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William E. Cooper

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Portland State University

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HOST: Good morning, and welcome to the public lecture series sponsored by the Portland chapter of Sigma Xi and Earth Resources Ltd. We are going to try to set the pace a little bit, of informality, for those of us involved, but we'd like to comment just briefly on—like, about thirty seconds—on the Sigma Xi. This is the research society of North America, scientific research society of North America, including disciplines of psychology, sociology, and physics, chemistry, engineering, and all of those. It's an important research-motivating kind of society, and they're the sponsors of the lecture part at 9:00 and at 1:00 on the first four days of this week and on the twelfth, when John Platt comes. The vice president of the Portland chapter in charge of the programs is Michael Fiasca, who is in—stand up, Mike, and let 'em see you! You're the… we'll introduce you probably every day as the program chairman for Sigma Xi, and he is also a co-teacher. Now, his partner next to him, George Tsongas—he'll stand also—is from our department of Applied Science and Engineering; he'll be with us part of the time. His research is in the area of energy conservation and he has research projects mostly related to insulation and monitoring and measuring how that works in specially designed houses, and a lot of other things; lasers, also.

Now, I'd like to introduce our speaker, just to get started on our topic, and in order to be sure that we don't worry about things at the end because we have to be out at ten-thirty for the next group to move in, we'd like to say that for the class, those from the Earth Resources Limited class, we reconvene, you'll meet as groups privately during break time, and at eleven we have at it with Bill Cooper again on discussion questions and all of the details you want to pursue.

Bill Cooper is Professor of Biology at Michigan State University; he is an outstanding ecologist, having done a lot of computer research and design… model designs of water resources, river resources, ponding of sewage and waste disposal, and many, many other aspects, and more recently become involved with toxic chemicals in the environment. So this morning is to lay the framework of ecosystems; this afternoon on toxic chemicals. He does have a lot of interesting things to say in terms of background, which we are not going to go into, because we want it to remain informal and get to the subject. So, Bill Cooper is on.

BILL COOPER: Do I need to wear a mic, or can you all hear me? Do you want a mic so you can tape me, is that the idea?

HOST: We are going to tape you, and we'd rather have this around you. Thank you.

COOPER: I'd like to emphasize what Dave said about keeping this very informal. We'll be together all day today; two very brief presentations formally, and then hopefully some very productive nose-to-nose debate and discussion, whatever you want, during the off hours.

[some background noise while they adjust the microphone]

COOPER: [continuing] I'll give you a little bit about my background. I am a biologist; right now I teach the population ecology courses at Michigan State. I also teach courses in engineering in terms of environmental systems modeling. My current research right now, they're paying me to muck around in the bottoms of ponds chasing fish. I tend to like to study ecological systems without man, because ecological systems without man are rational. They're constrained by both thermodynamics and evolution. If I have a particular biological component who decides that he wants to operate in violation of those two basic, fundamental laws or constraints or principles, however you look at them, he very rapidly becomes a fossil. So I tend to study systems that are rational systems, and at least to some degree they are predictable. As a scientist, although I realize it's socially important to face up to human-type problems, it's much more traumatic as soon as I go out and look at an ecosystem that includes human beings. Because as soon as you put human beings in an ecosystem, you don't have the luxury of assuming that it's going to act or behave rationally. Humans have the ability to abstract and anticipate things they want, and start out with the assumption that there's some damn way the engineers can provide it, as long as the economists say it's possible.

So what I want to do today is to talk about human ecosystems; the whole theme of the Earth Resources Limited is to build on the Earth 2020 program, so we were here several years ago and tried to update our knowledge of many of these environmental problems. I happen to be one of a number of speakers who were here several years ago, and everybody was talking about doom and gloom. Energy crisis, population crisis, land use crisis, food production, pollution of the ocean, upper atmospheres; you could get a shopping list as long as your arm with the crises of the day. Depending on what your bag was, you'd put them in different orders in terms of importance of priority. A lot depends on what part of the country you're from and what discipline you come to it from as to which ones you think are important. Our attempt, in this particular program, was to go to the next step and say, "Well, what have we learned in the last few years? What do we know about going out and using our scientific expertise to begin to solve some of these problems?"

So my purpose today was to pick some case studies of issues that are environmental in nature and involve human beings and the environment jointly; issues that are very large and contemporary in the sense that you've probably seen them on *60 Minutes* or read about them in newspapers, and for which the scientific answers are partially there. If I show you or get across to you the state of our understanding as ecologists as to how well we can go out and injure your ecosystems to solve human problems. It's kind of a naïve attempt that we first had, when we got started with this, we always held the engineers and physicists and all… because they were very quantitative, they're very analytical, they're very predictive. They could go out and they could design an airplane, they could put it on a computer and fly it a few hundred times, they could make sure if it worked under all kinds of extreme conditions, so the first time they built a 747 there wasn't much question it wouldn't crash. They had crashed it under all kinds of simulated conditions, and they were pretty sure they knew how to make it work. The question is, can we do that with Lake Michigan, could we do it with a pipeline on the north slopes of Alaska, could you go out and simulate offshore oil tanker unloading facilities on the coast of Oregon, and do it in a scientifically abstract mode so you went to the public and argued the pros and cons of some kind of major human endeavor that would have potentially important environmental impacts. But you could argue with science, with predictability, with objectivity, and minimize the amount of social rhetoric and rationality that usually is involved with these environmental issues.

Now, I'm not at all naïve to think that we can do this in an hour and a half, this morning and this afternoon, so my purpose is to pick case studies that I personally know where I know how the data was collected, how the bureaucrats and politicians used it, how the public reacted to it—either reacted in an intelligent fashion or, in the case of my state, in a somewhat less intelligent fashion—to try to focus on the kinds of things that we can do and what the priority problems are going to be for research for the next four or five years. So as you sit down and draft materials that you're going to go and teach from, or you're going to go and use in your own classroom situations, you can get a pretty good perspective as to what is hard and what is soft. One of the most difficult things, at least in terms of my experience with environmental issues, is somebody presents you with an environmental crisis—be it toxic materials like PBB in Michigan or Kepone in the Chesapeake, which I'll talk about that this afternoon—or be it land use, […] planning, water management, water quality—which I'll talk about this morning—it always comes to you as a major environmental confrontation. The […] or the TVA, for instance. And what you first have to realize, what you've got to do off the bat, is to somehow separate the hard physical, chemical, engineering, biological science out of it from the pure social confrontation. Because more often than not, somewhere between zero to a hundred percent of the issue has nothing to do with biology at all. It really has nothing to do with the physical natural environment. It's a human environment. It really boils down to a screwer and a screwee. And it's the distribution [tape skips] …to where the hell the social confrontation is. And that is not always obvious as to what that distribution is.

Now, if I may have the first slide please. When you talk about managing ecosystems, I've got kind of a conceptual paradigm that I keep in the back of my head. I abstracted it here so that you can kind of get an image of what I'm talking about. When I talk about the natural environment, the type of thing as the ecologists that I study, I'm talking about a system that was designed by evolution, run by a process of natural selection; it's a system that man has very limited ability to directly affect. We do very little in terms of genetic engineering out there in the real world, even though with DNA recombinant research people are talking about it, in actual fact the only way you're going to modify nature is to modify genes in any significant way. We do this in a very limited extent; only like in agriculture or biomedical research, where we get into the area of animal and plant breeding, where we've got a specific monetary yield out to justify the tremendous research time it takes to that kind of genetic engineering.

I'm talking about a system, then, that operates with its own rules, its own controls, its own regulation, its own criteria of success, and that's survivorship. It's the only thing that counts. If you don't survive in the ecological game, you're a fossil, and you're only a fossil once. That's a very permanent ending to a game. What we have done, at least, and I'm going to talk about systems here in industrialized, technological worlds; some of the other speakers will talk about Third and Fourth World countries, and we can have that discussion if you want, but I thought we'd start with something we all think we know, the system we were brought up in, and look at the conflicts there. It's much more tenuous when you extrapolate to other countries and to other environments around the world that none of us have had firsthand experience with. I'm talking about a system which basically was designed by engineers and run by economists. It doesn't make it bad; it just makes it human-oriented. I'm talking about systems that have agriculture, have industry, have cities, have transportation systems. I'm talking about systems in our form of lifestyle that's energy-intensive, capital-intensive, machine-intensive. That's generated by a modern-day technology. And much of what you're going to hear from myself and the other speakers in the next four days are looking at the social and environmental implications of that technology. That doesn't mean that technology is bad. It's designed to do a specific thing: provide a quality of life for human beings that they demanded. It was so successful that much of the rest of the world is demanding the same technology no matter what the social and environmental trade-offs are going to be. Of course, one of the questions we can talk about is about the ethical implications of shipping that technology overseas, knowing what we are beginning to learn about our own.

