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Abstract.—Moratoria on fishing directly impact fishers, distributors and marketers of product and can have serious socio-economic implications. Moratoria can impact communities but usually populations closely linked to the banned activity. In an unprecedented example, a moratorium on fishing in Virginia has directly impacted a nonfishing citizenry by thwarting plans for a public utility. In May 2003, a panel empowered to regulate marine resources denied permission to withdraw raw water from a pristine freshwater river, the Mattaponi. The controversial action spoiled a multi-million dollar plan to establish the King William Reservoir, a water source considered essential to future growth and development in the region. The facility was designed to serve a projected 600,000 people in 2040 but the Mattaponi Indians, environmentalists, local citizens and commercial fishers opposed the plan. A central issue was conservation of American shad *Alosa sapidissima*, an anadromous clupeid native to the U.S. east coast. An inriver moratorium on fishing for American shad imposed in 1994 remains in effect. In the reservoir debate, scientists advised the panel that the project would withdraw water in the center of the larval nursery area for this species and in a river that accounted for the highest statewide production of juveniles. Scientists recommended relocating the intake since losses of larvae to withdrawal could be counter to restoration goals of the moratorium. Using quantitative models, municipal authorities argued that only six American shad would be lost annually to impingement or entrainment. The panel rejected this argument and proposals to mitigate losses.

Introduction

Moratoria on commercial fishing directly impact fishers, distributors, and marketers of product and can have serious socio-economic implications (Lear and Parsons 1993; Loch et al. 1995; Haedrick and Fischer 1996; Allen and Gough 2004). Prohibitions on the taking and possession of fish and shellfish can impact communities but usually human populations that are closely linked to the banned fishing activity, such as small fishing villages or family groups practicing traditional fishing methods. In an apparently unprecedented example, a regulatory action in the form of a total moratorium on the taking of a

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fish species in Virginia (USA) has directly impacted a nonfishing citizenry by thwarting plans for a public utility.

In March 2003, the City of Newport News, Virginia (located within a large metropolitan area known as Hampton Roads including the cities of Hampton, Poquoson, Newport News and parts of York County) requested a permit from the Virginia Marine Resources Commission (VMRC) to withdraw water from a pristine freshwater river, the Mattaponi (Figure 1). The VMRC is a panel of private citizens and associated support staff. The panel consists of a Commissioner and eight associate Commissioners who are appointed by the governor and empowered to regulate most marine resources (fish and shellfish) and coastal habitats (including subaqueous bottom lands) in Virginia. Fulfilling its state-mandated role as a science advisor to the VMRC, the Virginia Institute of Marine Science (VIMS, the graduate school of marine science of the College of William and Mary) was asked by the

