentile) withdrawal rates are substantially lower than the average rates demonstrates that in most years withdrawal will be at levels well below the overall average rates. In fact, average monthly withdrawals will be less than 10 percent of the design capacity (i.e. less than 7.5 mgd) more than half of the time and less than 33.2 mgd more than 75 percent of the time. This safe yield analysis demonstrates that the King William Reservoir withdrawals from the Mattaponi River will rarely occur at maximum pumping capacity. In fact, withdrawals can be expected to be only a small faction of the intake's design capacity most of the time. In the years prior to 2040, water demands are expected to be less and Mattaponi River withdrawals should be even lower than presumed for this assessment.

These analyses do not take into account any specific pumping restrictions that may be recommended by the Fisheries Panel. Additional safe yield modeling may be prepared following receipt of the Panel's final report.

Since actual water withdrawal rates are expected to be substantially less than maximum capacity much of the time, it is also reasonable to expect that through-slot velocities will also be considerably less under most operating conditions than the maximum design through-slot velocity of 0.25 fps. Using the above estimates of expected water withdrawals, typical through-slot velocities for the Mattaponi River intake will be as follows:

Season	Average	Median	Upper Quartile
Winter	0.05 fps	0.02 fps	0.08 fps
Spring	0.04 fps	0.03 fps	0.03 fps
Summer	0.03 fps	0.02 fps	0.02 fps
Fall	0.07 fps	0.02 fps	0.11 fps

As can be seen above, through-slot velocities are expected to be in the range of 10 percent or less of the maximum through-slot design value (0.25 fps) for 50 percent the time and less than

0.1 fps for 75 percent of the time. Therefore, since through-slot velocity is an important determinant in wedge wire screen performance, it is reasonable to conclude that the overall protection from entrainment and impingement at the Mattaponi River intake afforded by the proposed intake design will be considerably greater than the high level provided under the current Virginia intake screen criteria (Gowan, C., G. Garman, and W. Shuart. 1999. Design Criteria for Fish Screens in Virginia: Recommendations Based on a Review of the Literature. Prepared for Virginia Department of Game and Inland Fisheries (VDGIF)).

Clarification of Simulated Withdrawals During Drought Emergencies

Based on the March 5, 2004 working draft of the Fisheries Panel report, it is anticipated that the Panel will recommend a pumping hiatus during the American shad spawning season. In order to protect public health and welfare, a normal pumping hiatus during the shad spawning season would be lifted if a severe water supply emergency exists. Only during such rare times when a water supply emergency has been declared would the intake be operated during any portion of the shad spawning season. A prior Technical Memorandum that we provided to the Panel on February 18, 2004 showed that out of a 74-year historical period, only the Spring months of 1931 and 1955 were within drought periods capable of depleting reservoir levels to VDEQ drought action trigger levels. Our conclusion from that analysis was that the expected probability that a pumping hiatus might be lifted due to a State-declared drought emergency would be on the order of 3 percent or less (2 years out of a 74-year record represents only 2.7 percent of the years).

We have conducted further analysis to determine what might actually occur during a rare drought emergency that coincides with a normal shad spawning season pumping hiatus. We must emphasize that until regional demands exceed 65 mgd, and with the addition of KWR storage, there is almost no risk (less than 1 out of 74 years or less than 1.4 percent) of a drought emergency during this portion of the year. In other words, no shad spawning season withdrawals would be expected prior to approximately 2025. However, even when such rare events do occur in future decades, the Mattaponi River MIF levels would significantly restrict pumping as indicated by our analysis presented in the following table of allowable monthly average Mattaponi withdrawals during the Spring of 1931 and 1955. Although our model simulations to date do not specifically include a pumping hiatus period, these figures clearly show that availability of Mattaponi River withdrawals would still be controlled by the river MIF levels, the KWR transfer rate restriction, and all other conditions required by the VDEQ permit.

Month	1931	1955
March	20.0 mgd	75.0 mgd
April	34.7 mgd	49.5 mgd
May	41.0 mgd	10.5 mgd
Averages	32 mgd	45 mgd
Averages as % of Maximum Withdrawal Rate	43%	60%

3.0 MATTAPONI RIVER INTAKE DESIGN

Design and analysis of the proposed Mattaponi River withdrawal facilities has been carried out only to the extent necessary for the preparation of a Joint Permit Application for the project. Changes to the descriptions presented can be expected once detailed, final design of the components is completed.

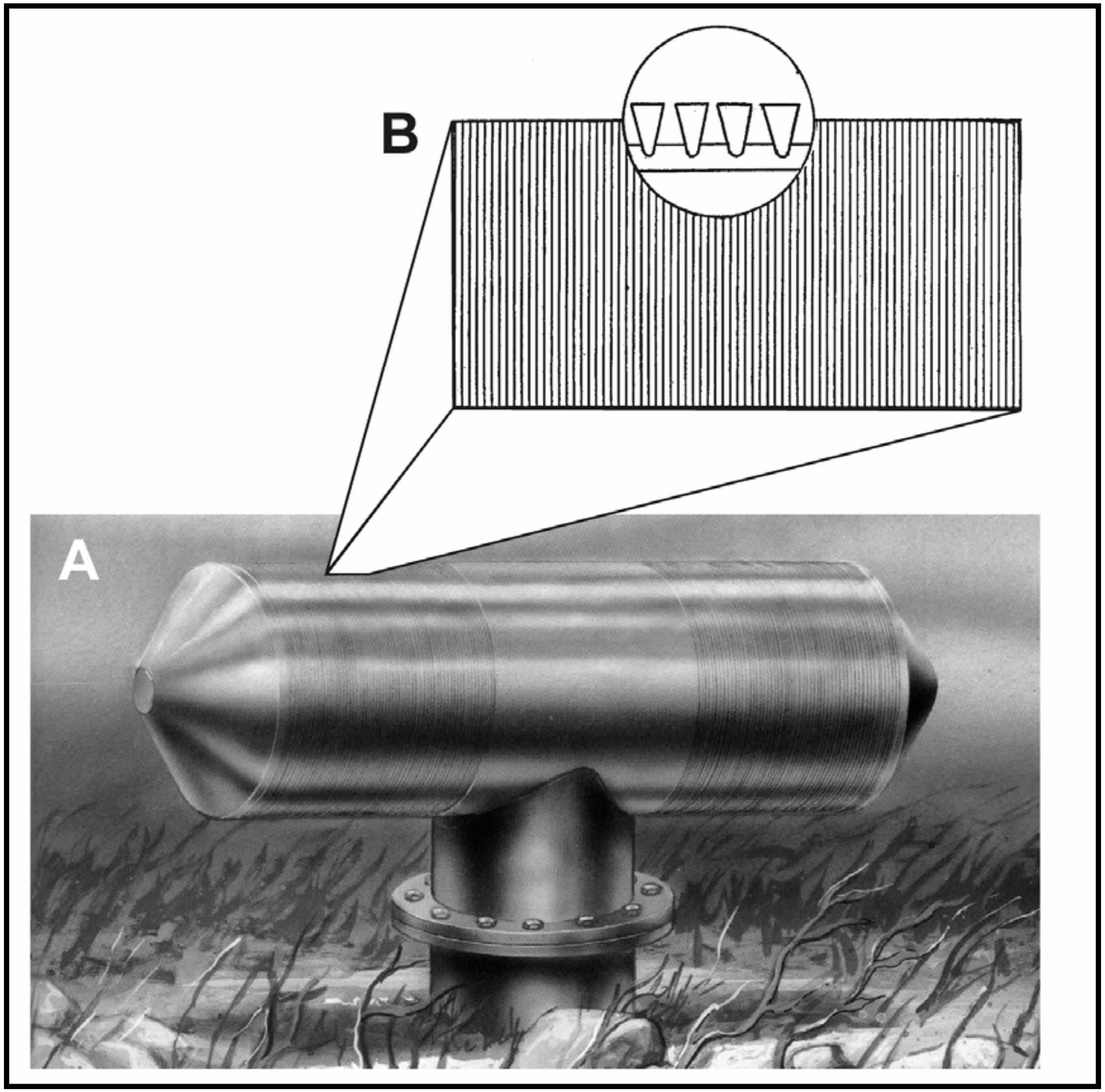
The Mattaponi Intake is designed in accordance with all of the guidelines and criteria contained in the VDGIF's formal recommendations for protecting fish at water withdrawals (Gowan, C., G. Garman, and W. Shuart, 1999). The Mattaponi Intake design also more than satisfies the USEPA 316(b) Track I design through-screen velocity requirements for cooling water intakes.

The intake screens will consist of twelve submerged, cylindrical, wedge-wire screens. The screens will have 1 mm slot openings, a maximum through slot velocity of 0.25 feet per second (fps), and an average approach velocity of 0.08 fps, in accordance with the VDGIF's design criteria recommendations. The approach velocity is the velocity that occurs 3 mm (1/8-inch) from the screen surface. The screens will be installed in the form of tee assemblies, with two screens per tee screen assembly. An internal air burst backwash screen cleaning system will be provided. **Figure 3** illustrates the basic shape of this type of screen assembly and highlights the wedge shape of the screen wires.

The intake screens will have a rated (or firm) capacity of 75 mgd (that is the capacity with one of the six tee screen assemblies out of service). This capacity will be achieved while limiting the maximum through slot velocity to 0.25 fps. With all six tee screen assemblies in service, the maximum through slot velocity at a 75 mgd withdrawal rate will be 0.21 fps. Normally, all six tee screen assemblies will be in service. Individual tee screen assemblies would only be out of service during air backwashing or if they were removed for repair. The following table presents calculated flow velocities at several distances from the screen face for the range of potential withdrawal rates.

Figure 3

Cylindrical Wedge-Wire Tee Screen Assembly Illustration



Flow Velocities vs. Withdrawal Rates

Withdrawal Rate (mgd)	Intake Velocity (Feet per Second)				
	All Tee Screens in Service				
	Average 12-inches from screen	Average Approach	Average Through Slot	Maximum Approach	Maximum Through Slot
15	0.01	0.01	0.04	0.02	0.04
30	0.02	0.03	0.07	0.03	0.08
45	0.03	0.04	0.11	0.05	0.13
60	0.04	0.06	0.14	0.07	0.17
75	0.05	0.07	0.18	0.08	0.21
	5 of 6 Tee Screens in Service				
	Average 12-inches from screen	Average Approach	Average Through Slot	Maximum Approach	Maximum Through Slot
15	0.01	0.02	0.04	0.02	0.05
30	0.03	0.03	0.08	0.04	0.10
45	0.04	0.05	0.13	0.06	0.15
60	0.05	0.07	0.17	0.08	0.20
75	0.06	0.08	0.21	0.10	0.25

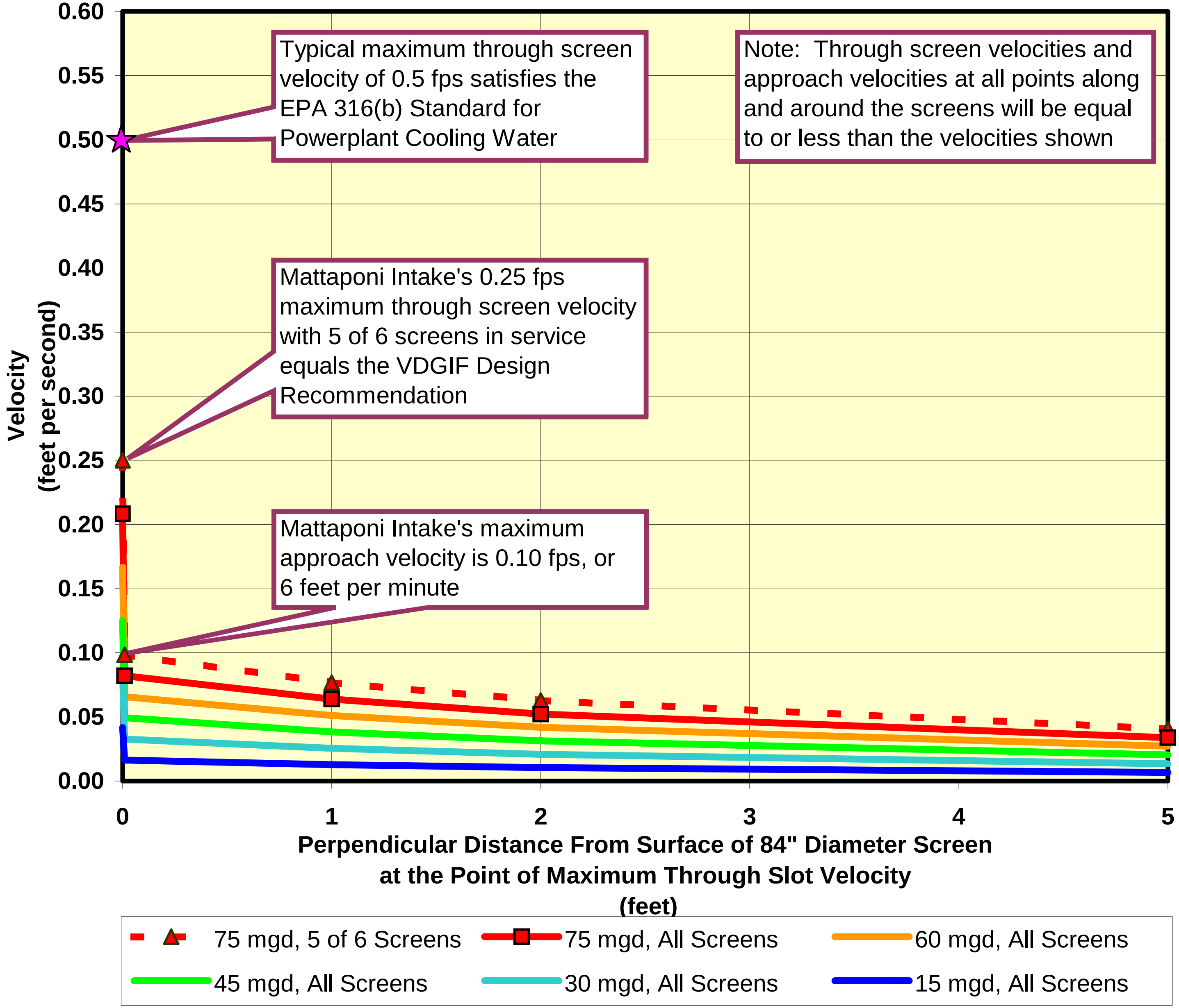
Average Approach Velocity: Velocity 3 mm (1/8 inch) from face of screen.
Average Through Slot Velocity: Average of through slot velocities along the length of the screen.
Maximum Through Slot Velocity: Maximum of through slot velocities along the length of the screen.

The velocity values presented above represent the component of velocity perpendicular to the screen surface. The values were calculated based on the assumption that the velocity field around the screen is cylindrically shaped, which is a worst case, conservative assumption. The velocity perpendicular to the surface of the screen decreases very quickly in the first fraction of an inch outside the surface of the screen and then continues to decrease at a reduced, approximately linear rate. **Figure 4** shows this decrease in velocity over a distance of 5 feet, for withdrawal rates between 15 and 75 mgd with all screens in service, and for the worst case design condition of 75 mgd with only 5 of the 6 tee screen assemblies in service.

The highest velocity point plotted is the maximum through screen velocity of 0.25 fps, the second is the maximum approach velocity which occurs approximately 1/8-inch away from the screen surface. The graphed velocities show that even under the maximum, worst-case design condition of 75 mgd and only 5 of 6 tee screens in service, the maximum approach velocity is only 0.10 fps. As previously discussed, the average withdrawal under projected 2040 to 2050 demand conditions is on the order of 15 mgd. At this flow, the maximum approach velocity with only 5 of 6 tee screens in service is only 0.02 fps.

Figure 4

Maximum Velocities Perpendicular to Screen Surface



The Mattaponi Intake screens will be oriented parallel to the river shoreline and thus parallel to the direction of natural tidal velocity, in accordance with the VDGIF's recommendations. **Figure 5** shows the estimated range of tidal velocities in the river over a typical tidal cycle. It also shows a banded area of velocities up to 0.5 fps, which is twice the maximum through screen velocity (0.25 fps) that would occur when pumping 75 mgd with 5 of 6 tee screens in service. Under normal conditions, all 6 tee screens would be in service and the projected average withdrawal rate is only 14.5 mgd, so the period of time when the river velocity is not at least twice the intake velocity would normally be much less than shown in this graph.

The tidal velocity would generally occur parallel to the screen face, which in addition to limiting entrainment and impingement also has the beneficial effect of gently "sweeping" debris and suspended particles across and off the surface of the screens. The natural tidal velocity across the face of the intake screens will vary from near zero during the slack periods at high and low tide to between 2 and 3 fps at the midpoint of the tide. Over the course of a typical tidal cycle, the natural sweeping velocity across the screen will be more than two times the screen intake for over 90 percent of tidal cycle. The predicted tidal velocities are from Basco, 1996.

A total of twelve screens, each a maximum of 7 feet in diameter by approximately 7 feet long will be installed. The screens will be constructed to form six tee screen assemblies. Three of these tee screen assemblies will be connected to each of the two intake lines. All six tees will be aligned in a single row parallel to the shoreline so debris will be swept along and then off the surface of the screens and not be forced into the screen face. This orientation and arrangement is in accordance with the VDGIF's recommendations. The screens will be removable (by means of bolted connections) from the intake lines for major maintenance or replacement and flanged plates will be available to plug the resulting open riser pipe.

The screens will be located in a naturally deep portion of the Mattaponi River. A bathymetric survey of the river at the intake site was performed in November 2003 to determine the bottom elevations in the area of the intake. The elevation contours developed from this survey are shown in **Project Drawing 8** attached to this memorandum. Actual water surface levels at the intake site were recorded with a submerged pressure transducer and an electronic datalogger from January 11, 2004 to February 15, 2004. From the recorded water level data, the actual elevation of Mean Low Water and Mean High Water at the intake site has been determined. **Figure 6** presents the recorded water level data and resulting calculated Mean Low Water and Mean High Water elevations.

Mean Low Water at the intake site is at Elevation –1.8 on the NAVD 88 Vertical Datum. Mean High Water is at Elevation 1.7, resulting in a mean tidal range at the site of 3.5 feet. These elevations are included on the Project Drawings included as an attachment to this memorandum.

The existing water depth at the screen location varies from approximately 22 to 24 feet at Mean Low Water. The top of the screens will be set a minimum of 8 feet below Mean Low Water. This will provide at least 7 feet of vertical clearance between the bottom of the screens and the restored river bottom. The river bottom will be restored to match the pre-existing bottom contours. The surface will be restored with riprap, in order to minimize the potential for damaging scour to occur around the base of the riser pipes.

Figure 5

Estimated Mattaponi River Tidal Velocity at Scotland Landing

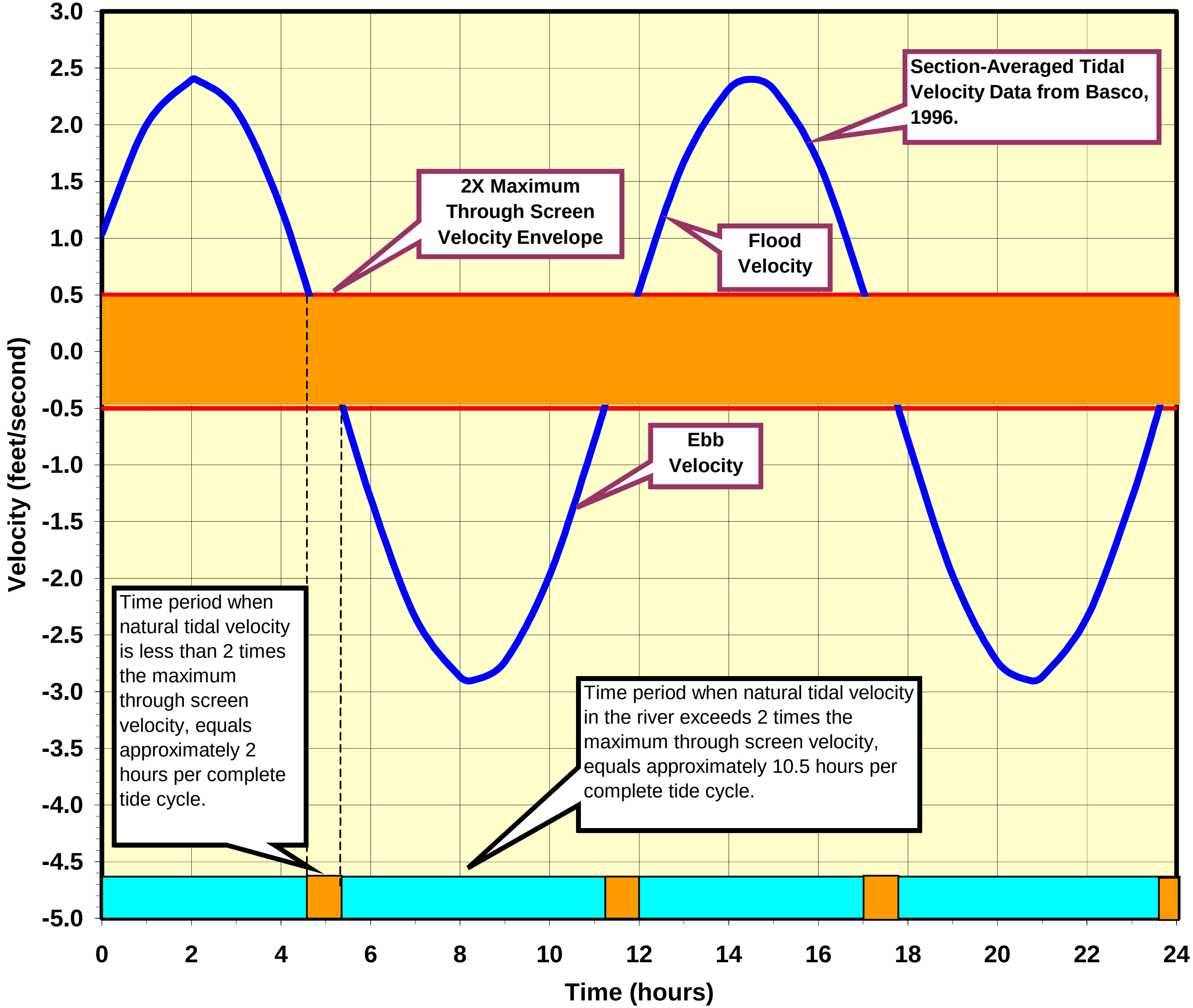
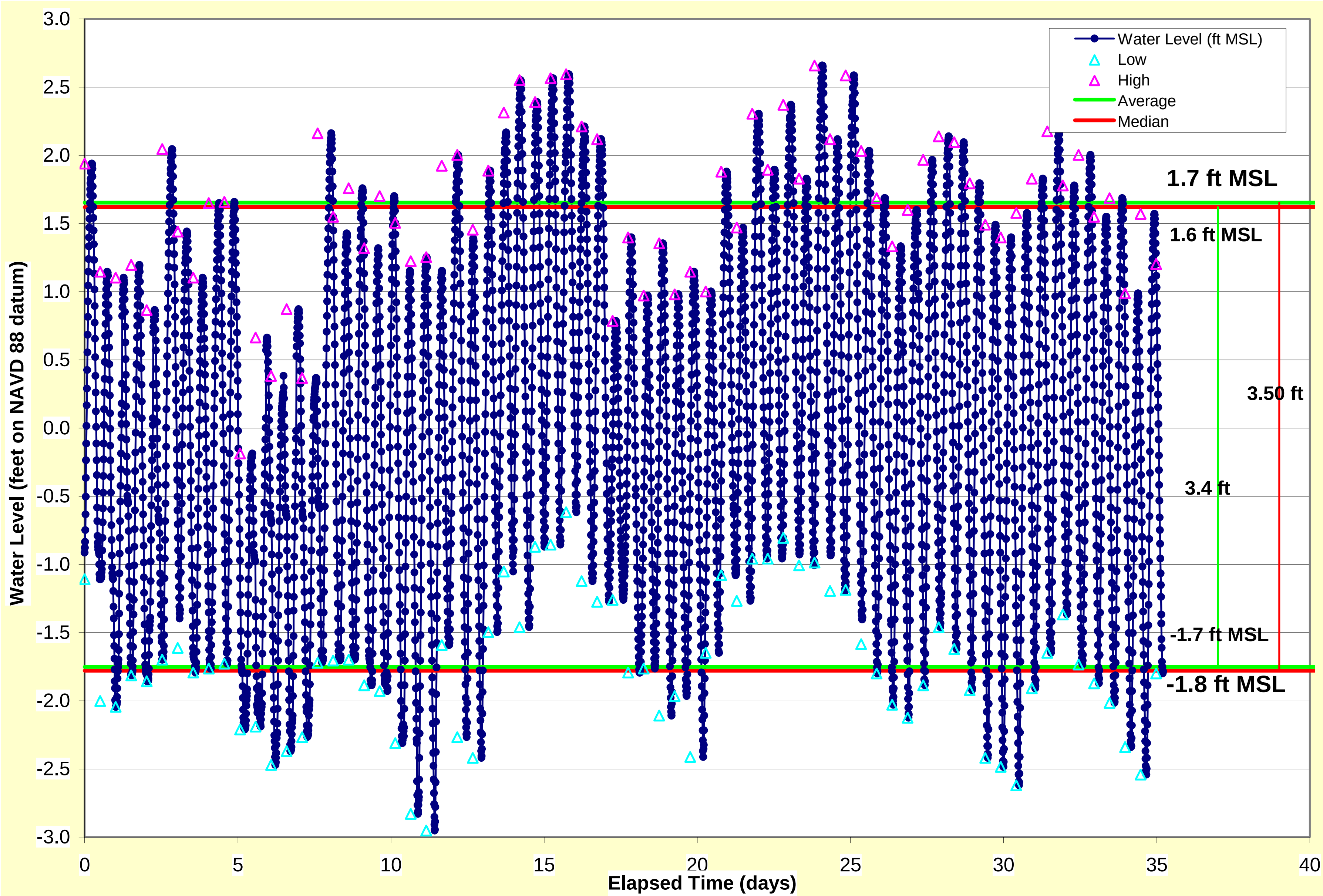


Figure 6

Mattaponi River Water Levels (January 11 to February 15, 2004)



4.0 MATTAPONI RIVER INTAKE CONSTRUCTION AND OPERATION

Dredging and work from barges will be required to construct the buried intake screen header piping, concrete encasement, and riser pipes. Clamshell or backhoe excavator equipment will be used for dredging within a sheet pile enclosure, to minimize the area of disturbance on the bottom and the movement of turbid water created during the excavation phase of the work. Clamshell equipment and excavators also produce a dredge spoil with the lowest possible water content, thus reducing hauling and disposal costs. Barges will be loaded with the dredge spoil within an area enclosed by a temporary turbidity curtain. All dredge spoils will be disposed of at the Craney Island Dredged Material Area or the Craney Island Rehandling Basin. The total estimated volume of material to be excavated and disposed of at Craney Island is 2,500 cubic yards. The sheet piles will be removed after construction of the intake is complete.

During construction, an unobstructed 100 foot wide corridor with a depth of at least 10 feet at MLW will be maintained between the work area and the north shore of the river, so that the movement of recreational and commercial boating traffic on the river will not be impeded. The intake facilities will be located in King William County at least 50 feet away from the King and Queen County line.

The two parallel 60-inch (internal diameter) intake lines, air backwash lines and a chemical feed line casing pipe will be installed using microtunneling technology or other trenchless methods. The existing shoreline, any shoreline wetlands that may exist, and the wooded bluff will not be disturbed by the installation of these pipes.