Both of these systems by themselves are perfectly rational. There's no problems, there's no inherent, necessarily, inherent conflicts between the two, as long as they are kept separate. The whole, you know, [...] feedback, capitalistic, growth-oriented economy we have up here in our system is perfectly good given the assumptions we had back in the early 1900s. The ecological kinds of control systems you find out in natural systems make a lot of sense, because they're oriented over survivorship over 700 million years. The conflict comes when you put the two together in the same finite Earth, the same closed system. The real design and management problem of ecosystems is how do you manage the two subsystems in concert, to couple them together? That's the kind of thing we're going to talk about.

I can't talk about, in the short time we have, all the dimensions of it, so I picked two. One is, how would you design and manage a piece of the ecosystem down here as the environment, given the fact that it's supposed to provide certain kinds of goods and services for human beings? The kind of examples I'm going to pick are from the Great Lakes region, because I happen to know those, again, the Great Lakes is a major aquatic ecosystem. It's 20% of all the surface fresh water in the world. It's one great, big, huge drainage basin. I'm going to talk about that one, and I'm going to talk about the various kinds of problems with land use, water quality, the fisheries and so forth, as an integrated system. You could take that same example, a case study, and apply it to a valley here in Oregon, or, when I get… for those of you who have ever been to Hawai'i, talking with a group there, it's the same thing with the Hawai'ian islands. They're a smaller ecosystem nested in a bigger world. The point is, how do you design and control it to have it provide a certain quality of things for human beings and still stay within certain constraints in terms of thermodynamics and evolution? The natural… the kind of natural things that I worry about as a natural scientist.

So I'm going to talk this morning about examples of the way ecologists think in terms of designing and managing a system here as a unit, given the fact that it has to provide something here, either processing waste or providing recreation and food. The other example I'm going to talk about this afternoon is, to me, the single most important class of environmental issues coming down the pipe, the whole problem of toxic materials. PBBs and Kepones and PCPs and PCBs and vinyl chlorides and, you know, there's a shopping list as long as the organic chemist has an imagination. That is a particular class of problems called residual managements, that is, given the discharge of waste here, and given certain limitations on ecology and public health down here, how do you manage this particular coupling right here? OK? These are the two aspects of the situation I'm going to talk about.

Now, I'm going to have to move along fairly rapidly, I usually like… I prefer to have people stop and give me questions as we go along, but this format is set up where I talk like mad for an hour and a half and you organize yourselves for fifteen or twenty minutes and you chew on me for the next hour. So I'll have to forego questions for the sake of getting the information across for the first little while.

This is the ecosystem I'm talking about. This is the Great Lakes: Lake Ontario, Lake Erie, Lake Huron, Lake Michigan, Lake Superior. The upper three lakes are three of the largest freshwater bodies of water in the world. Lake Baikal and I think Lake Tanganyika are both bigger. Baikal is number one, Superior is number two, and I think Huron and Michigan are four and five, or some combination like that. The upper three Great Lakes are very unique kind of ecological systems; they are what we call "oligotrophic," they're very deep, they're very cold, they have very low productivity. They have very low phosphorus and nitrogen cycles, much like many of your alpine lakes here in the West. They are lakes, essentially these were dug out by glaciers out of the old Laurentide shield that came down out of Canada; it's very barren kind of soils in the North, so the leachates are very low. So the rainfall normally brings in a very low amount of nitrogen, a very low amount of phosphorus. These lakes have evolved species of fish, species of invertebrates, species of plants, that have been designed by evolution to grow very slowly, to process chemicals very slowly, to take a very long time to develop; the whole life cycle is retarded in the sense of speed. It's slowed up. Now, you could almost stop and look at the conflict right there. Because in general, when we want something, we want it in a hurry. We want a lot of it, and we want it in a hurry, and here's an ecosystem that by evolutionary design was designed to operate very slowly. OK?

There are two dimensions of the kinds of management and control decisions one could make, two different aspects of it. One is physical manipulations themselves of the watershed, both in terms of land development, shoreline management, pollution abatement and all this kind of land use planning that goes on. I know Oregon's had a history of this. The other is physical manipulations of the lakes themselves. I'm going to give you examples of proposed projects by the Army Corps of Engineers and the Coast Guard and so forth that will be major physical perturbations of that lake. What I want to do is to lay them out and ask you the question, how would you go about deciding whether or not these… the total cost-benefit trade-off, in the long run, not the short run, but the pure social benefits versus risks involved with these kinds of projects, how good or bad? To a great degree, that's the kind of decision-making mentality you've got to develop. Supposedly that's what we do with an environmental impact statement. For the last four years, I've been chairman of the environmental review board for the state of Michigan for our governor. We're the ones that receive all the state and federal environmental impact statements, hold the public hearings, and vote on them. And supposedly an EIS, an environmental impact statement, is a model, it's a predictive model. It allows a bureaucrat to sit here today and predict in the future whether what he's going to propose to do is going to have, in the long run, a social benefit. And that is a very easy thing to say and a very, very difficult thing to do when you're talking about environmental resources.

The other aspect is not the physical one, but the biological one. The biological component to that ecosystem. And that's the one I want to talk about first. It's one that's usually ignored, because most biologists demand that engineers and chemists write environmental impact statements; most biologists don't know how to write one and don't want to. So they weave and dodge all the time and say that really isn't something that we're supposed to do.

Now, when you talk about the biological structure of the Great Lakes, if you look back prior to the 1940s—and this was published by Stan Smith in the *Canadian Journal of Fisheries*—you found the lake essentially had… is that in focus? Am I just too close to it? It looks blurred for me, but I guess that… Essentially, the lake trout was a dominant fish in the lake; the lake trout is a salmonid, it's a very large, slow-growing—it takes seven years to become sexually mature, and that's an important number to remember—so if I had to put lake trout back in that lake, I'd have to plant it for seven years in a row before it'd even get the first reproduction. That's a time lag in terms of what it takes to go out there and manage that lake. It's a fish that we call a top predator, and it preyed upon about seventeen different species of fish in the lake, and I just listed a few of them here. There are lake […] herring, there were smelt, there were ciscoes, there were perch, there were sculpins, and about another twelve others. So there's a whole array of different fish, and these are all… many of them were endemic to the lake, meaning these lakes are very unique and these are species that evolved there; you don't find them in any other lake systems. Which means these were unique biological events in terms of… in fact, several of them right now are listed as endangered species, since this was their sole breeding ground, as far as we know. And the lake trout preyed upon all of these, and these particular forage fish preyed upon all kinds of zooplankton and midges and creepy-crawly bugs and all that kind of stuff that guys like myself study in the bottom of lakes, and those all fed on algae and diatoms and various types of plant tissue.

The point is, there's a whole biological structure there, and as ecologists we organize that structure in terms of flows of energy and flows of materials. In exactly the same way your engineers talk about dynamics of economies in terms of material and energy flow, we talk about the dynamics of ecological systems, in terms of the continuity of the flows of materials and energy. That's what it takes to keep your biological world alive; it's got to process materials and energy the same way a human economy has to, and in that way they're very similar.

Now, up through the 1940s, man essentially preyed upon the lake trout at the commercial fisheries. That harvested somewhere around about five million pounds of lake trout a year; it would shift the stock of the lake trout somewhat depending on the fishery, so you'd get fewer bigger ones and a few more little ones. That kind of stress, that kind of man's impact in that lake was very tolerable. The species was still there; they were not endangered; they could work out their own competition and predation and all the biological interaction that it takes to stabilize a biological community. Remember that date: this is through 1940. I can back up a slide. In about 1825, Niagara Falls over here was a barrier. It was a barrier to migratory fish from the Atlantic Ocean. As you know here in Oregon, there's a number of fish we call anadromous fish that can run from saltwater to freshwater to spawn. Salmon are perfect examples. They physiologically can tolerate both salt and fresh water. Well, there are a number of fish in the Atlantic Ocean that are the same way, and they would characteristically run up the Hudson River, or run up the St. Lawrence River; they could get as far as Lake Ontario but they couldn't get into the upper Great Lakes because Niagara Falls was a physical barrier to any farther upstream migration. They got into the Finger Lakes in New York State, but not up here.

In 18… I can't remember the exact date, 1825 or somewhere in there, we built the Welland Canal around Niagara Falls, hooking up the St. Lawrence system, and the Erie Canal, hooking up the Hudson River system to Lake Erie. When it was built, nobody worried about environmental impact statements; the Army Corps didn't exist; the Sierra Club, as far as I know, didn't write any protest letters; the Department of the Interior and the fisheries biologist, nobody worried about it. It was done for economic reasons. It opened up the whole interior of the Great Lakes to industrialized shipping. And as a result of those canal systems—if you look at Buffalo, Erie Pennsylvania, Cleveland, Toledo, Detroit, Flint, Saginaw, Bay City, Muskeegan, Gary Indiana, Chicago, Milwaukee, Duluth—you have some of the heaviest industrial development, urbanization, steel industries, automobile industries, chemical industries developed in the whole country. They developed because of the Great Lakes system. Industry needs fresh water for transportation, for cooling electrical energy generating plants, and for industrial use. And they're located there because of water. It's a tremendous physical natural resource in the United States. You consider that's twenty percent, one-fifth of all the surface fresh water in the world, that's a non-trivial ecological resource for both human use as well as for ecological kinds of activities.

