COAL COMBUSTION WASTE IS A *DEADLY* POISON TO FISH

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What makes coal combustion waste so hazardous to fish?

Coal wastes contain the trace element selenium, which causes severe reproductive impacts on fish. The basis for this toxicity is quite simple. Selenium is leached out of coal waste by rain or ash disposal water, dissolves into solution, and is carried into nearby lakes, rivers, and wetlands. From there it moves into the food chain and bioaccumulates in the organisms eaten by fish, birds, and other animals that utilize aquatic habitats (Figure 1). By consuming a contaminated diet, fish can further concentrate selenium in their tissues until it reaches over 5,000 times the original water concentration. However, even though they have an elevated level of selenium in their body, and some direct toxicity may result, the primary hazard of selenium is to developing embryos. Selenium consumed by parent fish is passed to their offspring in eggs, where it is highly concentrated in the yolk. When eggs hatch, larval fish absorb and metabolize selenium-laden yolk as a source of nutrition while they are developing. Selenium exerts its toxicity by preventing normal development of proteins and tissues. Visible symptoms of selenium poisoning include such things as skeletal deformities (teratogenic effects) and missing body parts (Figures 2-5, Lemly 1993b). Inside, a variety of tissue abnormalities occur in major organs (Sorensen 1986). Collectively, these symptoms will quickly kill a larval fish. The end result is reproductive failure which, over time, will cause fish populations to collapse. This mechanism of toxicity, in which adult fish can live relatively unaffected yet experience total reproductive failure, constitutes a particularly deceptive threat to fish health. The ease with which selenium moves from coal waste into aquatic systems, its propensity to bioaccumulate, and its insidious mode of toxicity combine to make coal waste a highly hazardous material (Lemly 2002b).

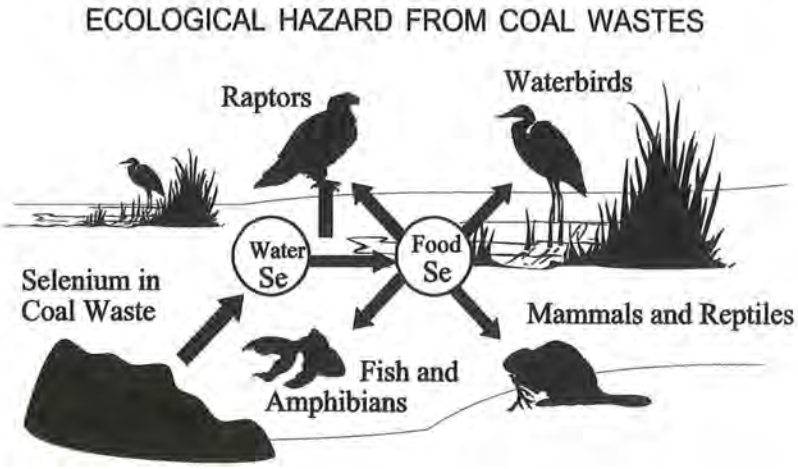

Figure 1. Pathways for selenium movement from coal wastes, bioaccumulation in food chains, and dietary exposure of fish and wildlife populations.

Figure 2. One of the most common and outwardly visible teratogenic effects of selenium in fish is deformity of the spine. Shown here are examples of dorso-ventral abnormalities (kyphosis and lordosis) caused by exposure to selenium in coal ash leachate water.

Figure 3. Lateral curvature of the spine (scoliosis) caused by exposure to selenium in coal ash leachate water. Individual on right is normal.

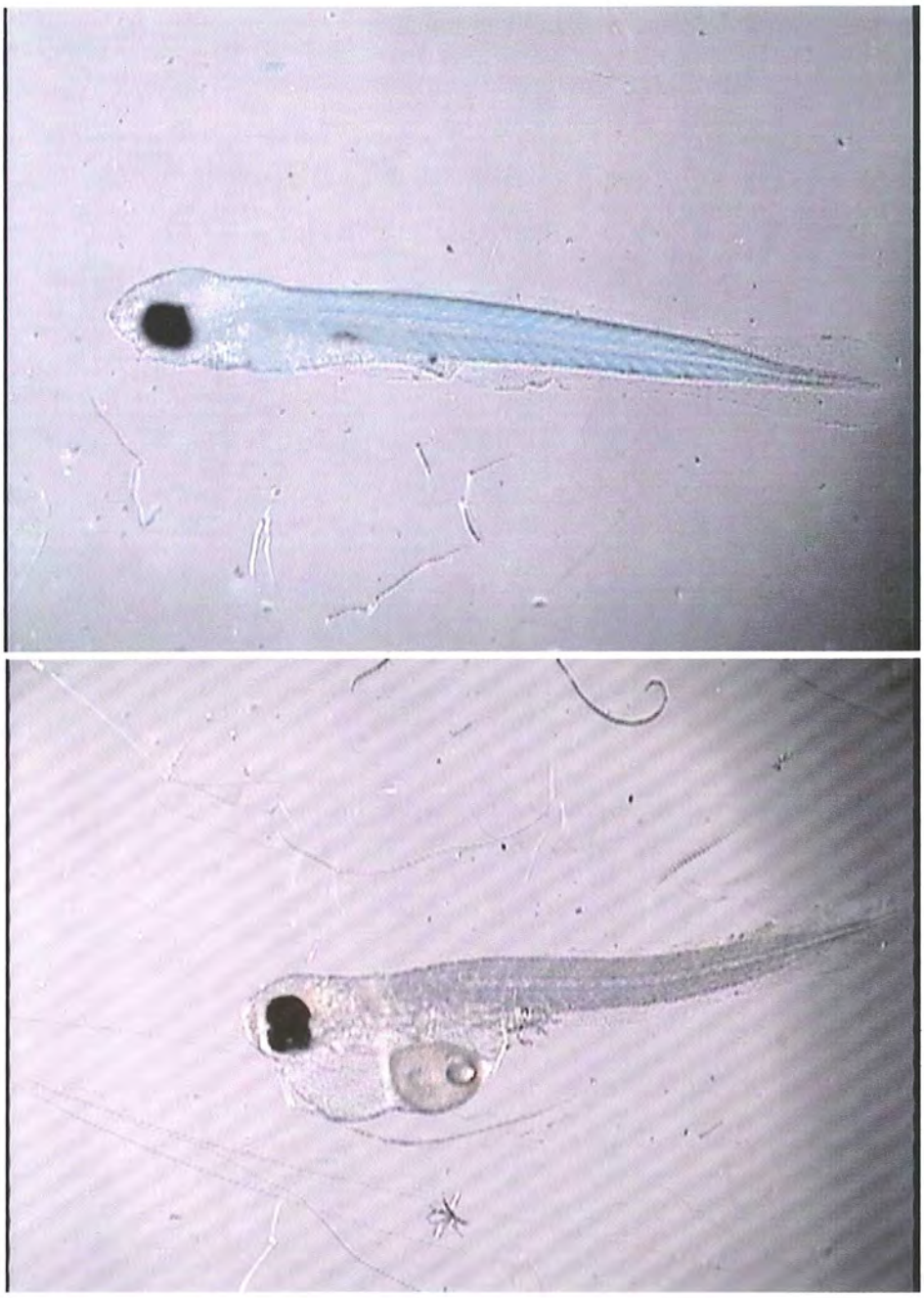

Figure 4. TOP: Typical fish larva showing normal eye development, straight spine, and complete yolk absorption with no evidence of edema or a swollen, deformed yolk sac. BOTTOM: Abnormal fish larva from parents exposed to selenium in coal waste. Note the distended, fluid-filled yolk sac (edema) and delayed yolk absorption. This individual also has dorso-ventral curvature of the spine (kyphosis) and deformed pectoral fins and eyes (both eyes are on the same side of the head). All of these abnormalities are characteristic biomarkers of selenium poisoning and will kill this fish.