Only granular and stone materials will be used for backfill of the intake pipes and associated concrete embedment. Dredge spoils will not be used for backfill of the intake screens or header piping. Dredge spoils will not be reused in any way at the site. The intake piping will extend a total of approximately 140 feet under the river bottom from the mean high water line.

The top of the screens will be set a minimum of 8 feet below Mean Low Water and the intake area will be marked by warning buoys, so recreational craft should not interfere with or be endangered by the screens. Approximately 120 feet of unobstructed water at least 20 feet deep at MLW and approximately 200 feet of unobstructed water at least 10 feet deep at MLW will exist beyond the screens once construction is complete. The screens will be positioned landward of the deepest portion of the river at the intake site, so the passage of large commercial or pleasure craft on the river will not be impacted by the intake. Approximately 1.3 miles downstream of the intake site is an area identified on nautical charts as De Farges Bar . The deeper water adjacent to De Farges Bar is indicated to have depths of 11, 17, and 12 feet. The area of water with a depth of at least 10 feet is narrower at De Farges Bar than at the intake site. Based on these observations, the natural river conditions in the De Farges Bar area will be more limiting to the movement of large craft up the river than the intake screens.

A manually controlled air backwash screen cleaning system will be installed with the screens to allow the screens to be cleaned. This system cleans debris from the screen surface by releasing a burst of compressed air from a small diffuser pipe located within the screen. The water turbulence created by the air bubbles and the rising air bubbles themselves lift debris off the screen, allowing it to be carried away by the natural river current. Debris is neither added nor removed from the river by this system. The air bubbles simply lift debris from the screen surface and return it back to the water column. Installation of a screen cleaning system is in accordance with the VDGIF's recommendations.

The screens will likely be cleaned sequentially, starting from one end of the screen array and proceeding to the other in the direction of the tidal flow in the river that exists at the time of cleaning. With this approach, debris blown off the first screen to be cleaned, which might settle on the next screen, will be removed from the second screen as soon as it is cleaned. After all the screens have been air backwashed, the debris that had settled on the screens will have been returned to the flowing water of the river.

Cleaning is expected to be required on an intermittent basis only. There are very few screen installations with slots as small and approach velocities as low as those proposed in this installation and debris loads in the water column are site specific and vary seasonally. As a result, it is difficult to predict the frequency of air burst backwash screen cleaning that will be required. Similar installations have reported backwash frequencies varying from once per week to three times a day. The air burst backwash of each tee screen assembly will include approximately 5 seconds of high intensity air release and have a total duration of approximately 15 seconds.

An air backwash observation station will be located on top of the bluff at a location with a clear view of the water surface above all the screens and the upstream and downstream approaches to the screens. The six air pipes will be installed below the river bottom to the area of the screens. A separate air pipe will supply each tee screen assembly. The air backwash pipes will be installed by microtunneling, directional drilling, or other trenchless technology, similar to the intake pipes.

The pump station design will include provisions to allow for entrainment sampling of the water withdrawn from the river. The wetwell will include two types of chambers, a stilling well and a pumping well. Provisions will be included in the design of access ports to the stilling well as needed to accommodate entrainment sampling of water flowing from the intake pipes into the stilling wells. This is in accordance with the VDGIF's recommendations.

Zebra Mussel infestation of the Mattaponi River in the future is considered possible. Due to this possibility, the intake screens will be constructed of alloys resistant to zebra mussel veliger attachment and chemical feed piping will be installed from the pump station to the interior of each screen during initial construction. These control methods are listed as appropriate zebra mussel control strategies for water supply intakes in the U.S. Army Corps of Engineers (USACE) zebra mussel control handbook (Zebra Mussel (Dreissena polymorpha) Control Handbook for Facility Operators, first edition, by Shawn F. Boelman, et al.; prepared for the USACE, June 1997).

5.0 MATTAPONI RIVER PUMP STATION DESIGN

The pump station will have a wetwell extending approximately 45 to 50 feet into the ground and will be designed to minimize its above ground area and height. Maximum outside dimensions will be approximately 60 feet by 120 feet. The pump station will be located approximately 150 feet back from the top of the bluff on relatively flat ground at approximate ground surface elevation 36, well above the 100-year flood elevation and outside the 100-foot wide Chesapeake Bay Preservation Act Resource Protection Area buffer. The pump station will be approximately 900 feet from the nearest house, which is located downstream across a small creek. This house is on the nearest existing subdivided land in the area.

The pump station and associated structures will be designed to the maximum extent possible in a residential or rural farm style similar to other structures visible along this section of the river. The pumps will be located inside the station. The station will be designed to minimize exterior noise levels due to pump and equipment operation. The pump room and mechanical equipment rooms in the building will include noise reducing and absorbing features, such as acoustical concrete block, acoustical wall panels, insulating sound control glass, acoustical louvers and ducting for external exhaust fans, and acoustical exterior doors.

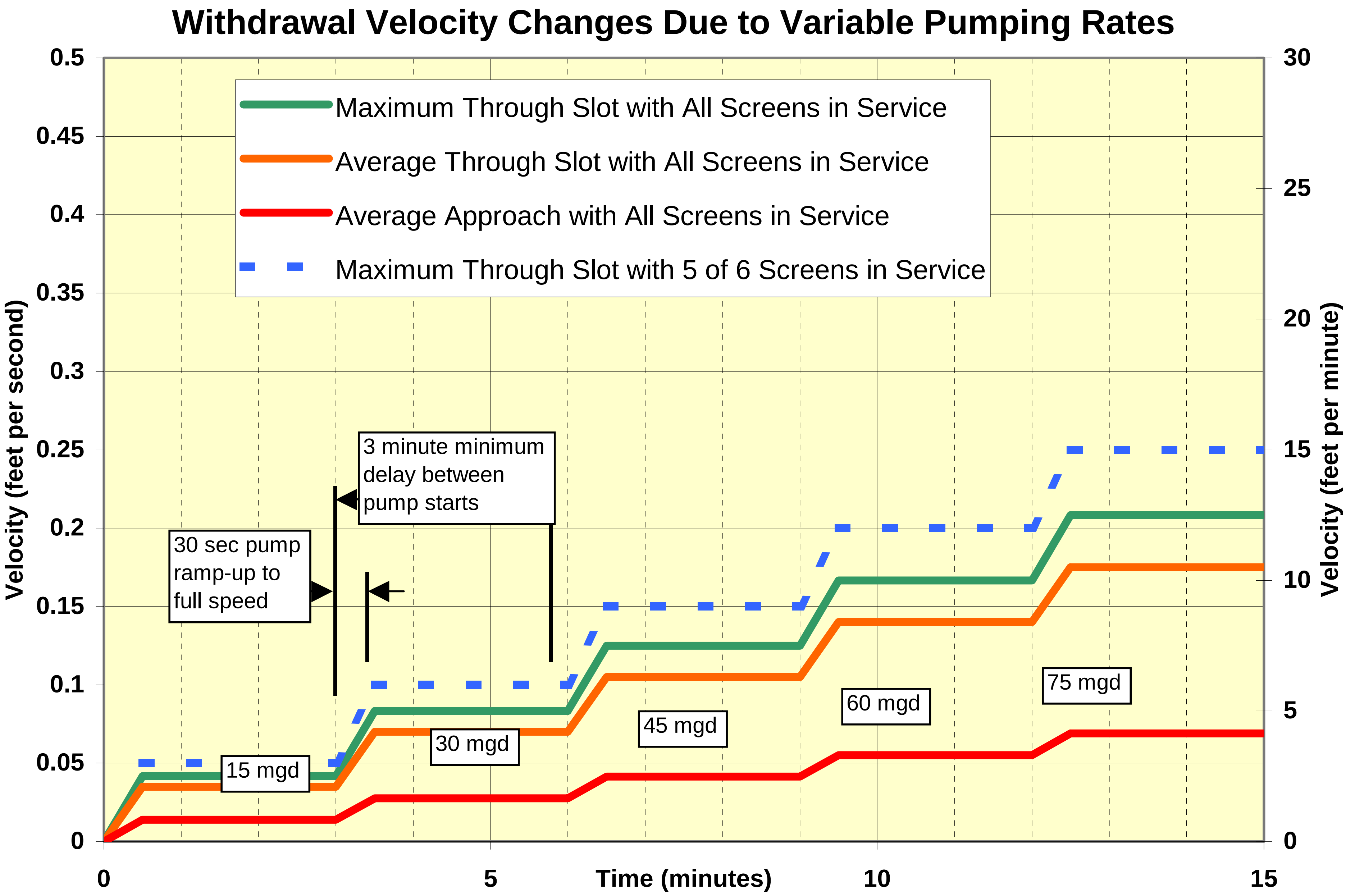
The pump station site is located on King William County Tax Map Section No. 38, Parcel 79, consisting of 188 acres and currently owned jointly by the City of Newport News and King William County. A low impact, residential style site layout is planned within a 25-acre portion of the parcel. The 25-acre portion of the site will include all the property from the river shoreline to the secondary escarpment, a distance of approximately 800 feet. The existing small pond on the west side of the parcel is not included in the 25-acre site. The access road would be in addition to the 25-acre site.

To provide 75 mgd of firm pumping capacity (i.e., the capacity with one pumping unit out of service), a total of six 15-mgd (nominal unit capacity) pumps will be installed. These pumps will be vertical turbine style, with the pump motors, discharge heads and discharge control valves located in a partially below grade pump room in the center of the pump station building. The pumps will extend vertically down into the wetwell below the pump room. Pumps will be operated in order to maintain the desired water level in the King William Reservoir, to the extent allowed by the MIF conditions stipulated in the VDEQ's December 2002 VWPP and any other withdrawal limitations.

Variable pumping rates will be achieved by adjusting the number of operating pumps. Pumps will be started one at a time under normal conditions with at least a three minute delay between pump starts. Based on this minimum delay between pump starts, it will take at least 12 minutes for the station to transition from a no flow condition to the full 75 mgd permitted maximum withdrawal rate. Under normal operating conditions, changes in pumping rates are likely to occur much less frequently than this. **Figure 7** illustrates the minimum pump startup timeline and the corresponding intake velocities. Pumps will normally be stopped one at a time, but emergency conditions and power failures could cause all pumps to stop at once.

Monitoring of the Mattaponi River at the Beulahville gage and computation of the corresponding freshwater inflow at the intake site at Scotland Landing is required by the VWPP. Because the pump station and intake are located on a tidal portion of the Mattaponi River, a gauging station at the pump station site would not be useful. The nearest reasonable

Figure 7



Withdrawal Velocity Changes Due to Variable Pumping Rates
Maximum Through Slot with All Screens in Service
Average Through Slot with All Screens in Service
Average Approach with All Screens in Service
Maximum Through Slot with 5 of 6 Screens in Service
Velocity (feet per second)
Velocity (feet per minute)
Time (minutes)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
5
10
15
20
25
30
3 minute minimum delay between pump starts
30 sec pump ramp-up to full speed
15 mgd
30 mgd
45 mgd
60 mgd
75 mgd

location for measuring flow in the non-tidal portion of the river is the existing USGS gauging station at Beulahville (upstream of U.S. Route 360 off of County Route 628). Flows measured at Beulahville must be adjusted for the 30 percent larger drainage area of the Mattaponi River at Scotland Landing.

An automatic data download system using phone lines or radio telemetry for communication will be used to periodically (at least several times per day) transmit the Beulahville gage data to the pump station computer control system. The corresponding river flow at Scotland Landing and the resulting maximum allowable withdrawal rate will automatically be calculated and saved to a database several times per day by the computer control system. A backup, manual approach (including use of USGS stage/flow curves) to acquire Beulahville gauge data will also be developed. In accordance with the requirements of the VWPP, the VDEQ must approve the entire flow measurement program and method of calculating maximum allowable withdrawal rate.

Measurement of pumped flows will be provided by one or more flowmeters in the discharge piping on the pump station site, and recorded daily in accordance with the requirements of the VWPP. Pumpage will be reported monthly to the VDEQ, in accordance with the requirements of the VWPP.

6.0 MATTAPONI RIVER TIDAL WETLANDS AND WATER QUALITY

Tidal Wetlands

The Scotland Landing intake site consists of a large tract of upland situated on a small bluff well above the floodplain of the Mattaponi River. Site selection criteria included avoidance of tidal wetlands. No wetlands are found within the footprint of the proposed pump station and intake site; scouring on the outside bend of the river has prevented the accumulation of fringe wetlands on the southern bank of the Mattaponi. Location of the intake in a tidal freshwater zone will preclude water level impacts to the Mattaponi River.

An extensive tidal freshwater marsh, Garnetts Creek Marsh, is located directly across from the intake site, on the King and Queen County side of the Mattaponi. A small tidal freshwater marsh is located about 600 feet upstream of the intake site on the south side of the Mattaponi. Changes to these wetland systems are not anticipated as a result of intake operation.

Dr. David Basco, a coastal engineer from Old Dominion University was hired by the applicant to study changes in water velocities and sediment transport associated with the intake. He concluded that the impacts of increased turbulent energy resulting from the water withdrawal at the intake structure would be negligible when compared to natural freshwater floods. The relative changes in water velocities and sediment transport potential would be so small that the possibility for increased erosion on either side of the river, as a result of intake operation, is minimal to nonexistent (Basco, 1996).

Salinity

The water quality characteristic of the Mattaponi River, which is of greatest concern regarding the floral and faunal communities of the tidal wetlands in the river, is salinity. An analysis was conducted by the Virginia Institute of Marine Science (VIMS) to estimate the impacts of the proposed withdrawal on salinity concentrations in the Mattaponi River (Hershner et al., 1991). VIMS salinity model predictions for tidal freshwater zone transects showed that increases in long-term mean and maximum salinity levels, either on an annual or seasonal basis, should be less than or equal to 0.08 ppt (Hershner et al., 1991). Even the 0.08 ppt figure overestimates the change due to the highly conservative nature of the Mattaponi River MIF and withdrawal assumptions used in the modeling.

The VIMS salinity model is based on the assumption that the Mattaponi River is completely mixed from top to bottom and side to side. Therefore, the salinity value predicted for each transect represents an average of the salinity levels across the river's cross-section. Salinity has been reported to increase with depth along the lower 19.6 miles of the Mattaponi River (Mattaponi River Slack Water Data Report - Temperature, Salinity, Dissolved Oxygen 1970-1978 (Brooks, 1983). The average salinity levels used in the model will tend to slightly overestimate near surface salinity levels. Model predictions are, therefore, considered conservative because the aquatic species that are the most sensitive to salinity variation (i.e., plants) persist in the surface waters.

VIMS concluded that "minimal impact to wetland plant species distributions are anticipated as a result of salinity changes caused by proposed withdrawals" (Hershner et al., 1991). Based in part on VIMS' report, the Norfolk District USACE concluded in its Final EIS that natural salinity fluctuations in the Mattaponi River greatly exceed any changes predicted due to the proposed withdrawals (USACE, 1997). The VIMS salinity modeling results demonstrate that the applicant's withdrawals, and other existing and reasonably foreseeable consumptive Mattaponi River Basin water uses, would not affect the upstream limits of detectable salinity intrusion. The proposed withdrawals, in combination with other existing and reasonably foreseeable consumptive Mattaponi River Basin water uses, would, however, cause small increases in the frequency of given levels of salinity intrusion at points which already are periodically exposed to comparable salinity levels. The Corps' Waterways Experiment Station (WES) reviewed the VIMS model at the request of the Norfolk District and concluded that it was "essential and technically sound" (Johnson and Wang, 1997).

WES recommended modeling a "Cumulative Effects Scenario," combining projected withdrawals from the Pamunkey River as well as the Mattaponi. The resulting analysis was extremely conservative; projected withdrawals from the two Rivers were overestimated, and several significant freshwater inputs were not included. Nevertheless, results of the Cumulative Effects analysis were quite similar to prior findings – any possible changes to salinity levels will be minimal and overwhelmed by the natural range of salinity concentrations.

The salinity modeling analyses were highly conservative for another reason: they used the less stringent proposed 40/20 Tennant minimum instream flowby requirement in modeling the timing and quantities of Mattaponi River withdrawals. The VDEQ imposed the more restrictive Modified 80% Exceedence MIF requirement as a condition of the VWPP, further ensuring that there will be no adverse effects from salinity intrusion. In times of low freshwater inflows, when salinity levels reach their peak under natural conditions, there will be no impacts at all. Withdrawals will be prohibited.

In December 1997, the VDEQ issued a VWPP for the KWR Project. The permit was modified in 2002 to allow for the time delay in obtaining other necessary project permits. As stated by VDEQ during the May 14, 2003 VMRC Commission Meeting, VDEQ "… did consider project need in relation to other regional water needs in Virginia" and "… decided that there was a reasonable need (for the project)" (VMRC, 2003). VDEQ staff also stated that the VWPP contained specific withdrawal conditions designed to protect the Mattaponi River ecology by keeping salinity within a historical range (VMRC, 2003). The VWPP also requires development of river monitoring plans that will require public notice and VDEQ final approval. As stated in Governor Gilmore's May 2001 Public Interest Review, "The Virginia Water Protection Permit (VWPP) conditions imposed by the State Water Control Board will fully protect the environment and mitigate any potential impact" (Gilmore, 2001).

Governor Gilmore reaffirmed that, "The State took a very conservative stance in issuing its water quality certificate and not only raised the proposed minimum instream flowby levels for the Mattaponi River, but set additional conditions on the total amount of water that could be transferred from the Reservoir in any three year period…. by reversing the simulation model's priority system for taking water, i.e., taking local water first and King William Reservoir water second, the average withdrawal over the period of record would fall from 40 mgd to 18 mgd….(Gilmore, 2001). In further explanation of this King William Reservoir transfer restriction, Dr. Ellen Gilinsky of VDEQ made an oral presentation to VMRC Commission members at their May 14, 2003 meeting. In her remarks she stated that: "… The permit directs Newport News to exhaust other water sources first before withdrawing from the

Mattaponi by limiting inner basin transfer in any given year to a certain amount, so this will be the source of last resort, not first resort" (VMRC, 2003).

Endangered Species

No federally listed endangered species are located in the project area. One species listed as threatened has been found in the tidal wetlands upstream and across the river from the intake site, i.e., sensitive joint vetch. The USFWS has determined, in a formal Biological Opinion under the Endangered Species Act, that the project will not jeopardize this listed species or adversely affect any critical habitat (USFWS, 1998).

A large sensitive joint-vetch population exists along a 15-mile stretch of the Mattaponi River in King and Queen and King William Counties, including a sub-population located across the River from the proposed intake site in Garnetts Creek Marsh, and another approximately 600 feet upstream of the intake site. In a 1993 study of potential sensitive joint-vetch impacts, VIMS concluded "it appears that no existing plant will be impacted within the primary or secondary study areas by the proposed [King William Reservoir] project" (Perry, 1993).

Salinity changes are the primary concern regarding survivability of the sensitive joint-vetch. As stated above, VIMS analyses of potential salinity impacts have shown that salinity changes will be minimal; and it concluded that "minimal impact to wetland plant species distributions are anticipated as a result of salinity changes caused by proposed withdrawals" (Hershner et al., 1991). Under current conditions, the average annual predicted salinity level at the farthest downstream sensitive joint-vetch colony on the Mattaponi is 0.46 parts per thousand (ppt). With expected maximum (Year 2040) withdrawals, the projected average annual predicted salinity level is 0.49 ppt, or 0.03 parts per thousand greater than the baseline value. Sensitive joint-vetch has been found thriving in the Pamunkey River at Sweet Hall Marsh, where the average annual salinity level is 0.67 ppt.

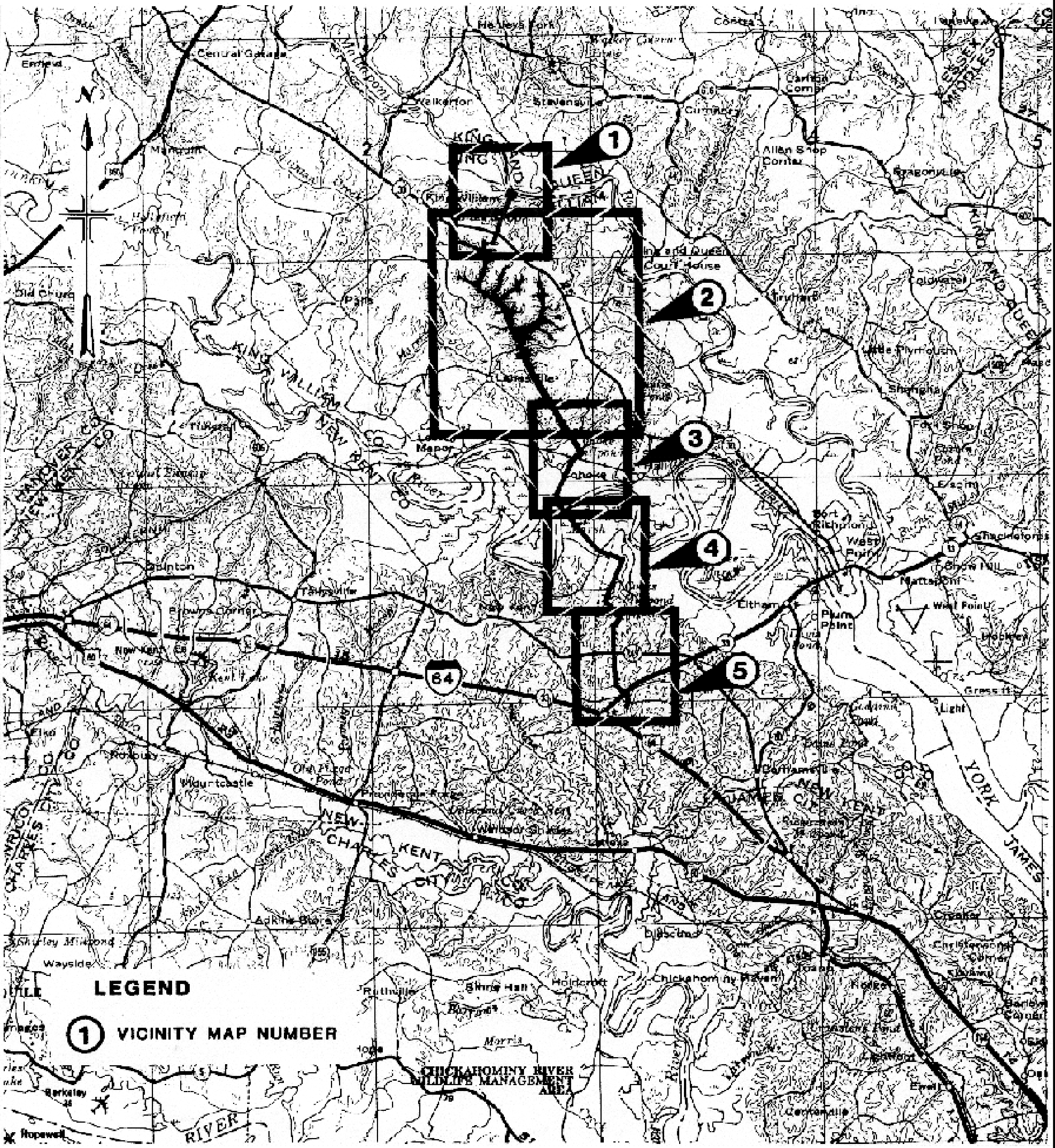
As discussed previously, another study was conducted in response to suggestions that changes in water velocities and sediment transport could alter sensitive joint-vetch habitat (Basco, 1996). The report concluded that any increase in mean velocities and sediment transport potential would be so small that the possibility of erosion of sensitive joint-vetch sites is minimal to non-existent.

The December 2002 VWPP issued by the VDEQ requires detailed monitoring of the vegetative composition and distribution of flora within the tidal wetlands of the Mattaponi River, and it specifically includes monitoring of the condition and viability of the sensitive joint-vetch colony located just upstream of the intake site. In the highly unlikely event that this monitoring should detect adverse impacts to the sensitive joint vetch, the VDEQ can modify the permit to rectify the situation.

Additional protection to the sensitive joint-vetch is afforded by the State-permitted MIF requirements, which would limit or preclude withdrawals from the Mattaponi River during low flow periods when salinity levels may be above normal. Therefore the project will not cause any additional stresses to downstream populations that may be under stress due in part to salinity increases during periods of decreased freshwater flows.