Because of that, all right, 1825, 1826, somewhere in there, they built the canal. The first sea lamprey… what it did, I'm sorry, it allowed two fish to get into the Great Lakes: the sea lamprey and the alewife. The first fish that got in there was the sea lamprey. Let me… I forgot one slide, let me back up just a minute here. Remember, I laid out the distribution of those fishes for you, about fifteen forage fish? I think I forgot to tell you there. These fish are not just uniformly distributed around the lake. These fish are distributed in very highly selective what we call ecological niches. They are specialized in their behavior, their morphology, their physiology to do very specific kinds of things. You'll find a certain subset of those fishes, for instance, that you'll only find in shallow water. Many of your perch, many of your smallmouth bass, many of your small minnows, their whole life cycle is oriented towards rocky, sandy shoals, oriented towards the substrate. And the whole energy/food chair is oriented towards sunlight being fixed in diatoms and algae being eaten by small insects like caddis flies and mayflies that […] being eaten by the fish. There's a whole food chain that is oriented towards the bottom, the substrate of the lake.

There's another group of fish that only live down in the deep bottoms of these lakes. Lake Michigan, for instance, it gets up over six, seven hundred feet deep; Lake Superior gets up to fifteen hundred feet deep. These are very, very deep lakes. There's very little primary production down there; very little sunlight hits the bottom of the lake. So these whole food change work on detritus, dead plant and animal tissue raining down, much like your deep bentho-pelagic ocean communities live. A completely different kind of ecological system. There's another group of fish that spend their whole life cycle living in the open water. They are called pelagic; they're free-swimming. Most of them don't even have swim bladders; they can't stop swimming or they'll sink to the bottom and die. Your menhaden—menhaden are East Coast—your anchovies out here are examples of those. Where you get large, huge schools of fish that are constantly in motion, constantly swimming. And they're feeding on another food chain entirely, of small little algae, fixing sunlight, that are floating in the water being eaten by zooplankton, small little crustaceans get eaten by small fish and bigger fish and bigger fish. There's a whole… again, a whole kind of structure here in the open water.

Now, the Great Lakes have exactly that same kind of structure. Ecological niches are a way, in a teleological sense, of minimizing competition, because each of these communities don't compete for the same energy. They all have different pathways of energy and materials. So you can pack in lots of species. That's one of the reasons that in many of these natural communities you have a high biological diversity, because there's specialization in that ecological world and it's there for a very, very important purpose.

Again, as a result of the opening up of the Welland Canal, we allowed the sea lamprey into the Great Lakes. The sea lamprey is a rather unique fish; it's a cartilaginous fish, meaning it's very primitive and it's related to something like sharks. It normally is a larva in what we call an ammocoete, it's a little worm-like larval fish that lives in the mud along your freshwater streams. It just sits there with its head sticking out and eats small insects that flow down the streams and so forth. After five years—and again, that's a critical number to remember—five years it spends as a larval fish. It then metamorphoses into a large eel-like fish that's about that long, about that big around, and it's got a big round kind of… well, it's an oval mouth with big, fleshy lips, OK, that locks onto the side of a fish like that and chews a hole in the side of it, secretes enzymes that keep the blood from coagulating, and it sucks on the body, the blood of the fish. It's a predator, but it doesn't go out and kill something the way a lion would in one stroke, it's got to chew on it two or three times. It takes a couple of days for it to lock onto the side of a lake trout, and if it actually drains enough of its body fluid it'll eventually kill the fish.

The first sea lamprey we found in the upper Great Lakes showed up in about 1938. So it took about 110 to 120 years for that sea lamprey to work its way up into Lake Huron after they built the canal. So if you're going to sit there in the 1920s writing an environmental impact statement to predict the impact of a human activity in terms of ecosystem perturbation, you'd have to predict in a time course of a hundred to two hundred… period of years time. One of the lessons you've got to learn is that you can't go out and say, "Well, gee, we did something and two years later nothing happened. That means it was safe." Ecological systems don't necessarily operate… think about it. The poor lamprey didn't know Duluth was there. He wasn't sitting there thinking, "Hey, now the canal's built, let's go over to Duluth," and took off! Heck, no. He'd never been there before, he had no idea it was there. It was one of the passive diffusion models where every year they went a couple more miles and went back again; a couple more miles the next year. It took that look for the system, for them to essentially work their way up, and now they are permanently established in the Great Lakes.

We probably have done more biological damage—ecological damage by biological introductions—than all the chemical and thermal production you have heard about to date. If you really had to go out and document ecological disruption, I can give you better case studies by introduction of biological pollutants than I can chemical pollutants. Because biological ones are self-reproducing, and once you get 'em in, you don't get 'em out. This is an irreversible act.

There's no way we could extract the sea lamprey from the Great Lakes. We're going to have to baby-sit with that animal for the rest of our lives. In general, I think that's a principle, one of the things you should emphasize, and people haven't. People have spent far more time worrying about chemical and industrial pollutants than they have agriculturalists or fishery biologists or foresters or agronomy clubs bringing in exotic plants and animals and turning them loose. One of the things you might look at is pet dealers. Go look at Miami sometime, with all the exotic fish and birds in southern Florida, brought in by a multi-billion-dollar pet industry that turns them loose periodically, and you'll see some ecologically interesting examples.

What happened is, the sea lamprey comes in and it preyed upon the lake trout. It was competing with man, OK? Preying upon the lake trout exactly the same way. Man was trying to maximize his economic efficiency; the lamprey was trying to maximize his energetic efficiency. So what it was doing, it was taking the biggest fish in the lake and chewing on that first. Now, the sea lamprey in the Atlantic Ocean is not a pest. It evolved there with whatever the checks and balances are, and that's one of the things about ecology that you've got to learn. That's one of the things that man disrupts. The Atlantic Ocean, that community has had several hundred million years to evolve all the relationships, so predation, competition, disease, parasitism, whatever it is, whatever the biological mechanism is, the sea lamprey is not a pest in the Atlantic Ocean. We haven't any idea what controls it, whether control is in the ocean on the adults, or whether the control is on the young larvae up in the freshwater streams along the East Coast. Nobody's ever studied it. But by definition, it's not a pest.

When it gets to the Great Lakes, whatever those control options were, they were left behind in the Atlantic Ocean. So the thing is, the fish are like a kid in a candy store. They've got great big lake trout sitting all over the place with no defensive mechanisms, a ready food source, and what's going to happen? Well, the sea lamprey population is going to take off, like you'd expect. And by the early 1950s, the sea lamprey and man together, both of them operating on the lake trout as a primary food object, had completely eliminated all the lake trout in Lake Huron, Lake Michigan, and half of Lake Superior. Wiped it right out. Remember I said that this is a case where I could more easily document biological disruption to the ecology? You name me a pesticide, an insecticide, a toxic compound that has completely eliminated a species from a major ecosystem like that [snaps fingers] in a matter of ten years. That's a tremendous ecological impact. That's why I say biological pollutants or biological introductions probably have more potential negative impacts than many of the kind of toxicants that we talk about. One of the reasons we emphasize more of the toxic compounds is because they affect man with public health. They're carcinogenic or mutagenic, and most of our laws are based on human health and protecting man, not on protecting dickie birds and fungi in the soil and that kind of stuff. But if you're really worried about it from the point of view of ecological impacts, the biological introductions are probably more of a critical thing to look at. And again, we don't do it.

What happened, as soon as the lake trout was eliminated, both the sea lamprey and man then moved on to the next largest species of fish and started chomping on those. So they're kind of working their way down, taking the biggest species in the lake and systematically overloading them with mortality rates and driving their stocks to zero. Now, we're arguing from curves, but just about at the same… at the time that the sea lamprey drove the lake trout to extinction, the second fish, the alewife, was right around the corner. It's been sitting down in Lake Erie for about seventy years, but it never got established in the upper Great Lakes. It appears, in hindsight, that as long as that community was stable, as long as all the little niches were filled, it was very difficult for an exotic species to get introduced; it couldn't get a toehold. All the energy was tied up; there was good competition, there was all kinds of resistance to introduction. And a good, unperturbed community is resistant to introductions. That's one of its positive properties. But if you begin to disrupt that community, either by pollution or, in this case, by the sea lamprey, one of the impacts you have is you make that community more vulnerable to exotic introductions. You make it susceptible to something coming down in the future that wouldn't have normally happened, and the alewife here is a classic case. When the lake trout was driven to zero by the sea lamprey, all of a sudden the system got out of synchrony, the things that controlled it were not there, and the alewife took off like mad.