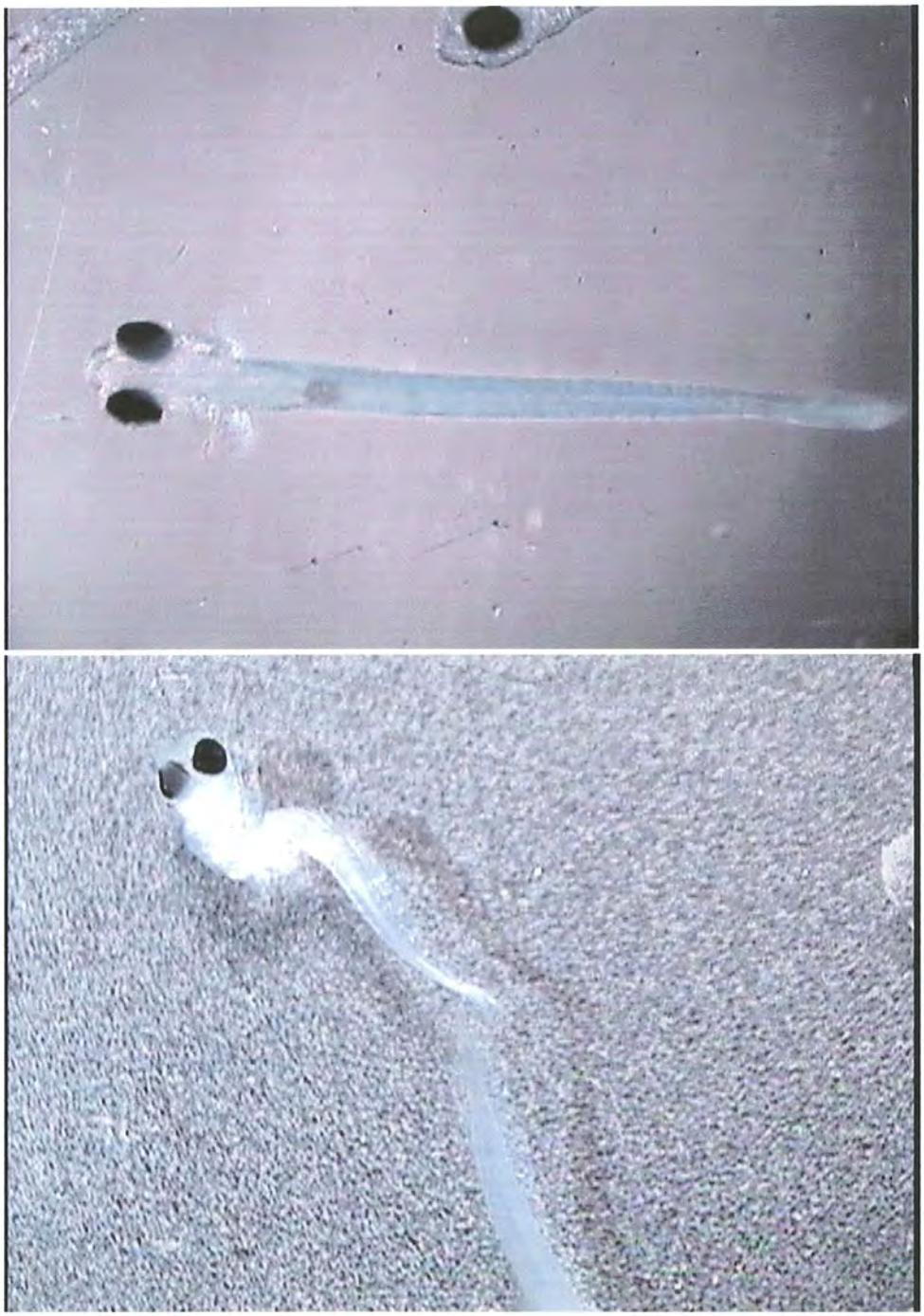

Figure 5. TOP: Dorsal view of normal fish larva showing well developed pectoral fins and straight spine. BOTTOM: Dorsal view of abnormal fish larva from parents exposed to selenium in coal waste. Note deformed spine in "S" shape, typical of scoliosis due to selenium poisoning. This fish will die because it cannot swim or feed normally.

What are the toxic concentrations of selenium to fish and what are the levels of selenium in coal combustion waste?

Detailed field and laboratory investigations have determined that waterborne concentrations of selenium in the 1-5 ug/L (micrograms per liter or parts-per-billion) range can bioaccumulate and begin to cause reproductive failure in fish. The exact number is site-specific, and depends on the kind of aquatic system (stream, reservoir, wetland), its biological productivity, and the chemical form of selenium present in the water. Field case studies show that if waterborne selenium reaches 10 ug/L, complete reproductive failure and population collapse can occur in reservoirs, and reproduction may be reduced by 40% in streams (Cumbie and Van Horn 1978, Lemly 1985b, Gillespie and Baumann 1986, Hermanutz et al. 1993). In one particular case, 19 species of fish were totally eliminated over a period of 4 years due to reproductive failure (Lemly 2002b).

Concentrations of selenium in coal wastes are far greater than the toxic levels for fish (Figure 6). For example, the largest component of coal waste (fly ash) produces leachate and disposal water with up to 2,700 ug/L selenium (Lemly 1985a), a concentration that is several orders of magnitude greater than the range for toxic bioaccumulation in aquatic habitats.

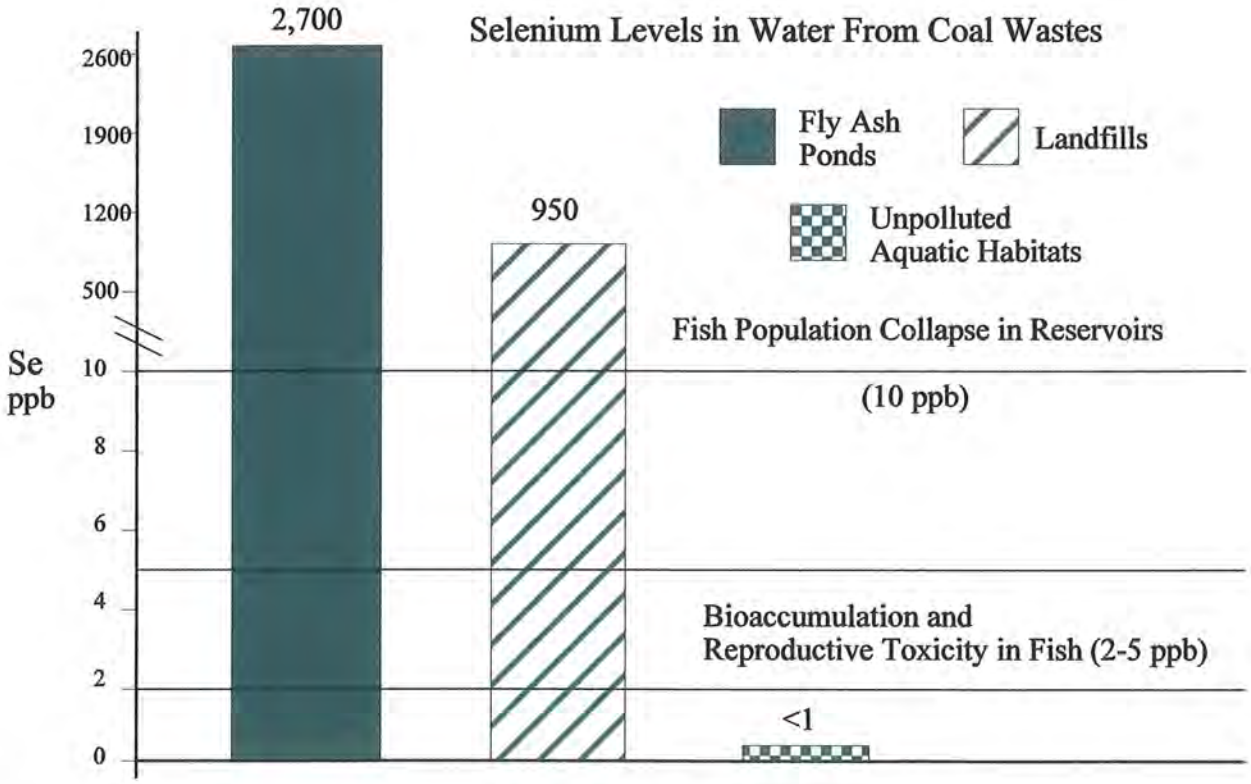

Figure 6. Levels of selenium emanating from coal waste relative to toxic levels for fish.

How widespread is selenium poisoning associated with coal combustion waste?

Because adult fish may be unaffected by selenium concentrations that impair their ability to reproduce, reductions in spawning success or impacts to fish population must be determined by something more than routine monitoring surveys, that is, simply finding fish does not indicate the absence of selenium poisoning. Moreover, the residency status of fish must be known because movement patterns may bring uncontaminated individuals from other locations into the study area. These individuals would not exhibit the same selenium concentrations in tissues and associated reproductive failure as resident fish. Thus, proper assessment techniques must be applied in order to definitively evaluate selenium poisoning. In most locations where coal waste could be an issue, there has been either no fish health assessment at all, or the investigation did not look closely enough, using the proper evaluation techniques, to determine actual impacts. At sites where proper techniques were applied, numerous cases of impacts have been identified and documented (Figures 7-8). Moreover, the number of documented cases is growing rapidly. For example, the USEPA found that substantiated coal waste environmental damage cases more than doubled during the period 2000-2005 (USEPA 2005). These cases are spread across the nation and involve surface impoundments as well as landfills (Table 1), so the hazard and impact from coal waste is not limited to one disposal method. Since 2005 new cases have been steadily added to this unfortunate, but preventable, coal waste pollution legacy. The most remarkable of these is the massive December 2008 spill at the TVA Kingston Coal Plant in Tennessee (Figures 9-10), which released over 5 million cubic yards of coal ash (the largest US industrial spill on record) and contaminated an entire river ecosystem for many miles downstream. Fish have already accumulated selenium to toxic levels at this site (Babyak et al. 2009).