Attachment

Updated Mapping and Preliminary Engineering Drawings for King William Reservoir Project



DATUM: USGS

REF: USGS 1:250,000 RICHMOND

OVERALL PROJECT LOCATION MAP & VICINITY MAP INDEX

KING WILLIAM RESERVOIR PROJECT

SCALE: 1" = 3.95 MILES

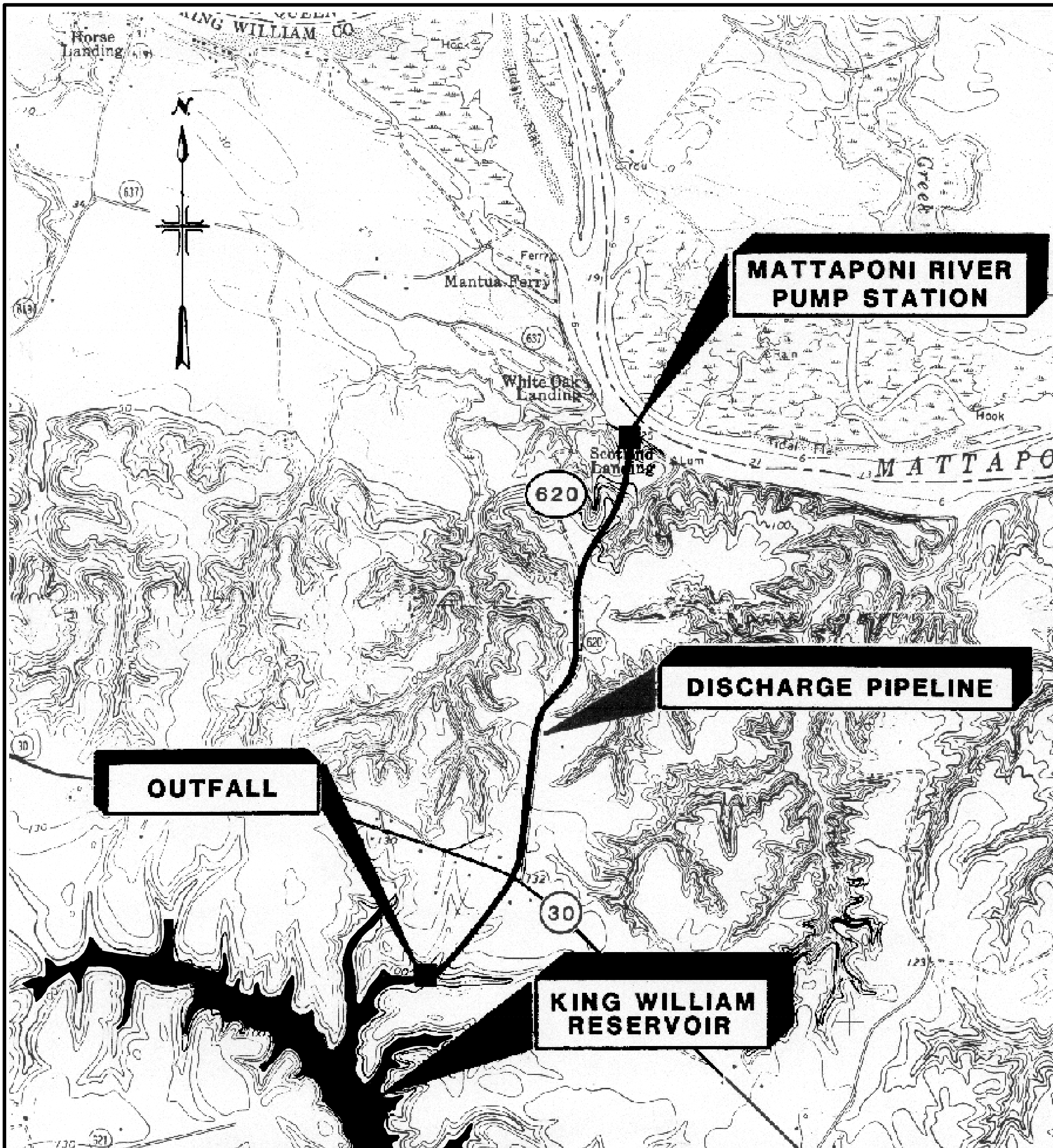
PROPOSED PUBLIC WATER SUPPLY PROJECT

COUNTY OF KING WILLIAM & NEW KENT

STATE VA

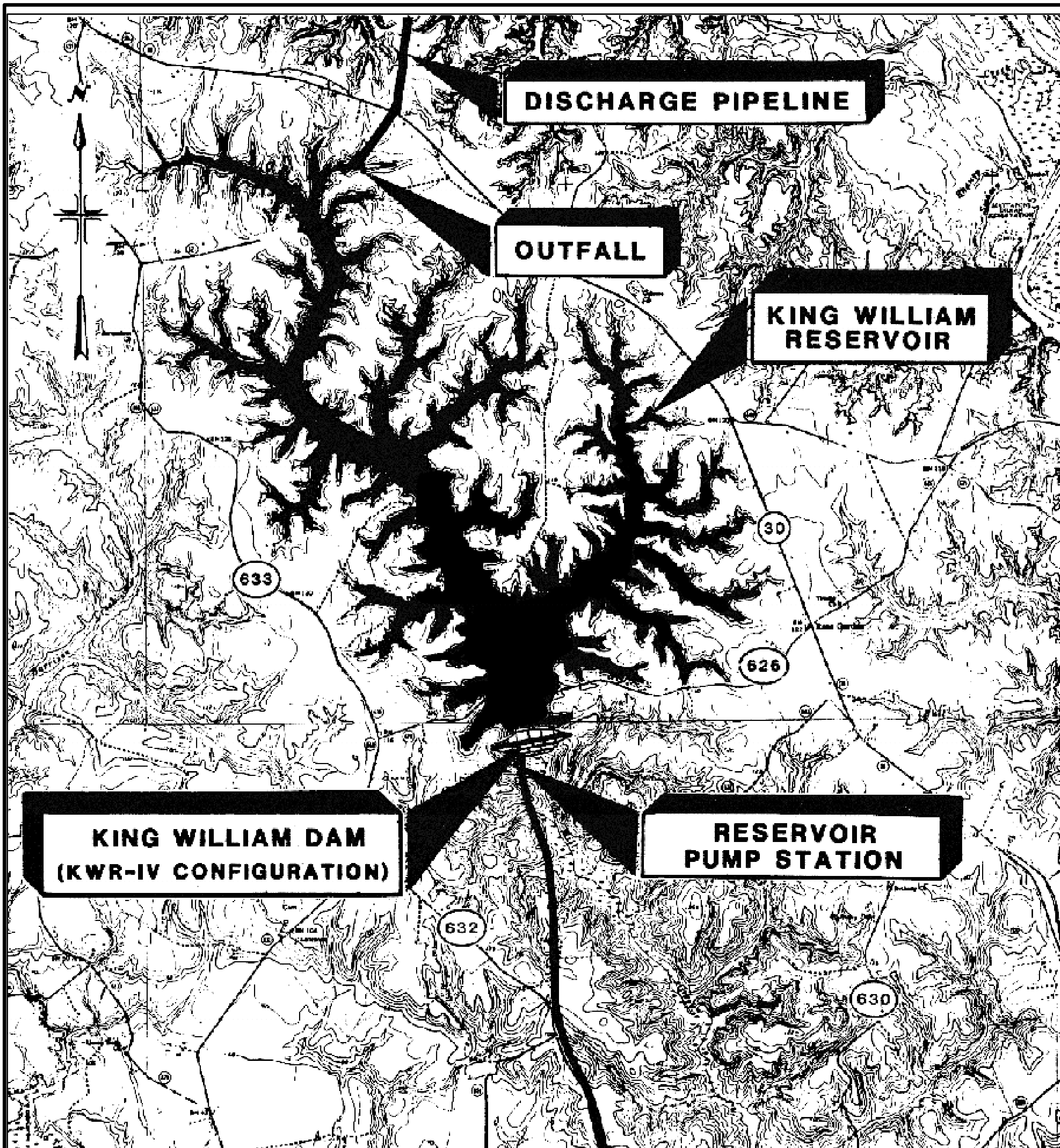
APPLICANT CITY OF NEWPORT NEWS

SHEET 1 OF 20 DATE 03/05/04



DATUM: USGS REF: USGS 7.5' KING AND QUEEN COURTHOUSE QUADRANGLE	**VICINITY MAP 1** MATTAPONI RIVER PUMP STATION, DISCHARGE PIPELINE & OUTFALL SCALE: 1"=2000'	PROPOSED PUBLIC WATER SUPPLY PROJECT COUNTY OF KING WILLIAM & NEW KENT STATE VA APPLICANT CITY OF NEWPORT NEWS SHEET 2 OF 20 DATE 03/05/04

User: cutler Spec: PIRNIE STANDARD File: L:\3114 - Newport News City of\017 - Raw Water Study\Cadd\J_PERMIT\March 2004 Amendment\SHEET 03.DWG Scale: 1:1 Date: 03/10/2004 Time: 09:10 Layout: Layout1



DATUM: USGS

REF: USGS 7.5' KING AND QUEEN COURTHOUSE AND NEW KENT QUADRANGLES (REDUCED)

VICINITY MAP 2

KING WILLIAM RESERVOIR, DAM, AND PIPELINE

SCALE: 1"=4000'

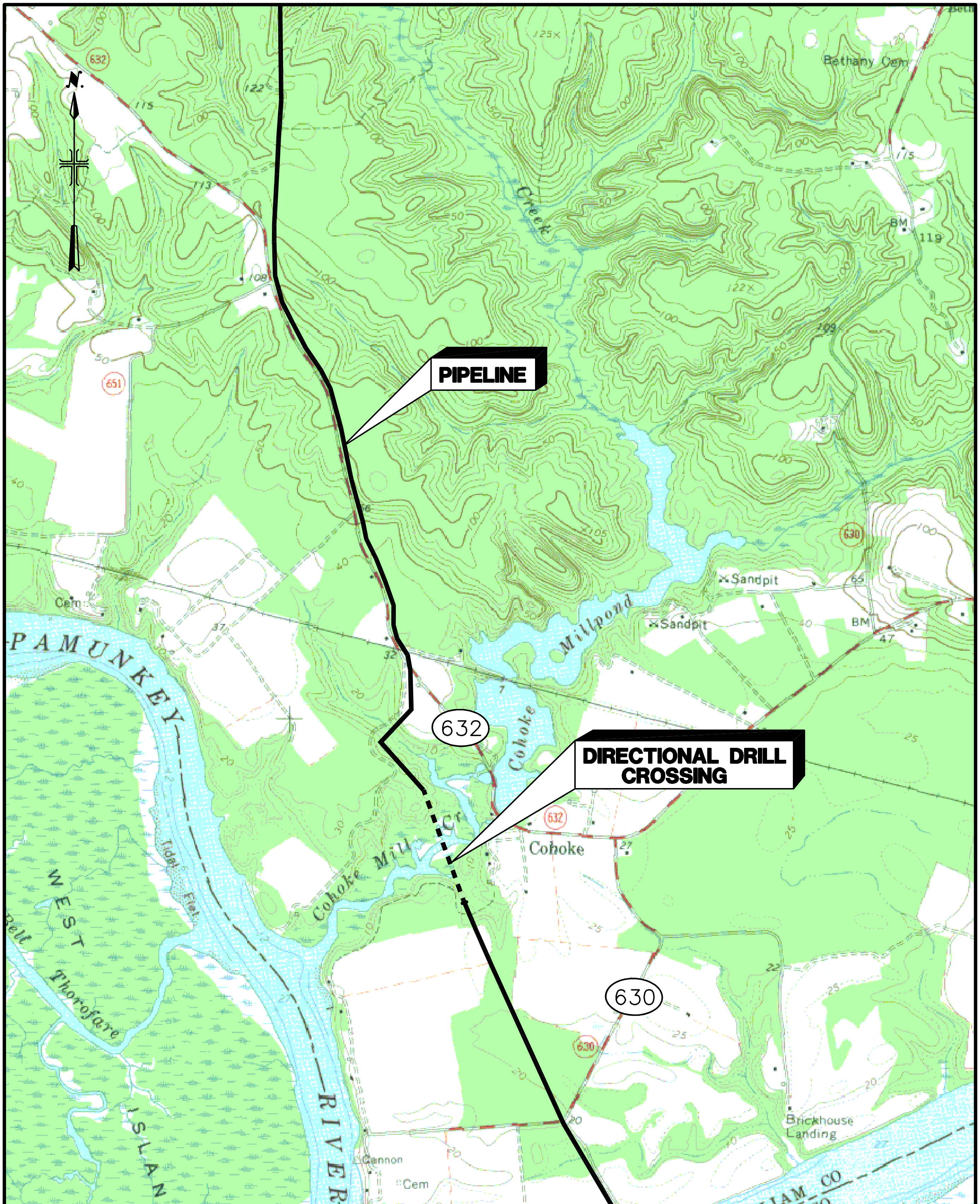
PROPOSED PUBLIC WATER SUPPLY PROJECT

COUNTY OF KING WILLIAM & NEW KENT

STATE VA

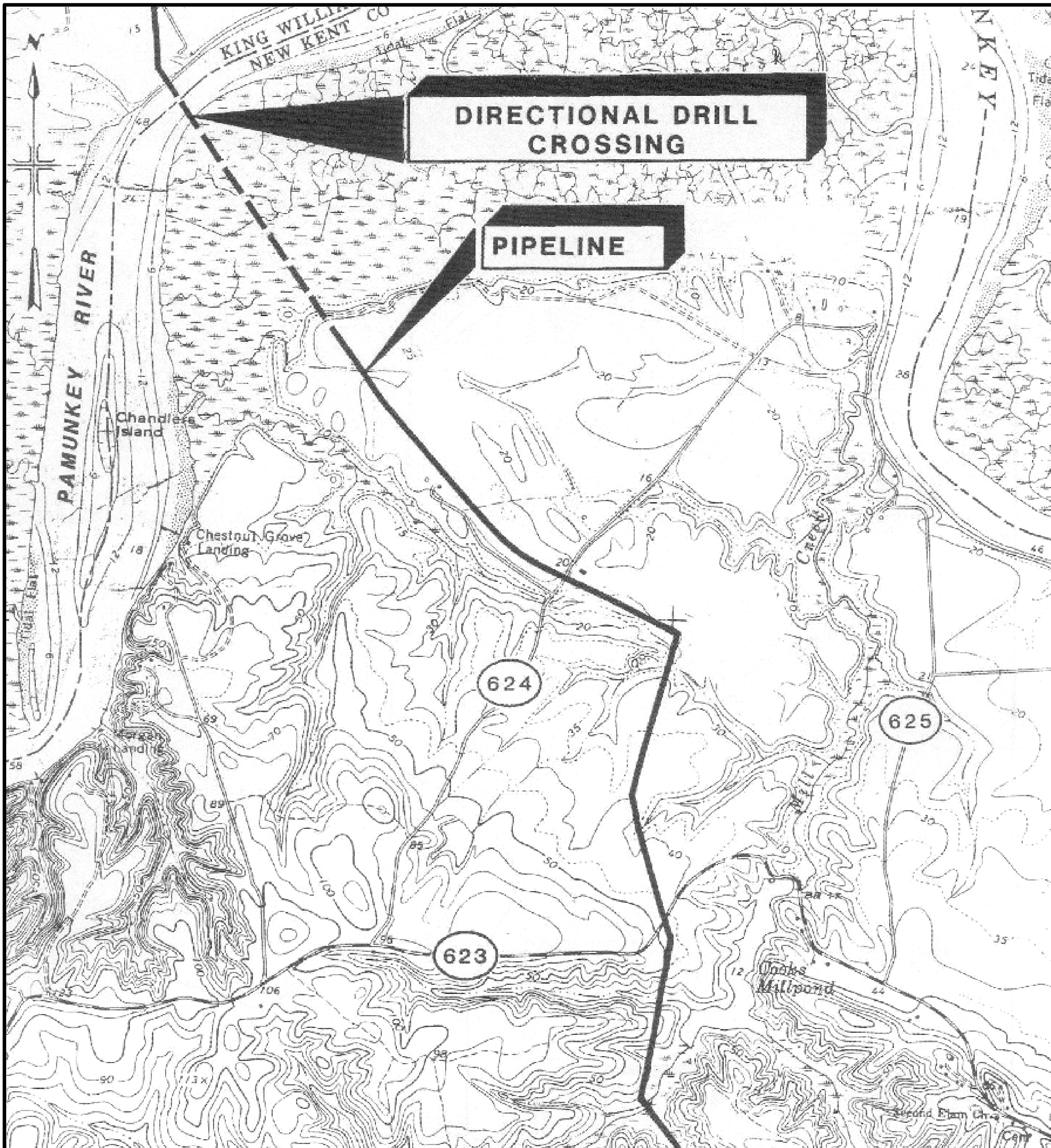
APPLICANT CITY OF NEWPORT NEWS

SHEET 3 OF 20 DATE 03/05/04

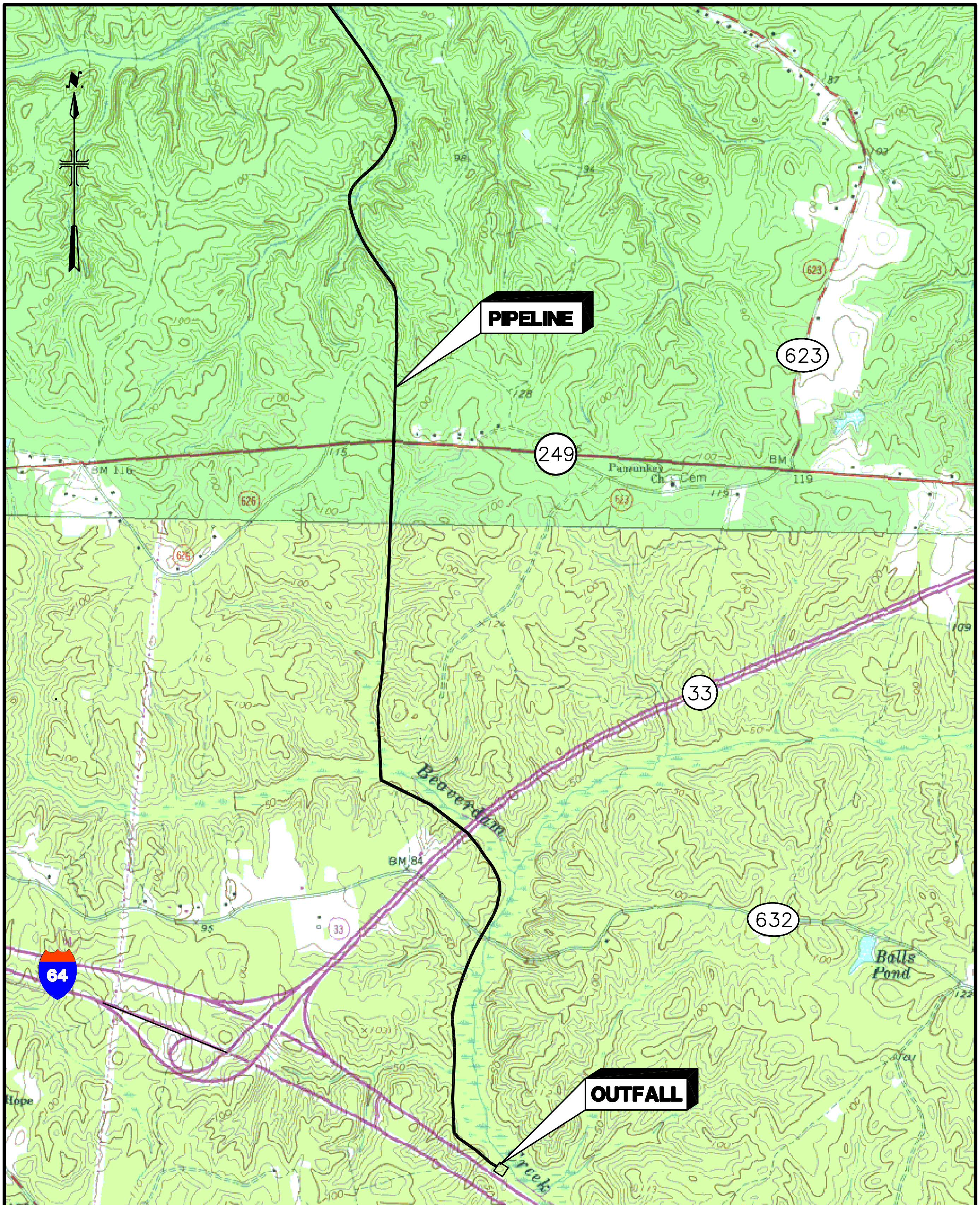


DATUM: USGS REF: USGS 7.5' NEW KENT QUADRANGLE	**VICINITY MAP 3** PIPELINE SCALE: 1"=2000'	PROPOSED PUBLIC WATER SUPPLY PROJECT COUNTY OF KING WILLIAM & NEW KENT STATE VA APPLICANT CITY OF NEWPORT NEWS SHEET 4 OF 20 DATE 03/05/04

User:cutler Spec:PIRNIE STANDARD File:L:\3114 - Newport News City of\017 - Raw Water Study\Cadd\J_PERMIT\March 2004 Amendment\SHEET 04.DWG Scale:1:1 Date:03/10/2004 Time:09:10 Layout:Layout1



DATUM: USGS REF: USGS 7.5' NEW KENT QUADRANGLE	**VICINITY MAP 4** PIPELINE & PAMUNKEY RIVER CROSSING SCALE: 1"=2000'	PROPOSED PUBLIC WATER SUPPLY PROJECT COUNTY OF KING WILLIAM & NEW KENT STATE VA APPLICANT CITY OF NEWPORT NEWS SHEET 5 OF 20 DATE 03/05/04



DATUM: USGS

REF: USGS 7.5' NEW KENT & WALKERS QUADRANGLES

VICINITY MAP 5

PIPELINE & OUTFALL

SCALE: 1"=2000'

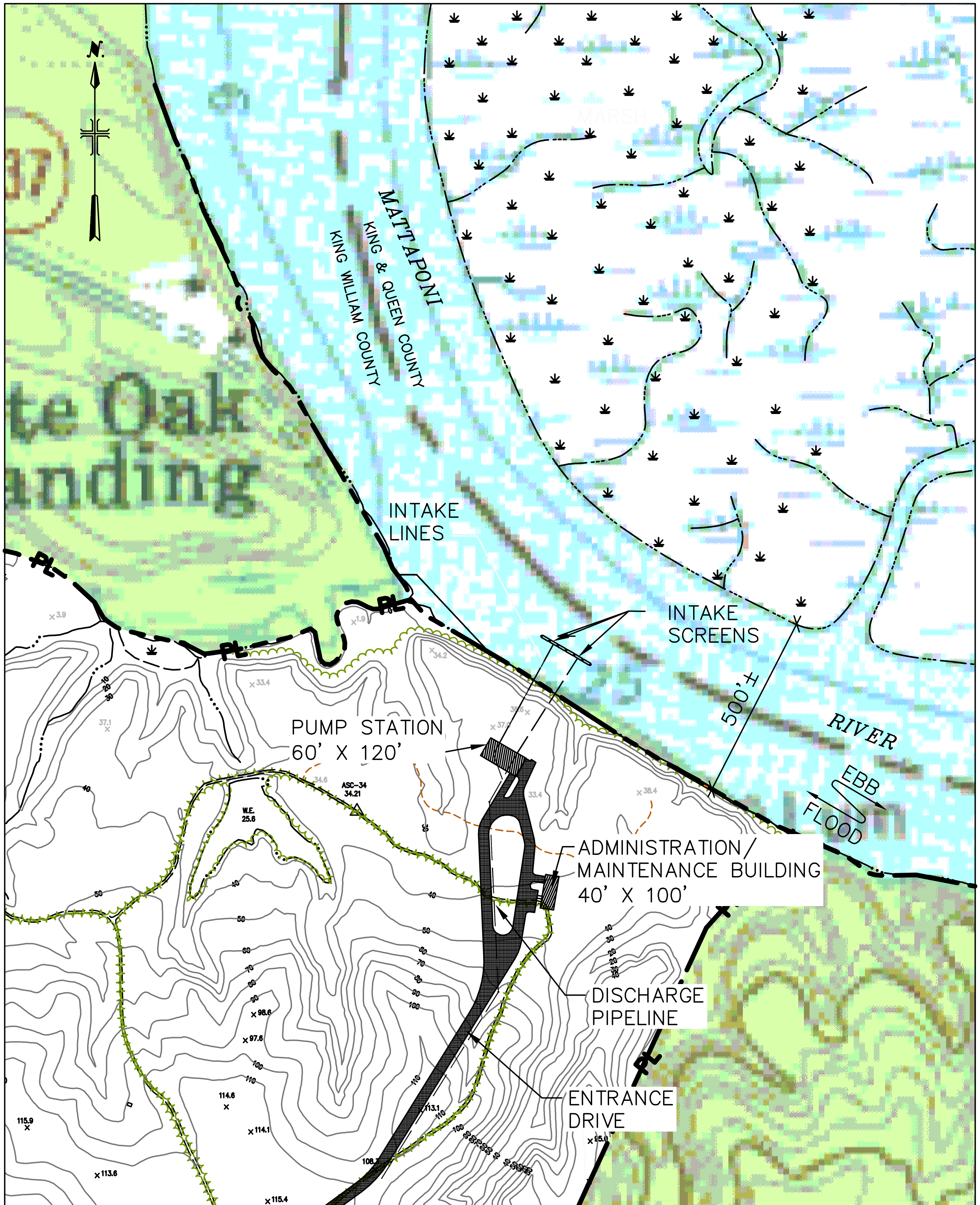
PROPOSED PUBLIC WATER SUPPLY PROJECT

COUNTY OF KING WILLIAM & NEW KENT

STATE VA

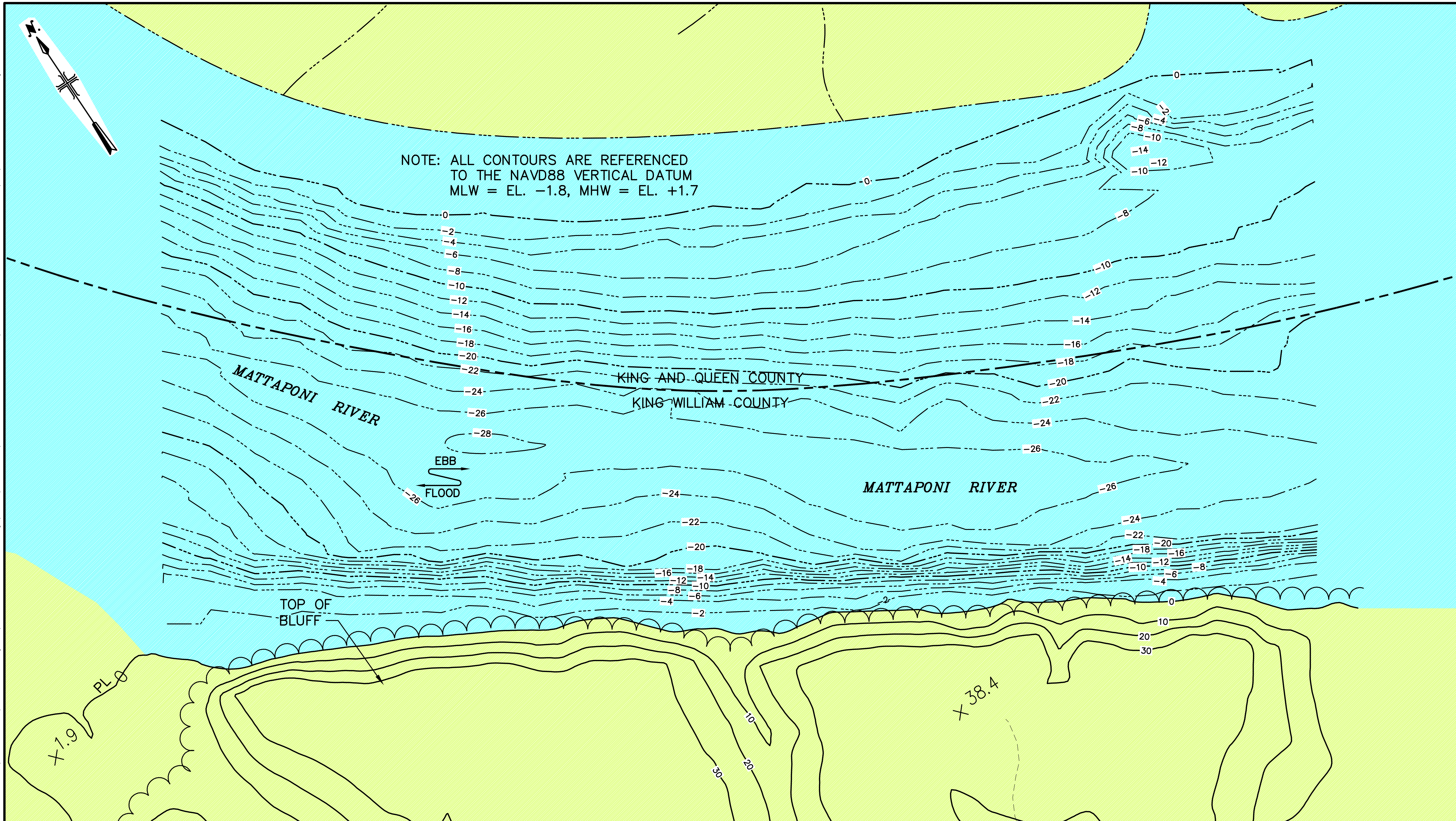
APPLICANT CITY OF NEWPORT NEWS

SHEET 6 OF 20 DATE 03/05/04



DATUM: USGS AND NAVD 88 REF: USGS 7.5' KING AND QUEEN COURTHOUSE QUADRANGLE (ENLARGED) AND ASC TOPOGRAPHIC MAPPING FROM AERIAL PHOTOGRAPHY	PLAN MATTAPONI RIVER PUMP STATION SITE SCALE: 1"=400'	PROPOSED PUBLIC WATER SUPPLY PROJECT COUNTY OF KING WILLIAM & NEW KENT STATE VA APPLICANT CITY OF NEWPORT NEWS SHEET 7 OF 20 DATE 03/05/04

User: cutler Spec: PIRNIE STANDARD File: L:\3114 - Newport News City of\017 - Raw Water Study\Cadd\J_PERMIT\March 2004 Amendment\SHEET 08.DWG Scale: 1:1 Date: 03/05/2004 Time: 12:59 Layout: 11 x 17