Now, the alewife is another kind of a beastie. It's not a predator on smelt and perch and these foreign fishes, but it competes with it. Remember I said one of the properties of evolution is to minimize the competition? That's what ecological niches do. Everybody becomes a specialist and kind of isolates themselves. Well, the alewife didn't evolve in the Great Lakes and it doesn't play by those same rules. It moves around the lake at different times of the year. This time in the summertime, the surface waters are fairly warm, so it's down in deep water and it competes with the sculpins and the various fish down there, preys upon the eggs of the some of the young that are here. In the springtime when the water is cold, it's right up on the beach, and so it interacts with the shallow-water fishes. In the middle of the winter, it's out under the ice and it interacts with the pelagic, open-water fishes. And the alewife has had a far more diversified impact on the fishes, and as a result of the alewife impact, by the early 1960s, the alewife had essentially wiped out the smelt, perch, about seven or eight of those fifteen species, and we ended up with a lake, in the early 1960s, where fifty percent of all the fish in the lake were alewives. About forty percent of that remaining thing was one species of sculpin on the bottom, and that was it!

So in about a thirty-year period, two fish completely destroyed the fish community of the upper three Great Lakes. Wiped ‘em right out. Now, at that stage of the game is where man becomes involved. Up until then, we really had no interest in the Great Lakes. We had no institutional interest, put it that way. There were no planning bodies, there were no major international commissions of Canada and the seven states—Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, and New York state, all of the riparian owners of the Great Lakes along with Ontario—there were none of these governmental institutions to look at the lake as an ecological system and say, "How are you going to manage it?" Until you had a crisis. In this country, we tend to do our decision-making and management in response to crisis. We do it all the way through, and environmental issues are no different. So you could almost assume that when you're dealing with environmental problems, it's always going to be under a crisis mode. You're going to wait until you run up and hit your nose right against a wall, you're going to back up and say, "Whodunnit?" And after a while when you find out there's nobody you can pin the blame on, you say, "Well, what can I do about it?" And then you start getting constructive about your alternatives.

At this stage of the game, you have a choice, don'tcha? You can say, "Well, what are we going to do with the Great Lakes?" It's a non-trivial environmental resource. We could sit down and say, "Well, we're obviously going to have to put it back together again,"—and that's the whole purpose of me picking this case study—is how well can we do ecological engineering? Can you go out, if you make a mistake, intentionally or unintentionally mess up a hunk of your environment, do you know how to put it back together again? OK? Well, the question of course is, put it back for whom? What do you want out of the Great Lakes? Do you want that resource to be purely pristine, pretend it's an ecological reserve, and put it back the way it was before? Do you want to put it back together for human use? Because if it's going to be pristine, you're not going to use it with human beings, and remember, there are tremendous cities around the shores of those lakes. Obviously people want to use those lakes for industrial use, for recreation use, for water use, for irrigation use. But what combination?

We have no Great Lakes policy. In fact, in my part of the country, and I know it's true out here in Oregon, as far as I can tell everywhere in this country we really have no integrated—and I emphasize the word *integrated*—land use policy, urbanization policy, ag policy, population policy, water policy, or any other policy. We have federal laws that say, "Thou shalt not pollute the Great Lakes." They say by 1983 there will be no water pollution. Well, big damn deal. I'm talking about a functional policy where you can go out and say, "Yes, we should do this and not do that, because this is what people want out of the Great Lakes." That's the way a planner would do it. We tend to do a lot of planning and then put the plans on the shelf and go ahead and make decisions otherwise. This is a classic case of that.

The other alternative is to say, “Well, nah, this is really a fish problem, so what we’re going to do is turn this over to a fisheries biologist, and obviously they can go out and solve the problem.” They have the expertise; they’re technocrats, they went to university for a long period of time, they’re supposed to have all this kind of knowledge, and by the way, that’s why we educate ‘em. Obviously, from my bias, you can hear that the latter is the way this has operated. Nobody sat down and had a big public meeting and asked people what they want out of the Great Lakes over the next thirty or forty years. The message went up through the state governments, trickled back down to our Department of Natural Resources, down to the fish division, and there were three or four people there—one of them happened to be my dad, so I followed this fairly closely, he’s a fishery biologist—and everyone said, “Hey, go out and put our lakes back together again.” And for the next half, or third of the story, it’s purely some fishery biologists doing their job.

If you stop and think about it, it’s pretty obvious that if you’re going to go out and try to put that system back together again, one of the first things one has to do is to… [aside] I don’t want that one yet… is to get control of the alewife, and to get control of the alewife you’ve got to get something in there big enough to eat it. You can’t get something in there big enough to eat it until you get control of the sea lamprey, because the sea lamprey will wipe out every big fish you put in there. So it doesn’t take any mathematical genius to sit down and figure out what your scenario ought to be. The first thing one has to do is develop some kind of control for sea lampreys. And we’ve messed around about five or six years trying to develop alternative ways to go in and regulate a small component in that lake: sea lamprey. Hard to get rid of it. Well, you can’t get rid of it. There is no way you can go in and pump that species out. Almost by definition, if something has the population characteristics: high growth rate, high reproductive rate, short generation time, all these kinds of biological properties make it a good introduction in terms of species that colonize rapidly. Almost by definition. I defy any agency, state or federal, to say they can go in and eradicate it. You can take the word “eradication” right out of the ecological dictionary as far as I’m concerned. Most of your pests and diseases, their biological properties are such that you *can’t* eradicate it. Which means you’ve got to think in terms of control, not removal. Once you do something, this is irreversible. OK?

How do you control it? Well, we’ve played around with a lot of kinds of things, like if you could stop its migratory runs—it runs up in the creeks and spawns—it would just die of attrition. So we built electric weirs and we built mechanical weirs and we did all kinds of stuff, and nothing worked. So the fisheries biologists went out and discovered the world of agriculture. And they took a compound, which is a fluorinated, chlorinated organic compound, it was a bacteriocide that Dow Chemical used, and modified it to kill lampreys. We now have a lampricide. And it’s no doggone different than any other pesticide. You worry about the ecological implications of the breakdown products, the secondary accumulations in the food chains, secondary impacts in terms of what else it kills. If you used the same criteria with this thing as you did with […] or anything else the EPA uses when it registers insecticides, there's somewhat of a question of just how much we'll be using this. But it's the only compound they have right now, and what they do is they go around to all the creeks all around the Great Lakes—remember I said the lamprey were in the stream for how long? Five years, right?—so every five years they go along the headwaters, and if there are lamprey larvae in these streams they poison the whole watershed.

Now, if you know your toxicology, and you know your water temperature, and you know your stream velocity, and you put in just the right amount, you'll kill larval lamprey for five years right on downstream. If you misjudge, you wipe out your trout population right on downstream. And these are, if you know anything about the Great Lakes area, these are our premier trout streams: the Au Sable, the Black, the Manistee, the Pere Marquette, the Pigeon, the Sturgeon, OK? The Betsie… there's a whole bunch of them. So it's a very, very sensitive kind of operation. So what we're doing, we're doing nothing different than an agriculturist does. It's an insecticide-oriented fish farming, is what it's going to boil down to, on a massive, massive scale. So you ask the question, "Is there any ecological insight that allows ecologists, in this case fishery biologists, to have any more unique tricks than an agriculturalist does, an agronomist, confronted with a pest problem?" No. Not at all. In this particular case, they have not developed alternative biological controls, and the whole story I'm going to lay out to you now is based on this lampricide working. If the lamprey ever gets resistance to that lampricide, which it will eventually, or if anybody discovers this thing is carcinogenic or ecologically damaging under the new Toxic Materials Act and is removed in terms of its license, this whole story can flip-flop like that.

So at least we've got the sea lamprey controlled. The next question, then, is, "What do you introduce to bring in to eat the alewives?" Well, you essentially want something that has a short generation time, because the sea lamprey's still out there—you could knock down its numbers, but the lake trout take seven years to sexually mature, so it's very vulnerable to predation—so you want something that matures fairly rapidly. You want something you can raise in a hatchery, because that's a big lake out there. If you put in five of them you'll wait for two hundred thousand years to get a population. You want to release them by the millions! So it's got to be something you can raise commercially in a hatchery and turn it loose; it's going to be […] for a while. Just like you do agriculture, this is going to be a great big fish farm, where you rear 'em in a hatchery and turn 'em loose and get 'em in the lake. You want something that has… essentially, that eats alewives; it's got to do that, of course, it's got to be something that will eat that kind of fish. It's got to be something that has a sport commercial value. If you put this thing back for humans, obviously, it's got to be something that they want to have, so it's got to have some economic value. And everybody had their pet fish. Striped bass and coho salmon and exotic things from Africa and South America. The world's full of exotic fishes. Basically, the biologists weren't really sure what would happen. I mean, with all due respect, they never did an environmental impact statement process on this at all. If you asked them to, they would just weave and dodge all the time. The best rationale they've made is that a salmonid, salmon as a group, have had a history of pretty good introductions. Brown trout in New Zealand, rainbow trout on the East Coast, all over the place. So they picked salmon, salmonids, and they went around the country fishing, and they came out here to Oregon with salmon fishing. And for $150,000 they bought 300,000 coho salmon eggs from the state of Oregon.