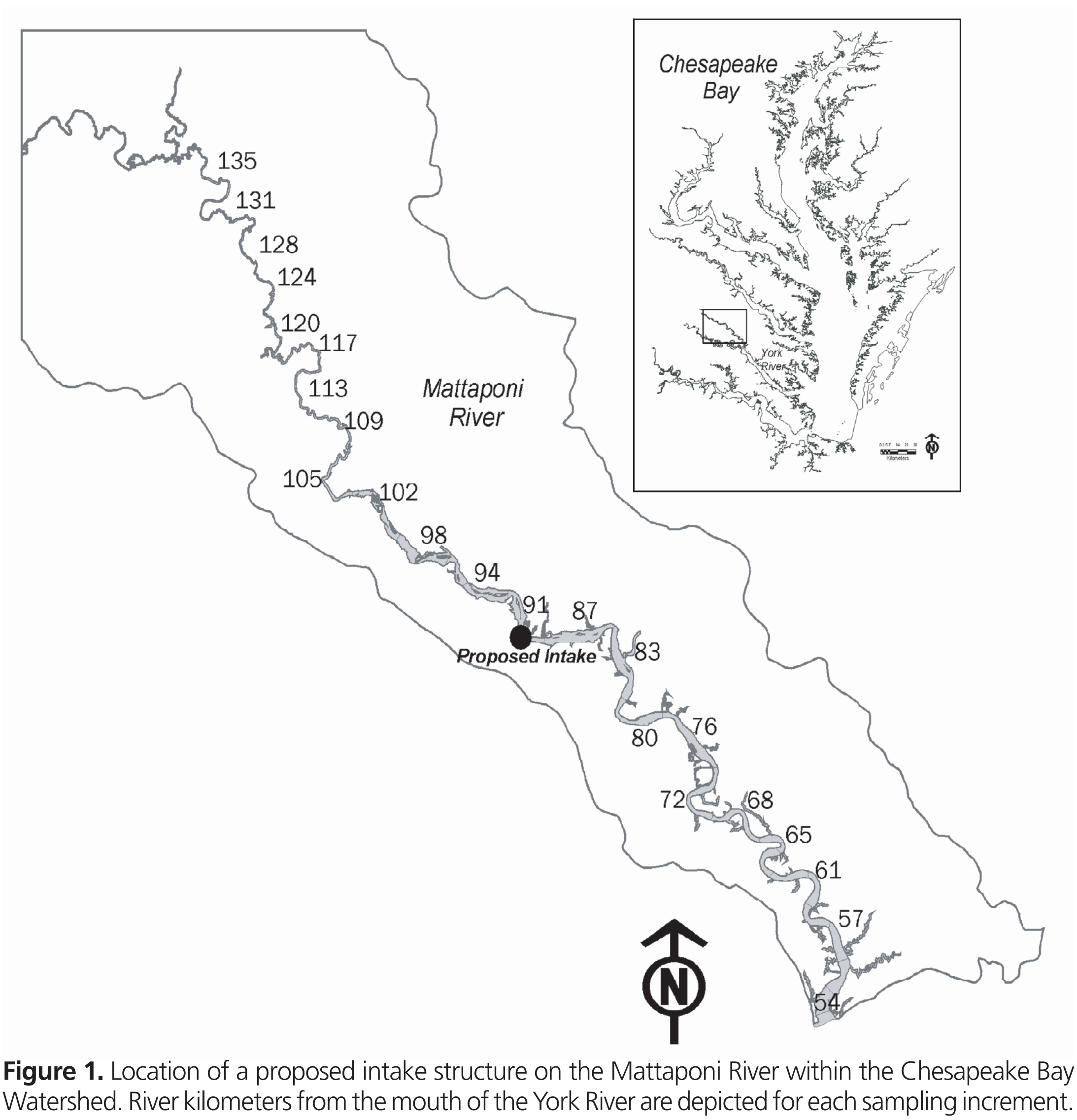

Figure 1. Location of a proposed intake structure on the Mattaponi River within the Chesapeake Bay Watershed. River kilometers from the mouth of the York River are depicted for each sampling increment.

Commissioner to provide an advisory on potential fisheries and ecological impacts of the proposed withdrawal. The intake facility and its storage reservoir were designed to serve a projected 600,000 people in the year 2040. The Virginia Department of Environmental Quality (VDEQ) had previously issued a Water Protection Permit for the proposed facility, prohibiting construction activity during spring spawning periods of anadromous fishes and specifying minimum instream flow requirements that constrain the amount of water that can be removed from the river based on flow rates recorded upstream of the proposed site.

After a public hearing in May 2003, where consultants of the City of Newport News and VIMS scientists testified, and private citizens who opposed or advocated the proposed reservoir were heard, the VMRC denied the permit. A central issue in the debate was the conservation of American shad *Alosa sapidissima*, an anadromous alosine clupeid fish native to the United States East Coast (Limburg and Waldman 2003). Harvest of American shad along the U.S. East Coast peaked in the late 1800s but landings have declined precipitously in the last century (ASMFC 1999). Mature fish migrate annually from mixed stock assemblages at sea to their natal rivers. In Virginia tributaries, shad spawn in February-June, producing batches of eggs every 2–3 d (Olney et al. 2001). After hatching, young remain in the freshwater nursery area, migrating to sea at as young of the year or age 1. The species is currently under an inriver fishing moratorium imposed by the VMRC in 1994 (Olney and Hoenig 2001). The fishing moratorium and local efforts to restore depleted stocks of American shad (Olney et al. 2003) were viewed as decisive issues that contributed to the rejection of the permit. While there are many examples of environmental (especially biodiversity) issues that have affected utility and agricultural projects (Bagg 1977; Hickman and Fitz 1978; Cooperman and Markle 2003), there are few instances of a fishery regulation producing such an unanticipated result. For this reason, our purpose here is to document these proceedings and their outcome by presenting a synopsis of the available scientific information on the potential impacts of water withdrawal and the arguments presented by the applicant and its consultants. We take no position on the correctness of the VMRC decision in 2003 and note in postscript that litigation required the VMRC to hold another hearing on this permit.