DATUM: NAVD 88

REF: TOPOGRAPHIC: ASC TOPOGRAPHIC MAPPING FROM FEB 1994 AERIAL PHOTOGRAPHY
BATHYMETRIC: WATERWAY SURVEYS & ENGINEERING LTD NOV 2003 SURVEY

PLAN

MATTAPONI RIVER PUMP STATION
RIVER BOTTOM EXISTING CONTOURS

SCALE: 1"=100'

PROPOSED PUBLIC WATER SUPPLY PROJECT

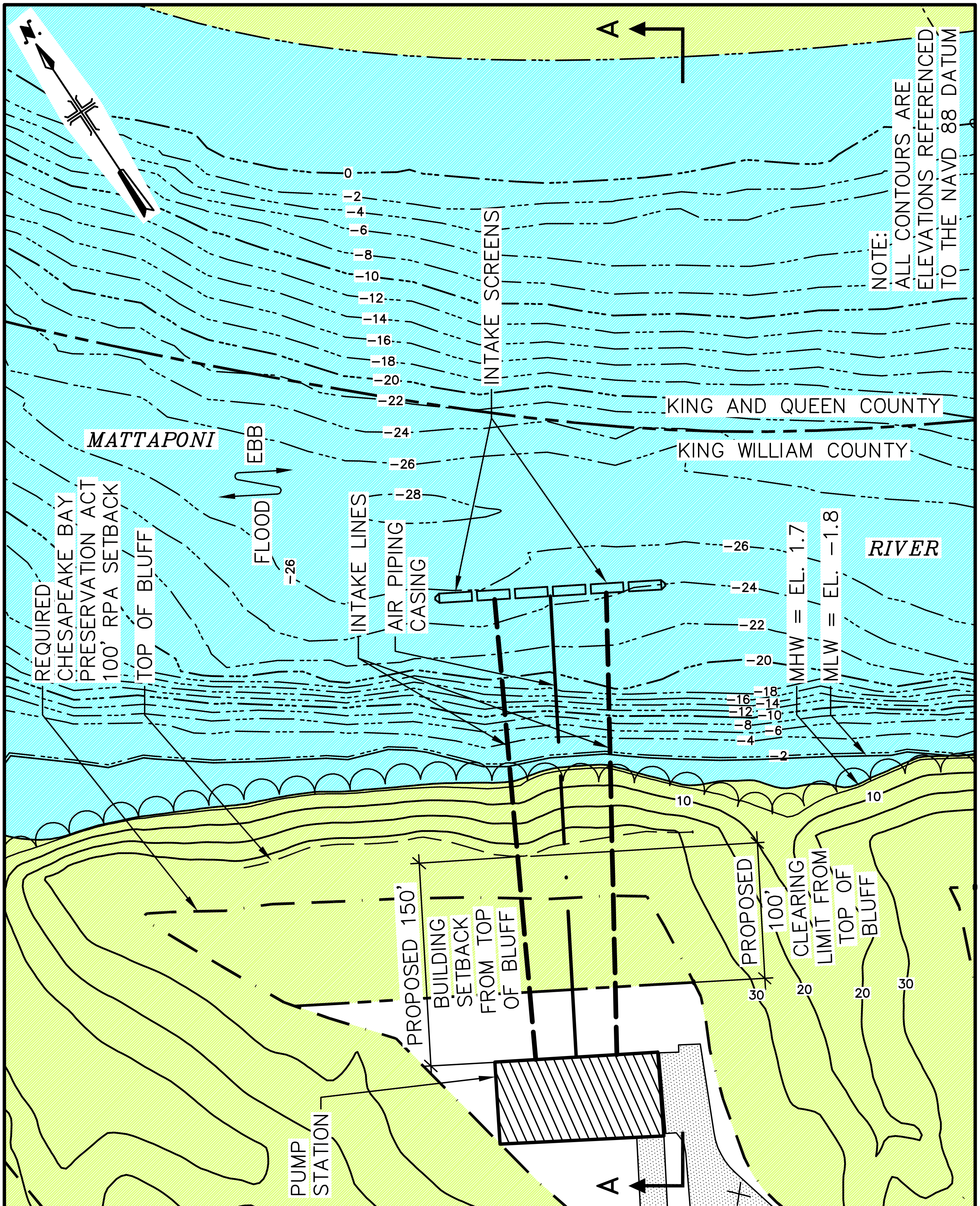
COUNTY OF KING WILLIAM & NEW KENT

STATE VA

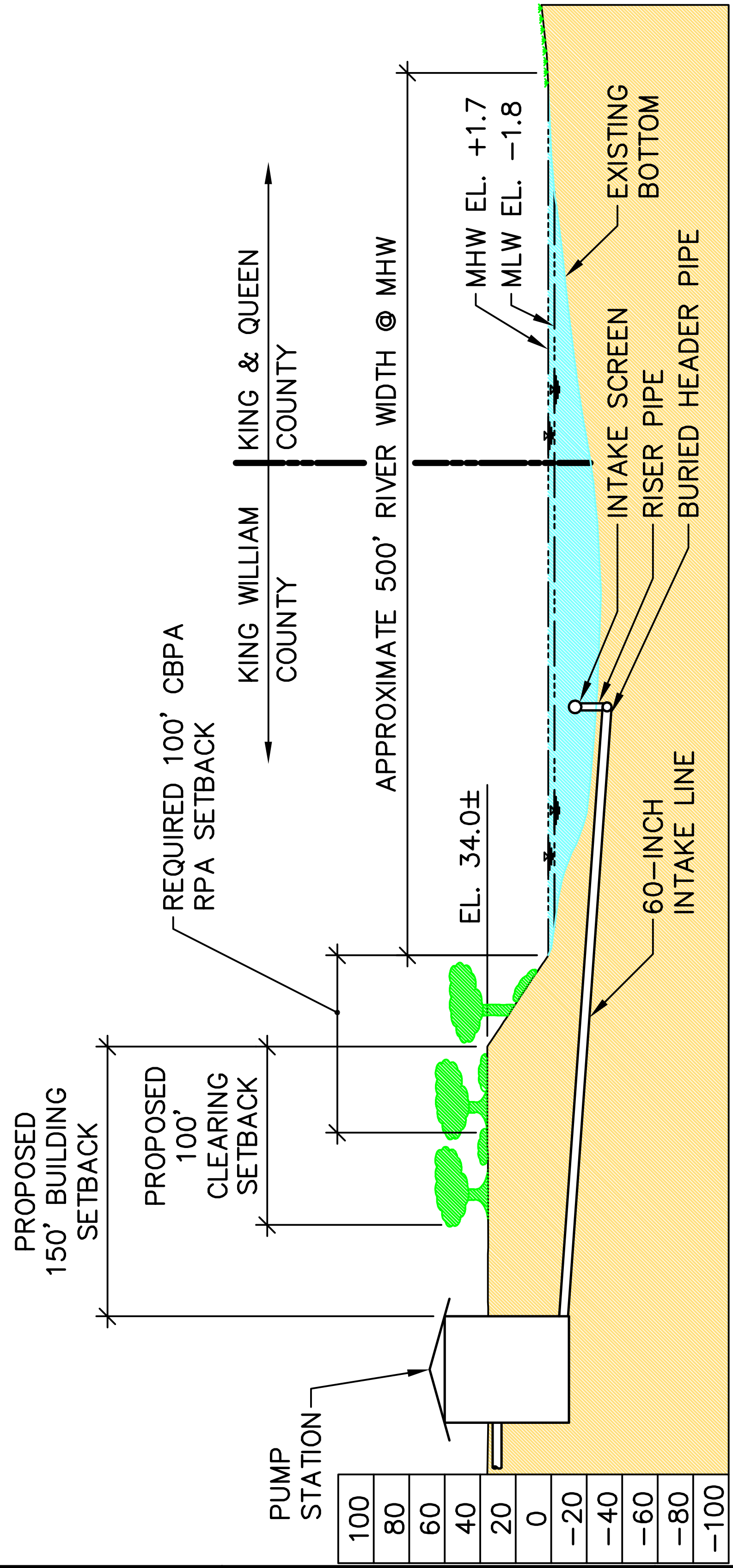
APPLICANT CITY OF NEWPORT NEWS

SHEET 8 OF 20

DATE 03/05/04



DATUM: NAVD 88 REF: TOPOGRAPHIC: ASC TOPOGRAPHIC MAPPING FROM AERIAL PHOTOGRAPHY BATHYMETRIC: WATERWAY SURVEYS & ENGINEERING LTD SURVEY	**PLAN** MATTAPONI RIVER PUMP STATION INTAKE SYSTEM SCALE: 1"=100'	PROPOSED PUBLIC WATER SUPPLY PROJECT COUNTY OF KING WILLIAM & NEW KENT STATE VA APPLICANT CITY OF NEWPORT NEWS SHEET 9 OF 20 DATE 03/05/04



DATUM: NAVD 88

REF: TOPOGRAPHIC: ASC TOPOGRAPHIC MAPPING FROM AERIAL PHOTOGRAPHY
BATHYMETRIC: WATERWAY SURVEYS & ENGINEERING LTD SURVEY

PROFILE A-A

MATTAPONI RIVER
PUMP STATION
INTAKE SYSTEM

SCALE: HORIZONTAL: 1"=100'
VERTICAL: 1"=100'

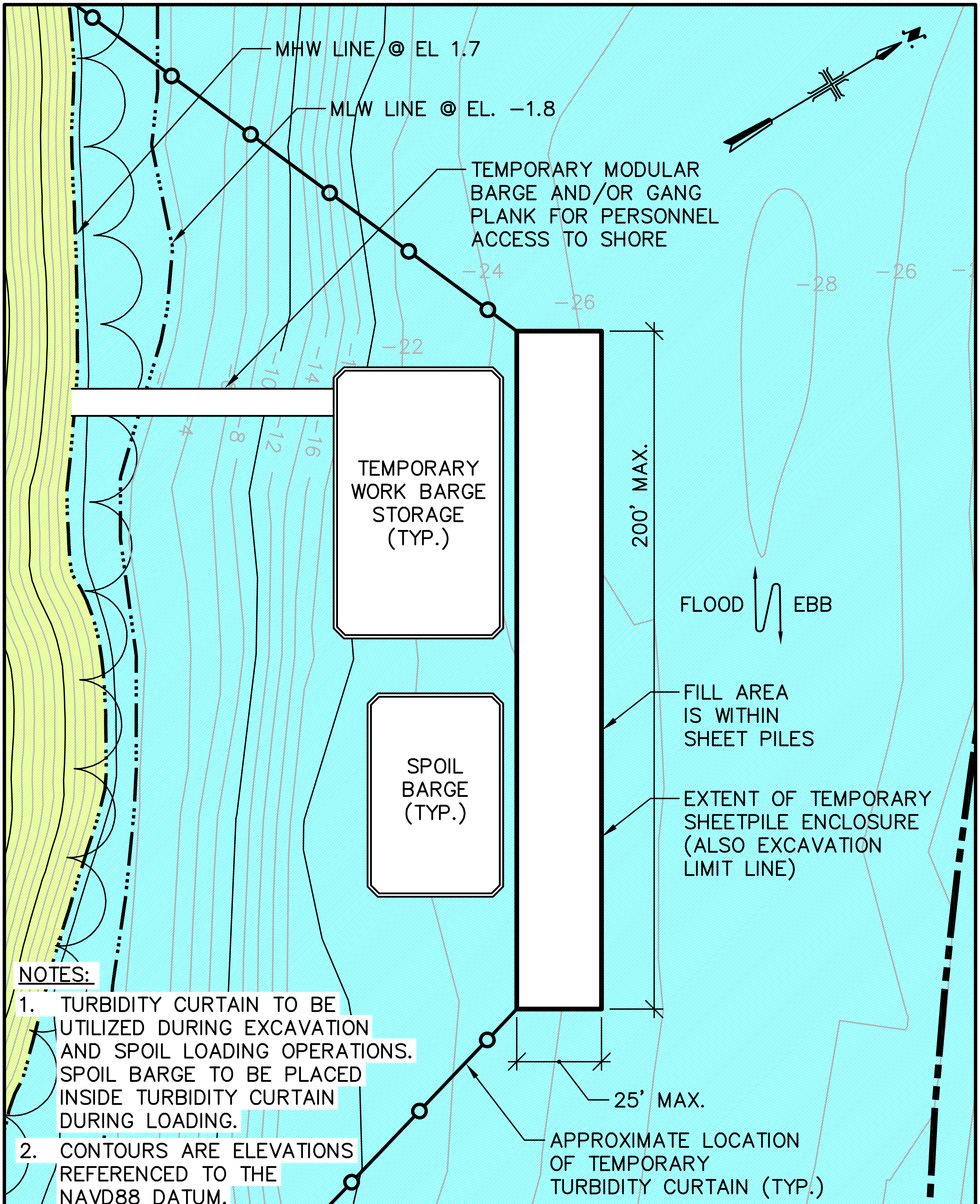
PROPOSED PUBLIC WATER SUPPLY PROJECT

COUNTY OF KING WILLIAM & NEW KENT

STATE VA

APPLICANT CITY OF NEWPORT NEWS

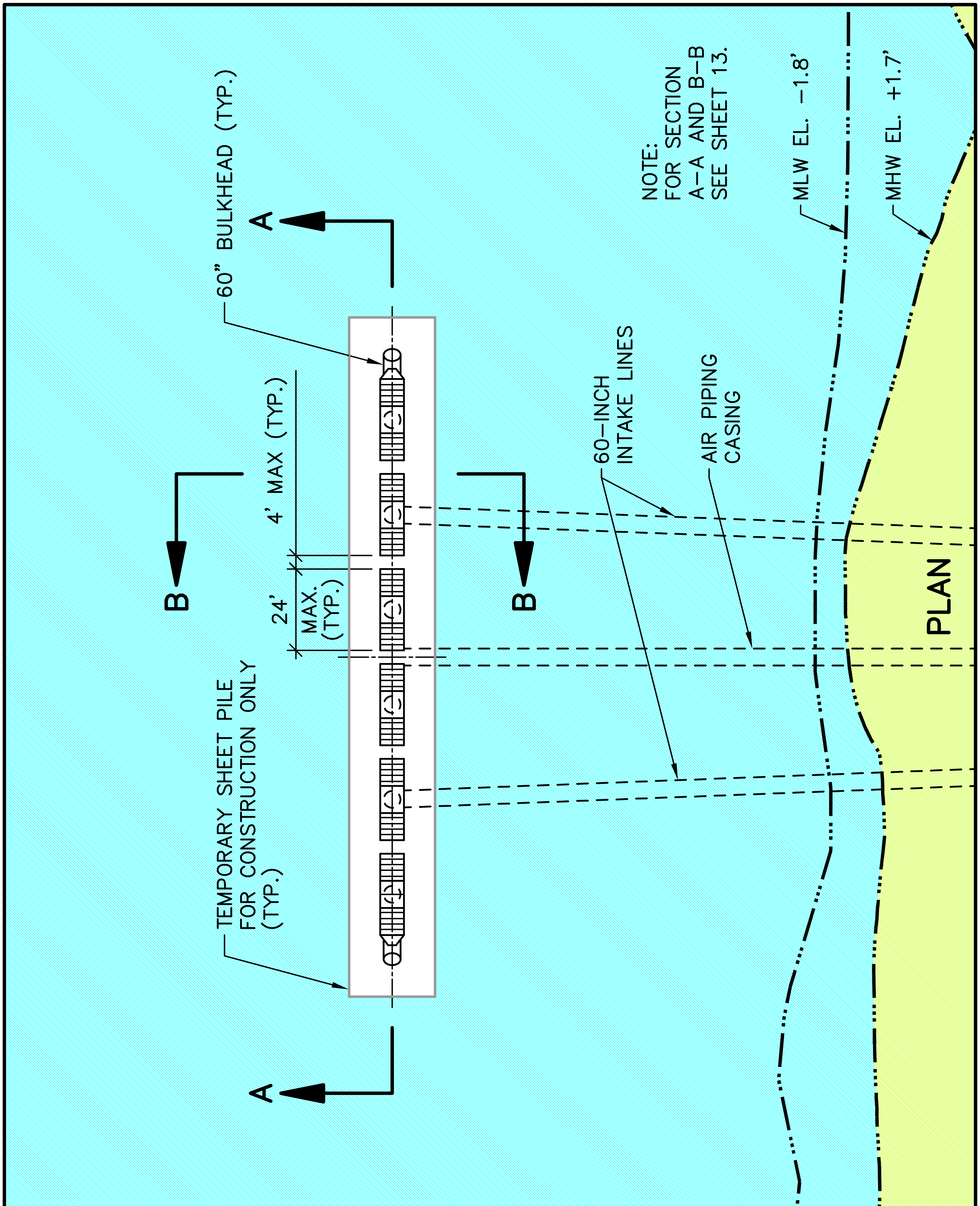
SHEET 10 OF 20 DATE 03/05/04



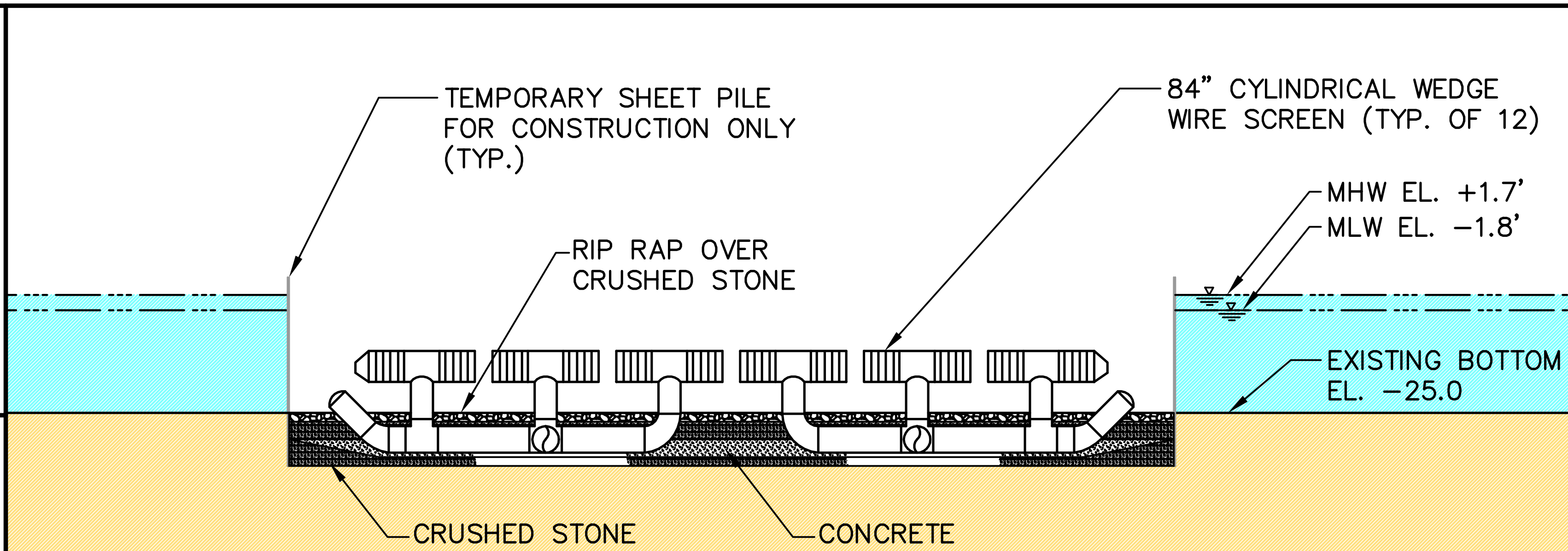
NOTES:

1. TURBIDITY CURTAIN TO BE UTILIZED DURING EXCAVATION AND SPOIL LOADING OPERATIONS. SPOIL BARGE TO BE PLACED INSIDE TURBIDITY CURTAIN DURING LOADING.
2. CONTOURS ARE ELEVATIONS REFERENCED TO THE NAVD88 DATUM.

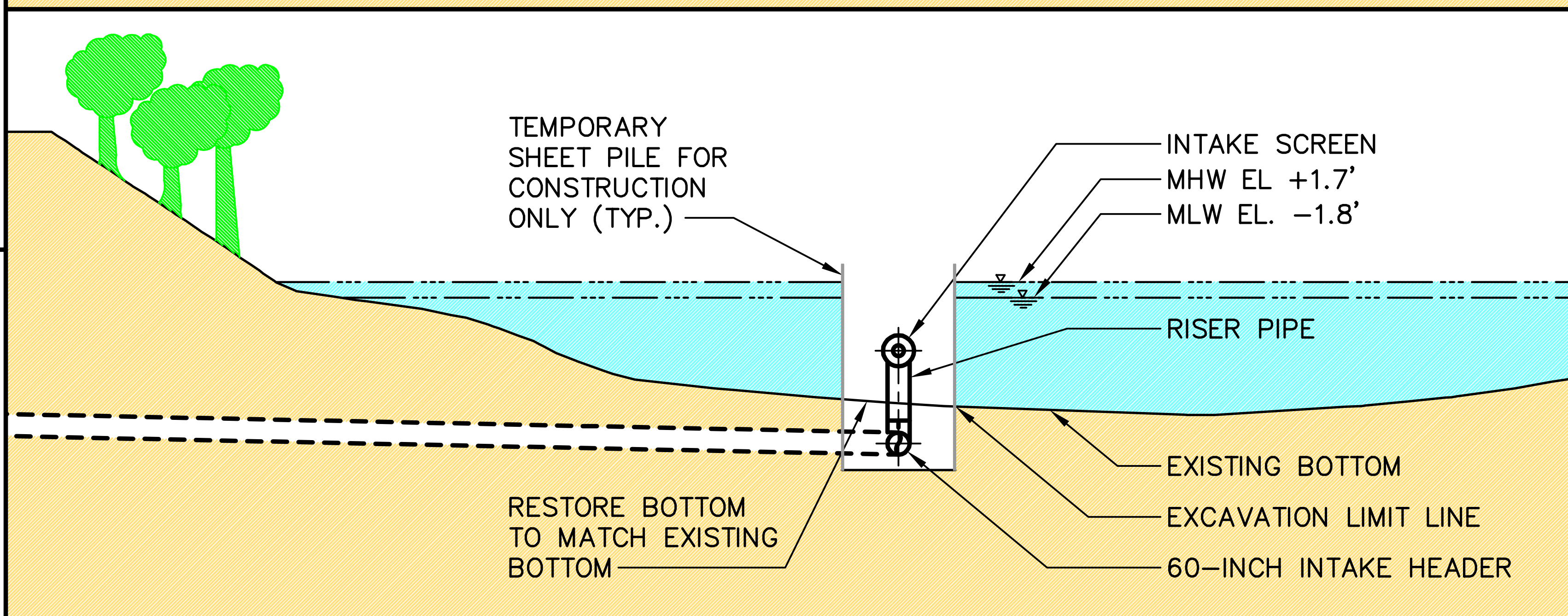
DATUM: NAVD 88 REF: TOPOGRAPHIC: ASC TOPOGRAPHIC MAPPING FROM AERIAL PHOTOGRAPHY BATHYMETRIC: WATERWAY SURVEYS & ENGINEERING LTD SURVEY	**PLAN** MATTAPONI RIVER PUMP STATION EXCAVATION AND FILL PLAN SCALE: 1"=40'	PROPOSED PUBLIC WATER SUPPLY PROJECT COUNTY OF KING WILLIAM & NEW KENT STATE VA APPLICANT CITY OF NEWPORT NEWS SHEET 11 OF 20 DATE 03/05/04



DATUM: NAVD88 REF: BATHYMETRIC SURVEY BY WATERWAY SURVEYS & ENGINEERING LTD.	**PLAN** MATTAPONI RIVER PUMP STATION INTAKE SCREEN ARRAY SCALE: 1"=40'	PROPOSED PUBLIC WATER SUPPLY PROJECT COUNTY OF KING WILLIAM & NEW KENT STATE VA APPLICANT CITY OF NEWPORT NEWS SHEET 12 OF 20 DATE 03/05/04



SECTION A–A



SECTION B–B

DATUM: NAVD88

REF: BATHYMETRIC SURVEY BY WATERWAY SURVEYS & ENGINEERING LTD.