We came back and built a hatchery in the upper Great Lakes… let me back this up a little, I've got to get my map back again here… I think I'm going to get my map back again. There it goes. What we did is we went up here to Platte Bay, and built a hatchery, a modern commercial fish hatchery on the river there. What you do is you take these fish and the way you commercially raise fish is you take the eggs of the female and you milk the eggs into a bucket, you grab a male and you milk the sperm in a bucket, and you mix it up with your hands; it's a very, very callous kind of procedure. You dump the eggs out in a great big trough and run cold water over them, and a few weeks later your baby fish fry hatch out, and you feed 'em pelletized fish food for awhile until you get 'em about that big, OK, and you turn them loose in the lake. Part of the process of the salmonid life cycle is also a homing instinct; during that process, these young fish will imprint on their little minds the odor of that watershed. Each little drainage basin has its own little combination of chemicals that leach out of the soil and it makes the water have a particular odor to it in parts per billion, just really traces. And that little fish remembers that, and it has a homing instinct. You turn it loose, and it goes swimming out on the lake, and two and a half years later it wanders back, it comes along the shoreline, it picks up that slight gradient, that odor that it remembers for two and a half years, follows that thing upstream, comes right back to where it was spawned—originally, hatched—spawns, and dies.

So it has a three-year life cycle, it's a time […] life cycle, which means that we're going to have to manage that fishery with a three-year time lag in the steering wheel, aren't we? If you want to have *x* number of salmon come back for commercial and sports yield, three years ahead of time you've got to get those eggs and sperm and put them in the hatchery and raise them. Which means you're going to have to, if you're going to operate that thing, manage it, you're going to have to anticipate events three years into the future in order to know how many salmon you should rear and how many salmon you should release to get the fishery back where you want. That's the kind of time […] fishing you're talking about in managing an ecological system of that scale.

What you do is you plunk these things out in the lake, and you sit and wait. We didn't have any idea what was going to happen. We took West Coast salmon. They go out in the Pacific Ocean; when they get ready to migrate, they migrate east, right? What happens if you put those fish here? Well, that's fine, they go out and when they come back, they come back to Michigan. We want them to go over to eat Wisconsin alewives and we want them to come back to Michigan so we can harvest them. See, these states don't have any rivers that go into the Great Lakes; Michigan's got a monopoly on them. These all go into the Mississippi drainage; these mostly go into the Ohio drainage. On the other hand, what happens if you put those fish in Lake Huron? These are some of the questions you've got to think about if you're going to go out there and design the system. Right? Are they all going to stack up over on the Canadian shore? Are they going to have enough sense to migrate west? Or should we have gone over and gotten Russian salmon and put them in Lake Huron, because they have enough sense to go the other way when they want to migrate? We really didn't have any idea. As it turns out, your Oregon salmon have enough sense to go both directions. We get 'em back on both shores, as far as we could tell. But when we put 'em in we didn't have the foggiest idea. There was no literature whatsoever. No experiments, just a pure guess.

Well, you dump these 300,000 fish into the lake and you sit and wait. And all of a sudden, about, oh, a month later, down here on the… this is Chicago right down here… on the shore of Chicago, an urban fisherman sitting there with cane poles on the beach, usually catching perch, started catching one-pound silver salmon. All of a sudden, little vibrations went up through the system. And it became, from then on out—up until now it's been biology—from now on out, with the costs, they're only thinking in terms of biology. One of the points I want to make is the way you've got to integrate disciplines and think in terms of ecosystem management. You can't go out and just think like a biologist. We did. We designed that thing by a half a dozen fishery biologists making good biological decisions. From now on out, the social, economic, and political things came back to haunt you. Because the rest of this story has nothing to do with biology. The biology worked, and that was the problem. As soon as the biology worked, we discovered people again, and that was the other half of the problem.

What happens is, in the early spring, the alewives start spawning on the beach. And the salmon are right up there eating them. So, Michigan City, Indiana right down here calls themselves the "Coho Capital of the World." You can go out on the beach in March and sit there and catch silver salmon off the beach in about three feet of water until your arm gets tired. But then, what happens is that these fish start moving up the lake, and they're a cold-water fish that lives between fifty-two and fifty-four degrees Fahrenheit, and in our lakes in midsummer that means they're down around eighty to a hundred feet. And those are big lakes; those of you who live along the ocean take it for granted, but if you take a bunch of characters from Chicago and Detroit who have never been out on the lake, and you go out there two miles offshore and show them a couple hundred thousand salmon, then you've got another whole class of human problems called "boaters." Guys out there in canoes without any idea what it takes, and that lake gets real rough, and we had a lot of problems with people getting in trouble. We had a big storm come up and seventy people drowned, 500 boats got busted up, no common sense whatsoever. Well, that one somewhat resolved itself. We've got some natural selection of boaters. [laughter] The… but when you need to go fishing it became very apparent. You had to have 20- to 25-foot boats, and these guys use downriggers—I don't know if you use them out here, but great big spools of great keeled weights with little tiny releases so they can fish whatever depth they want—they've got fish finders, they're talking about five to ten thousand dollars' capital outlay to go fishing.

So here we took a public resource called the Great Lakes, we took public funds and bought fish, we put 'em in the lake, and all of a sudden people said, "Hey, but you put that lake together just for rich people. All my urban kids don't have ten thousand bucks to go fishing." Well, that was a dimension that nobody had really thought about. And it's correct. To go out in midsummer and catch those fish, you not only have to be an ardent fisherman, but you've got to be affluent, OK? And that precludes one heck of a lot of access to that particular sport fishery. Well, the biologists said, "Well, hang on guys, your time's a-comin.'" During the midsummer, that's a correct statement. And you can catch salmon out there like you can't believe; we've got a limit of five of day, those party boat guys take out two parties a day for a half-day, and they say if you don't catch fish you don't have to pay half the time, at least half the boats do that. The largest coho that they caught was about 38 pounds; the largest Chinook to date is about 45 pounds. That first year, we got 30% survival from egg to adult, their first three years. You see, we had no predators on the salmon in there either. All the things that give you 2% survival here on the West Coast with your hatchery operation, we ain't got, and so the salmon would do just what the alewives did. It's a beautiful great big lake full of fish for them to eat, and no predators, no disease! And so they showed the same kind of growth rates, the same kind of survivorship. It's a fantastic fishery.

What happens, then, is that these fish move north during the summertime; about August, they start accumulating off these river mouths, and this, of course, is where they start to get into in-shore fisheries, and this is where the biologists said, "Well, all right, the rest of you kids just wait. Your time's comin.'" And what happens is when those fish start accumulating off the river mouths, they're essentially undergoing a physiological shift… what I want to do is illustrate the kind of science you need to get in to understand the thing you're designing, all right? So I'm kind of going horizontally for a while and then going vertically to show you the in-depth… you'd have to go into to really understand why the fish are doing it, and go on and manage it. They're coming into shore because they have a physiological stress coming up. They're going to go, supposedly, in their normal life cycle out here, they go from salt to fresh water. And when you make a shift from salt to fresh water you're going from a more dense to a less dense environment in terms of salt concentration. And all organisms have to balance the flow of chemicals in their body. The way a fish does this is when a fish is in the ocean, essentially the ocean is a much more concentrated media in terms of salt concentration than its body fluids. Its gills are semi-permeable, which means that, if you remember your high-school chemistry, if I've got a semi-permeable membrane with a concentrated salt solution on one side, what happens? The water diffuses across the membrane to try to bring the salt concentrations into equilibrium, don't they? OK. Well, the same thing's happening with the fish. He's losing water all the time across his gills, trying to dilute the ocean. Which is obviously why he becomes dehydrated and would die, so he drinks water all the time. Well, when he drinks water, he drinks water and salt, so he has to balance his salt budget. He's got his water back, but he's got salt coming in. So his gills act as a salt pump; it's an active transport system that pumps salt outward. If you've ever seen sea turtles or seagulls, they cry. They have tear ducts. Their eyes don't have tear ducts, they have salt ducts. They're pumping salt. Balancing this equilibrium. All organisms are doing this all the time. You're doing it. That's why your kidney functions the way it does.

Now, what happens when that fish goes into fresh water? It starts its migratory run? All of a sudden it's going from an environment, which now, fresh water is a less dense medium, right? Now which way is the water going to flow? Inward, isn't it? So in fresh water the fish is going to blow up, get bloated with water. So it doesn't drink, but it urinates all the time. But since your kidney can't make distilled water, what happens? You lose salt. So which way do the gills have to pump salts? The other way. And that's the reason these fish sit in these brackish estuarian bays, river mouths, for about a month making this physiological transition. You just don't hop from salt water to fresh; you've got to go through this migratory… not migratory, but this physiological shift. So they sequentially work more and more into fresh water from brackish… from salt, to brackish, to fresh water, and it takes sometimes a month, two months, for them to make that transition. So that's why they're aggregating along these river mouths, at this interface. And they're doing this in the Great Lakes. At that stage of the game is where all of a sudden, people can get at them, because there are large schools, they're close to the shore.