Site and Characteristics of the Withdrawal Facility

The proposed reservoir and its intake facility is located in the York River watershed that covers approximately 6,900 km^2 of Virginia's Piedmont and Coastal Plain, and is predominately forested (66.6%), with the remaining land use comprised of agriculture (25%), wetlands (7%), and urban areas (1.4%) (Dobson et al. 1995; U.S. EPA 1996). The York River is formed by the confluence of the Mattaponi and Pamunkey Rivers with watersheds of 2,274 and 3,768 square km^2, respectively. This system is a partially-mixed, microtidal estuary characterized by a two-layer flow of saltwater movement upstream at depth and downstream freshwater surface flows. Salinities generally range from 16 to 22 ppt at the mouth of the York and decrease to zero in the Pamunkey and Mattaponi rivers, generally within 10–20 km from their confluence. The intake structure would be located at Scotland Landing (Virginia) on the Mattaponi River at River Kilometer (Rkm) 91 (Figure 1). Rkm 91 is 91 km from the mouth of the York River and approximately 37 km from the confluence of the Mattaponi and Pamunkey rivers. The mean annual fall line discharge of the

Mattaponi River is approximately 16.3 m^3/s, with an average annual spring discharge rates of 27.2 m^3/s (Belval et al. 1995; Bilkovic 2000; USGS 2002).

Water would be withdrawn at an intake facility situated on the outside edge of a natural river channel through 12 wedge-wire screens, each approximately 2 m in length and 2 m in diameter, arranged in series along the axis of the river. The water depth at the screens is 7–8 m and the top of the screens would be set at approximately 2.5 m below the mean low water mark, providing about 2 m of clearance above the river bottom. Each wedge-wire screen would have a slot width of 1 mm and an estimated through-slot water velocity of 7.6 cm/s when the intake is withdrawing water at its maximum capacity.

Available Scientific Information

Management and Stock Status of American Shad in the York River System

The Atlantic States Marine Fisheries Commission (ASMFC) is a deliberative body consisting of Commissioners from 15 Atlantic coastal states including Virginia. By federal law, the ASMFC coordinates the conservation and management of 22 Atlantic coastal fish species or species groups including American shad (ASMFC 1999). The overarching goal of the ASMFC interstate fishery management plan for American shad is to "protect, enhance, and restore east coast migratory spawning stocks of American shad, hickory shad, and river herrings in order to achieve stock restoration and maintain sustainable levels of spawning stock biomass." Section 2.1.4D (ASMFC 1999) directs States to "ensure that decisions on river flow allocation (e.g., irrigation, evaporative loss, out of basin water transport, and hydroelectric operations) take into account flow needs for alosine migration, spawning, and nursery usage." Section 2.1.4E further recommends that management actions "ensure that water withdrawal (e.g., cooling water, drinking water) effects (e.g., impingement and entrainment mortalities, turbine mortalities) do not affect alosine stocks to the extent that they result in stock declines."

Declines in catch rates of American shad in the Chesapeake Bay region prompted an in-river moratorium on harvest and possession in Maryland in 1980 and Virginia in 1994. These fishery regulations remain in effect. To lift the current moratorium in Virginia, the VMRC must petition to seek approval of the ASMFC Shad and River Herring Management Board. Amendment 1 (ASMFC 1999) requires that states establish restoration targets for stocks under fishing moratoria and that states conduct annual monitoring to assess stock status. Virginia's strategy to address Amendment 1 goals has included hatchery production of larvae and stocking efforts in the James River where historic decline in stock abundance was especially severe. Broodstock for this hatchery restoration program in the James River comes from the York River system (Olney et al. 2003).

In Virginia, status of American shad stocks is assessed through a monitoring program that compares an index of contemporary catch rates of adult shad in staked gill nets to a similarly constructed index derived from historic data in the 1950s and 1980s (see Olney and Hoenig 2001; Olney et al. 2003 for details of this assessment method). During 1998–2002, monitoring suggested that the spawning run of American shad on the York River was stronger than it was on any other Virginia tributary since the average gill net catch index in the York River was higher than the average index obtained in either the James or Rappahannock rivers (Olney 2003). At that time, the average of the York River index was higher than the average index recorded in the 1980s but lower than the average index recorded in the 1950s (after adjustment for gear differences), a period when landings of American shad were relatively stable in the York River (Nichols and Massmann 1963). Thus, the York River stock of American shad is considered to be under restoration.

Tributary-Specific Juvenile Abundance

Annual monitoring of the abundance of juvenile *Alosa* (American shad, hickory shad *A. mediocris*, blueback herring *A. aestivalis*, and alewife *A. pseudoharengus*) was conducted on the York River system with a push net developed in the late 1970s (Kriete and Loesch 1980). The data record extends from 1979 to 2002 but sampling was not conducted during 1987–1990 (see Wilhite et al. 2003 for details of the survey method and data analysis). Ratios of Mattaponi to Pamunkey juvenile abundance indicate that relative abundance is almost always greater on the Mattaponi River. For reasons yet unknown, total American shad production in the York River watershed is more heavily influenced by Mattaponi River production than Pamunkey River production (Figure 2). Furthermore, juvenile production on the James and Rappahannock rivers is low compared to the York production.