SECTIONS

MATTAPONI RIVER
PUMP STATION
INTAKE SCREEN ARRAY

SCALE: 1"=40'

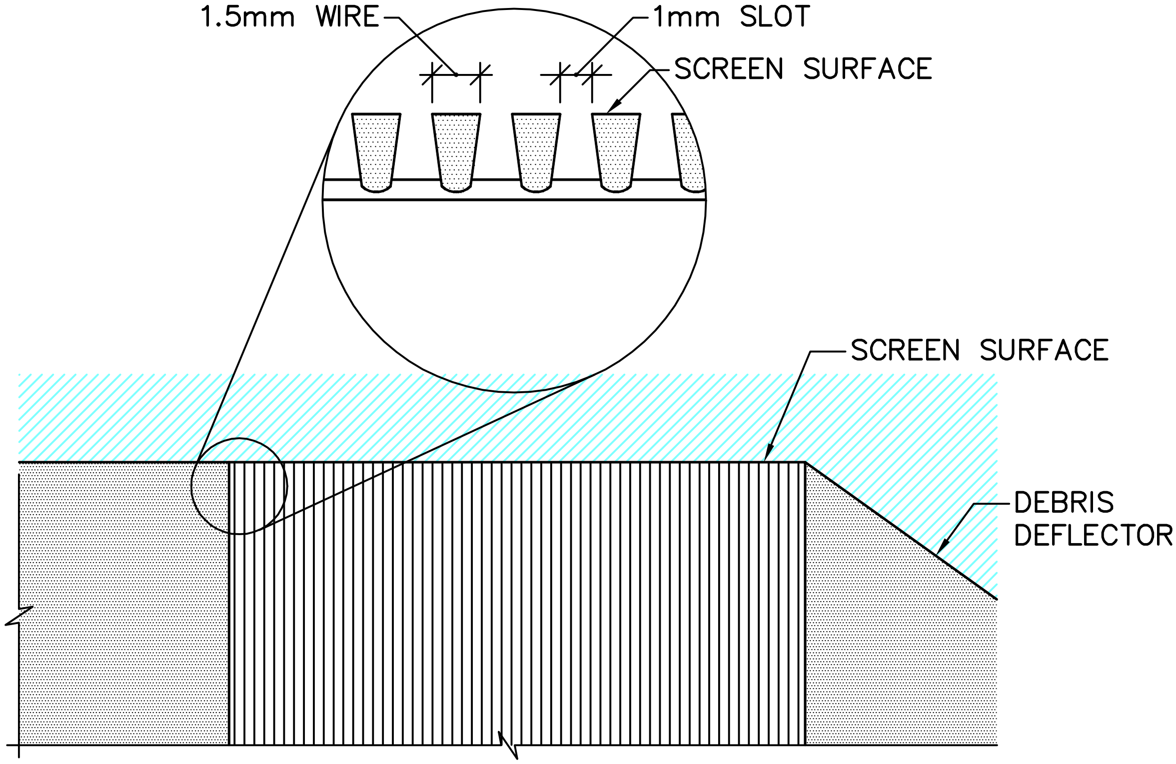
PROPOSED PUBLIC WATER SUPPLY PROJECT

COUNTY OF KING WILLIAM & NEW KENT

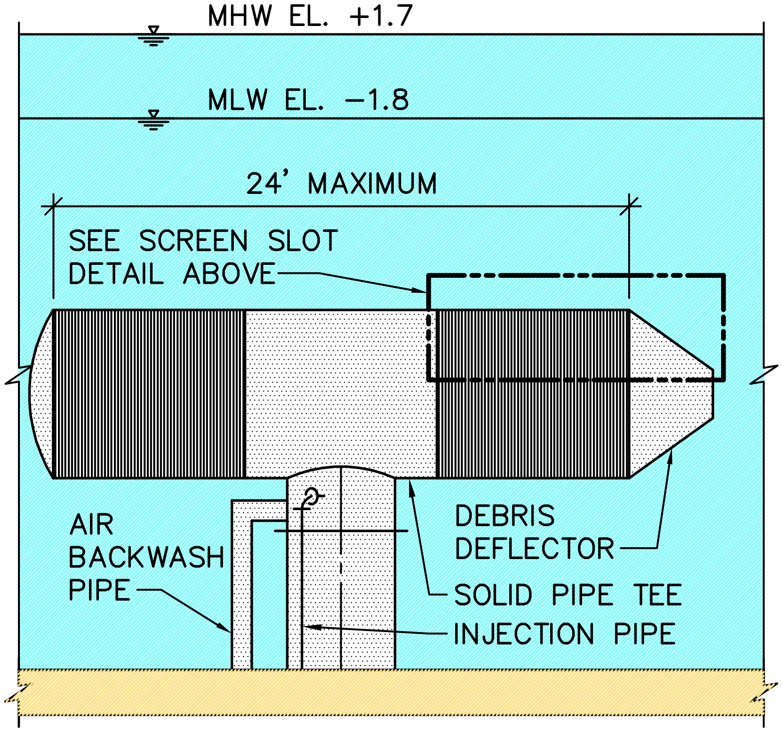
STATE VA

APPLICANT CITY OF NEWPORT NEWS

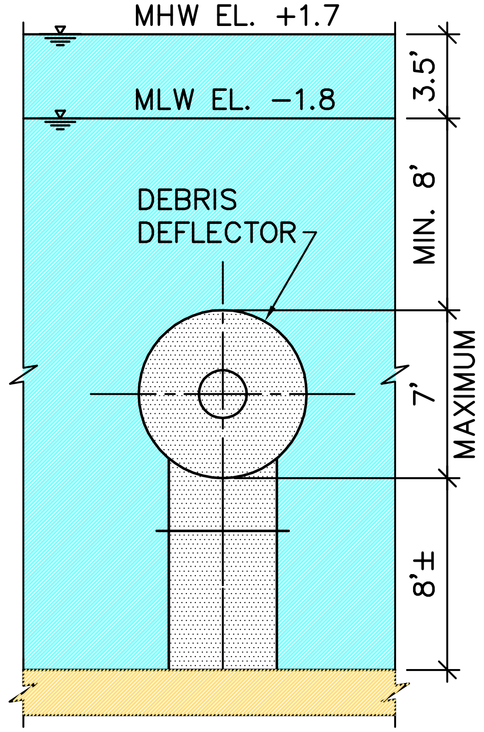
SHEET 13 OF 20 DATE 03/05/04



SCREEN SLOT DETAIL
NOT TO SCALE



SIDE SECTION
SCALE: 1/8" = 1'−0"



END SECTION
SCALE: 1/8" = 1'−0"

DATUM: NAVD 88
REF: USGS 7.5' KING AND QUEEN COURTHOUSE QUADRANGLE

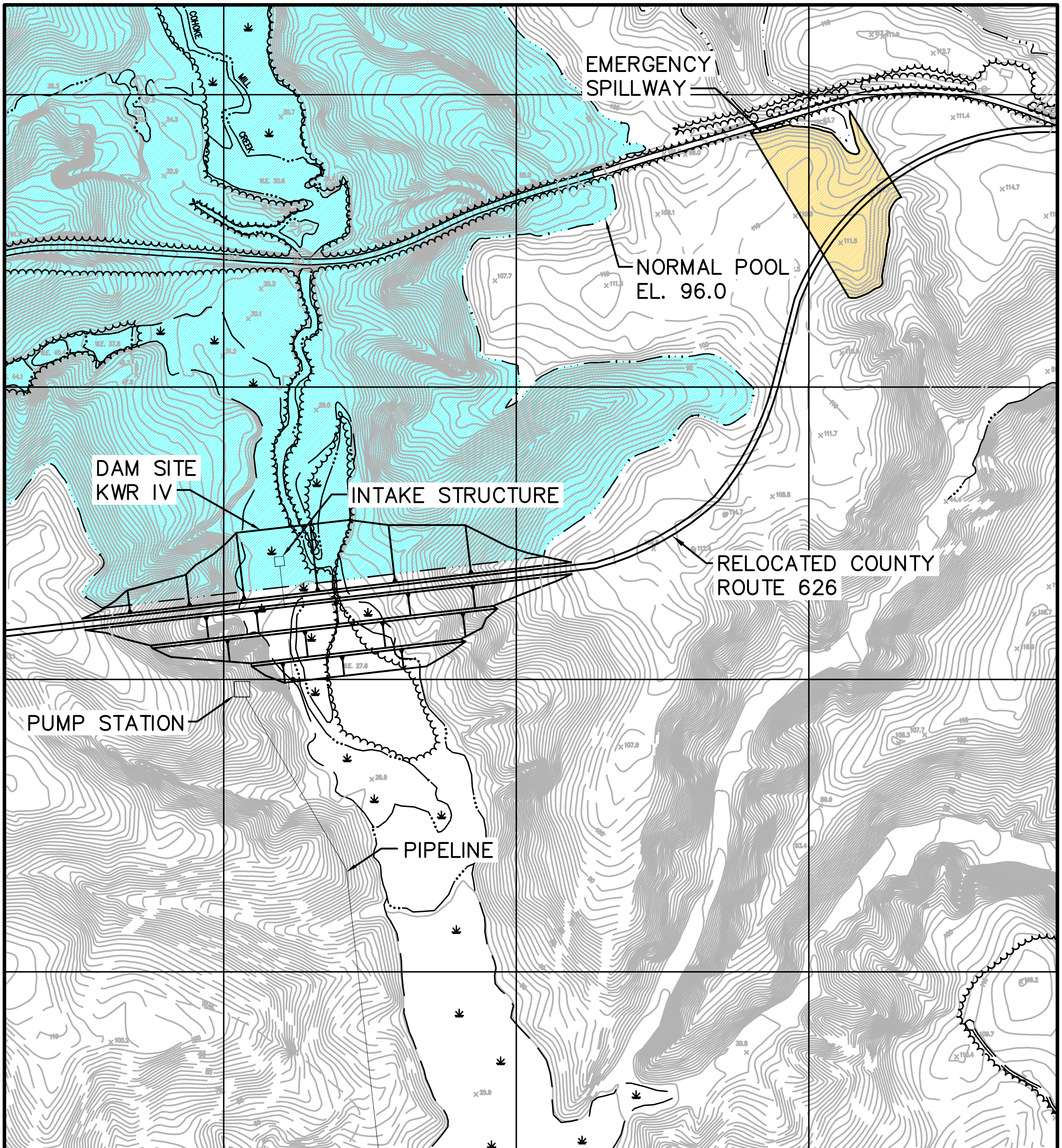
SECTIONS AND DETAILS

MATTAPONI RIVER PUMP STATION
TEE SCREEN ASSEMBLY

SCALE: AS NOTED

PROPOSED PUBLIC WATER SUPPLY PROJECT

COUNTY OF KING WILLIAM & NEW KENT
STATE VA
APPLICANT CITY OF NEWPORT NEWS
SHEET 14 OF 20 DATE 03/05/04



DATUM: NAVD 88

REF: ASC TOPOGRAPHIC MAPPING FROM AERIAL PHOTOGRAPHY

PLAN

KING WILLIAM DAM
AND EMERGENCY SPILLWAY

SCALE: 1" = 500'

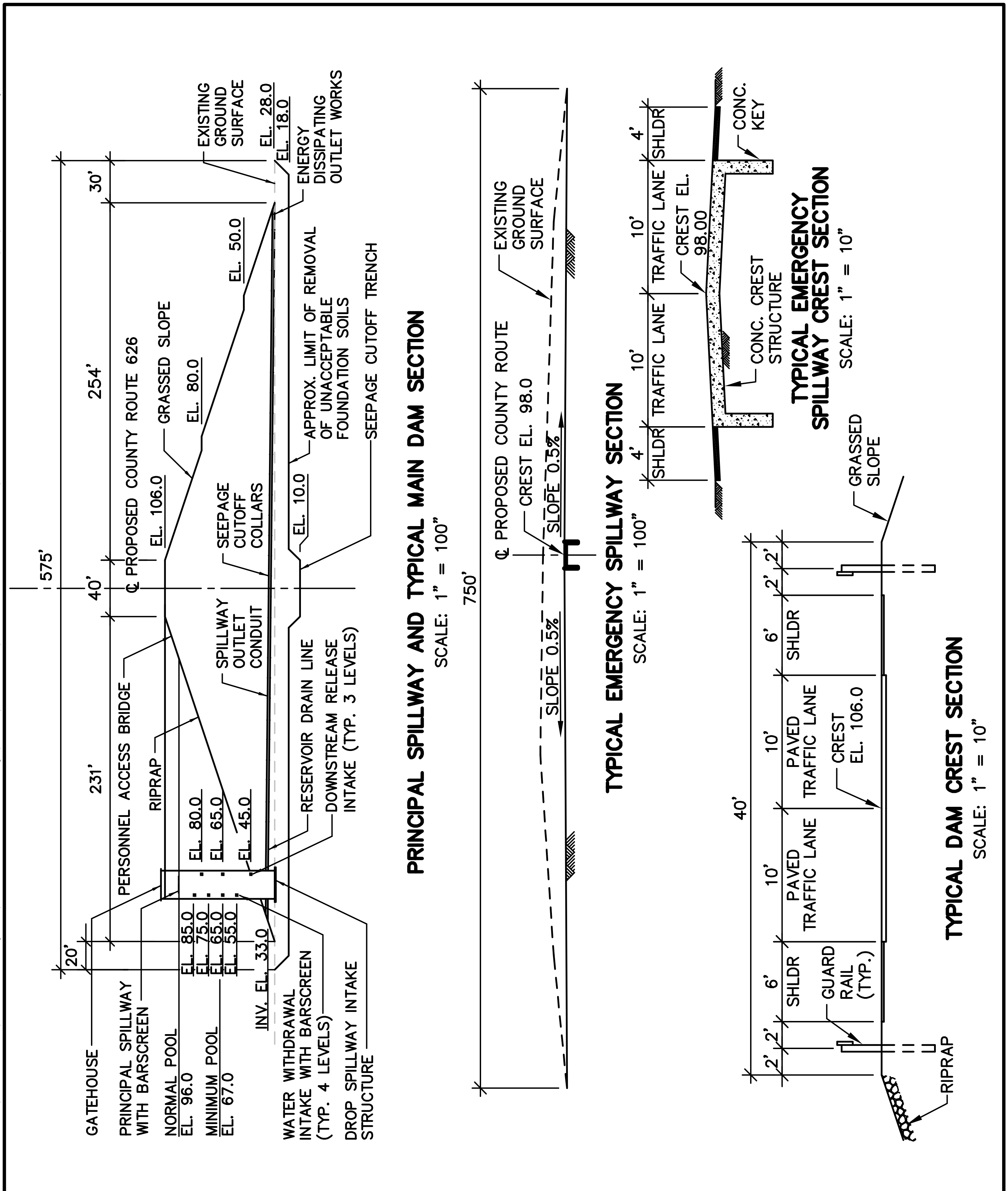
PROPOSED PUBLIC WATER SUPPLY PROJECT

COUNTY OF KING WILLIAM & NEW KENT

STATE VA

APPLICANT CITY OF NEWPORT NEWS

SHEET 15 OF 20 DATE 03/05/04



DATUM:	NAVD 88
REF:	N/A

TYPICAL SECTIONS

KING WILLIAM
DAM AND EMERGENCY
SPILLWAY

SCALE AS NOTED

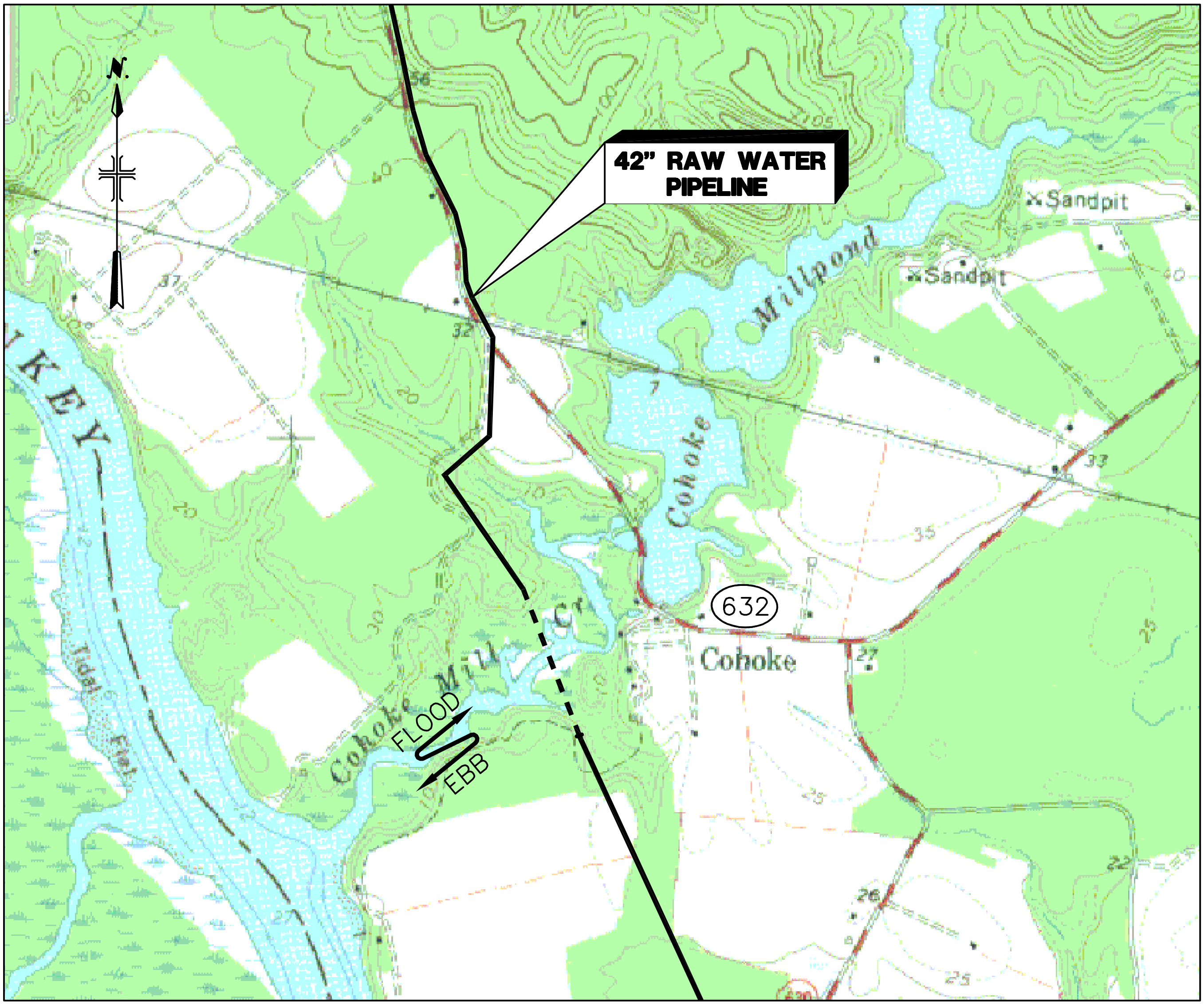
PROPOSED PUBLIC WATER SUPPLY PROJECT

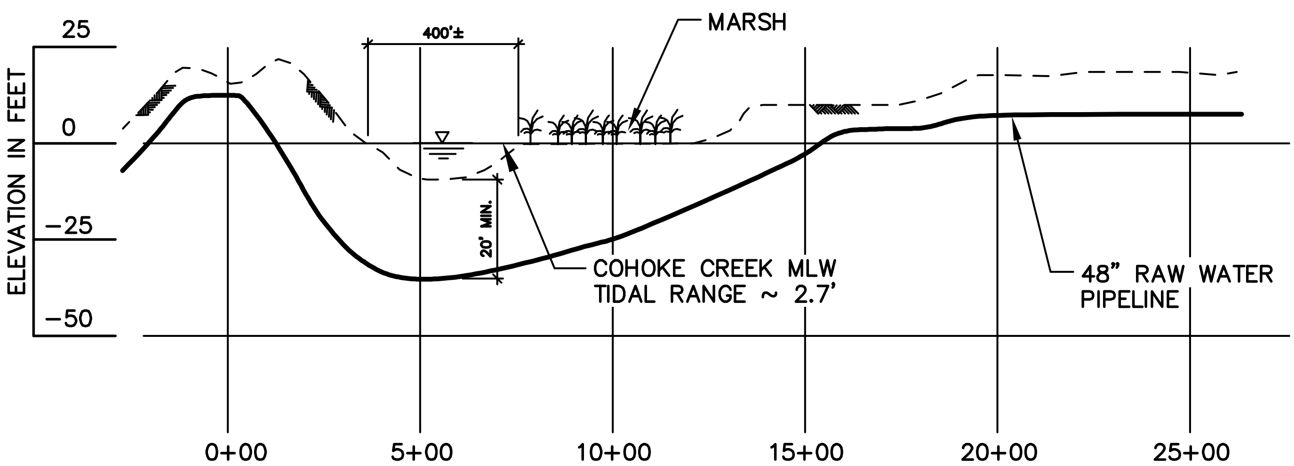
COUNTY OF KING WILLIAM & NEW KENT

STATE VA

APPLICANT CITY OF NEWPORT NEWS

SHEET 16 OF 20 DATE 03/05/04

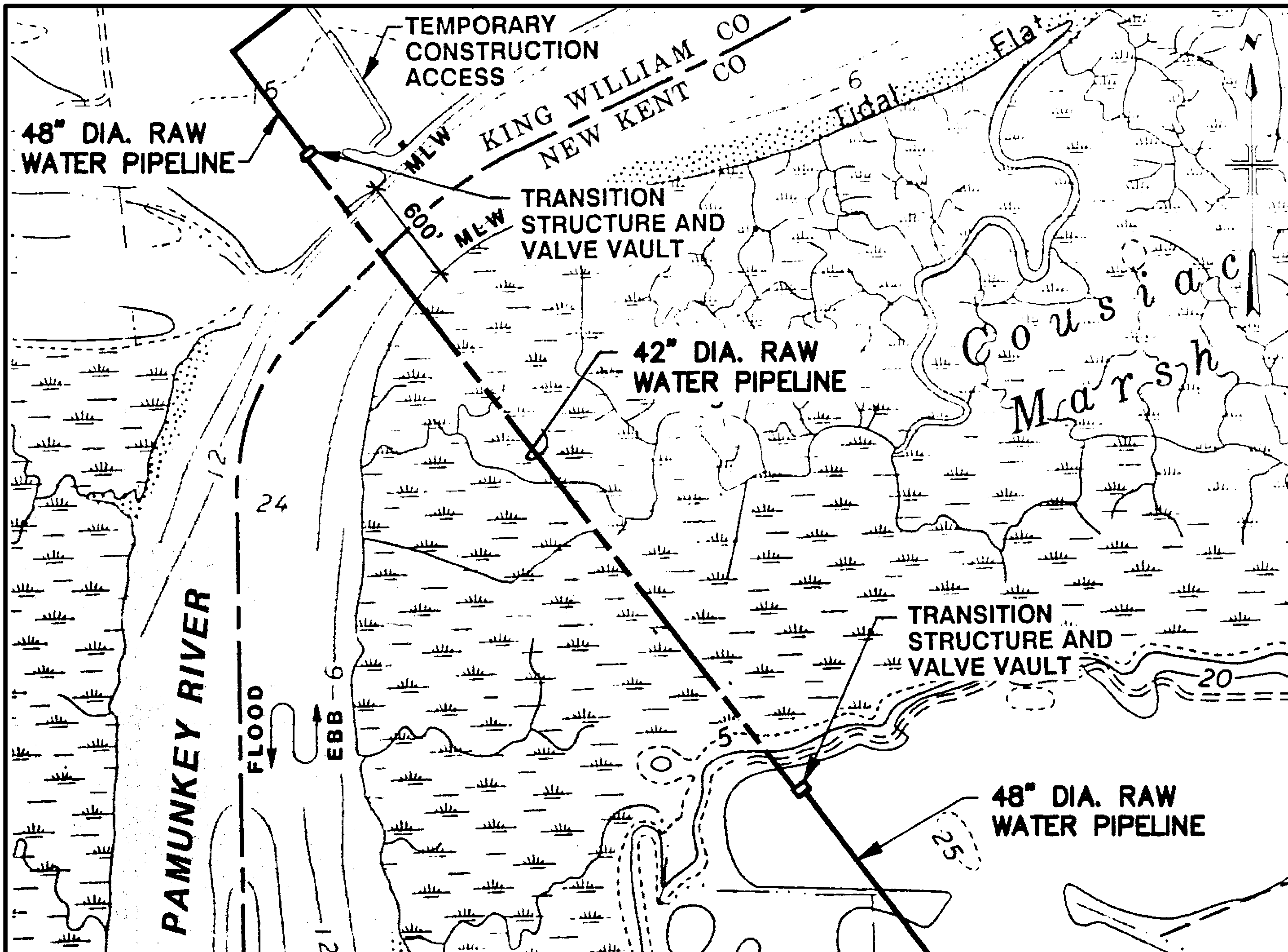


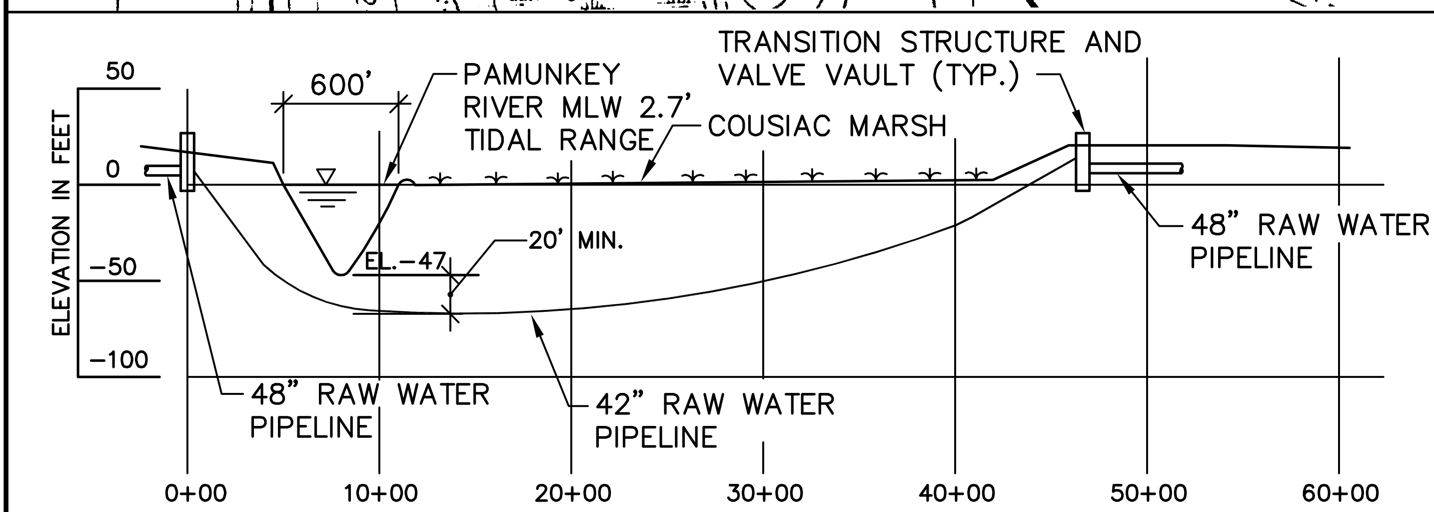


PROFILE

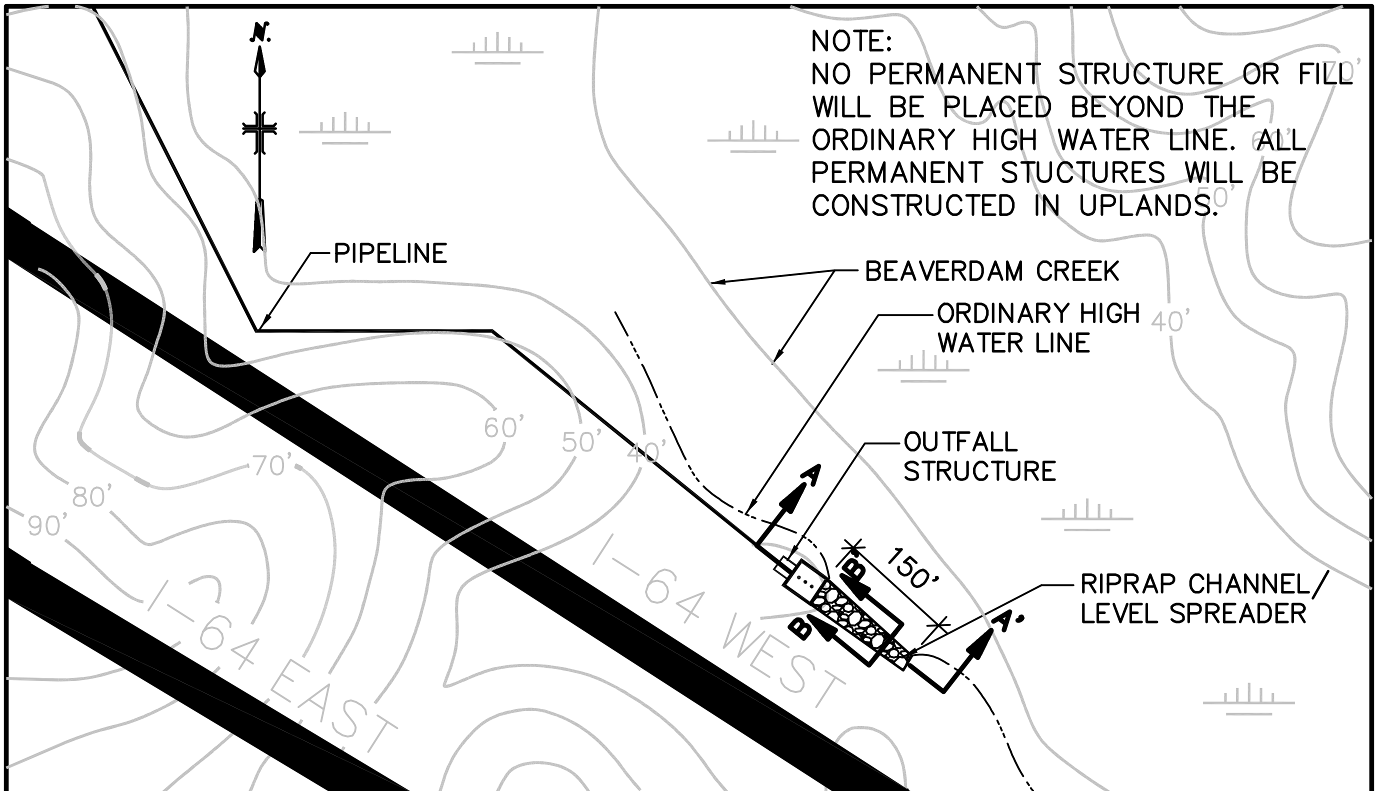
DATUM: MLW – MEAN LOW WATER REF: USGS 7.5' NEW KENT QUADRANGLE (ENLARGED)	**PLAN AND PROFILE** COHOKE MILL CREEK DIRECTIONAL DRILL SCALE: HORIZONTAL: 1" = 500' VERTICAL: 1" = 100'	PROPOSED PUBLIC WATER SUPPLY PROJECT COUNTY OF KING WILLIAM & NEW KENT STATE VA APPLICANT CITY OF NEWPORT NEWS SHEET 17 OF 20 DATE 03/05/04