And in Michigan, then, of course, what they do is they start their migratory runs up these streams, and in Michigan our streams are like… our rivers are like from here to that wall. You know, our state's not very big, and most of our rivers are only maybe fifty or a hundred miles long, it's not like your rivers out here on the West Coast. Of course, the fish don't know that. You take these rivers about yay deep, OK, most of them about that deep, and you take the shoreline of these rivers and you line 'em with a couple thousand fisherman from Chicago and Detroit that are used to seeing five-inch sunfish in a little farm pond, and you run a few hundred thousand coho salmon by them with their backs sticking about this far out of of the water. And we discovered a whole new social set of problems called "humans under stress." [laughter] There's nothing more stressful than exposing humans to fish you can see and they won't bite.

Now remember, they've been storing energy for the last two and half years getting ready to do what? Do a six-hundred-mile migratory run, right? Spawn and die. And they've stored a large amounts of body fat, and that's the reason that when they're ready to start their run, the majority of the time they're not feeding very much. So these guys are out there, you know, throwing everything in the tackle box at 'em, and hell, they're going right on by, all right, and they're getting frustrated so they rip out all the vegetation, they kick 'em up on the bank, they hit 'em with clubs, they snag 'em. And we ran into that whole class of social problems, then. We have laws in Michigan, fishing laws. And in general, your fishing laws are written by Isaac Walton Club and Michigan United Conservation and Trout Unlimited, you know, organizations of fisherman who felt strongly enough to lobby for and help draft legislation on fishing laws, and in general they're based on the concept that at least if you fish, you should fish with dignity. Hook in the mouth, no dynamite, no pitchforks, no gill nets… [laughter] OK? And of course, this is a completely different game, isn't it?

And you could say, "Well, you shoulda anticipated that," should've sat and realized what would happen if your fisheries had worked—we didn't—we bounced right into that when we were getting bounced off the wall. So we had that first year up there, these fish were coming back and Jesus, there were just ten or twenty thousand people at these feed mouths. They were putting five thousand boats a day in at the beach with no facilities, just launching them out there. And they were all catching fish, just fish all over the damn place. They came back like bandits. So, they'd go out and snag fish and they'd get fined, they'd jump back in the river and bonk a salmon on the head. Slowly, the government adjusts. But, you know, it's a painful process, and you don't expect the system to adjust rapidly. So for one year we had a law that said you could snag salmon as long as it was unintentional. [laughter] Well… you know, it was barbaric! You go to talk to a good old ardent dry fly fisherman, to go up there with a great big metal cable and a great big treble hook with a lead […] and sit there and snag two hundred pounds of salmon in a half hour, is just beyond his comprehension. Now, for someone who's never seen a fish before, and that to them is fishing, it is one heck of a fun thing to do. And besides, it tastes just as good on the plate whether you snag him in the head or snag him in the tail.

Well, since then they have legalized snagging, and you can go out and you can snag salmon. What happens, of course, is that these fish start their migratory runs, they're all going to spawn and die, right? We planted nine and half million coho in Lake Michigan alone last year, with about 20% survivorship to adults. There isn't any way, coming back at an average of twenty pounds apiece, that you can allow those fish to go upstream and die, because you'd have the worst water pollution problem you ever saw in your life. So we built weirs about four miles up these river mouths, and we commercially harvest all these fish and sell them. So why not let 'em take 'em? We bought 'em with their fishing license money, we might as well let them do it. So you've redefined the concept of fishing. Well, we got over that crisis.

The next one that came along is, what do you do in terms of economics? Every little… well. The little town of Manistee sat right there at the mouth of the Platte River. And those salmon were still running in January. And every weekend, five thousand boats, campers, guys hauling coho fishing boats come up there from all over the Midwest, came from Florida, all over the place. It was the hottest fishing going. And they were spending money on outboard motors and on food and on fishing tackle and lodging and so forth, and that little town made ten, twenty, thirty million dollars that winter. On recreational fisheries! A brand-new thing, we never had anything like that before, because the lake trout were the deep-water fish, meaning nobody could fish for them. All of a sudden, every little town in Michigan wanted a coho salmon run. So, a perfectly good design question, right? What's the carrying capacity of the lake? You'd think an ecologist ought to be able to define that. They can't. They haven't the foggiest idea how to calculate the carrying capacity. Who should get salmon runs and who shouldn't? Well, they had no policies. They really didn't have any way to say yes to this town and no to that one.

So they put salmon in every damn river in the system. We got 'em coming up the Kalamazoo River right through Battle Creek, right through the paper mills, we got 'em coming up the Tittawabasee right through Dow Chemical. The Black legislators in Detroit said, "How about my urban kids?" OK, so we got a salmon run on Belle Isle on the Detroit River. You can sit right down there and you can catch salmon in the pond. You put 'em in the fireplace and they'll burn blue, green, and yellow, but you can… OK? [laughter] Well, see, most people think that salmon only take clean water. Salmon can tolerate all kinds of pollution. They can live in the most polluted water you've ever seen. They can't take high temperatures, it's depending on what pollution you're talking about. They can't take low oxygen concentrations very well. But they can tolerate mercury and they can tolerate PCBs, and they can tolerate all kinds of nasty compounds as long as it doesn't affect the oxygen concentration. So they'll accumulate crud like mad. Just because you can catch salmon doesn't mean they're edible. Which brings on the next dimension. You see, when you get into this thing, there's all kinds of ancillary dimensions. This is the thing I want to bring out. It's no longer just a matter of fishes' biology. If you're going to manage something like this, you've got to integrate your economics, your political science, your sociology, just pure old common sense, and everything else along with your biology.

It got, for instance, in terms of recreational patterns, this thing changed the whole… next to the snowmobile, the salmon in our state changed probably the most important aspect in terms of recreational development in the state. This and the snowmobile. Because what happened, prior to this time, people would go up and buy little cottages on the lake in northern Michigan. […] now, people are interested in salmon, and salmon are moving, so they want to be mobile. And you can sit and watch the expressways coming out of Detroit and Chicago every Friday night, there's a continuous stream of motorhomes, campers, all kinds of recreational four-wheeled vehicles; in the summertime they're holding a coho fishing boat and in the wintertime a trailer with three snowmobiles. And they've invested now twenty to thirty thousand dollars in rolling recreation stock. And that whole city every Friday night goes like this, and comes back every Sunday night like a big accordion. If you've ever spent a summer weekend in Detroit, you'd know why. You'd bail out too if you had affluence. People who stay in the city are too poor to leave. So all of a sudden, it became a very political issue. If you ever want to get any mileage or influence on laws in the state, just tie it to the coho salmon program and you've got organized labor behind you 100%, because they love their salmon, and they're affluent enough in our state to afford to go salmon fishing. Well, that developed. These people don't always say what they're developing, what they're doing, but that developed.

And then, this is about '68, '69, we discovered DDT in the salmon. Some graduate student went out and did the horrible thing of looking, and there it was. The FDA action levels say five parts per million DDT for interstate commerce, for commercial sales, and we had about seven in the fish. So the governor had to shut down the fisheries for that year—of course, the fish didn't know it, the DDT didn't bother them, they were still coming back—and so for one year you could go up to these weirs at the river mouths and if you had a fishing license they would give you a fish, iced and cleaned, every day. Now, here's a moral issue. The toxic materials were such that we couldn't sell them in interstate commerce. The FDA action levels, if you know anything about that—we're going to talk about it this afternoon on food—only affect interstate commerce. The FDA cannot tell you what you can sell in the state of Oregon. It just tells you what you can put on the market that goes across state boundaries. So all these action levels only deal with interstate commerce. For intrastate commerce, that is within the state, the state can set their own levels and still sell them within the state of Michigan. We were selling them, the vast majority of these things were being caught at the weirs, the fishermen would catch them and ship them to other states, and that had to be cut out. So they're giving them away. Now, that year—this all went to the Supreme Court, it's all been documented, to show you the legal loop in the thing—there was a meat-processing plant that bought a bunch of these salmon because they were cheap, and they made mink food out of them and they sold them to mink farmers in Wisconsin. And the mink had 100% cessation in reproduction. Wiped it right out. And the mink farmers sued the meat-processing plant, and the meat-processing plant tried to sue the state of Michigan. And the decision went to the Wisconsin Supreme Court, and the decision was that the meat-processing plant was liable, but not the state, because everybody knew the fish were unfit for animal consumption. So there's an interesting example of a legality, a liability, in an environmental case, again. It was determined in this particular case that it was public knowledge. Now, as it turned out, it probably wasn't DDT. In those days, we couldn't separate PCBs from DDT. And now, in hindsight, probably a lot of that was polychlorinated biphenyls. Michigan hadn't been using DDT for quite a while; PCBs were still very, very common in the system.