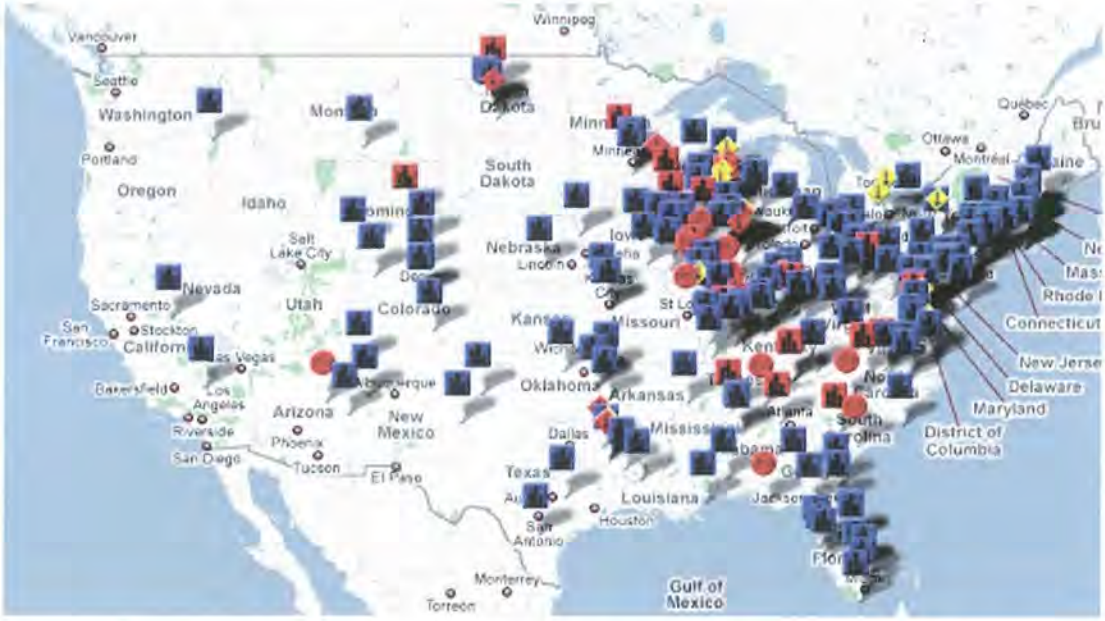

Figure 7. Coal combustion waste sites where toxicity to fish is suspected (blue), has been confirmed (red). and is also implicated in human health effects (yellow).

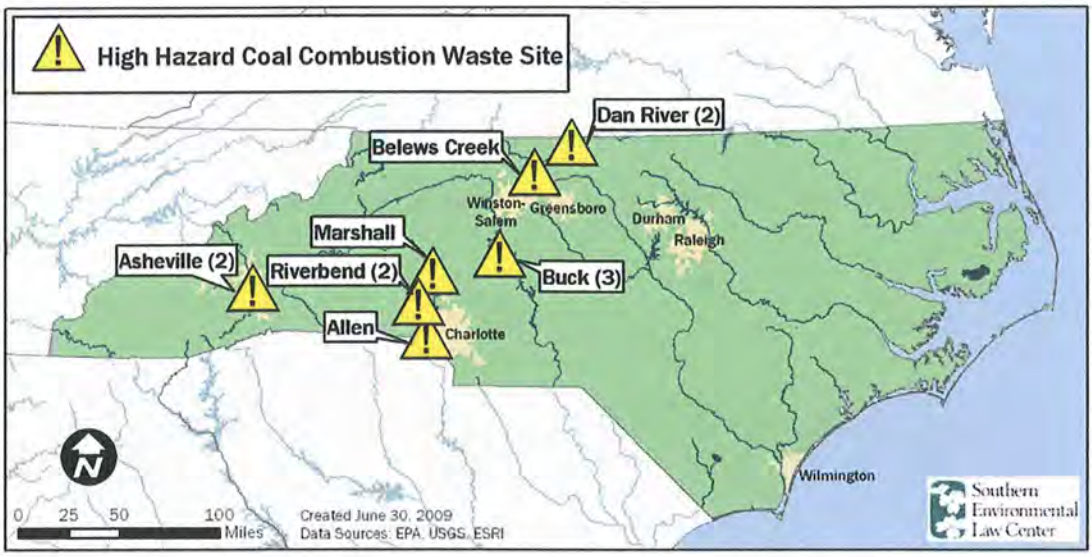

Figure 8. Multiple hazardous coal waste sites have been identified in some states. For example, North Carolina has 12 high hazard sites.

Table 1. Environmental Protection Agency proven environmental damage cases due to coal combustion wastes as of 2005.

Facility	Type	State
Vitale Fly Ash Pit	Landfill	MA
Salem Acres	Landfill	MA
Don Frame Trucking	Landfill	NY
PEPCO Faulkner Off-site Disposal Facility	Landfill	MD
VEPCO/Virginia Power Possum Plant	Surface Impoundment	VA
VEPCO/Vvirginia Power Chisman Creek	Landfill	VA
Chestnut Ridge Y-12 Steam Plant Operable Unit 2	Surface Impoundment	TN
Georgia Power Bowen	Surface Impoundment	GA
South Carolina E&G Canadys Plant	Landfill	SC
Savannah River Project	Surface Impoundment	SC
Belews Lake	Surface Impoundment	NC
Hyco Lake (CP&L Roxboro)	Surface Impoundment	NC
Lansing Board P&L North Lansing Landfill	Landfill	MI
Daryland Power Ash Pond - Cassville Site	Surface Impoundment	WI
WEPCO Highway 59 Landfill	Landfill	WI
Alliant Nelson Dewey	Landfill	WI
WEPCO Cedar Sauk Landfill	Landfill	WI
WEPCO Port Washington	Landfill	WI
Yard 520, Pines	Landfill	IN
Martin Creek Reservoir	Surface Impoundment	TX
Brady Branch Reservoir	Surface Impoundment	TX
Welsh Reservoir	Surface Impoundment	TX
Basin Electric W.J. Neal Station	Surface Impoundment	ND
Cooperative Power Association-United Power Coal Creek	Landfill	ND