User: cutler Spec: PIRNIE STANDARD File: L:\3114 – Newport News City of\017 – Raw Water Study\Cadd\J_PERMIT\March 2004 Amendment\SHEET 18.DWG Scale: 1:1 Date: 03/10/2004 Time: 09:24 Layout: Layout1

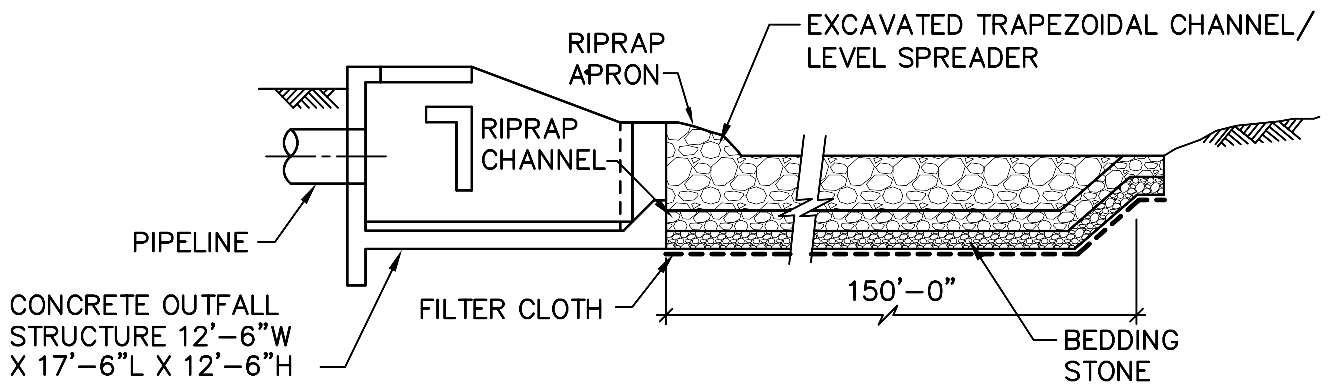




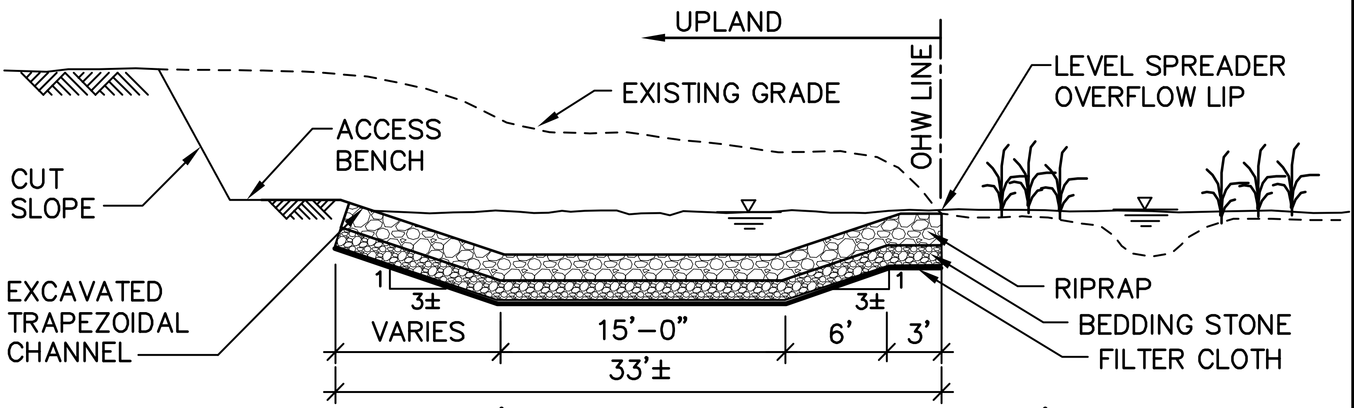
DATUM: USGS & MLW – MEAN LOW WATER REF: USGS 7.5' NEW KENT QUADRANGLE (ENLARGED)	**PLAN AND PROFILE** PAMUNKEY RIVER DIRECTIONAL DRILL SCALE: HORIZ. 1" = 1000' VERT. 1" = 100'	PROPOSED PUBLIC WATER SUPPLY PROJECT COUNTY OF KING WILLIAM & NEW KENT STATE VA APPLICANT CITY OF NEWPORT NEWS SHEET 18 OF 20 DATE 03/05/04



PLAN

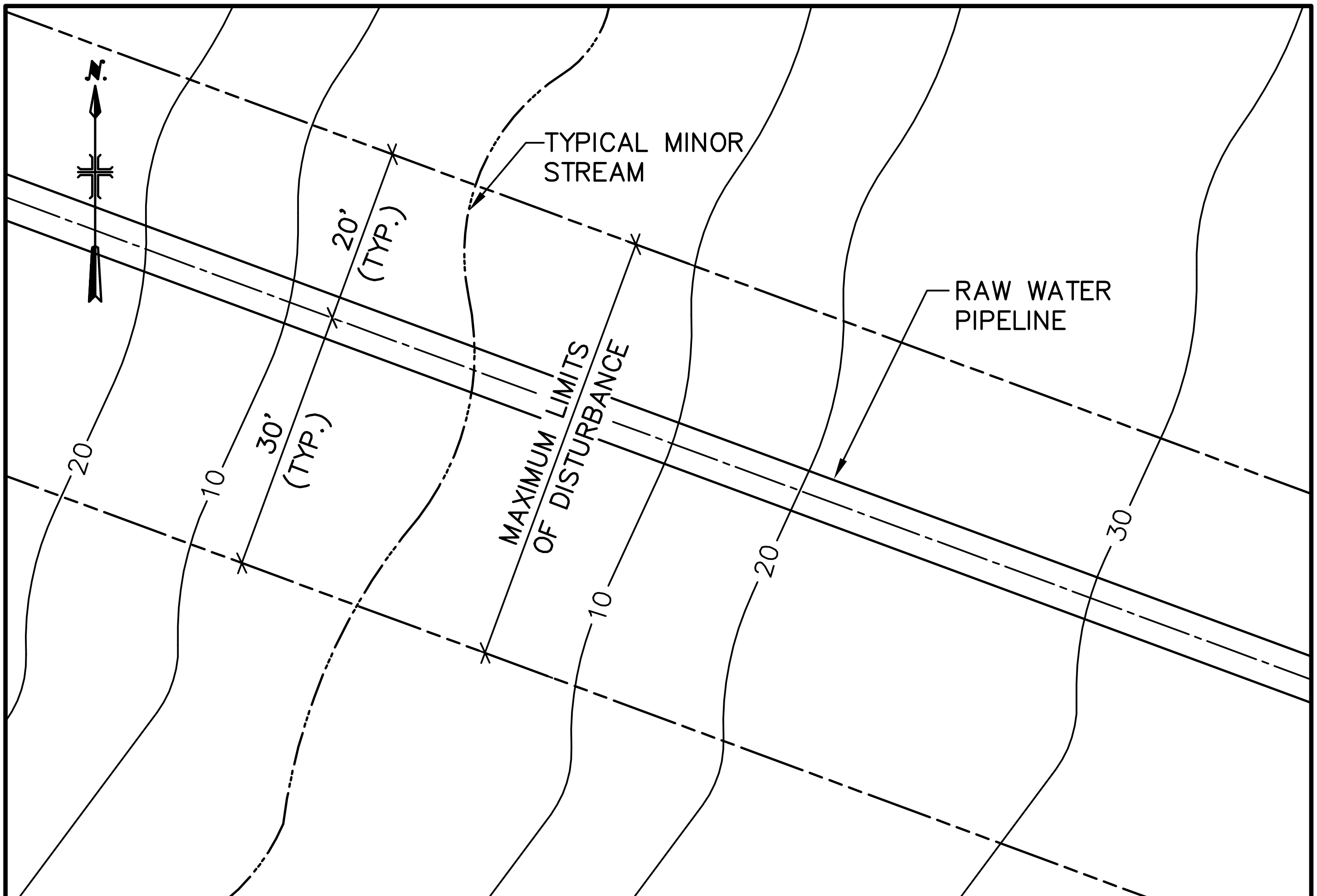


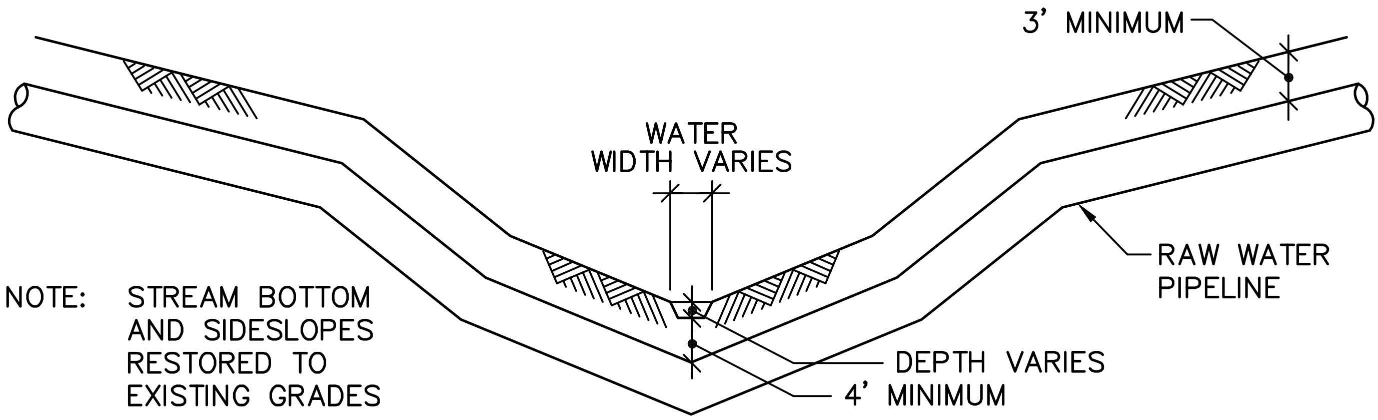
STRUCTURE CROSS-SECTION A-A'



RIPRAP CHANNEL/LEVEL SPREADER CROSS-SECTION B-B'

DATUM: USGS REF: USGS 7.5' WALKERS QUADRANGLE (ENLARGED)	**PLAN AND SECTIONS** BEAVERDAM CREEK OUTFALL STRUCTURE AND LEVEL SPREADER CHANNEL SCALE: PLAN: 1" = 200' SECTIONS: 1" = 10'	PROPOSED PUBLIC WATER SUPPLY PROJECT COUNTY OF KING WILLIAM & NEW KENT STATE VA APPLICANT CITY OF NEWPORT NEWS SHEET 19 OF 20 DATE 03/05/04





DATUM: USGS (ENLARGED)

REF: N/A

PLAN AND SECTION

TYPICAL PIPELINE STREAM CROSSING

SCALE: 1" = 20'

PROPOSED PUBLIC WATER SUPPLY PROJECT

COUNTY OF KING WILLIAM & NEW KENT

STATE VA

APPLICANT CITY OF NEWPORT NEWS

SHEET 20 OF 20 DATE 03/05/04

APPENDIX H

MARINE ACOUSTICS WEDGEWIRE SCREEN SOUND SURVEY

MARINE ACOUSTICS, INC.

4100 Fairfax Drive, Suite 730
Arlington, VA 22203
(703) 465-8404
FAX (703) 465-8420

23 March 2004

Malcolm Pirnie, Inc.
c/o Versar, Inc.
9200 Rumsey Road
Columbia, MD 21045

Attn: Mr. William A. Richkus

Dear Sir:

Please find enclosed the Lake Gaston Pumping Station Noise Measurement Report, with Addendum. The data provided in the Addendum were obtained on 20 March 2004, and confirm our original report conclusions. The Addendum further describes the recent Lake Gaston data collection effort, the data obtained, results and conclusions.

I want to express our sincere appreciation for your consideration and understanding during our very trying experiences with unanticipated equipment problems and seemingly interminable weather delays. We appreciate your business and look forward to the opportunity to work with you in future endeavors.

Please contact Mr. Jim Messegee or myself if you have any questions or comments regarding the enclosed report.

Sincerely,

C. H. Spikes

Clayton, H. Spikes
Chief Operating Officer

Encl: Lake Gaston Pumping Station Noise Measurement Report

Background:

Marine Acoustics, Inc., was contacted to measure the acoustic levels at the Lake Gaston pumping station. These measurements will be used as a measure of acoustic levels expected at the proposed King William Reservoir pumping station. This type of acoustic measurement must first assess the background ambient noise and then determine the acoustic levels above the ambient noise. Since ambient noise can be expected to vary from site to site, several sites clear of the intake screens must be measured to determine a reasonable average background level to determine the pumping station contribution.

The proposed King William Reservoir will employ a water intake using 1 mm (0.04 in) mesh wedgewire screens, 7-ft diameter, that will be situated in the middle of the water column. The pumps will be located on land. The screens will be cleaned by infrequent 15-second air bursts. An issue was raised concerning the potential effects on fish, particularly American shad, from underwater noises associated with the operation of this water withdrawal system. No data are available on the frequency and level of sounds produced by water being withdrawn through wedgwire screens or by the air bursts used to clean the screens.

To assess the potential impacts of sounds generated by the proposed King William Reservoir pumping station, the frequency and level of sounds produced at a similar facility were measured and analyzed. The facility selected for these measurements was the Lake Gaston pumping station, located in Virginia on the shores of Lake Gaston at Pea Hill Creek. Figure 1 shows the facilities location (http:www.mapquest.com).

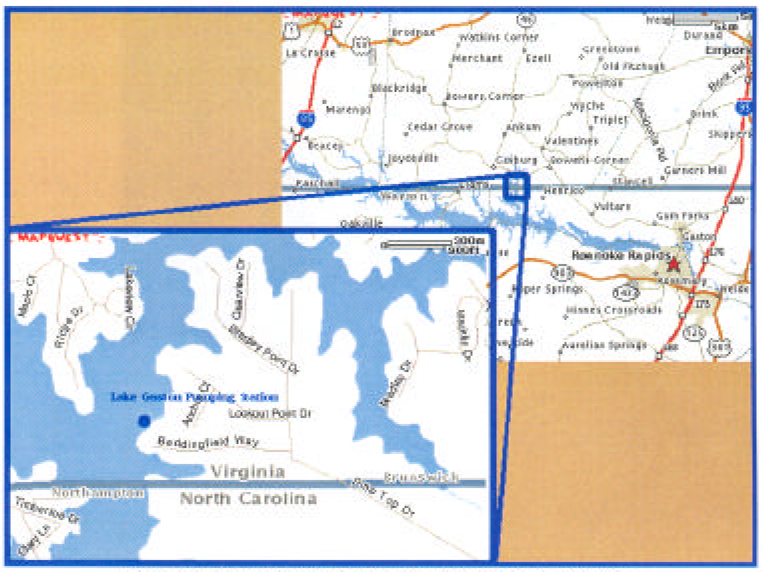


Figure 1: Map of Lake Gaston Pumping Station Location

The following specific data regarding the pumping station's equipment and operations were extracted from the Virginia Beach Public Utilities web site (http://www.vbgov.com/dept/putility/gaston/lg-facilities.asp#).

The pumping station contains six vertical-turbine centrifugal pumps. Five of the six pumps are dual-speed, 500/1250 horsepower pump and motor combinations operating at 4,000 volts AC (VAC). The nominal capacity of each of these five pumps is approximately 10 million gallons per day (mgd) at low speed (900 rpm) and 15 mgd at high speed (1200 rpm). The sixth pump is a 250 horsepower, 440 VAC pump and motor combination that can deliver 4 to 8 mgd. This pump is used for filling the line and for maintaining small flows when larger flows are not necessary. During the data collection this was the only pump being operated at a flow rate of 8 mgd.

The pumping station is based upon a flooded wetwell design. Underneath the pump station is a large, deep basement (i.e., a wetwell), the bottom of which is some 35 ft below the normal pool level of the lake. Two 60 in diameter pipelines connect the wetwell to a series of intake screens, several hundred feet offshore. Water flows through the intake screens and into the wetwell until the water elevation in the wetwell is the same elevation as the lake (hence the term "flooded wetwell"). Vertical-turbine centrifugal pumps, which extend down into the wetwell, pump the water from the wetwell into the pipeline.

The top of the intake screens are 15 ft below the normal pool level of the lake. The screen size is 1 mm (0.04 in), which is slightly less than the thickness of a dime. Maximum velocity at the screen surface is 0.5 ft/sec (one-third of a mile per hour). One inch away from the screen surface the maximum velocity is 0.17 ft/sec (one-tenth of a mile per hour). These maximum velocities exist only when one intake line and one screen array are in service. Most of the time, velocities will be one-half to one-third of the maximum velocities stated above. The withdrawal of water through the intake screens do not disturb the water surface.

The flooded wetwell design for the Lake Gaston pumping station was selected specifically to aid in noise containment. The use of the submerged vertical-turbine pumps keeps much of the noise contained in an underground vault of concrete surrounded by tons of rock and earth. To further reduce noise, maximum allowable noise levels are called out in the motor specifications. The motors installed at the pumping station are among the quietest available for that size and type. Finally, the interior of the pumping station is lined with a special sound-reducing concrete block.

Data Collection

Marine Acoustics, Inc. was charged with obtaining and analyzing sound level measurements at and around the Lake Gaston water withdrawal intake screens. Equipment was set up on 19 February 2004 and data was collected on 20 February 2004. The weather on 20 February was clear. The water surface of the lake was flat calm early in the morning with a very light chop developing as wind speed increased later in the day. Recreational boating activity was very light with only an occasional power boat passing near the site. This infrequent traffic did not impact the data collection effort.

A Model BM 8178-8 wideband, omni-directional underwater hydrophone was used to collect sound level measurements. The frequency response of this hydrophone is from approximately 20 Hz to 200 kHz. The hydrophone itself is a small lead titanate (PZT) spherical sensor. The low-noise hydrophone electronics include a high-pass filter set at 10 Hz to reduce geophysical noise. Calibration curves for the hydrophone are provided in Figure 2.

To prevent aliasing, data from the hydrophone were filtered through a *Frequency Devices, Inc* Model 818 Series 8-Bit Programmable 8-Pole Filter mounted on a *Frequency Dynamics* FMA-04A Single Channel Filter Mounting Assembly. DEP switches on the card's selectable low pass filter were set to filter out sound above 180 kHz. Two 2.2 kΩ resistors were added to the board to increase gain from unity to 11.10. This setup allowed for digital recording from approximately 20 Hz to 180 kHz (110 Hz to 180 kHz required by statement of work).

Analog to digital conversion was accomplished using a *National Instruments* Model 6062E PCMCIA Data Acquisition Card. This analog input 12-bit card is capable of sampling at 500,000 samples per second.

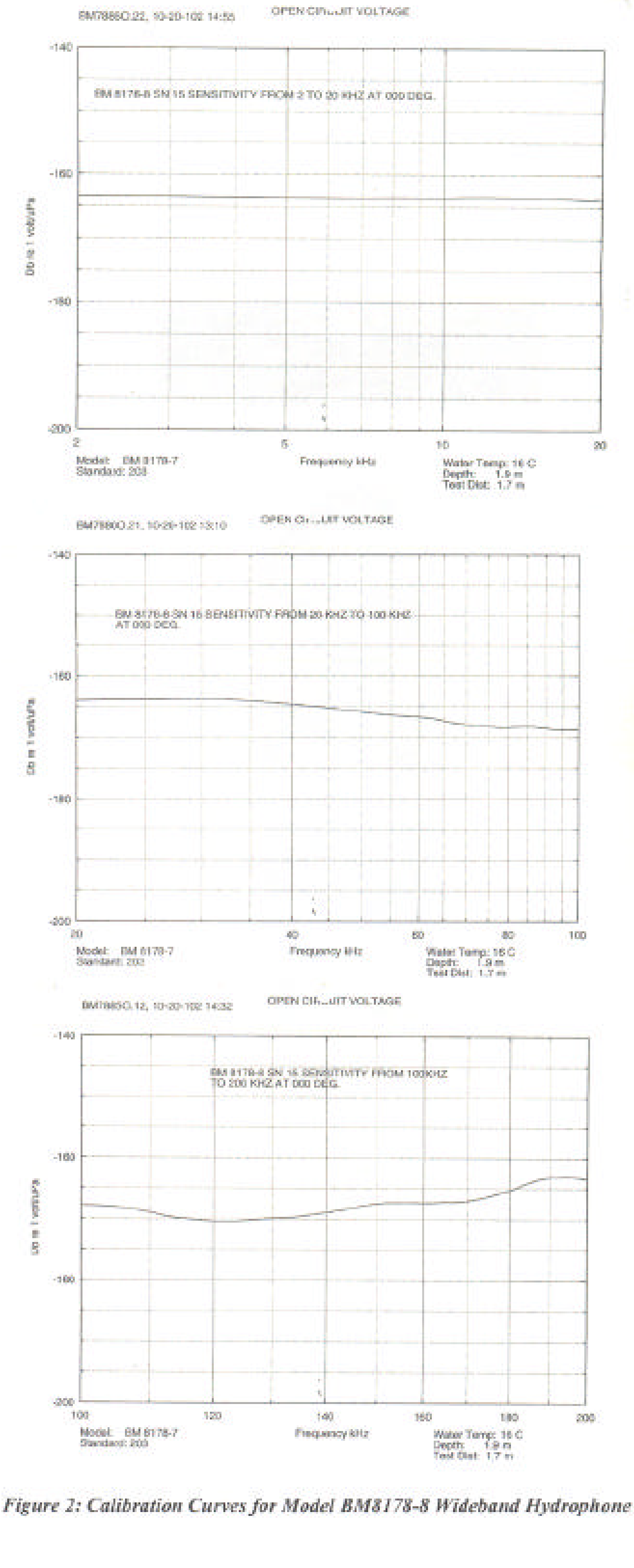


Figure 2: Calibration Curves for Model BM8178-8 Wideband Hydrophone

Sound level measurements were recorded on a Dell Inspiron 7500 laptop computer running the Windows 2000 Operating System. *Ishmael,* a sound recording and analyzing program jointly developed by the Office of Naval Research and the National Marine Fisheries Service, was used as the computer record interface. Data were recorded in WAV File format at 360 samples per second. The laptop computer's built in microphone was disabled to eliminate the possibility of airborne noise contaminating the data. The complete equipment setup is shown in Figure 3.

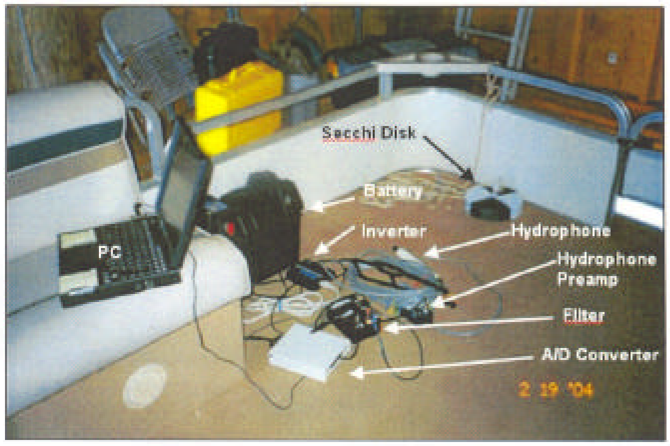


Figure 3: Equipment Setup

Initially, background (ambient) noise measurements were obtained at 5 sites not in the immediate vicinity of the withdrawal intake. The first of these sites was just outside the pumping station boathouse about 50 yds from the water intake screen. Two additional sites were in small inlets adjacent to the water intake screen basin; thus, not in a direct line from the screens. Two other measurements were taken across the basin from the intake screen at a distance of about a quarter mile. For record purposes, photographs were taken of these sites (Figure 4).

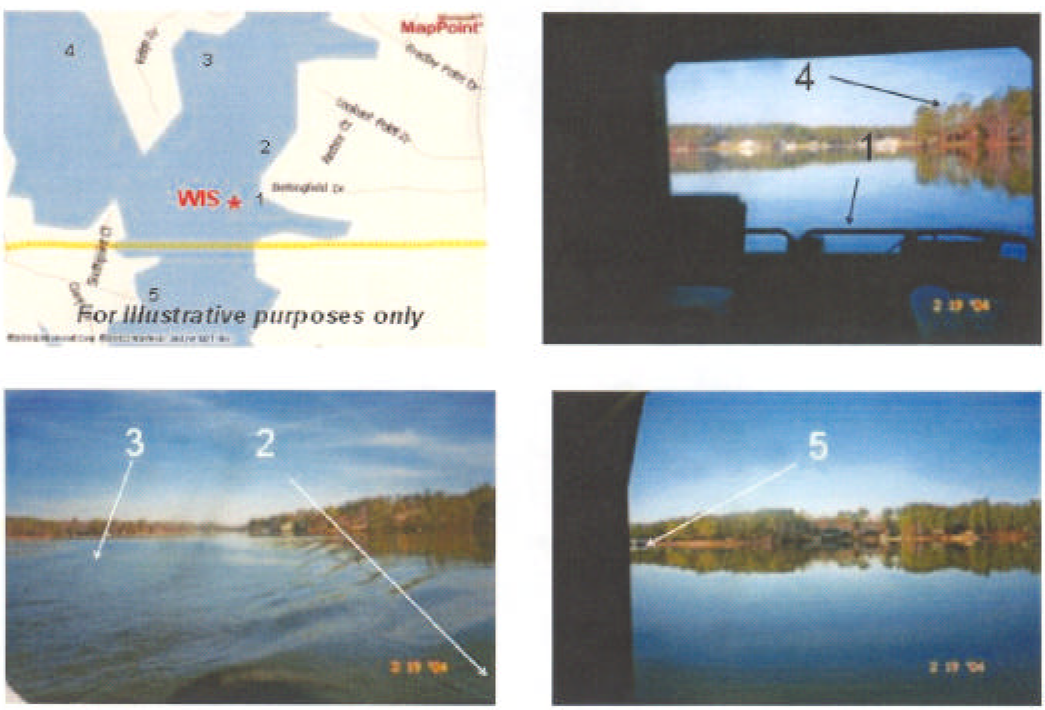


Figure 4: Ambient Noise Measurement Sites

Actual water intake screen sound measurements were recorded along three transects: one vertical (from the surface down, in front of the intake screens), one axial (outbound from the entrance screens along the axis of the intake pipes), and one perpendicular (across the axis of the intake pipes). Measurements were made at regular intervals along each transect Prior to data collection, a deployable range consisting of 100 and 200 ft sections of polypropylene line, marked at 5 ft intervals was constructed and deployed on Lake Gaston. At each data collection site, both range positions and GPS positions (using a Garman Model 76 GPS) were recorded.