We have been monitoring now the toxic materials in these fish for the last six or seven years; the DDT has dropped down lower than five parts per million, the […] has dropped down, the mercury's dropped down; the PCBs, polychlorinated biphenyls, is still… has leveled off very high, the salmon that came back to the Manistee River here last fall were about 20 to 30 parts per million. The FDA regulations are five parts per million; that is, if you have that much in the fish, less than that you can safely eat it, using the average fish consumption of 19 grams per week per person, which is what the statistic is that they use. These fish were then six to seven times that level. We have lake trout from Lake Superior; Lake Superior's a pristine lake, right? It's way up there in the northern part of the state and there isn't any industry on it except Duluth, where there is mining. They have up to 120 parts per million PCBs in them—the lake trout does. Organic compounds like this are stored in fat, and these large lake trout are very slow-growing with very high fat content, so they accumulate this stuff over a very long period of time. They accumulate it and don't lose it. So there could be low levels in the environment, but it's like a great big storage bin. If you live long enough with a high enough fat content, you could store a tremendous concentration.

So for the last six to seven years we have buried every salmon we've harvested from the weirs. We've buried—I don't know, twenty, thirty, forty million salmon probably. You could ask the question, "Why do you keep planting salmon, if they are unfit for human consumption by FDA laws and you have to bury them?" Because they still are. Well, the sport fisheries are still going. That sport fishery last year in Michigan was worth—I called up the DNR here last week to get the estimate—between four to five hundred million dollars to the state of Michigan, as the sport fisheries. If you calculate all the sales tax and revenues on all the purchasing that these fishermen do on an annual basis, it's worth between four hundred and five hundred million dollars.

Now, it doesn't take much to realize the fact that what started out as a small little experiment in biological renovation very rapidly turned out to be a classic case of all the pitfalls and all the management problems associated with big-scale ecosystem design and management. A big enough scale that humans take interest in it, and as soon as that happens, it's a completely different ball game in things that biologists traditionally are not trained to handle. Most guys in my field never take a course in economics, we don't know anything about political science or public management; definitely human psychology, we do our best to stay away from it; and yet you see this is a good case to look at. What would you do? What kind of training would you lay out for a student? If you said, "I want to train you for the next generation of environmental decision-makers, so you can handle a true, honest-to-God ecosystem type of decision-making process." Here's a classic case. Stop and think of the tremendous array of information that you would have to either have access to yourself or train people to work in integrated, interdisciplinary teams. You forget individual decision-making, and you get clusters of six or eight people in different disciplines and train them to talk to each other, which is just about as difficult as it is to educate the individual. In this ecosystem modeling course that I teach, we have integrated groups of five to six kids all modeling as a team, and it takes one heck of a lot to get engineers, economists, and ecologists to sit down and work together in a constructive mode, even if they want to.

So that's the kind of one of the reasons I picked that particular case study, because it does, I think as well as anything, graphically illustrate the tremendous diversity of problems that will emanate from something as simple as just fish management, if it works. Now, we didn't really stop there. I'll give you the corollary to the thing, it's still going on. I was talking about the coho here; that's just one of them. I followed that enough with the biology so that you'd see how much you'd have to know to understand what you're doing. The next year we brought in the king salmon and Chinook salmon, that's that great big hook-jawed, black-jawed, five-year life cycle, that's the bigger of the two salmon. Again, it's a West Coast salmonid. It's a five-year life cycle. This is a three-year life cycle. This thing runs a hatchery operation, the coho runs in the fall; the Chinook is a hatchery operation, and it runs in the fall. There've been plenty of lake trout in that lake for seven, eight years now, so this summer should be the first successful breeding, if they do it, of mature lake trout in the lake. Now, this one is not a hatchery, it will breed in the lake itself and it won't die, it's a continuous life cycle. So this one we can't control once we get it back. We've been planting the steelhead, the lake-running rainbow, which is again an introduced fish, but it was in there before. This, again, runs in both the spring and the fall; it's a continuous breeder, so we don't raise it in the hatchery. Once we get it going, it breeds itself naturally, so you don't control its reproduction. Three years ago we brought in the Atlantic salmon from the East Coast, so guys wanted to try that one, that's a three-year life cycle; it runs in the summertime. It is a terminal life cycle; it breeds once or twice and then dies. The Canadians have brought in splake—that's a hybrid between a lake trout and a brook trout. They also introduced, accidentally, by mistake—not on purpose, biologists on their own dumped pink salmon in Lake Superior, and that thing's spreading. We now have every species of salmonid in the world except one in the Great Lakes system. I think it's the dog salmon—I can't remember the exact name—but there's one species that we haven't put in yet.

Now Ohio wants to put in striped bass, in Lake Erie, and of course stripers just love to eat salmon, so the first time our Director of Natural Resources said, "Nope, we shouldn't have any more introductions until we do an environmental impact statement." Because they're worrying about Ohio putting in something else. Up to date! Remember what I said—decision making? The riparian owners? The states that own shoreline are seven states and Ontario. We still do not have a single working agreement with any of the states as to what to do with the Great Lakes. Each state's doing their own individual little process. I was down in Illinois here just last spring, and Illinois is proposing a bill for a $17 million fish hatchery. They've got a unique thing; they've got 60 miles of shoreline and about four to five million people living on it, called Chicago. They don't have any rivers. So you know what they did? They went out and they bought a bunch of salmon because they wanted to have the sport fisheries, OK? They didn't realize… so they had these lagoons where they park all their fancy yats, yachts [pronouncing it "yatchets"]… all their sailing craft, you know how you build a lagoon like this and you put your little mooring sites? They put the salmon in there. Well, the salmon came back. And here last fall they watched these big old salmon rolling under the surface, the […] sitting around on the shoreline with these fishermen with their great big leaded snagging hooks, and they did about $50,000 in damage putting out windows in the boats and ripping awnings off the back of them. [laughter] They had public riots down there! Unbelievable situations.

Anyway, here we got coho… See, what they're trying to do is they're trying to get lake-and-stream fisheries spring, summer, and fall. Something for somebody all times of year. They're trying to do social engineering now! You know, they're trying to pick every combination of fish that they can get so that everybody has a piece of the action somewhere, at some part of the lake at some time of year. So here we've got this tremendous social, economic, political investment. We have coho, Chinook, lake trout, steelhead, […], and splake, all doing what? Eating alewives. Remember how I showed you the way that initial community was designed? What'd it look like? Lake trout doing what? Feeding on fifteen species of fish? Now what do I got? Fifteen species of predators doing what. Eating one species of fish. I've got the damn thing upside down. They haven't any idea what they invested their money in. Where I started out to control the alewife, I've got to protect it now! The whole fishery is built, is dependent on the bloody little alewife!

Now you could say, “Well, what’s the matter with you guys? What you’ve got to start doing is getting the diversification down here, don’t you?” This is one, again, one of the differences between physical engineering and biological engineering. These are not just objects. Part of evolution is that they co-evolve their behaviors. Part of the community ecology is all the interactions of these species are evolved as well as the physical structure itself. It’s behavioral evolution.

If, for instance, you look at a coho, it’s got its own preference for feeding. Maybe you like beefsteak better than you like asparagus. Well, it don’t like alewives. If you take a lake herring, a ciscoe, a smelt, and a perch and put it in a tank with an alewife and a coho, the alewife is the last one it eats. It’s bony and oily; they don’t like it. Now, it’s 90% of its diet, because it’s 99% of the fish out there. So they will eat it, but if you’re going to get another fish to increase its numbers, given differential predation by the coho with competition for the alewife, you’ve got to find one that tastes as bad as the alewife does to the coho. Now, if you just put those back and wait, in a hundred thousand years it will evolve so there won’t be any pests in that lake. If you just sit and… my time scale as an ecologist, oh, around 150, 200 generations, you will get the core evolution of those behaviors. No question about it in my mind whatsoever. That system will recalibrate itself. But the time coefficients of change are, in general, not socially acceptable. If you want that thing for human use with a constant economic performance in your lifetime, you’re going to have to get in the job of babysitting that lake and doing it on a professional basis. Now up to date, there is still not a single mathematical computer model that we could use for decision-making built on that fisheries. The guys right now are sitting there saying, “Well, back at the […] calculations, where shall we put ‘em this year? Who’s yelling the loudest? How many have we got in the hatchery?” We still operate at that scale, but it’s the best example I can give you of ecosystem management at that level.

Let me go on—I can’t go into all the alternative, other events in as much detail as I did the biological one, because we’re going to run out of time here—but let me show you the other kinds of things that are impinging on that lake at the same time. This was just to one dimension. We, as part of this environmental review board that I sit on, we have the responsibility of reviewing all the federal environmental impact statements, all the proposed projects that Army Corps, Coast Guard, Interior, EPA, ERDA, DOE (Department of Energy), all of them come up with. And these things come through in front of you oh, six months apart, individually; they’re all individual kinds of projects proposed. Let me just walk you through just a small set of what’s sitting there.