Fish Eggs and Larvae in the Zone of Influence of the Proposed Intake

Information on distribution and relative abundance of fish eggs and larvae were obtained

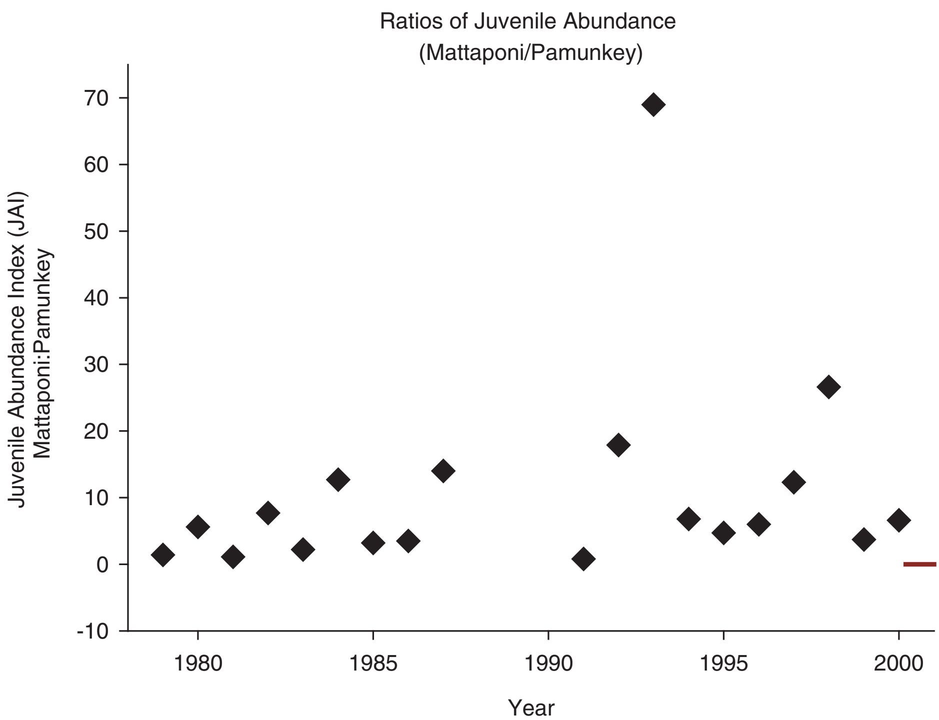

Figure 2. Ratios (Mattaponi/Pamunkey rivers) of an index of abundance of juvenile American shad (25–80 mm total length) in a 19-year time series, 1979–2002. The JAI is calculated as a geometric mean number of juveniles per tow.

from ichthyoplankton collections on the Mattaponi River during April and May of 1997–1999 (see Bilkovic et al. 2002a, 2002b for detailed methods). The survey grid included plankton samples from the "zone of influence" of the proposed intake structure. The zone of influence was defined as a section of river stretching from 4.6 km upriver to 4.6 km downriver of the intake. This designation was based on tidal excursion data, the horizontal distance traveled by water-born materials for an ebb cycle. Tidal excursion values in the vicinity of the proposed intake are estimated to be approximately 4.6 km (2.5 NM) (R.L. Mann, Virginia Institute of Marine Science, March 12, 2003 Memo to Mr. William A. Priutt, Commissioner, Virginia Marine Resources Commission. Available: http://www.vims.edu/newsmedia/pdfs/KWR_Response.pdf [April 2006]).

Species collected by Bilkovic (2000) from the intake structure's estimated zone of influence included blueback herring, alewife, and American shad (Clupeidae); white perch *Morone Americana* and striped bass *M. saxatilis* (Moronidae); and yellow perch *Perca flavescen* (Percidae). The potential significance of the intake's zone of influence varies with species and life history stage. The proportion of each species' eggs and larvae that Bilkovic (2000) collected in the intake's zone of influence is presented in Table 1. 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 (Figure 3). Although additional species were observed in high relative proportions in the zone of influence, the debate focused on American Shad due to its protected status under the moratorium. Bilkovic's (2000) data are consistent with VIMS' juvenile American shad monitoring data with respect to relative importance of the Mattaponi and Pamunkey rivers; the average densities of individual American shad life stages were greater in the Mattaponi River than the Pamunkey River.