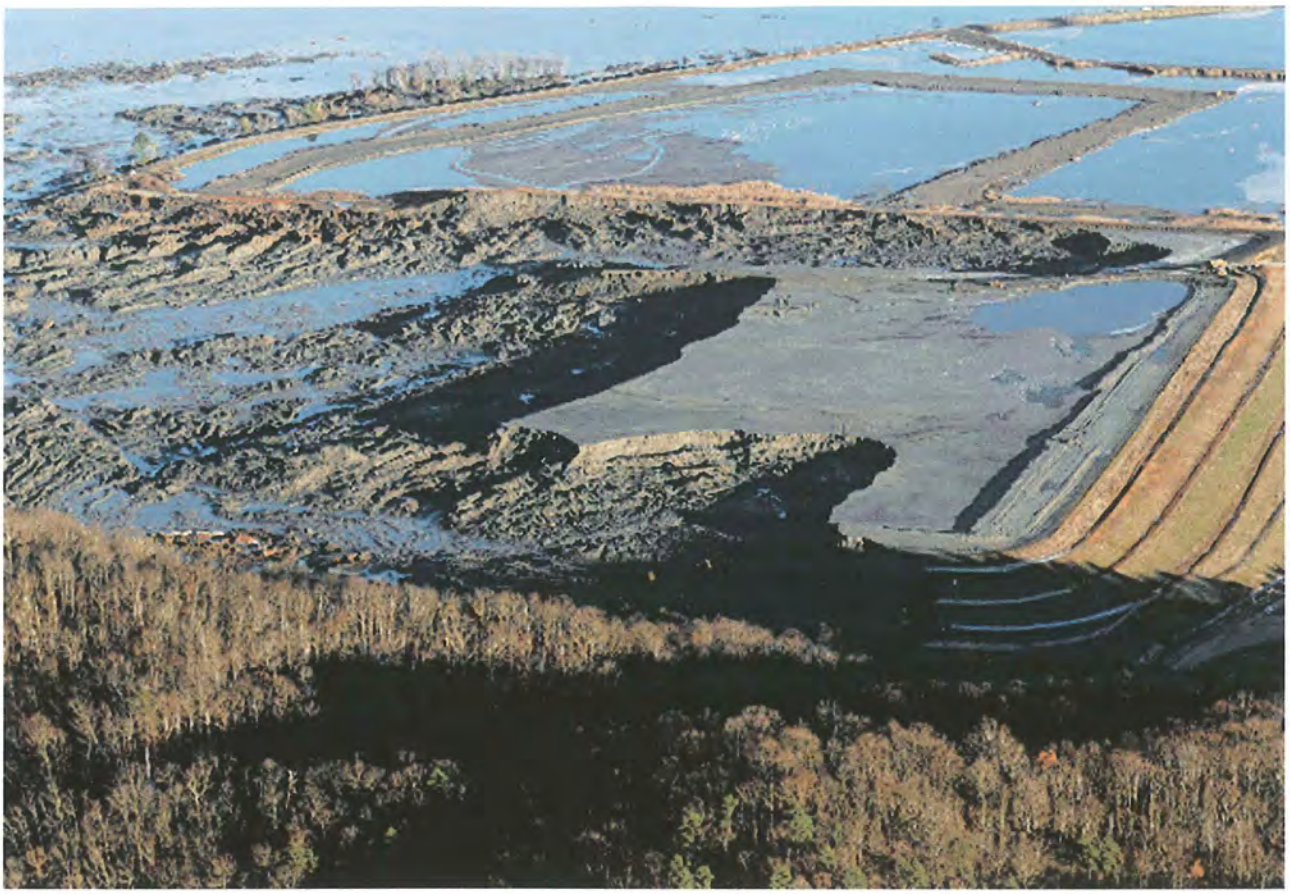

Figure 9. Aerial view of the TVA Kingston Coal Plant Ash Disposal Basin shortly after the retaining dyke failed in December 2008, releasing over 5 million cubic yards of ash onto adjacent lands and into the Emory River. Prior to the spill, the intact ash pile was approximately one mile long and 50-100 feet deep.

Figure 10. View looking downstream into the Emory River shortly after the TVA Kingston Coal Plant ash spill in December 2008. The river is almost entirely plugged by coal ash. The Kingston Plant can be seen in the background.

What is the outlook for the future?

Coal use continues to increase, as does the amount of waste that must be disposed. The track record we as a society have established tells us what the future will look like unless some fundamental and far reaching changes are made.....more pollution, more fish poisoning, more tabulating cases of management and disposal failures appended by scientist "I told you so's" and "should have done's". I, for one, do not want to continue investigating cases of selenium poisoning in fish from coal waste.....as I have repeatedly done for the past 30 years. There is no need for this. The information presented above, along with the scientific reports listed in Supplemental Information, provide clear, irrefutable evidence that coal combustion residues are a hazardous waste. They should be treated as such with respect to regulatory policy. Safeguarding the nation's water supply is of utmost importance. This can be done only if environmentally sound regulations governing the disposal and management of coal waste are established and enforced. Ironically, as we strive to make coal "cleaner" by removing particulates and airborne emissions, we simply add to the amount of ash and other residual wastes that must be disposed. With respect to fish health, there is no such thing as clean coal. The only long-term solution is to replace coal with alternative energy sources. Until we achieve this transition it is imperative that adequate regulatory controls are in place. EPA and the Office of Management and Budget can, and should, take the steps necessary to provide this control. The US needs to assert a leadership role in coal waste regulation, not only for the benefit of our nation, but also to set an example for other countries to follow with respect to their own coal waste management policies.

References

Babyak, C., S. Carmichael, S. Edwards, A. George, D. Lemly, D. Lisenby, B. Payne, and S. Tuberty. 2009. Preliminary Summary Report From Water, Sediment, and Fish Samples Collected at the TVA Ash Spill by Appalachian State University, Appalachian Voices, Tennessee Aquarium, and Wake Forest University. Technical Report, Department of Biology, Appalachian State University, Boone, NC.

Cleveland, L., E.E. Little, D.R. Buckler, and R.H. Wiedmeyer. 1993. Toxicity and bioaccumulation of waterborne and dietary selenium in juvenile bluegill (Lepomis macrochirus). Aquatic Toxicology 27: 265-280.

Coyle, J.J., D.R. Buckler, C.G. Ingersoll, J.F. Fairchild, and T.W. May. 1993. Effect of dietary selenium on the reproductive success of bluegills (Lepomis macrochirus). Environmental Toxicology and Chemistry 12: 551-565.

Cumbie, P.M. and S.L. Van Horn. 1978. Selenium accumulation associated with fish mortality and reproductive failure. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies 32: 612-624.

Finley, K.A. 1985. Observations of bluegills fed selenium-contaminated Hexagenia nymphs collected from Belews Lake, North Carolina. Bulletin of Environmental Contamination and Toxicology 35: 816-825.

Gillespie, R.B. and P.C. Baumann. 1986. Effects of high tissue concentrations of selenium on reproduction by bluegills. Transactions of the American Fisheries Society 115: 208-213.

Hamilton, S.J. 2003. Review of residue-based selenium toxicity thresholds for freshwater fish. Ecotoxicology and Environmental Safety 56: 201-210.

Hermanutz, R.O., K.N. Allen, T.H. Roush, and S.F. Hedtke. 1993. Effects of elevated selenium concentrations on bluegills (Lepomis macrochirus) in outdoor experimental streams. Environmental Toxicology and Chemistry 11: 217-224.

Holland, E.A. 1979. Arsenic and selenium in the water, sediments, and biota near a coal-fired power plant – Belews Lake, North Carolina. Master's Thesis. Department of Environmental Sciences and Engineering, University of North Carolina at Chapel Hill, Chapel Hill, NC.

Lemly, A.D. 1985a. Ecological basis for regulating aquatic emissions from the power industry: The case with selenium. Regulatory Toxicology and Pharmacology 5: 465-486.

Lemly, A.D. 1985b. Toxicology of selenium in a freshwater reservoir: Implications for environmental hazard evaluation and safety. Ecotoxicology and Environmental Safety 10: 314-338.

Lemly, A.D. and G.J. Smith. 1987. Aquatic cycling of selenium: Implications for fish and wildlife. Fish and Wildlife Leaflet 12. U.S. Fish and Wildlife Service, Washington, DC.

Lemly, A.D. 1993a. Metabolic stress during winter increases the toxicity of selenium to fish. Aquatic Toxicology 27: 133-158.

Lemly, A.D. 1993b. Teratogenic effects of selenium in natural populations of freshwater fish. Ecotoxicology and Environmental Safety 26: 181-204.

Lemly, A.D. 1997. Ecosystem recovery following selenium contamination in a freshwater reservoir. Ecotoxicology and Environmental Safety 36: 275-281.

Lemly, A.D. 2002a. Symptoms and implications of selenium toxicity in fish: The Belews Lake case example. Aquatic Toxicology 57: 39-49.

Lemly, A.D. 2002b. Selenium Assessment in Aquatic Ecosystems: A Guide for Hazard Evaluation and Water Quality Criteria. Springer-Verlag, New York, NY.

Lohner, T.W., R.J. Reash, V.E. Willet, and L.A. Rose. 2001a. Assessment of tolerant sunfish populations (Lepomis sp.) inhabiting selenium-laden coal ash effluents. 1. Hematological and population level assessment. Ecotoxicology and Environmental Safety 50: 203-216.

Lohner, T.W., R.J. Reash, and M. Williams. 2001b. Assessment of tolerant sunfish populations (Lepomis sp.) inhabiting selenium-laden coal ash effluents. 2. Tissue biochemistry evaluation. Ecotoxicology and Environmental Safety 50: 217-224.

Lohner, T.W., R.J. Reash, V.E. Willet, and J. Fletcher. 2001c. Assessment of tolerant sunfish populations (Lepomis sp.) inhabiting selenium-laden coal ash effluents. 3. Serum chemistry and fish health indicators. Ecotoxicology and Environmental Safety 50: 225-232.

Sorensen, E.M.B. and T.L. Bauer. 1984. Planimetric analysis of redear sunfish (Lepomis microlophus) hepatopancreas following selenium exposure. Environmental Toxicology and Chemistry 3: 159-165.

Sorensen, E.M.B. 1986. The effects of selenium on freshwater teleosts. Pages 59-116 in E. Hodgson, editor. Reviews in Environmental Toxicology 2. Elsevier Science Publishers,

Amsterdam, Netherlands.
Sorensen, E.M.B. 1988. Selenium accumulation, reproductive status, and histopathological changes in environmentally exposed redear sunfish. Archives of Toxicology 61: 324-329.
USEPA (United States Environmental Protection Agency). 2005. Damage Case Assessment. USEPA, Municipal and Industrial Solid Waste Division of the Office of Solid Waste, Washington, DC.
Woock, S.E., W.R. Garrett, W.E. Partin, and W.T. Bryson. 1987. Decreased survival and teratogenesis during laboratory selenium exposures to bluegill, Lepomis macrochirus. Bulletin of Environmental Contamination and Toxicology 39: 998-1005.

SUPPLEMENTAL INFORMATION:

This is a sampling of the many studies on environmental damage and risks to human health from power plant ash and other coal combustion wastes.

The scientific reports listed below provide clear evidence that coal combustion residues are a hazardous waste. That fact has been know for many years as indicated by the early publication dates (pre-1990) for much of this research.