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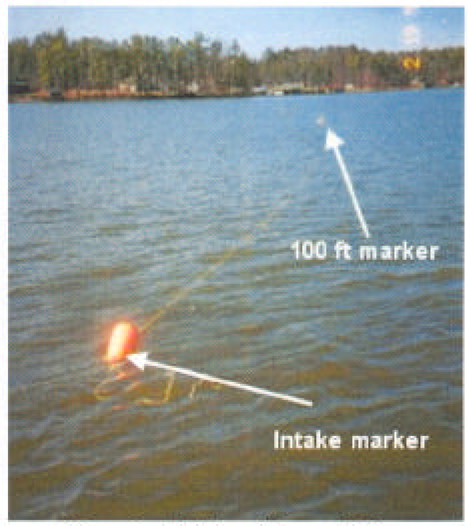

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Collection of sound measurements along the transect across the water intake opening was complicated by increasing wind speed. The wind made it difficult for the pumping station's pontoon boat to maintain position (engine was shut down and anchor was dragging). Because the wind was blowing directly down the transect line, it was determined that the best way to proceed was to record data as the boat drifted down the line. During the drift, data were continuously recorded and precise times and positions were logged. As on the other transects, no measurements were observed to be at higher intensity than those recorded at the ambient noise sites.

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Temperature, using a digital probe, and turbidity measurements, using a Secchi disk, were taken at all data recording sites. A summary of the data collected by sites is provided in Figure 6.

Point	Grid Location (ft)			Recorded GPS Location			Data directory/file name	Record Time Mark	SECHI Depth	Temp °F	Remarks
	X	Y	Z	Latitude	Longitude	Accuracy					
Intake location	0	0	-17.5								
Ambient Noise 1	N/A	N/A	N/A	36-32.809N	077-51.802	41.2 ft	C:\Program Files\Ishmael\Bin\Amb Noise\1.wav	N/A	N/A	40.9°F	in boathouse
Ambient Noise 2	N/A	N/A	N/A	36-32.886N	077-51.763W	14.9 ft	C:\Program Files\Ishmael\Bin\Amb Noise\2.wav	N/A	6-7 ft	41.2°F	calm, no boat traffic
Ambient Noise 3	N/A	N/A	N/A	36-32.996N	077-51.832W	16.8 ft	C:\Program Files\Ishmael\Bin\Amb Noise\3.wav	N/A	5ft	42.7°F	calm, boat passed at 250 - 300 yards
Ambient Noise 4	N/A	N/A	N/A	36-32.966N	077-52.104W	17.3 ft	C:\Program Files\Ishmael\Bin\Amb Noise\4.wav	N/A	5 ft	42.1°F	calm, no boat traffic
Ambient Noise 5	N/A	N/A	N/A	36-32.680N	077-51.912W	17.2 ft	C:\Program Files\Ishmael\Bin\Amb Noise\5.wav	N/A	5ft	41.6°F	calm, boat passed at ~100 yards
Vertical transect 1	1	0	-5	36-32.789N	077-51.830W	15.6 ft	C:\Program Files\Ishmael\Bin\Vertical\1.wav	N/A	5 ft	42.3°F	light breeze (<5 knots), no boat traffic
Vertical transect 2	1	0	-10	36-32.791N	077-51.829W	23.9 ft	C:\Program Files\Ishmael\Bin\Vertical\2.wav	N/A	5ft	42.3°F	light breeze (<5 knots), no boat traffic
Vertical transect 3	1	0	-15	36-32.792N	077-51.830W	37.9 ft	C:\Program Files\Ishmael\Bin\Vertical\3.wav	N/A	5 ft	42.3°F	light breeze (<5 knots), no boat traffic
Vertical transect 4	1	0	-17.5	36-32.792N	077-51.829W	16.5 ft	C:\Program Files\Ishmael\Bin\Vertical\4.wav	N/A	5 ft	42.3°F	light breeze (<5 knots), no boat traffic
Vertical transect 5	1	0	-20	36-32.791N	077-51.831W	20.7 ft	C:\Program Files\Ishmael\Bin\Vertical\5.wav	N/A	5 ft	42.3°F	light breeze (<5 knots), no boat traffic
Vertical transect 6	1	0	-25	36-32.792N	077-51.829W	20.9 ft	C:\Program Files\Ishmael\Bin\Vertical\6.wav	N/A	5 ft	42.3°F	light breeze (<5 knots), no boat traffic
Axial transect 1	1	0	-17.5	36-32.792N	077-51.829W	16.6 ft	C:\Program Files\Ishmael\Bin\Axial\1.wav	N/A	5 ft	42.3°F	copy of vertical transect 4
Axial transect 2	5	0	-17.5	36-32.792N	077-51.830W	20.0 ft	C:\Program Files\Ishmael\Bin\Axial\2.wav	N/A	6 ft	42.3°F	5 - 10 kts of wind, no boat traffic
Axial transect 3	10	0	-17.5	36-32.793N	077-51.836W	25.6 ft	C:\Program Files\Ishmael\Bin\Axial\3.wav	N/A	5ft	42.3°F	5 - 10 kts of wind, no boat traffic
Axial transect 4	20	0	-17.5	36-32.799N	077-51.838W	32.9 ft	C:\Program Files\Ishmael\Bin\Axial\4.wav	N/A	5 ft	42.3°F	5 - 10 kts of wind, no boat traffic
Axial transect 5	30	0	-17.5	36-32.813N	077-51.843W	20.4 ft	C:\Program Files\Ishmael\Bin\Axial\5.wav	N/A	5 ft	42.3°F	5 - 10 kts of wind, no boat traffic
Axial transect 6	40	0	-17.5	36-32.810N	077-51.847W	19.5 ft	C:\Program Files\Ishmael\Bin\Axial\6.wav	N/A	5 ft	42.3°F	5 - 10 kts of wind, no boat traffic
Axial transect 7	50	0	-17.5	36-32.806N	077-51.849E	15.6 ft	C:\Program Files\Ishmael\Bin\Axial\7.wav	N/A	5 ft	42.3°F	5 - 10 kts of wind, no boat traffic
Axial transect 8	75	0	-17.5	36-32.803N	077-51.861E	23.7 ft	C:\Program Files\Ishmael\Bin\Axial\8.wav	N/A	5 ft	42.3°F	5 - 10 kts of wind, no boat traffic
Axial transect 9	100	0	-17.5	36-32.806N	77-61.864N	22.3 ft	C:\Program Files\Ishmael\Bin\Axial\9.wav	N/A	5 ft	42.3°F	5 - 10 kts of wind, no boat traffic
Transverse transect 1	20	100	-17.5	36-32.797N	077-51.835W	19.5 ft	C:\Program Files\Ishmael\Bin\Transverse\1.wav	0 Sec	5 ft	42.3°F	10 - 15 kts of wind, no boat traffic, Note 1
Transverse transect 2	20	50	-17.5	36-32.783N	077-51.831W	22.3 ft	C:\Program Files\Ishmael\Bin\Transverse\1.wav	18 sec	5 ft	42.3°F	10 - 15 kts of wind, no boat traffic, Note 1
Transverse transect 3	20	0	-17.5	36-32.788N	077-51.836W	24.9 ft	C:\Program Files\Ishmael\Bin\Transverse\1.wav	37 sec	5 ft	42.3°F	10 - 15 kts of wind, no boat traffic, Note 1
Transverse transect 4	20	-50	-17.5	36-32.797N	077-51.836W	27.0 ft	C:\Program Files\Ishmael\Bin\Transverse\2.wav	0 sec	5 ft	42.3°F	10 - 15 kts of wind, no boat traffic, Note 1
Transverse transect 5	20	-100	-17.5	36-32.802N	077-51.836W	31.4 ft	C:\Program Files\Ishmael\Bin\Transverse\2.wav	35 sec	5 ft	42.3°F	10 - 15 kts of wind, no boat traffic, Note 1
Note 1:	Continuous data recorded while drifting between transect points										

Figure 6: Lake Gaston Data Collection

Analysis of Sound Field

Analysis of the frequency spectrum and intensity of the water intake acoustic field was conducted at the technical offices of Marine Acoustics, Inc. in Arlington, Virginia. Specifically, collected noise samples were analyzed in 1-octave frequency bands to determine the received level referenced to 1 microPascal in each band. The same analysis technique was used for both ambient noise measurements and measurements along the transect lines. The recorded voltage was modified to account for the hydrophone calibration and the gain in the pre-amplifier and two amplifier stages of the system. The measurement of the acoustic energy from the air burst was made about fifty yds from the intake screen. To determine the acoustic intensity at the screen, spherical spreading was assumed with a transition to cylindrical spreading at two times the water depth. This resulted in an additional 18 dB being added to the measured readings. Underwater acoustic intensity is by custom stated in dB relative to 1 micro-Pascal. To calculate this metric the calibrated pressure (P) is converted from volts to μPa and then 20 log P = dB level re 1 μPa.

Graphs of frequency and dB level at selected recording points are shown in Figures 7 through 9 below.

Results and Conclusions

There was no recognizable sound produced by the pumping station with the one small pump being operated at a flow rate of 8 mgd. That means any sound from the pumping station was less than the variation in the background noise. Only during the thirty-second activation of the air-burst screen cleaning system was any sound recognizable above ambient noise and this amounted to approximately a 10 dB increase above the ambient noise in the frequency band from 110 Hz to about 2 kHz. Above 2 kHz the air-burst noise faded rapidly with increasing frequency and was within 1 dB of the ambient noise by about 12 kHz.

There were occasionally narrow-band signals at high frequencies (> 40 kHz) that were at magnitudes as much as 10 dB above ambient noise. However, these signals were at higher magnitudes in the ambient noise surveys than in the acoustic transects and therefore are assumed to be unrelated to the pumping station. Figure 7 below shows a typical ambient noise spectrum. The ambient noise is about 85 dB re 1 μPa in the first octave band (100-200 Hz) and decreases by about 6 db per octave from the second to the seventh octave and then decreases by about 3 db from the seventh to ninth octave. The remainder of the spectrum from 50 kHz to 180 kHz is nearly flat. Ignoring a few high-magnitude discrete tones, the variance from site to site was no more than 2.5 dB in any octave. It is concluded by this analysis that the pumping station operating with a single pump at a flow rate of 8 mgd would have no impact on marine life. Moreover, the only acoustic energy from the pumping station that was recognizable above background ambient noise was the air burst cleaning system. Due to the wide frequency band over which the air burst energy is spread, the increase in amplitude of the background ambient noise is small (i.e., on the order of 10 dB at frequencies below 8 kHz) and it is not believed the air burst cleaning system would have any significant impact on marine life. Note the frequency scale is different in the figures shown below. This is done to emphasize the band where interesting phenomena were observed. In Figure 7 the entire frequency band to 180 kHz is shown. This spectrum was very typical of all ambient noise sites as well as the transects.

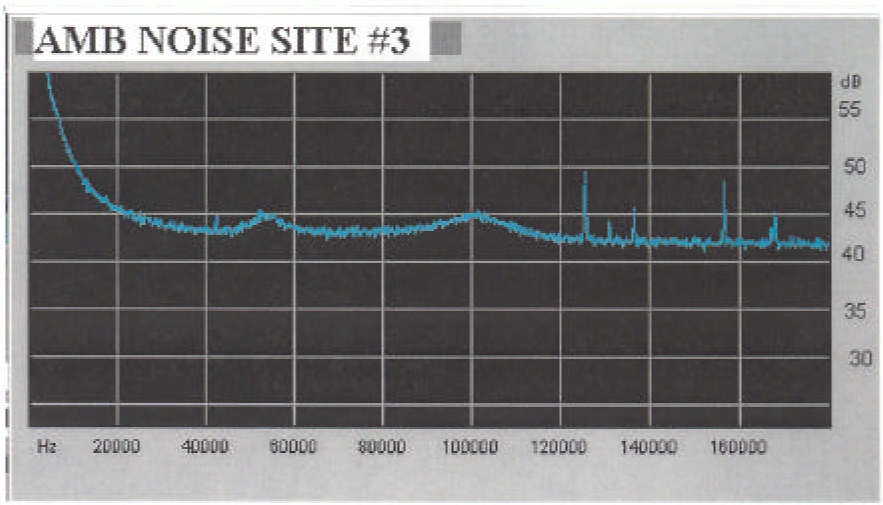

Figure 7. Ambient Noise Spectrum at AMB NOISE SITE 3 (Amplitude in dB re 1μPa).

Figure 8 below shows the spectrum up to 22 kHz. As can be seen, the largest part of the acoustic energy from the air burst cleaning system is at low frequencies. Likewise, Figure 9 is a typical transect spectrum. The high frequency signal shown at about 42 kHz is an unknown tonal not believed to be related to the pumping station.

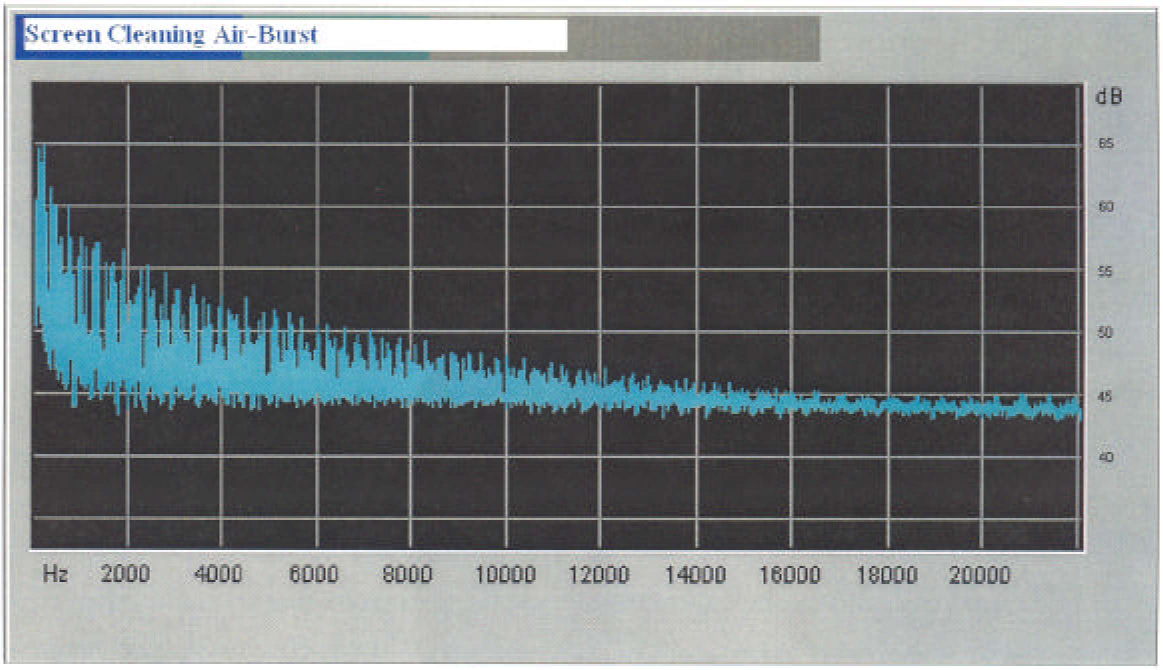

Figure 8. Spectrum of Screen Cleaning Air Burst (Amplitude in dB re 1μPa).

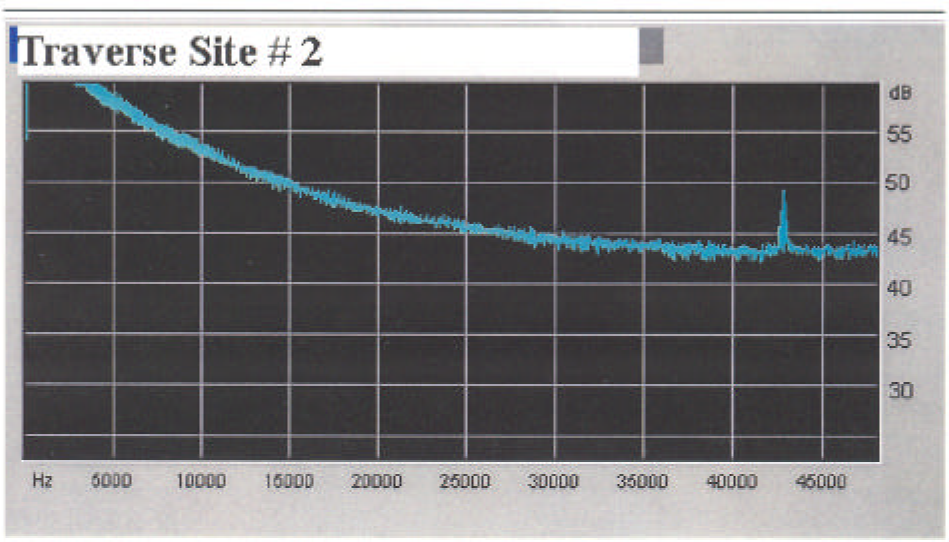

Figure 9. Spectrum of Transect Site #2 (Amplitude in dB re 1μPa).

Recommendations. More measurements could be obtained with one or more large pumps in operation. However, it is not believed to be necessary nor cost-effective due to the extremely good acoustic design of the pumping station. It is believed acoustic detection of the large pumps may be possible if operating at high pumping rates but their acoustic output will still be near the variance seen in the ambient noise and of negligible impact on marine life, particularly when compared to the underwater acoustic energy produced by power boats and jet skis.

Average Ambient Noise Readings by Octave (Average of 15 sites).

Below are the average noise levels for 15 sites rounded to the nearest dB level.

Octave	Frequency Band (Hz)	Average Noise Level (dB re 1 µPa / Hz)
1	100 -200	85
2	200 - 400	82
3	400 - 800	76
4	800 - 1600	70
5	1600-3200	64
6	3200-6400	58
7	6400-12800	52
8	12800-25600	49
9	25600-51200	46
10	51200-102400	43
11	102400-204800	43

MARINE ACOUSTICS, INC.

March 3, 2004

4100 Fairfax Drive, Suite 730
Arlington, VA 22203
(703) 465-8404
FAX (703) 465-8420

Malcolm Pirnie, Inc.
c/o Versar, Inc.
9200 Rumsey Rd.
Columbia, MD 21045

Attn: Mr. William A. Richkus

Dear Sir:

Enclosed is the Lake Gaston Pumping Station Acoustic Survey Report. As you are aware, difficulties in calibrating hardware and software as well as weather delays has made this report overdue. Your patience has been greatly appreciated and please accept our apologies.

The report is largely self-explanatory, however unfortunately a hardware failure prevented the survey from obtaining good high-frequency data (> 50 kHz) for the transects near the intake screens. We believe we have good high frequency data in the ambient noise surveys at some distance from the screens and we don't believe there would be any significant difference near the screens but due to corrupted files we don't have the data to prove that as fact. However, we are completely confident the acoustic levels produced by the pumping station, for the pump configuration measured, will have negligible effect on marine life. Since we only measured the pumping station acoustic output with the smallest pump in operation, we are unable to say with certainty the effect with one or more large pumps operating. However, by extrapolating the data, even with several large pumps operating it is highly unlikely any acoustic level would be reached that would cause any significant negative effect on marine life. By far the largest normal acoustic effects will be the result of surface craft and jet skis.

Our data acquisition system is currently on a task in Hawaii, but if you desire, upon its return we will conduct a high-frequency survey at our expense to fulfill the contract requirements. If this survey could be coordinated with one or more of the large pumps in operation we would have an important extension to the data.

Thank you again for your patience and your business.

Sincerely,

C. H. Spikes

Clayton H. Spikes
Chief Operating Officer

Lake Gaston Pumping Station Noise Measurement

Background.

Marine Acoustics, Inc., was contacted to measure the acoustic levels at the Lake Gaston pumping station. These measurements will be used as a measure of acoustic levels expected at the proposed King William Reservoir pumping station. This type of acoustic measurement must first assess the background ambient noise and then determine the acoustic levels above the ambient noise. Since ambient noise can be expected to vary from site to site, several sites clear of the intake screens must be measured to determine a reasonable average background level to determine the pumping station contribution.

The proposed King William Reservoir will employ a water intake using 1 mm (0.04 in) mesh wedgewire screens, 7-ft diameter, that will be situated in the middle of the water column. The pumps will be located on land. The screens will be cleaned by infrequent 15-second air bursts. An issue was raised concerning the potential effects on fish, particularly American shad, from underwater noises associated with the operation of this water withdrawal system. No data are available on the frequency and level of sounds produced by water being withdrawn through wedge[1]wire screens or by the air bursts used to clean the screens.

To assess the potential impacts of sounds generated by the proposed King William Reservoir pumping station, the frequency and level of sounds produced at a similar facility were measured and analyzed. The facility selected for these measurements was the Lake Gaston pumping station, located in Virginia on the shores of Lake Gaston at Pea Hill Creek. Figure 1 shows the facilities location (http:www.mapquest.com).

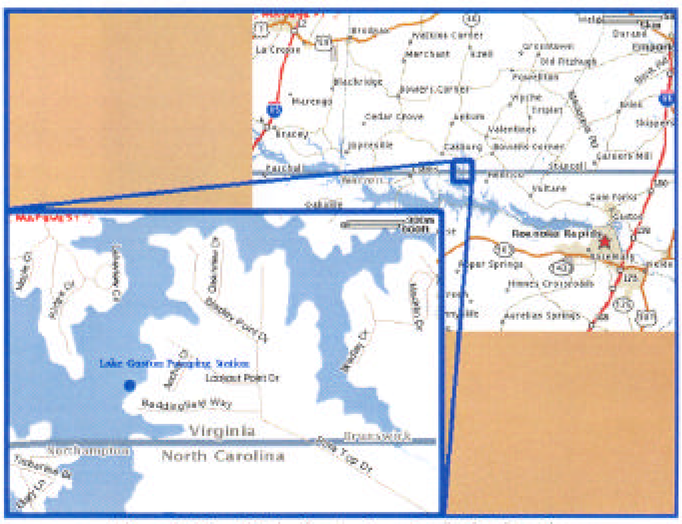

Figure 1: Map of Lake Gaston Pumping Station Location

The following specific data regarding the pumping station's equipment and operations were extracted from the Virginia Beach Public Utilities web site (http://www.vbgov.com/dept/putility/gaston/lg-facilities.asp#). The pumping station contains six vertical-turbine centrifugal pumps. Five of the six pumps are dual-speed, 500/1250 horsepower pump and motor combinations operating at 4,000 volts AC (VAC). The nominal capacity of each of these five pumps is approximately 10 million gallons per day (mgd) at low speed (900 rpm) and 15 mgd at high speed (1200 rpm). The sixth pump is a 250 horsepower, 440 VAC pump and motor combination that can deliver 4 to 8 mgd. This pump is used for filling the line and for maintaining small flows when larger flows are not necessary. During the data collection this was the only pump being operated at a flow rate of 8 mgd.

The pumping station is based upon a flooded wetwell design. Underneath the pump station is a large, deep basement (i.e., a wetwell), the bottom of which is some 35 ft below the normal pool level of the lake. Two 60 in diameter pipelines connect the wetwell to a series of intake screens, several hundred feet offshore. Water flows through the intake screens and into the wetwell until the water elevation in the wetwell is the same elevation as the lake (hence the term "flooded wetwell"). Vertical-turbine centrifugal pumps, which extend down into the wetwell, pump the water from the wetwell into the pipeline.

The top of the intake screens are 15 ft below the normal pool level of the lake. The screen size is 1 mm (0.04 in), which is slightly less than the thickness of a dime. Maximum velocity at the screen surface is 0.5 ft/sec (one-third of a mile per hour). One inch away from the screen surface the maximum velocity is 0.17 ft/sec (one-tenth of a mile per hour). These maximum velocities exist only when one intake line and one screen array are in service. Most of the time, velocities will be one-half to one-third of the maximum velocities stated above. The withdrawal of water through the intake screens do not disturb the water surface.

The flooded wetwell design for the Lake Gaston pumping station was selected specifically to aid in noise containment. The use of the submerged vertical-turbine pumps keeps much of the noise contained in an underground vault of concrete surrounded by tons of rock and earth. To further reduce noise, maximum allowable noise levels are called out in the motor specifications. The motors installed at the pumping station are among the quietest available for that size and type. Finally, the interior of the pumping station is lined with a special sound-reducing concrete block.

Data Collection

Marine Acoustics, Inc. was charged with obtaining and analyzing sound level measurements at and around the Lake Gaston water withdrawal intake screens. Equipment was set up on 19 February 2004 and data were collected on 20 February 2004. The weather on 20 February was clear. The water surface of the lake was flat calm early in the morning with a very light chop developing as wind speed increased later in the day. Recreational boating activity was very light with only an occasional power boat passing near the site. This infrequent traffic did not impact the data collection effort.

A Model BM 8178-8 wideband, omni-directional underwater hydrophone was used to collect sound level measurements. The frequency response of this hydrophone is from approximately 20 Hz to 200 kHz. The hydrophone itself is a small lead titanate (PZT) spherical sensor. The low-noise hydrophone electronics include a high-pass filter set at 10 Hz to reduce geophysical noise. Calibration curves for the hydrophone are provided in Figure 2.

To prevent aliasing, data from the hydrophone were filtered through a *Frequency Devices, Inc* Model 818 Series 8-Bit Programmable 8-Pole Filter mounted on a *Frequency Dynamics* FMA-04A Single Channel Filter Mounting Assembly. DEP switches on the card's selectable low pass filter were set to filter out sound above 180 kHz. Two 2.2 kΩ resistors were added to the board to increase gain from unity to 11.10. This setup allowed for digital recording from approximately 20 Hz to 180 kHz (110 Hz to 180 kHz required by statement of work).

Analog to digital conversion was accomplished using a *National Instruments* Model 6062E PCMCIA Data Acquisition Card. This analog input 12-bit card is capable of 500,000 samples per second.

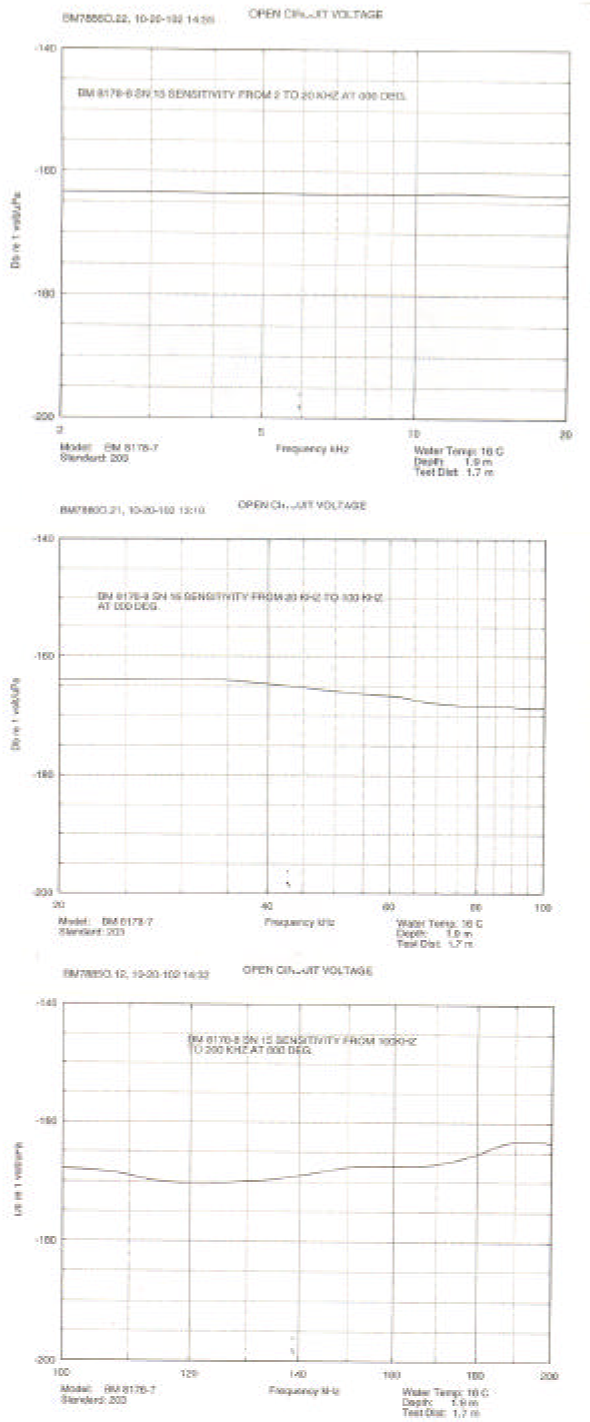

Figure 2: Calibration Curves for Model BM8178-8 Wideband Hydrophone

4

Sound level measurements were recorded on a Dell Inspiron 7500 laptop computer running the Windows 2000 Operating System. *Ishmael,* a sound recording and analyzing program jointly developed by the Office of Naval Research and the National Marine Fisheries Service, was used as the computer record interface. Data were recorded in WAV File format at 360 samples per second. The laptop computer's built in microphone was disabled to eliminate the possibility of airborne noise contaminating the data. The complete equipment setup is shown in Figure 3.