Table 1. Proportion of fish distributed in the intake zone of influence[a]

Species by life stage	Percentage in zone
American shad eggs	19.6%
American shad larvae	58.6%
Herring eggs	1.5%
Herring larvae	39.5%
Striped bass eggs	1.4%
Striped bass larvae	9.9%
White perch eggs	15.8%
White perch larvae	38.1%
Yellow perch larvae	34.4%

[a] Zone of influence—a section of river stretching 4.6 km (2.5 nm) upriver and downriver of the proposed intake site.

Decision Process: Opposing Testimony

While numerous areas of concern were examined, three major themes dominated discussions prior to, during and after the public hearing: need assessment, impact assessment and mitigation effectiveness. Scientific advisors to the VMRC and the applicant's consultants offered conflicting views on each theme, which are briefly summarized in Figure 4. In general, the applicant argued for applying a modeling approach to extrapolate the limited available early life stage data and expected high natural mortality rates of young stages with the outcome of insignificant equivalent adult loss, while VIMS argued for the application of the precautionary principal leading to conservative interpretation of the available data.

Resulting Decision

In the face of conflicting and sometimes equivocal expert testimony, the VMRC voted

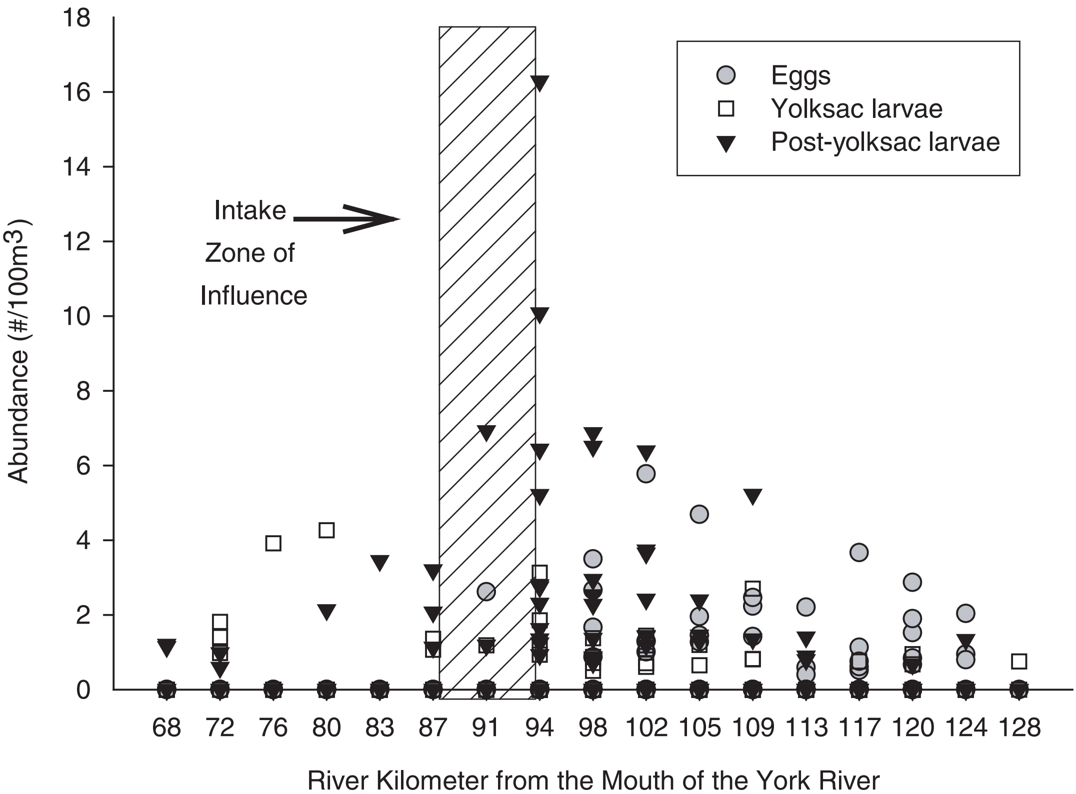

Figure 3. Distribution and relative abundance of eggs, yolksac larvae and postyolksac of American shad in the Mattaponi River from 1997 to 1999. The approximate location of the proposed intake structure is depicted by the shaded bar.

to deny the permit for construction of the water intake structure. The only irrefutable evidence before the Commission was the moratorium on shad fishing and associated fisheries assessment (the current rebuilding status of the York River stock, the importance of the Mattaponi River to juvenile shad production, and the ichthyoplankton data). All other elements of the project (the question of need, the potential environmental impact, and the practicability of suitable mitigation strategies) were subject to divergent expert opinion. In the face of this lack of certainty, the Commissioners apparently focused on their responsibility to conserve fish resources, and opted for a precautionary approach. If experts could not agree on estimation of potential impacts associated with permitting the intake, then the only certain decision outcome was associated with denial of the permit. If the reservoir intake was not allowed to operate, no adverse impacts could occur from operation of the reservoir.