Ecological Damage:

* Anonymous. 1991. Remedial Investigation Report for Chestnut Ridge (Filled Coal Ash Pond/McCoy Branch) at the Oak Ridge Y-12 Plant, Oak Ridge, TN. Prepared by CH 2 M Hill in Oak Ridge, TN for US Dept of Energy and Martin Marietta Energy Systems, Inc., Oak Ridge, TN.

* Bamber, R. N. 1984. The Benthos of A Marine Fly-Ash Dumping Ground. J. Mar. Biol. Assoc. U.K. 64:211-226.

* Belanger, S. E. and D. S. Cherry. 1990. Interacting Effects of pH Acclimation, pH, and Heavy Metals on Acute and Chronic Toxicity to Ceriodaphnia dubia (Cladocera). J. Crustacean Biol. 10(2):225-235.

* Cairns , J., Jr. and D. S. Cherry. 1982. Field and Laboratory Verification of Power Plant Effluent (Thermal, Chlorine, Fly Ash) Effects upon Fish. Proc. Internatl. Conf. on Coal Fired Power Plants and the Aquatic Environ. August 16-18, 1982, Copenhagen , Denmark , p. 10-29.

* Cairns , J., Jr. and D. S. Cherry. 1983. A Site-Specific Field and Laboratory Evaluation of Fish and Asiatic Clam Population Responses to Coal Fired Power Plant Discharges. Wat. Sci. Tech. 15:31-58.

* Carlson, C. L. and D. C. Adriano. 1993. Environmental Impacts of Coal Combustion Residues. J. Environ. Qual. 22:227-347.

* Cherry, D. S. and R. K. Guthrie. 1975. The Significance of Ash Discharged into Aquatic Drainage Systems. Aware 56:12-14.

* Cherry, D. S., R. K. Guthrie, J. H. Rodgers, Jr., J. Cairns , Jr. and K. L. Dickson. 1976. Responses of Mosquitofish (Gambusia affinis) to Ash Effluent and Thermal Stress. Trans. Am. fish. Soc. 105:686-694.

* Cherry, D. S. and R. K. Guthrie. 1977. Toxic Metals in Surface Waters from Coal Ash. Water Resour. Bull. 13:1227-1236.

* Cherry, D. S. and R. K. Guthrie. 1978. Mode of Elemental Dissipation from Ash Basin Effluent. Water, Air and Soil Pollution 9:403-412.

* Cherry, D. S. and R. K. Guthrie. 1979. The Uptake of Chemical Elements from Coal Ash and Settling Basin Effluent by Primary Producers. II. Relation between Concentrations in Ash Deposits and Tissues of Grasses Growing on the Ash. The Science of the Total Environment 13:27-31.

* Cherry, D. S., R. K, Guthrie, F. F. Sherberger and S. R. Larrick. 1979. The Influence of Coal Ash and Thermal Discharges upon the Distribution and Bioaccumulation of Aquatic Invertebrates. Hydrologia 62:257-267.

* Cherry, D. S., R. K. Guthrie, S. R. Larrick, E. M. Davis and F. F. Sherberger. 1979(a). Recovery of Invertebrate and Vertebrate Populations in a Coal-Ash Stressed Drainage System. J. Fish Res. Board Can. 36:1089-1096.

* Cherry, D. S., J. Van Hassel, W. L. Specht, R. A. Lechleitner, R. B. Nicholson, J. B. Whitaker and J. Cairns, Jr. 1984(a). Field and Laboratory Methods Useful in Predicting the Ecotoxicological Effects of Coal Ash. Workshop Proceedings: The Effects of Trace Elements on Aquatic Ecosystems. Carolina Power and Light, Raleigh , North Carolina and Electric Power Research Institute, Palo Alto , California . 31 pp.

* Cherry, D. S., R. K. Guthrie, E. M. Davis and R. L. Harvey. 1984(b). Coal Ash Ramifications (Particulates, pH, Heavy Metals) Upon Benthic Macroinvertebrates and Fish Populations: An Eight-Year Study. Water Resour. Bull. 20:535-544.

* Cherry, D. S. and J. Cairns , Jr. 1986. Toxicological, Physiological and Behavioral Responses of Selected Organisms to Fly Ash Effluent: Twelve-Year Summary. In : J. Cairns , Jr. and J. W. Clarkson, eds. Selected Aspects of Exposure to Heavy Metals in the Environment: Monitors, Indicators and High Risk Groups. Natl. Acad. Press, Washington , D.C. 7 pp.

* Cherry, D. S., J. H. VanHassel, J. Cairns , Jr. and P. Ribbe. 1987. Toxic Components of Fly and Bottom Ash from Power Plant Production upon Bluegill (Lepomis macrochirus) and Rainbow Trout (Salmo gairdneri). Water Resour. Bull. 23:293-306.

* Crossman, J. S., J. Cairns , Jr. and R. L. Kaesler. 1973. Aquatic Invertebrate Recovery in the Clinch River Following Hazardous Spills and Floods. Bulletin 63 of the Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University , Blacksburg , VA.

* Forbes, A.M., J.J. Magnuson and D.M. Harrel. 1981. Effects of Habitat Modification from Coal Ash Effluent on Stream Macroinvertebrates: A Synthesis. In , The Warmwater Streams Symposium, L.A. Krumholtz (editor). Southern Division, American Fisheries Society, pp. 241-249.

* Guthrie, R. K. and D. S. Cherry. 1975. Biological Cleanup of Effluent from an Ash Basin . Completion Report AEC Contract AT(38-1)-834, Savannah River Project, Aiken , South Carolina . 39 pp.

* Guthrie, R. K., D. S. Cherry and J. H. Rodgers. 1975. The Impact of Ash Basin Effluent on Biota in the Drainage System. Proc., Seventh Mid-Atlan. Indus. Waste Conf., Drexel Univ. , November 12-14, 1974, Philadelphia , Pa. pp. 17-43.

* Guthrie, R. K. and D. S. Cherry. 1976. Pollutant Removal from Coal-Ash Basin Effluent. Proc. 11th Annual Water Resources Conference. Water Resour. Bull. 12:889-902.

* Guthrie, R. K., D. S. Cherry and F. L. Singleton. 1978(a). Responses of Heterotrophic Bacterial Populations to pH Changes in Coal Ash Effluent. Water Resour. Bull. 14:803-808.

* Guthrie, R. K., D. S. Cherry, F. L. Singleton, and R. S. Harvey. 1978(b). The Effects of Coal Ash Basin Effluent and Thermal Loading on Bacterial Populations of Flowing Streams. Environ. Pol. 17:297-302.

* Guthrie, R. K. and D. S. Cherry. 1979(a). The Uptake of Chemical Elements from Coal Ash and Settling Basin Effluent by Primary Producers. I. Relative Concentrations in Predominant Plants. The Science of the Total Environment 12:217-222.

* Guthrie, R. K. and D. S. Cherry. 1979(b). Trophic Level Accumulation of Heavy Metals in a Coal Ash Basin Drainage System. Water Resour. Bull. 15:244-248.

* Guthrie, R. K., D. S. Cherry, E. M. Davis and H. E. Murray. 1981. Establishment of Biotic Communities within a Newly Constructed Ash Settling Basin and Its Drainage System. Ecological Assessment of Effluent Impacts on Aquatic Organisms. J. M. Bates and C. I. Weber, eds. American Society for Testing and Materials, ASTM No. 730, pp. 243-254.

* Guthrie, R. K., D. S. Cherry, E. M. Davis and R. S. Harvey. 1982(a). Some Environmental Aspects of Ash Pond Systems. The 75th Annual Meeting of the Air Pollution Control Association, June 20-25, 1982, New Orleans , Louisiana . 8 pp.

* Guthrie, R. K., E. M. Davis, D. S. Cherry and J. R. Walton. 1982(b). Impact of Coal Ash from Electric Power Production on Changes in Water Quality. Water Resour. Bull. 18:135-138.

* Hardy, M. A. 1981. Effects of Coal Fly-Ash Disposal on Water Quality in and around Indiana Dunes National Lakeshore, Indiana . US Geol. Survey, Water Resour. Div., Indianapolis , IN. 64 pp.

* Hatcher, C. O., R. E. Ogawa, R. E. Poe and J. R. P. French, III. 1992. Trace Elements in Lake Sediment , Macrozoobenthos, and Fish Near a Coal Ash Disposal Basin . J. Freshwater Ecol. 7:257-269.

* Homziak, J., L. Bennett, P. Simm and R. Henry. 1993. Metal Leaching from Experimental Coal Fly-Ash Oyster Clutch. Bull. Environ. Contam. Toxicol. 51:317-324.

* Hopkins, W. A., M. T. Mendonea and J. D. Congdon. 1997. Increased Circulating Levels of Testosterone and Corticosterone in Southern Toads, Bufo terrestris , Exposed to Coal Combustion Wastes. General and Comparative Endocrinology 108:237-246.