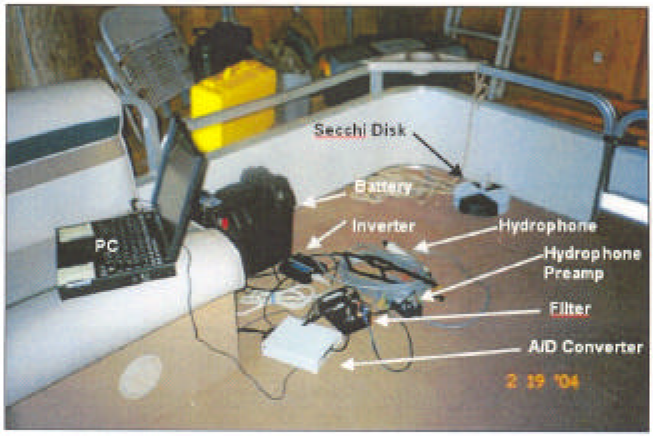

Figure 3: Equipment Setup

Initially, background (ambient) noise measurements were obtained at 5 sites not in the immediate vicinity of the withdrawal intake. The first of these sites was just outside the pumping station boathouse about 50 yds from the water intake screen. Two additional sites were in small inlets adjacent to the water intake screen basin; thus, not in a direct line from the screens. Two other measurements were taken across the basin from the intake screen at a distance of about a quarter mile. For record purposes, photographs were taken of these sites (Figure 4).

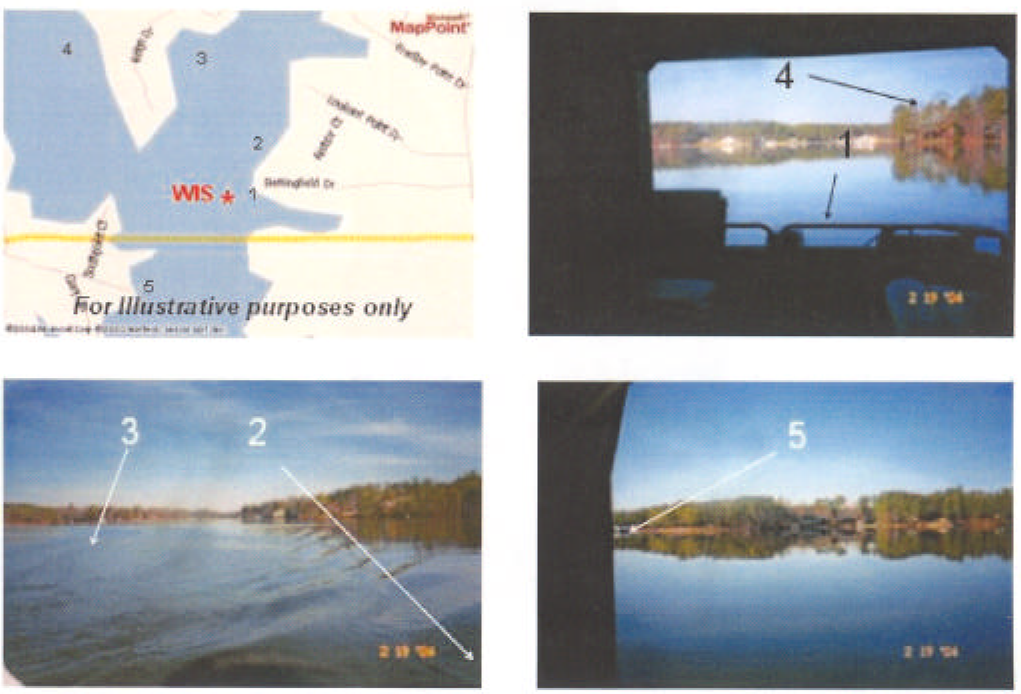

Figure 4: Ambient Noise Measurement Sites

Actual water intake screen sound measurements were recorded along three transects: one vertical (from the surface down, in front of the intake screens), one axial (outbound from the entrance screens along the axis of the intake pipes), and one perpendicular (across the axis of the intake pipes). Measurements were made at regular intervals along each transect. Prior to data collection, a deployable range consisting of 100 and 200 ft sections of polypropylene line, marked at 5 ft intervals was constructed and deployed on Lake Gaston. At each data collection site, both range positions and GPS positions (using a Garman Model 76 GPS) were recorded.

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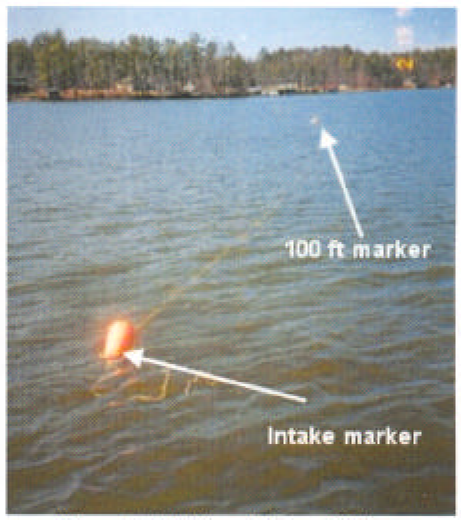

Figure 5: Axial Transit Range Markers

Collection of sound measurements along the transect across the water intake opening was complicated by increasing wind speed. The wind made it difficult for the pumping station's pontoon boat to maintain position (engine was shut down and anchor was dragging). Because the wind was blowing directly down the transect line, it was determined that the best way to proceed was to record data as the boat drifted down the line. During the drift, data were continuously recorded and precise times and positions were logged. As on the other transects, no measurements were observed to be at higher intensity than those recorded at the ambient noise sites.

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Ambient Noise 2	N/A	N/A	N/A	36-32.886N	077-51.763W	14.9 ft	C:\Program Files\Ishmael\Bin\Amb Noise\2.wav	N/A	6-7 ft	41.2°F	calm, no boat traffic
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Ambient Noise 4	N/A	N/A	N/A	36-32.966N	077-52.104W	17.3 ft	C:\Program Files\Ishmael\Bin\Amb Noise\4.wav	N/A	5 ft	42.1°F	calm, no boat traffic
Ambient Noise 5	N/A	N/A	N/A	36-32.580N	077-51.912W	17.2 ft	C:\Program Files\Ishmael\Bin\Amb Noise\5.wav	N/A	5ft	41.6°F	calm, boat passed at ~100 yards
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Vertical transect 3	1	0	-15	36-32.792N	077-51.830W	37.9 ft	C:\Program Files\Ishmael\Bin\Vertical\3.wav	N/A	5 ft	42.3°F	light breeze (<5 knots), no boat traffic
Vertical transect 4	1	0	-17.5	36-32.792N	077-51.829W	16.5 ft	C:\Program Files\Ishmael\Bin\Vertical\4.wav	N/A	5 ft	42.3°F	light breeze (<5 knots), no boat traffic
Vertical transect 5	1	0	-30	36-32.791N	077-51.931W	20.7 ft	C:\Program Files\Ishmael\Bin\Vertical\6.wav	N/A	5 ft	42.3°F	light breeze (<5 knots), no boat traffic
Vertical transect 6	1	0	-25	36-32.792N	077-51.829W	20.9 ft	C:\Program Files\Ishmael\Bin\Vertical\6.wav	N/A	5 ft	42.3°F	light breeze (<5 knots), no boat traffic
Axial transect 1	1	0	-17.5	36-32.792N	077-51.829W	16.5 ft	C:\Program Files\Ishmael\Bin\Axial\1.wav	N/A	5 ft	42.3°F	copy of vertical transect 4
Axial transect 2	5	0	-17.5	36.32.792N	077-51.830W	20.0 ft	C:\Program Files\Ishmael\Bin\Axial\2.wav	N/A	6 ft	42.3°F	5 - 10 kts of wind, no boat traffic
Axial transect 3	10	0	-17.5	36.32.793N	077-51.835W	25.6 ft	C:\Program Files\Ishmael\Bin\Axial\3.wav	N/A	5ft	42.3°F	5 - 10 kts of wind, no boat traffic
Axial transect 4	20	0	-17.5	36.32.799N	077-51.838W	32.9 ft	C:\Program Files\Ishmael\Bin\Axial\4.wav	N/A	5 ft	42.3°F	5 - 10 kts of wind, no boat traffic
Axial transect 5	30	0	-17.5	36-32.813N	077-51.843W	20.4 ft	C:\Program Files\Ishmael\Bin\Axial\5.wav	N/A	5 ft	42.3°F	5 - 10 kts of wind, no boat traffic
Axial transect 6	40	0	-17.5	36-32.810N	077-51.847W	19.5 ft	C:\Program Files\Ishmael\Bin\Axial\6.wav	N/A	5 ft	42.3°F	5 - 10 kts of wind, no boat traffic
Axial transect 7	50	0	-17.5	36-32.805N	077-51.849E	15.6 ft	C:\Program Files\Ishmael\Bin\Axial\7.wav	N/A	5 ft	42.3°F	5 - 10 kts of wind, no boat traffic
Axial transect 8	75	0	-17.5	36-32.803N	077-51.851E	23.7 ft	C:\Program Files\Ishmael\Bin\Axial\8.wav	N/A	5 ft	42.3°F	5 - 10 kts of wind, no boat traffic
Axial transect 9	100	0	-17.5	36-32.805N	77-51.854N	22.3 ft	C:\Program Files\Ishmael\Bin\Axial\9.wav	N/A	5 ft	42.3°F	5 - 10 kts of wind, no boat traffic
Transverse transect 1	20	100	-17.5	36-32.797N	077-51.829W	19.5 ft	C:\Program Files\Ishmael\Bin\Transverse\1.wav	0 Sec	5 ft	42.3°F	10 - 15 kts of wind, no boat traffic, Note 1
Transverse transect 2	20	50	-17.5	36-32.783N	077-51.831W	22.3 ft	C:\Program Files\Ishmael\Bin\Transverse\1.wav	18 sec	5 ft	42.3°F	10 - 15 kts of wind, no boat traffic, Note 1
Transverse transect 3	20	0	-17.5	36-32.788N	077-51.836W	24.9 ft	C:\Program Files\Ishmael\Bin\Transverse\1.wav	37 sec	5 ft	42.3°F	10 - 15 kts of wind, no boat traffic, Note 1
Transverse transect 4	20	-50	-17.5	36-32.797N	077-51.835W	27.0 ft	C:\Program Files\Ishmael\Bin\Transverse\2.wav	0 sec	5 ft	42.3°F	10 - 15 kts of wind, no boat traffic, Note 1
Transverse transect 5	20	-100	-17.5	36-32.802N	077-51.836W	31.4 ft	C:\Program Files\Ishmael\Bin\Transverse\2.wav	35 sec	5 ft	42.3°F	10 - 15 kts of wind, no boat traffic, Note 1

Note 1: *Continuous data recorded while drifting between transect points*

Figure 6: Lake Gaston Data Collection

Analysis of Sound Field

Analysis of the frequency spectrum and intensity of the water intake acoustic field was conducted at the technical offices of Marine Acoustics, Inc. in Arlington, Virginia. Specifically, collected noise samples were analyzed in 1-octave frequency bands to determine the received level referenced to 1 microPascal in each band. The same analysis technique was used for both ambient noise measurements and measurements along the transect lines. The recorded voltage was modified to account for the hydrophone calibration and the gain in the pre-amplifier and two amplifier stages of the system. The measurement of the acoustic energy from the air burst was made about fifty yds from the intake screen. To determine the acoustic intensity at the screen, spherical spreading was assumed with a transition to cylindrical spreading at two times the water depth. This resulted in an additional 18 dB being added to the measured readings. Underwater acoustic intensity is by custom stated in dB relative to 1 micro-Pascal. To calculate this metric the calibrated pressure (P) is converted from volts to μPa and then 20 log P = dB level re 1 μPa.

Graphs of frequency and dB level at selected recording points are shown in Figures 7 through 9 below.

Results and Conclusions

There were occasionally narrow-band signals at high frequencies (> 40 kHz) that were at magnitudes as much as 10 dB above ambient noise. However, these signals were at higher magnitudes in the ambient noise surveys than in the acoustic transects, which suggests they are unrelated to the pumping station.

Figure 7 below shows a typical ambient noise spectrum. The ambient noise is about 85 dB re 1 μPa in the first octave band (100-200 Hz) and decreases by about 6 db per octave from the second to the seventh octave and then decreases by about 3 db from the seventh to ninth octave. The remainder of the spectrum from 40 kHz to 180 kHz is nearly flat. Ignoring a few high-magnitude discrete tones, the variance from site to site was no more than 2.5 dB in any octave. It is concluded by this analysis that the pumping station operating with a single pump at a flow rate of 8 mgd would have no impact on marine life. Moreover, the only acoustic energy from the pumping station that was recognizable above background ambient noise was the air-burst cleaning system. Due to the wide frequency band over which the air-burst energy is spread, the increase in amplitude of the background ambient noise is small (i.e., on the order of 10 dB at frequencies below 8 kHz) and it is not believed the air burst cleaning system would have any significant impact on marine life. Note the frequency scale is different in the figures shown below. This is done to emphasize the band where interesting phenomena were observed. In Figure 7 the entire frequency band to 180 kHz is shown. This spectrum was very typical of all ambient noise sites as well as the transects.

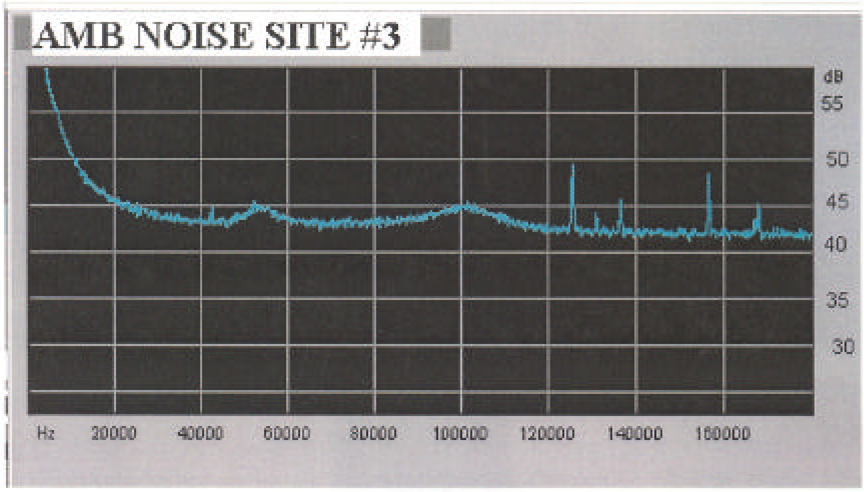

Figure 7. Ambient Noise Spectrum at AMB NOISE SITE 3 (Amplitude in dB re 1μPa).

Figure 8 below shows the spectrum up to 22 kHz. As can be seen, the largest part of the acoustic energy from the air-burst cleaning system is at low frequencies. Likewise, Figure 9 is a typical transect spectrum. The high frequency signal shown at about 42 kHz is an unknown tonal not believed to be related to the pumping station.

9

In conclusion, there was no recognizable sound produced by the pumping station with the one small pump being operated at a flow rate of 8 mgd. That means any sound from the pumping station was less than the variation in the background noise. Only during the thirty-second activation of the air-burst screen cleaning system was any sound recognizable above ambient noise and this amounted to approximately a 10 dB increase above the ambient noise in the frequency band from 110 Hz to about 2 kHz. Above 2 kHz the air-burst noise faded rapidly with increasing frequency and was within 1 dB of the ambient noise by about 12 kHz.

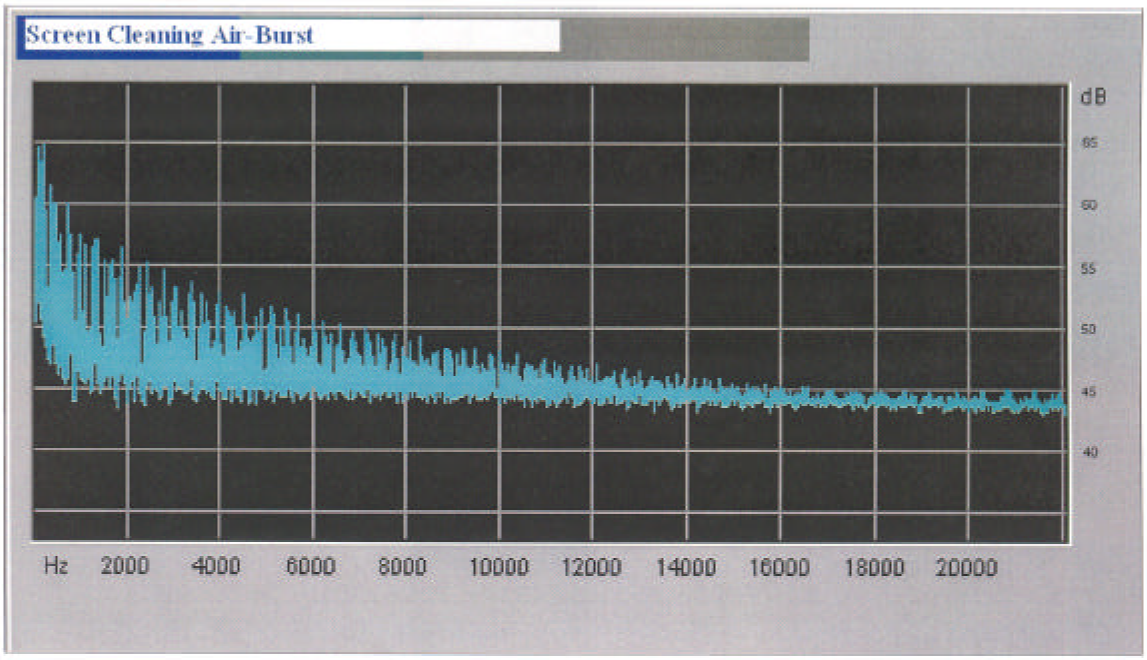

Figure 8. Spectrum of Screen Cleaning Air Burst (Amplitude in dB re 1μPa).

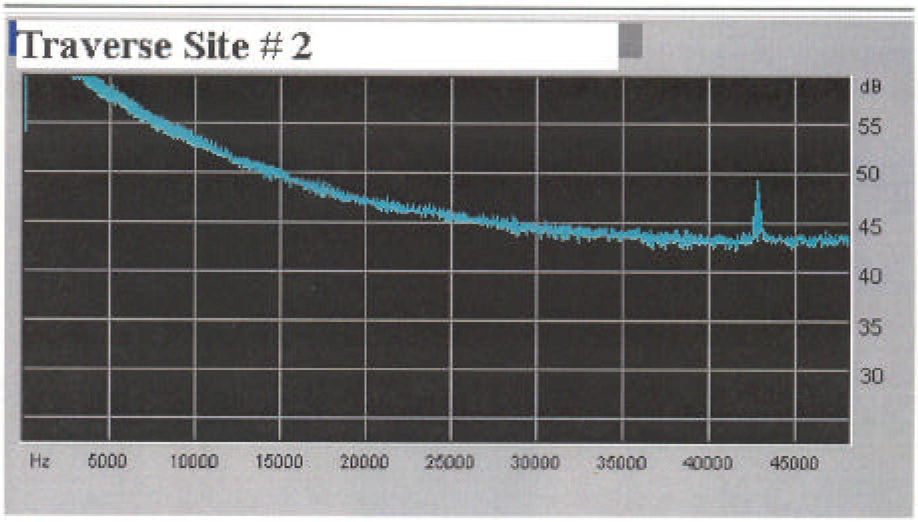

Figure 9. Spectrum of Transect Site #2 (Amplitude in dB re 1μPa).

Recommendations

More measurements could be obtained with one or more large pumps in operation. However, it is not believed to be necessary nor cost-effective due to the extremely good acoustic design of the pumping station. It is believed acoustic detection of the large pumps may be possible if operating at high pumping rates but their acoustic output will still be near the variance seen in the ambient noise and of negligible impact on marine life, particularly when compared to the underwater acoustic energy produced by power boats and jet skis.

Average Ambient Noise Readings by Octave (Average of 15 sites).

Below are the average noise levels for 15 sites rounded to the nearest dB level.

Octave	Frequency Band (Hz)	Average Noise Level (dB re 1 µPa / Hz)
1	100 - 200	85
2	200 - 400	82
3	400 - 800	76
4	800 - 1600	70
5	1600 - 3200	64
6	3200 - 6400	58
7	6400 -12800	52
8	12800 - 25600	49
9	25600 - 51200	46
10	51200 - 102400	43
11	102400 - 204800	43

Addendum

Background

An additional set of data were measured on March 20, 2004. The wind was from 8 to 12 mph and it was determined the anchor line was strumming and thereby generating unwanted noise. By drifting, the quietest conditions could be obtained. Three transects were conducted; all perpendicular to the centerline of the inlet pipes. The hydrophone was at a depth of 15 ft for all data. The first transect was a few feet in front of the inlet screens. The second was 50 ft in front of the inlet screens and the third was 100 feet in front of the inlet screens. Each of the three transects were sampled two times and approximately thirty data points were taken on each transect. The first set of data was conducted with the flow rate stabilized at 0.25 fps and the second set at the minimum flow rate which was approximately 0.05 fps. For reference, the flow rate for the original test was approximately 0.10 fps.

Calibration

The system calibration curves are the same as indicated in the original report.

Results and Conclusions

There was no substantial difference between this data set and the original set and there was no significant difference in acoustic level between the two different flow rates.

It is concluded that the inlet screens do not generate enough noise to be detected above the background noise. Background noise is generated by many sources in and around the lake. These include boats, vehicles on bridges and highways, wind, power lines and many other sources.

MARINE ACOUSTICS, INC.

Technical Superiority in the Ocean Environment and Information Technology

Marine Acoustics Inc.

MAI is a veteran-owned, small business. In business for more than 15 years, MAI was incorporated in 1988 to provide government agencies with engineering, technical, operational and environmental planning/compliance support services to ensure that the required testing, evaluation, and operational deployment of underwater sensor systems have been thoroughly analyzed to determine any potential environmental impacts and to meet all environmental regulatory requirements. MAI's specific areas of expertise include:

- Environmental assessment and compliance with particular emphasis on the marine environment,
- Acoustic and biologic research into the responses of marine mammals, fish, and other marine life to anthropogenic noise,
- Potential impacts of underwater sounds on human divers, and
- Planning and conducting scientific experiments and sea tests for various Government agencies.

MAI has extensive experience supporting many government agencies with professional support for a variety of environmental compliance issues with specific concentration on the marine environment. MAI provides operational services, advice, and support to agencies from the initial planning stages to the successful completion of complex environmental compliance processes. These services have involved development of regulatory requirements for numerous federal and state regulations including:

- National Environmental Policy Act (NEPA);
- Executive Order (EO) 12114 (Environmental Effects Abroad of Major Federal Actions);
- Endangered Species Act (ESA);
- Marine Mammal Protection Act (MMPA);
- Marine Protection, Research, and Sanctuaries Act (MPRSA);
- Coastal Zone Management Act (CZMA);
- Migratory Bird Treaty Act;
- Magnuson-Stevens Fisheries Conservation and Management Act (FCMA);
- Rivers and Harbors Act; and
- Specific state, regional, and local laws and regulations

MAI and its professional staff have experience at numerous locations on the U.S. East Coast and Gulf of Mexico including the Boston OPAREA, Narragansett OPAREA, Atlantic City OPAREA, VACAPES OPAREA, Jacksonville OPAREA, Key West OPAREA, AFWTF, and AUTEC. MAI also has experience at numerous Pacific ranges and locations including those off the U.S. West Coast, Alaska, Hawaii, and the Pacific Rim.

MAI has experience in visual and passive acoustic marine mammal surveys including shore-based acoustic and visual research, boat-based acoustic data collection, preparation of a moored hydrophone array system, and performance of aerial surveys. MAI has developed abundance, distribution, dive profiles, and density data for analyses of potential impacts to marine mammals for numerous NEPA and EO 12114 documents.

MAI provides services to the U.S. Navy in the area of physical oceanography and underwater acoustic propagation. Its expertise includes environmental acoustic (EVA) model analysis; algorithm development of submarine target strength at low frequencies; algorithm development testing accuracy of acoustic whale counting techniques and various EVA studies; and analysis of transmission loss and figure of merit (FOM) data for at-sea acoustic testing.

MAI utilizes state-of-the-art acoustic propagation models, such as the Parabolic Equation (PE) Model (Version 3.4), which is one of the validated acoustic transmission loss models in the Navy's Oceanographic and Atmospheric Master Library (OAML). The PE model has high spatial resolution, a factor that allows for a more detailed study of diving animals and provides transmission loss as a function of range and depth. It can use data from a wide variety of environmental acoustic databases to create realistic estimates for specific geographic locations and times of year, such as the Digital Bathymetric Data Base (DBDB).

MAI brings a wide range of expertise in at sea experimentation, testing, and data collection. These wide ranging efforts include:

- Resolving operational issues in the field of underwater acoustics,
- Coordinating Fleet liaison efforts and securing sea test platforms and equipment to execute experiment plans,
- Formulating experiment and test plans, including coordinated tracks, data collection, *in-situ* environmental data collection, at-sea modeling, communications, and reconstruction plans,
- Providing key personnel including chief scientists, test directors, unit coordinators, and project principal investigators for experiments, and
- Coordinating environmental data characterization, collection and analysis efforts.

MAI has developed the Acoustic Integration Model (AIM©), a state-of-the-art, quasi real-time virtual model for assessing the net impact of sound from a variety of sources (moving or stationary) on a dynamic population of marine wildlife. MAI has also developed a behavioral database of marine animals to utilize with AIM. These analyses include the performance of acoustic and biological modeling to determine the sound propagation field, distribution and abundance of marine species, and estimations of the potential effects of operating sound sources on marine mammals. This modeling technique has become the basis for the analyses of acoustic impacts on marine animals from acoustic sources for a series of environmental planning and compliance documents including environmental assessments and impact statements and inputs for permitting and consultation under the ESA, MMPA, and CZMA. It has been utilized for the analyses of impacts to marine mammals for the Surveillance Towed Array Sensor System Low Frequency Active (SURTASS LFA) sonar, Acoustic Thermometry of Ocean Climate (ATOC) source, North Pacific Acoustic Laboratory (NPAL) Project, and Littoral Warfare Advanced Development (LWAD) sea tests EIS/OEIS/EA/OEAs under NEPA and Executive Order 12114. AIM is currently being integrated with a worldwide marine wildlife database under a multi-year contract with the Office of Naval Research.