Many states manage water resources with an eye to preservation of habitat for endangered species. The federal Endangered Species Act makes it illegal to "take" an endangered species, where "take" is defined to include harming the species through significant habitat modification or degradation. Typically this requirement is implemented at the federal level, and in analogous state programs, through review and elimination of proposed activities at the very earliest stages of consideration. This did not happen in the King

Expert advice contrasted
Testimony at the VMRC Public Hearing for the Intake Permit

Applicant	VIMS scientists
Applicant argued that the available fisheries data could be extrapolated to show that the impacts to fish were small relative to the public benefit.	VIMS scientists argued for the application of the precautionary principal leading to conservative interpretation of the available fisheries data.

Need Assessment —How significant is the need for new water supply?

Applicant	VIMS scientists
Economics and population forecast models by a Regional Raw Water Study group indicated that the need for water will surpass available supplies in the immediate future (within 20 yrs).	VIMS scientists did not review these models and did not comment on the need for the reservoir. Other agencies (Norfolk District of the Army Corps of Engineers) refuted the applicant's claim.

Impact assessment—What would the effect be on existing fishery stocks?

Applicant	VIMS scientists
Applicant argued that concentrations of larval American shad at the intake are low and used adult equivalency models to predict that only six adult fish would be lost due to pumping. Recent research on wedge-wire screen intake designs using other species suggested the entrainment and impingement of shad larvae would be insignificant. Substantial financial and time investment in the project thus far argues against relocation of intake.	Scientists argued that there was too little quantitative information to support a rigorous analysis of loss due to withdrawal. The available data suggested that larvae were concentrated at the proposed intake site, maximizing the potential impact. In the absence of specific information on the impact of the intake screen on shad larvae, the potential for entrainment and impingement mortality was unknown. The proposed location was considered the worst possible choice since it is in the central spawning area for shad on a tributary with the highest juvenile production of all Virginia Rivers.

Mitigation effectiveness—Can the intake operation be modified to minimize the potential for impact on American shad?

Applicant	VIMS scientists
Applicant argued that a withdrawal schedule limiting or stopping pumping during spring spawning periods was practical and a monitoring program to record environmental conditions and larval occurrence might be implemented to provide a trigger for cessation of withdrawal that would protect stocks.	Little is known about variation in temporal patterns of larval shad distribution and abundance in the area of the proposed intake. It is difficult, if not impossible, to plan a pumping schedule that will avoid significant impact under all future conditions given available data. Evidence that late spawned larvae constitute a large portion of the year class adds risks of impact.

Figure 4. A summary of contrasting expert advice presented by the applicant (the City of Newport News, Virginia) for a permit to withdraw raw water from the Mattaponi River (Virginia, USA) and scientists at the Virginia Institute of Marine Science (VIMS) at a public hearing conducted by the Virginia Marine Resources Commission (VMRC) in May 2002.

William reservoir project because there are no endangered species threatened by the project. As a consequence, early environmental impact statement development failed to identify site-specific threats to any fish species.

Some states, particularly in the western United States, have developed proactive regulations to protect fishery habitats by advance determination of minimum instream flow requirements. This represents an a priori assessment of conditions sufficient to protect natural biota, and by difference defines opportunities for water resource development. While this is now a widely applied stratagem for some anadromous species, notably salmon, some states have found this to be an unsatisfactory approach when species behavior is not absolutely predictable. Environmental variation can result in population behaviors that alter relative risks from year to year. The need to respond to these variations is problematic without constant active management of risk-prone activities such as water withdraws. The VMRC lacks the authority to reopen and review their decisions on the placement of structures on subaqueous bottom within its current regulatory structure. Operational requirements are set at the time of permitting and only reviewed/revised at the periodic license renewals. The VDEQ permit for this project allows for permit modification if proposed eco-monitoring documents ecological problems.