* Hopkins, W. A., M. T. Mendonea, C. L. Rowe and J. D. Congdon. 1998. Elevated Trace Element Concentrations in Southern Toads, Bufo terrestris , Exposed to Coal Combustion Wastes. Archives of Environmental Contamination and Toxicology 35:525-129.

* Hopkins, W. A., C. L. Rowe, and J. D. Congdon. 1999a. Increased Maintenance Costs and Trace Element Concentrations in Banded Water Snakes, Nerodia fasciata , Exposed to Coal Combustion Wastes. Environmental Toxicology and Chemistry 18(6):1258-1263.

* Hopkins, W. A., M. T. Mendonca and J. D. Congdon. 1999b. Responsiveness of the Hypothalamo-Pituitary-Interreal Axis in an Amphibian (Bufo terrestris) Exposed to Coal

Combustion Wastes. Comparative Biochemistry and Physiology 122(2):191-196.

* Hopkins, W. A., J. D. Congdon and J. K. Ray. 2000. Incidence and Impact of Axial Malformations in Bullfrog Larvae Developing in Sites Impacted by Coal Combustion Byproducts. Environmental Toxicology and Chemistry 19(4):862-868.

* Rowe, C.L., W.A. Hopkins, J.D.Congdon. Ecotoxicological Implications of Aquatic Disposal of Coal Combustion Residues In the United States : A Review. Environmental Monitoring and Assessment , 80:207-276, 2002.

* Rowe, C.L., W.A. Hopkins, and V.R. Coffman. In press. Failed recruitment of southern toads (Bufo terrestris) in a coal ash-contaminated habitat: direct and indirect effects of trace elements leading to a local population sink. Archives of Environmental Contamination and Toxicology .

* Jenner, H. A. and T. Bowmer. 1992. The Accumulation of Metals and Toxic Effects in Nereis virens Exposed to Pulverised Fuel Ash. Environ. Monit. Assess. 21:85-98.

* Larrick, S. R., J. R. Clark, D. S. Cherry and J. Cairns , Jr. 1981. Structural and Functional Changes of Aquatic Heterotrophic Bacteria to Thermal, Heavy and Fly Ash Effluents. Water Res. 15:875-880.

* Lemly, A.D. 1985. Ecological basis for regulating aquatic emissions from the power industry: The case with selenium. Regulatory Toxicology and Pharmacology 5: 465-486.

* Lemly, A.D. 1985. Toxicology of Selenium in a Freshwater Reservoir: Implications for Environmental Hazard Evaluation and Safety. Ecotox. Environ. Saf. 10:314-338.

* Lemly, A.D. 1993. Teratogenic effects of selenium in natural populations of freshwater fish. Ecotoxicology and Environmental Safety 26: 181-204.

* Lemly, A.D. 1996. Assessing the toxic threat of selenium to fish and aquatic birds. Environmental Monitoring and Assessment 43: 19-35.

* Lemly, A.D. 1997. Ecosystem recovery following selenium contamination in a freshwater reservoir. Ecotoxicology and Environmental Safety 36: 275-281.

* Lemly, A.D. 1997. A teratogenic deformity index for evaluating impacts of selenium on fish populations. Ecotoxicology and Environmental Safety 37: 259-266.

* Lemly, A.D. 1998. Pathology of selenium poisoning in fish. Chapter 16 (Pages 281-296) in W.T. Frankenberger and R.A. Engberg, editors. Environmental Chemistry of Selenium . Marcel-Dekker Press, New York , NY .

* Lemly, A.D. 1998. Belews Lake : Lessons learned. Pages 3-6 and E15-20 in U.S. EPA Publication EPA-822-R-98-007. Report on the Peer Consultation Workshop on Selenium Aquatic Toxicity and Bioaccumulation. U.S. Environmental Protection Agency, Office of Water, Washington , DC .

* Lemly, A.D. 1999. Selenium impacts on fish: An insidious time bomb. Human and Ecological Risk Assessment 5: 1139-1151.

* Lemly, A.D. 2002. Symptoms and implications of selenium toxicity in fish: the Belews Lake case example. Aquatic Toxicology 57: 39-49.

* Magnuson, J.J, A.M. Forbes, D.M. Harrell and J.D. Schwarzmeier. 1980. Response of Stream Invertebrates to an Ashpit Effluent. EPA 600/3-80-081, Environmental Research Laboratory , U.S. EPA, Duluth , MN .

* Raimondo, S. M., C. L. Rowe and J. D. Congdon. 1998. Exposure to Coal Ash Impacts

Swimming Performance and Predator Avoidance in Larval Bullfrogs (Rana catesbeiana). J. of Herpetology 32:289-292.

* Rodgers, J. H., Jr., D. S. Cherry and R. K. Guthrie. 1978. Cycling of Elements in Duckweed (Lemna perpusilla Torrey) in an Ash Settling Basin Stream and Swamp Drainage System. Water Res. 12:765-770.

* Rose, C. D. T. J. Ward and V. E. dePass. 1985a. Ecological Assessment for Coal Ash Dumped at Deepwater Dumpsite - 106. In: Duedall, I. W., D. R. Kester, P. K. Park, B. H. Ketchum (Eds.) Wastes in the Ocean, Volume 4: Energy Wastes in the Ocean. John Wiley and Sons, New York , NY .

* Rose, H., P. M. J. Woodhead and H. B. O'Connors, Jr. 1985b. Coal Waste in the Sea I: Toxicity Assays with Culture of a Marine Diatom. In: Duedall, I. W., D. R. Kester, P. K. Park, B. H. Ketchum (Eds.) Wastes in the Ocean, Volume 4: Energy Wastes in the Ocean. John Wiley and Sons, New York , NY .

* Rowe, C. L., O. M. Kinney and J. D. Congdon. 1998a. Oral Deformation in Tadpoles of Bullfrogs (Rana catesbeiana) Caused by Conditions in a Polluted Habitat. Copeia 1998:244-246.

* Rowe, C. L., O. M. Kinney, R. D. Nugle and J. D. Congdon. 1998b. Elevated Maintenance Costs in an Anuran (Rana catesbeiana) Exposed to a Mixture of Trace Elements during the Embryonic and Early Larval Periods. Physiological Zoology 71(1):47-55.

* Rowe, C. L., O. M. Kinney, A. P. Mori and J. D. Congdon. 1996. Oral Deformities in Tadpoles (Rana catesbeiana) Associated with Coal Ash Deposition Effects on Grazing Ability and Growth. Freshwater Biology 36:723-730.

* Ryon, M. G. 1992. Ecological Effects of Contaminants in McCoy Branch 1989-1990. ORNLHM - 11926. Oak Ridge National Laboratory, Oak Ridge , TN. 84 pp.

* Soholt, L. F., R. W. Vocke, N. J. Beskid, W. K. Derickson, M. J. Knight, D. D. Ness, B. Siskind, W. S. White and D. J. Wyman. 1980. Handling of Combustion and Emission - Abatement Wastes from Coal-Fired Power Plants: Implications for Fish and Wildlife Resources, Natl. Power Plant Team , U.S. Fish Wildl. Serv. Ann Arbor , MI .

* Specht, W. L., D. S. Cherry, R. A. Lechleitner and J. Cairns , Jr. 1984. Structural, Functional and Recovery Responses of Stream Invertebrates to Fly Ash Effluent. Can. J. Fish Aquatic Sci. 41:884-896.

* Walia, A. and N. K. Mehra. 1998b. A Seasonal Assessment of the Impact of Coal Fly Ash Disposal on the River Yamuna, Dehli: II. Biology. Water Air Soil Pollut. 103:315-339.

* Webster, K.E., Forbes, A.M. and J.J. Magnusonl. 1981. Behavioral Responses of Stream Macroinvertebrates to Habitat Modification by a Coal Ash Effluent. In , The Warmwater Streams Symposium, L.A. Krumholtz (editor). Southern Division, American Fisheries Society, pp. 408-414.

* Woodhead, P. M. J. 1985. Coal Waste in the Sea II: Toxicity Tests with Shrimp and with Flounder Eggs and Larvae. In: Duedall, I. W., D. R. Kester, P. K. Park, B. H. Ketchum (Eds.) Wastes in the Ocean, Volume 4: Energy Wastes in the Ocean. John Wiley and Sons, New York , NY .

Hazardous Contaminants in Power Plant Fly Ash and Other Wastes:

* Bhumbla, D.K. and R.F. Keefer. 1994. Arsenic Mobilization and Bioavailability in Soils. J.O. Nriagu (Ed.) Arsenic in the Environment, Part 1: Cycling and Characterization. John Wiley and Sons, New, NY: pp 51-82.

* Bignoli, G. 1989. Health and Environmental Impact of Chromium Released from Coal Ash. Journal of Coal Quality, v 8 (3/4): 72-.

* Cherry, D. S. and R. K. Guthrie. 1977. Toxic Metals in Surface Waters from Coal Ash. Water Resour. Bull. 13:1227-1236.