In the King William reservoir case, the VMRC, given its mission of managing the Commonwealth's aquatic habitat, was confronted with a unique situation. The Commissioners were challenged by circumstances to step outside the bounds of their usual habitat management deliberations in order to fulfill their mission to manage the Commonwealth's marine fisheries. In habitat cases, the normal practice of the Commission has been to focus on the short and long term impacts associated with the physical presence of structures in the aquatic environment. Piers, docks, jetties, dredge cuts, subaqueous fill, and pipeline crossings are the typical projects considered in the habitat management actions of the Commission. The typical permit decisions focus on avoiding or minimizing the physical alteration of the environment on the assumption that this will result in the least detrimental impact to the biota. In the case of the reservoir intake, everyone agreed that physical impacts were likely to be minor or inconsequential.

The withdrawal of raw water through the reservoir intake poses the potential threat. As detailed above, the significance of the potential impact is a matter of considerable disagreement. The technical information available cannot support an unequivocal assessment. The only certainties are the relative importance of the Mattaponi River as a shad nursery in Virginia, and the existence of a fishing moratorium because of the poor status of the stock. Confronting these realities, the Commissioners, by majority vote (6–2), denied the permit to construct the intake, effectively preventing operation of the reservoir. This represents an unusual circumstance of a major water resource development project being halted over concern for impacts to a stressed fishery stock. The decision is unusual because it is not founded on regulatory concern for a federally or state listed rare, threatened, or endangered species. It is also not based on a general habitat protection objective such as preservation of minimum instream flows. This decision may be a precursor to the type of considerations intended under fishery multispecies ecosystem management. The VMRC voted to avoid additional stress on a recovering fish stock at the expense of another beneficial use of the water resource.

Similar aquatic resource use conflicts will become more prominent as re-licensing of electric generating stations continues under Section 316(b) of the Clean Water Act. The Act requires that Environmental Protection Agency (EPA) ensure a reduction or compensation for 60–90% of entrainment mortality and 80–95% of impingement mortality of aquatic organisms relative to baseline conditions at generating facilities (Available: http://www.epa.gov/waterscience/316b/. [April 2006]). The rule allows generating facilities flexibility in achieving compliance in consideration of energy reliability. It provides several compliance alternatives, such as using existing technologies, selecting additional fish protection technologies, and using restoration measures. Use of restoration measures may include direct enhancement of populations (by stocking) or target habitats that may have added ecosystem benefits. Uncertainty in the quantification of both impacts and restoration outcomes will undoubtedly lead to similar discussions as noted in the King William Reservoir case.

Postscript

As with many environmental decisions, the VMRC action was not final. An appeal was filed, a rehearing was negotiated, and expanded operating restrictions were proposed to minimize or eliminate potential impacts. On 12 August 2004, the Virginia Marine Resources Commission reversed itself (majority vote 5–3) and granted Newport News a permit to build an intake pipe. The permit incorporated restrictions to address potential fish impacts, such as seasonal shutdown of water withdrawal operations during spawning periods and required monitoring to provide additional ichthyoplankton data. Regardless of the final outcome, the attention drawn to the conflicts that are poorly resolved in current public policy is stimulating new legislative and regulatory proposals. If nothing else, the need for comprehensive and integrated fishery ecosystem management has been underscored.

Acknowledgments

Many thanks to the participants in discussions regarding potential impacts including members of VMRC, VIMS and representatives of the City of Newport News. We especially thank D. Perry, T. Barnard, S. Mills, J. Hoffman and K. Havens (all of VIMS) for their assistance.This is VIMS Contribution Number 2808.

References

Allen, S. D., and A. Gough. 2004. Monitoring environmental justice issues in fishery regulations. abstract, Fourth World Fisheries Conference, Vancouver.

ASMFC (Atlantic States Marine Fisheries Commission) 1999. Amendment 1 to the Interstate Fishery Management Plan for shad and river herring. Atlantic States Marine Fisheries Commission, Fishery Management Report No. 35, Washington, D.C.

Bagg, C. E. 1977. Snail darter, snapdragon, saccharin syndrome: more power to whom? Proceedings of the American Power Conference 39.

Belval, D. L., J. P. Campbell, S. W. Phillips and C. F. Bell. 1995. Water-quality characteristics of five tributaries to the Chesapeake Bay at the Fall Line Virginia, July 1988 through June 1993. US Geological Survey Water-Resources Investigations Report 95–4258.

Bilkovic, D. M. 2000. Assessment of spawning and nursery habitat suitability for American shad (*Alosa sapidissima*) in the Mattaponi and Pamunkey rivers. Doctoral dissertation. Virginia Institute of Marine Science, Gloucester Point.

Bilkovic, D. M., C. H. Hershner, and J. E. Olney. 2002a. Macroscale asessment of American shad spawning and nursery habitat in the Mattaponi and Pamunkey rivers, Virginia. North American Journal of Fisheries Management 22:1176–1192.

Bilkovic, D. M., J. E. Olney, and C. H. Hershner. 2002b. Spawning of American shad (*Alosa sapidissima*) and striped bass (*Morone saxatilis*) in the Mattaponi and Pamunkey Rivers, Virginia. Fisheries Bulletin 100:632–640.

Cooperman, M. S., and D. F. Markle. 2003. The Endangered Species Act and the National Research Council's interim judgment in Klamath basin. Fisheries 28(3):10–19.

Dobson, J. E., E. A. Bright, R. L. Ferguson, D. W. Field, L. L. Wood, K. D. Haddad, Iredale, J. R. Jensen, V. V. Klemas, R. J. Orht, and J. P. Thomas. 1995. NOAA Coastal Change Analysis Program (CCAP): guidance for regional implementation. NOAA Technical Report NMFS 123, United States Department of Commerce, Seattle.

EPA (Environmental Protection Agency). 1996. MRLC Region III land cover data set. EROS Data Center, Sioux Falls, South Dakota.

EPA (Environmental Protection Agency). 2006. Cooling Water Intake Structures–CWA §316(b). Available: http://www.epa.gov/waterscience/316b/. (April 2006).

Haedrick, R. L., and J. Fischer. 1996. Stability and change of exploited fish communities in a cold ocean continental shelf ecosystem. Senckenbergiana Maritima 27:237–243.

Hickman, G. D., and R. B. Fitz. 1978. A Report on the Ecology and Conservation of the Snail Darter (*Percina tanasi* Etnier) 1975–1977. Tennessee Valley Authority, Norris.

Kriete, W. H., Jr., and J. G. Loesch. 1980. Design and relative efficiency of a bow-mounted push net for sampling juvenile pelagic fishes. Transactions of the American Fisheries Society 109:649–652.

Lear, W. H., and L. S. Parsons. 1993. History and management of the fishery for northern cod in NAFO divisions 2J, 3K and 3L. Canadian Bulletin of Fisheries and Aquatic Sciences 226:55–90.

Limburg, K. E., and J. R. Waldman. 2003. Biodiversity, status, and conservation of the world's shads. American Fisheries Society, Symposium 35, Bethesda, Maryland.

Loch, J. S., M. Moriyasu, and J. B. Jones. 1995. An improved link between industry and science: review of case history of the southwestern Gulf of St. Lawrence snow crab fishery. Aquatic Living Resources 8:253–265.

Nichols, P. R., and W. H. Massmann. 1963. Abundance, age and fecundity of shad, York River, VA., 1953–59. Fishery Bulletin 63:179–187.

Olney, J. E, S. Denny and J. M. Hoenig. 2001. Criteria for determination of maturity stage in American shad (*Alosa sapidissima*) and a proposed reproductive cycle. Bulletin Francais de la Pêche et de la Pisciculture 362/363:881–901.

Olney, J. E., and J. M. Hoenig. 2001. Managing a fishery under moratorium: Assessment opportunities for Virginia's stocks of American shad (*Alosa sapidissima*). Fisheries 26(2):6–12.

Olney, J. E., D. A. Hopler, Jr., T. P. Gunter Jr., K. L. Maki, and J. M. Hoenig. 2003. Signs of recovery of American shad (*Alosa sapidissima*) in the James River, Virginia (USA). Pages 323–329 *in* K. E. Limburg and J. R. Waldman, editors. Biodiversity, status, and conservation of the world's shads. American Fisheries Society, Symposium 35, Bethesda, Maryland.

Olney, J. E. 2003. Monitoring relative abundance of American shad in Virginia's rivers. 2002 Annual Contract Report to the US Fish and Wildlife Service and the Virginia Marine Resources Commission, Newport News, Virginia.

Schmidt, R. E., B. M. Jessop, and J. E. Hightower. 2003. Status of river herring stocks in large rivers. Pages 171–182 *in* K. E. Limburg and J. R. Waldman, editors. Biodiversity, status, and conservation of the world's shads. American Fisheries Society, Symposium 35, Bethesda, Maryland.

USGS (United States Geological Survey). 2002. Water-Data Report VA-01–1. Water Resources Data, Virginia, Water Year 2001, Volume 1, Surface-Water Discharge and Surface-Water Quality Records. USGS,

Wilhite, M. L., K. L. Maki, J. M. Hoenig, and J. E. Olney. 2003. Towards validation of a juvenile index of abundance for American shad in the York River, Virginia. Pages 285–294 *in* K. E. Limburg and J. R. Waldman, editors. Biodiversity, status, and conservation of the world's shads. American Fisheries Society, Symposium 35, Bethesda, Maryland.