* Cherry, D. S. and R. K. Guthrie. 1978. Mode of Elemental Dissipation from Ash Basin Effluent. Water, Air and Soil Pollution 9:403-412.

* Chu , T.-Y. J., R. J. Ruane and P. A. Krenke. 1978. Characterization and Reuse of Ash Pond Effluents in Coal-Fired Power Plants. Water Pollution Contr. Fed. J. 50:2494-2508.

* Coutant, C. C., C. S. Wasserman, M. S. Chung, D. B. Rubin and M. Manning. 1978. Chemistry and Biological Hazard of a Coal Ash Seepage Stream. J. Water Pollut. Control Fed. 50:747-735.

* Dodd, D.J.R.; Golomb, A.; Chan, H.T.; and D. Chartier. 1981. "A Comparative Field and Laboratory Study of Fly Ash Leaching Characteristics," Hazardous Solid Waste Testing: First Conference, ASTM STP 760, R.A. Conway and B.C. Malloy , Eds., American Society for Testing and Materials, pp.164-185.

* Dudas, J. M. 1981. Long-Term Leachability of Selected Elements from Fly Ash. Environ. Sci. and Techn. 15:840-843.

* Fisher, G. L. and D. F. S. Natusch. 1979. Size Dependence of the Physical and Chemical Properties of Coal Fly Ash. In : Analytical Methods for Coal and Coal Products (Vol. III). C. Kar (Editor). Academic Press, New York , NY . Pp 489-541.

* Fulekar, M.H. and C.P. Jayalakshmi. 1989. Fly Ash Dynamics in Soil-Water Systems. Crit Rev Environ Control, 19 (n3): 251-.

* Gabbard, A. 1993. Coal Combustion: Nuclear Resource or Danger, , Oak Ridge National Laboratory REVIEW No. 3 and 4: 24-32.

* Hanson, R.L.; Henderson , T.R.; Hobbs , C.H.; Clark, C.R.; Carpenter, R.L.; Dutcher. J.S.; Harvey , T.M. and D.F. Hunt. 1983. Detection of Nitroaromatic Compounds on Coal Combustion Particles. Journal of Toxicology and Environmental Health 11: 971-80.

* Harrison , F.L.; Bishop, D.L. and B.J. Mallon. 1985. Comparison of Organic Combustion producst in Fly Ash Collected by a Venturi Wet Scrubber and an Electrostatic Precipitator at a Coal-Fired Power Station. Enviro. Sci. Technol. 19: 186-93.

* Hjelmer, O. 1990. Leachate From Land Disposal of Coal Fly Ash. Waste Manage. Res. 8:429-449.

* Mangani, F.; Cappiello, A.; Crescentini, C.; Bruner, F. and L. Bonfanti. 1987. Extraction of Low Molecular Weight Polynuclear Aromatic Hydrocarbons from Ashesof Coal-Operated Power Plants. Anal. Chem. 59: 2066-69.

* de Raat, W.K.; Boere J.P.; and G.R. Mohn. 1994. Contribution of PAH and some of their nitrated derivatives to the mutagenicity of ambient airborne particles and coal fly ash. Science of the Total Environment 65: 7-.

* Thakre, R. and A.L. Aggrawal. 1993. Disposal of Ash from Thermal Power Stations on Land: Environmental Pathways and Mitigation Mechanisms. Energy Environment Monitor 9: 1-9.

* Theis, T. L. and J. L. Wirth. 1977. Sorptive Behavior of Trace Metals on Fly Ash in Aqueous Systems. Environ. Sci. and Techn 11:1096-1100.

* Theis, T. L., J. A. Ripp and J. F. Villaume. 1989. Physical and Chemical Characteristics of Unsaturated Pore Water and Leachate at a Fly Ash Disposal Site. P. 161-172. In 43 rd Purdue Industrial Waste Conf. Proc. Lewis Publishers, Chelsea , MI .

Ground/Drinking Water Contamination from Power Plant Waste Disposal:

* Cherkauer, D.S. 1980. The Effect of Fly Ash Disposal on a Shallow Ground-Water System. Ground Water 18(6):544-550.

* Gschwend, P.M.; Backhus, D.A.; MacFarlane, J.K.; and A.L. Page. 1990. Mobilization of Colloids in Groundwater Due to Infiltration of Water at a Coal Ash Disposal Site. Journal of Contaminant Hydrology, 6: 307-320.

* Hutton, M. and C. Symon. 1986. The Quantities of Cadmium, Lead, Mercury, and Arsenic Entering the U.K. Environment from Human Activities. The Science of the Total Environment 57: 129-50.

* Kopsick, D.A. and E.E. Angino. 1981. Effect of Leachate Solutions from Fly and Bottom Ash on Groundwater Quality. J. Hydrology 54:341-356.

* Riewe, T. 1995. The Ones That Gave Us Gray Hair. Water Well Journal 49 (n2): 29-31.

* Spencer, L. and L.D. Drake. 1987. Hydrogeology of an Alkaline Fly Ash Landfill in Eastern Iowa . Ground Water 25 (n 5): 519-26.

* Walia, A. and N. K. Mehra. 1998a. A Seasonal Assessment of the Impact of Coal Fly Ash Disposal on the River Yamuna, Dehli: I. Chemistry. Water Air Soil Pollut. 103:277-314.

* U.S. EPA. Final Site Investigation Report, Groundwater Contamination, Township of Pines , Porter County , IN, Technical Direction Document No. S05-0204-013. December 30. 2002.

Human Health Impacts from Water Contamination by Power Plant Wastes:

* Agency for Toxic Substances and Disease Registry, Center for Disease Control, Health Consultation, Town of Pines Groundwater Plume, Town of Pines, Porter County, Indiana. June 14, 2002. http://www.atsdr.cdc.gov/HAC/PHA/townpines/top_pl.html.

QUALIFICATIONS STATEMENT
Dr. A. Dennis Lemly

I have spent over 30 years investigating the effects of selenium pollution in aquatic ecosystems. I have extensive experience conducting field and laboratory research on selenium toxicology, primarily involving aquatic cycling, bioaccumulation, and effects on fish. These studies include intensive investigations of the two most substantial cases of selenium pollution that have taken place in the USA; (1) Belews Lake, North Carolina, where 19 species of fish were eliminated, and (2) Kesterson Marsh, California, where thousands of aquatic birds were poisoned. My career began in the late 1970's with studies of the landmark pollution event at Belews Lake, which established the fundamental principles of selenium bioaccumulation and reproductive toxicity in fish. In the 1980's, I was a research project manager for the U.S. Fish and Wildlife Service, directing studies that determined impacts of selenium from agricultural irrigation on aquatic life at Kesterson and in 14 other western states. In the 1990's, the emphasis of my research shifted to the development of methods and guidelines for hazard assessment and water quality criteria for selenium, which led to the publication of a reference book (see item 42 below). This handbook contains the first comprehensive assessment tools for evaluating selenium pollution on an ecosystem scale. I have consulted on selenium contamination issues around the world, including such problems as power plant discharges in Australia, gold mining effluents in Russia, agricultural irrigation drainage in Egypt, and landfill leachate in Hong Kong. I provide the methods and technical guidance necessary to identify, evaluate, and correct aquatic selenium problems before they become significant toxic threats to fish and wildlife populations. I have devised and applied techniques for protecting aquatic life in habitats from the Arctic to the tropics, and from high mountain streams to coastal lagoons. My selenium evaluation guidelines and water quality criteria recommendations have been adopted by the U.S. Environmental Protection Agency, the U.S. Fish and Wildlife Service, 23 states and over 60 nations and provinces around the world. I have Masters and Doctorate degrees in biology from Wake Forest University.

PUBLICATIONS ON SELENIUM:

1. Lemly, A.D. 1982. Response of juvenile centrarchids to sublethal concentrations of waterborne selenium: I. Uptake, tissue distribution, and retention. *Aquatic Toxicology* 2: 235-252.
2. Lemly, A.D. 1982. Determination of selenium in fish tissues with differential pulse polarography. *Environmental Technology* 3: 497-502.
3. Lemly, A.D. 1983. A simple activity quotient for detecting pollution-induced stress in fishes. *Environmental Technology* 4: 173-178.
4. Lemly, A.D. 1985. Ecological basis for regulating aquatic emissions from the power industry: The case with selenium. *Regulatory Toxicology and Pharmacology* 5: 465-486.
5. Lemly, A.D. 1985. Toxicology of selenium in a freshwater reservoir: Implications for environmental hazard evaluation and safety. *Ecotoxicology and Environmental Safety* 10:

314-338.

6. Lemly, A.D. 1986. Effects of selenium on fish and other aquatic life. Pages 153-162 in J.B. Anderson and S.S. Anderson, editors. *Toxic Substances in Agricultural Water Supply and Drainage: Defining the Problems*. U.S. Committee on Irrigation Drainage, Denver, CO.
7. Lemly, A.D., and G.J. Smith. 1987. *Aquatic Cycling of Selenium: Implications for Fish and Wildlife.* Fish and Wildlife Leaflet 12. U.S. Fish and Wildlife Service, Washington, DC. 10 pages.
8. Lemly, A.D. 1989. Cycling of selenium in the environment. Pages 113-123 in A.Q. Howard, editor. *Selenium and Agricultural Drainage: Implications for San Francisco Bay and the California Environment*. The Bay Institute of San Francisco, Tiburon, CA.
9. Lemly, A.D., and G.J. Smith. 1991. Selenium in aquatic ecosystems: Potential impacts on fish and wildlife. In R.C. Severson, S.E. Fisher, Jr., and L.P. Gough, editors. *Proceedings of the Billings Land Reclamation Symposium on Selenium in Arid and Semiarid Environments, Western United States. U.S. Geological Survey Circular* 1064: 43-53.
10. Lemly, A.D. 1993. Subsurface agricultural irrigation drainage: The need for regulation. *Regulatory Toxicology and Pharmacology* 17: 157-180.
11. Lemly, A.D., S.E. Finger, and M.K. Nelson. 1993. Sources and impacts of irrigation drainwater contaminants in arid wetlands. *Environmental Toxicology and Chemistry* 12: 2265-2279.
12. Lemly, A.D. 1993. Guidelines for evaluating selenium data from aquatic monitoring and assessment studies. *Environmental Monitoring and Assessment* 28: 83-100.
13. Lemly, A.D. 1993. Teratogenic effects of selenium in natural populations of freshwater fish. *Ecotoxicology and Environmental Safety* 26: 181-204.
14. Lemly, A.D. 1993. Metabolic stress during winter increases the toxicity of selenium to fish. *Aquatic Toxicology* 27: 133-158.
15. Lemly, A.D. 1994. Agriculture and wildlife: Ecological implications of subsurface irrigation drainage. *Journal of Arid Environments* 28: 85-94.
16. Lemly, A.D. 1994. Irrigated agriculture and freshwater wetlands: A struggle for coexistence in the western United States. *Wetlands Ecology and Management* 3: 3-15.
17. Lemly, A.D. 1995. A protocol for aquatic hazard assessment of selenium. *Ecotoxicology and Environmental Safety* 32: 280-288.
18. Lemly, A.D. 1996. Selenium in aquatic organisms. Chapter 19 (pages 427-445) in W.N. Beyer, G.H. Heinz, and A.W. Redmon-Norwood, editors. *Environmental Contaminants in Wildlife: Interpreting Tissue Concentrations.* Lewis Publishers, Boca Raton, FL.
19. Lemly. A.D. 1996. Winter Stress Syndrome: An important consideration for hazard assessment of aquatic pollutants. *Ecotoxicology and Environmental Safety* 34: 223-227.
20. Lemly, A.D. 1996. Identifying and reducing environmental risks from agricultural irrigation drainage in developing countries. *Proceedings of the World Congress of Toxicology in Developing Countries* 3: 177-190.
21. Lemly, A.D. 1996. Assessing the toxic threat of selenium to fish and aquatic birds. *Environmental Monitoring and Assessment* 43: 19-35.

22. Lemly, A.D. 1996. Wastewater discharges may be most hazardous to fish during winter. *Environmental Pollution* 93: 169-174.
23. Lemly, A.D. 1996. Evaluation of the hazard quotient method for risk assessment of selenium. *Ecotoxicology and Environmental Safety* 35: 156-162.
24. Lemly, A.D. 1997. Ecosystem recovery following selenium contamination in a freshwater reservoir. *Ecotoxicology and Environmental Safety* 36: 275-281.
25. Lemly, A.D. 1997. Environmental hazard of selenium in the Animas La Plata Water Development Project. *Ecotoxicology and Environmental Safety* 37: 92-96.
26. Lemly, A.D. 1997. Role of season in aquatic hazard assessment. *Environmental Monitoring and Assessment* 45: 89-98.
27. Lemly, A.D. 1997. A teratogenic deformity index for evaluating impacts of selenium on fish populations. *Ecotoxicology and Environmental Safety* 37: 259-266.
28. Lemly, A.D. 1997. Environmental implications of excessive selenium. *Biomedical and Environmental Sciences* 10: 415-435.
29. Lemly, A.D. 1998. Pathology of selenium poisoning in fish. Chapter 16 (Pages 281-296) in W.T. Frankenberger and R.A. Engberg, editors. *Environmental Chemistry of Selenium.* Marcel-Dekker Press, New York, NY.
30. Lemly, A.D. 1998. A position paper on selenium in ecotoxicology: A procedure for deriving site-specific water quality criteria. *Ecotoxicology and Environmental Safety* 39: 1-9.
31. Lemly, A.D. 1998. Belews Lake: Lessons learned. Pages 3-6 and E15-20 in U.S. EPA Publication EPA-822-R-98-007. *Report on the Peer Consultation Workshop on Selenium Aquatic Toxicity and Bioaccumulation.* U.S. Environmental Protection Agency, Office of Water, Washington, DC.
32. Lemly, A.D. 1999. Case study: Contaminant impacts on freshwater wetlands at Kesterson National Wildlife Refuge, California. Chapter 6 (pages 191-206) in M.A. Lewis et al., editors. *Ecotoxicology and Risk Assessment for Wetlands*. SETAC Press, Pensacola, FL.
33. Lemly, A.D. 1999. Selenium transport and bioaccumulation in aquatic ecosystems: A proposal for water quality criteria based on hydrological units. *Ecotoxicology and Environmental Safety* 42: 150-156.
34. Lemly, A.D. 1999. Irrigation drainage. Pages 304-307 in M.A. Mares, editor. *Encyclopedia of Deserts*. University of Oklahoma Press, Norman, OK.
35. Hamilton, S.J., and A.D. Lemly. 1999. The water-sediment controversy in setting environmental standards for selenium. *Ecotoxicology and Environmental Safety* 44: 227-235.
36. Lemly, A.D. 1999. Selenium impacts on fish: An insidious time bomb. *Human and Ecological Risk Assessment* 5: 1139-1151.
37. Lemly, A.D., R.T. Kingsford, and J.R. Thompson. 2000. Irrigated agriculture and wildlife conservation: Conflict on a global scale. *Environmental Management* 25: 485-512.
38. Lemly, A.D. 2001. Irrigation-induced demise of wetlands. Pages 399-410 in R.E. Munn and I. Douglas, editors. *Global Environmental Change, Volume 3: Causes and Consequences of Global Environmental Change*. John Wiley & Sons Ltd., Chichester, United Kingdom.

39. Lemly, A.D. 2002. Symptoms and implications of selenium toxicity in fish: The Belews Lake case example. *Aquatic Toxicology* 57: 39-49.
40. Lemly, A.D., and H.M. Ohlendorf. 2002. Regulatory implications of using constructed wetlands to treat selenium-laden wastewater. *Ecotoxicology and Environmental Safety* 52: 46-56.
41. Lemly, A.D. 2002. A procedure for setting environmentally safe Total Maximum Daily Loads (TMDLs) for selenium. *Ecotoxicology and Environmental Safety* 52: 123-127.
42. Lemly, A.D. 2002. *Selenium Assessment in Aquatic Ecosystems: A Guide for Hazard Evaluation and Water Quality Criteria*. Springer-Verlag Publishers, New York, NY.
43. Lemly, A.D. 2004. Aquatic selenium pollution is a global environmental safety issue. *Ecotoxicology and Environmental Safety* 59: 44-56.
44. Kingsford, R.T., A.D. Lemly, and J.R. Thompson. 2006. Impacts of dams, river management, and diversions on desert rivers. Chapter 8 (pages 203-247) in R.T. Kingsford (editor). *Ecology of Desert Rivers*. Cambridge University Press, UK.
45. Lemly, A.D. 2007. A procedure for NEPA assessment of selenium hazards associated with mining. *Environmental Monitoring and Assessment* 125: 361-375.
46. Lemly, A.D., and J.P. Skorupa. 2007. Technical issues affecting the implementation of US Environmental Protection Agency's proposed fish tissue-based aquatic criterion for selenium. *Integrated Environmental Assessment and Management* 3: 552-558.
47. Lemly, A.D. 2008. Aquatic hazard of selenium pollution from coal mining. Chapter 6 (Pages 167-183) in G.B. Fosdyke (editor). *Coal Mining: Research, Technology, and Safety*. Nova Science Publishers, New York, NY.
48. Palmer, M.A., E.S. Bernhardt, W.N. Schlesinger, K.N. Eshleman, E. Fonfoula-Georgious, M.S. Hendryx, A.D. Lemly, G.E. Likens, O.L Louck, M.E. Power, P.S. White, and P.R. Wilcock. (In press). Mountaintop mining consequences. *Science*.