Of course, one of the things you’re going to hear about a lot is energy. Everybody’s concerned about energy. One of the questions that comes up a lot is “What is the environmental implication of alternative forms of energy production?” They are extremely important and in many cases, they are completely new classes of problems that we haven’t dealt with before. The obvious one that’s going to affect us, in Michigan anyway and on the East Coast, is coal. I’m not sure to what degree Oregon is dependent on coal versus nuclear out here, versus hydropower, but we definitely are. We don’t have much chance for hydropower; we’ve got a lot of water, but the damn topology is all flat. If you build a dam in Michigan, it’s got a thirty-foot head and it soaks in in about three years. So there isn’t a heck of a lot of option to build hydropower, because our whole state was in a lake bottom; half of it was marsh that we ditch-drained so we could live on it. So basically the alternative we have to nuclear, at least to date in our state has been a pitched battle with environmentalists, for a number of reasons, is coal. We're a state that imports 98% of our energy. Our three big industries are all energy-intensive: agriculture, automobiles, and recreation, and we import about 98% of it. So our state is sitting in a very, very vulnerable position in terms of what we can afford to say no to or yes to. To date, they've been environmentally very aggressive in terms of saying no to things they don't like, but the day of reckoning is going to come here fairly fast.

Coal seems to be the obvious alternative. If you go to low-sulfur western coal, because of air pollution reasons, there is a north-south line right through here, right through Chicago, where anything west of that, the most economically feasible way to transport it is by rail. Anything east of that, which means my whole part of the country, it's not economically feasible to do it by rail; what they do is they ship it up to Superior, Wisconsin, right across from Duluth, load it on barges, and take it down to the Great Lakes. So it's going to be a lake-oriented transportation system with coal carriers, both barge and ship, which means that once you start doing that, every one of these estuarine harbors along the Great Lakes is going to have to be dedicated to coal unloading facilities, or coal storage facilities, because of the cost of reloading and transporting coal. Most likely you're going to find the relocation of the energy-producing plants, the actual power plants themselves, close to the coal piles, which means there's going to be a tremendous energy-intensive development on the shore of that lake associated with the pure fact that transportation by water is more efficient than any other mode when you're talking about that bulk transport. And these are the same river mouths where these salmon are coming back. These are the same unique shoreline management that environmental groups want to protect for other kinds of recreational and aesthetic reasons. That conflict is just obvious as heck. It's coming, and nobody has yet addressed it.

I can show you a study, if you're interested we can talk about them, about doing total chemical budgets on leachates from coal piles and ash pits, from fly ash, that is, looking at the total discharge of chemicals from coal-fired plants, and these are very, very dirty in terms of the toxic materials industry. There isn't any way you can stop it. Look at this. You bring in a carload of coal, right? You burn it. What does a power plant sell? It sells kilowatts, doesn't it? Is there any chemicals in kilowatts? So the total chemicals that are coming out all have to leave in some form, don't they? It's a conservative system, there's mass balance; they have to sum to zero. Which means the total equivalent to those hundred tons of coal has to go off as either liquid, solid, or gaseous residuals. All of the inputs of the coal industry, a coal-fired plant, are chemical residuals that go into the environment in some form, the total load. It's probably one of the most intensively, potentially polluting industry you could get just from the pure nature of the chemical flows themselves. So, one tremendous potential class of problems.

The Army Corps of Engineers has proposed to expand the size of the Soo Locks, to both accommodate both the taconite iron ore industry in the Mesabi Range here in Wisconsin and Michigan, and also for these coal barges, they want to double the size of the Soo Locks. They want to allow the ships, about twice the size ships to transport for economics of scale in the Great Lakes. Ask the question, if you go in and truly expand the size of the Soo Locks, the concomitant dredging, filling, construction of every harbor, the St. Clair River, the Detroit River, the western end of Lake Erie, all the way down, to accommodate that increased scale of transportation. Right now, the vessels on the Great Lakes, the deepest vessel has about a twenty-seven-foot draft, it drags its bottom as it goes through the Detroit River; they're dredging that constantly. They want to go to thirty-two-foot draft, vessels 1300 feet long. Another aspect of that is they want to go to single-hulled vessels. We've never had a major oil spill in the Great Lakes, and we're having a big battle right now as to… for vessels that will be carrying toxic materials. Liquid materials. What kind of vessels should you operate, because the oil spill in the Great Lakes, the dynamics of oil there would be quite different than it would be in salt water. It's not the same kind of dynamics.

A third proposal that's being proposed is that the Coast Guard wants to go to year-round shipping. Because, see, if you don't go to year-round shipping, you've got to stockpile a tremendous amount of coal for the six winter months, don't you? Which means a tremendous commitment in terms of land and stockpiling facilities. What they want to do is operate the lakes year-round with icebreakers, ice booms, bubblers, and the whole works. Two years ago they set up a demonstration project and they operated year-round shipping. They tried it last year, and we had a bad winter last year. We had all kinds of vessels tied up in ice, all kinds of potential problems. So here, again, is another independent—associated economically, but independent assessment coming down the pipe.

ERDA, for instance, the Department of Energy. That industry is very much energy-intensive. They're having one hell of a battle trying to get sites for nuclear plants, for terminal storage in terms of salt deposits. We have beautiful salt deposits in Michigan for terminal storage of nuclear waste. We reviewed that process for the governor here two years ago, a year ago, in terms of using salt deposits in Michigan. They're getting a lot of flack in terms of site location. So what ERDA has proposed are "energy parks," four sites, one here, one here, one here, and one here, where they go out and they take over fifty square miles of land on the shore of the lake, fence it right off, and put all their energy production systems inside that fence. Well, you have your fuel processing, you have your production plants, you have your thermal discharge, you have your reprocess of spent fuel, you have your underground storage, isolated in one great big dedicated facility. And there are about three or four really unique conditions, locations in the state, where you have just the right source of water, far enough from urban areas, you don't get too much flack. We don't have Indian reservations to put 'em on, but they find other kinds of remote areas to stick 'em in. Again, a major industrial development. Quite independent from all the others.

We have, for instance, a proposal from Interior, there's a Niagara reef that runs through here which is oil and natural gas. They've been drilling for oil and natural gas and finding a fair amount of it in northern Michigan, in this […] marine bottom. We know damn well that that reef goes out here to Lake Michigan, and it goes out here in Lake Huron. We've had a policy in the state—because this is state land; bottom land's the state, the federal government has no jurisdiction there, in terms of resources—not to even allow them to look for oil or natural gas in the Great Lakes. We said you can't even look. The industry said, "Well, we're not going to get in there; we just want to look to see if it's there." The state's attitude is like that's like the white man standing outside of the Black Hills telling the Indian, "We don't want to get that gold, we just want to see if it's up there." You know damn well that we know it's there. The question is how much. If they found out it was a lot, there isn't even a doggone *way* that you're going to regulate that with the political pressure. So we say you don't even look. So there's no—in the Michigan waters, there's no exploration or development of oil or natural gas. Ohio, because of this last energy crisis, is starting to develop natural gas wells on Lake Erie. Ontario's been doing it for a number of years. Again, there's a policy question. From our own particular state's point of view, the environmental risks—the Great Lakes are so unique that the environmental risks of that kind of exploration and development wouldn't be worth the amount of oil one would get. And we wonder if we could make our economic trade-off somewhere else, or energy trade-offs. How long we can maintain this particular posture, again, is a big question.

[…] Here's another… all I want to do is show you the interaction of all of these. If I went into the same depth with each one of these as I did with the salmon, you'd see the magnitude of what you have in terms of trying to manage this as a closed system, aren't you. You're not going to just manage the lake, you've got to manage the watershed. We have been recently reviewing all of the 208 plans—I don't know the exact posture of this out here in Oregon—208 is essentially the EPA planning process that was supposed to have been done by states before they spent all of the construction monies under the 201 federal construction grant that built all your sewage disposal plants. They were supposed to do the planning first and then do the construction. In typical form, we got it backwards. By the time they get the 208 planning done, they've already spent about 90% of their funds upgrading existing systems, without really having any good analysis of what the impact's gonna be.

In the state of Michigan, we tried a different experiment. About four states have done this, I don't think Oregon is one. In most states, the state had maintained the planning process. In the state of Michigan, it was a decision by the governor and some people that know that planning should be done at the local level. So they passed on the funds right through the state down to fourteen developmental districts. That is, we have developmental districts in the state that they used for transportation planning, for hospitalization planning, for all the social service planning. They used that same fourteen districts that kind of cut the state up in a puzzle, and passed that money to them and said, "You guys do your water management planning. Lay out your priorities as to what you want, what kind of quality of water you want, lay out your position and procedures for doing it." It is an interesting sort of trade-off in the sense that it gets relevance in terms of local priorities. The local cities, municipalities, counties, townships can have a lot of personal input as to what the goals should be for their particular region. The obvious counterpart to that, of course, is what happens when you take all fourteen of those plans and put 'em together? Have you ever tried to fit a puzzle together when all fourteen pieces come from a different box? Because all these different regions went out and hired their own individual consulting firms, and all of them went their own way. And it's the most intellectual goulash you've ever seen in your life. It's total chaos. But it did, however, surface some real fundamental issues that I'm sure are true here.

For instance, when we talk about control of toxic discharges. If you're going to worry about the regulation of water quality in the Great Lakes, if you're going to get PCBs out of salmon, the only damn way you're going to do it is control it at the point of the industry that makes it. Or the weak disposal system that stores it. You can't manipulate it once it gets into the environment; you've got to manipulate it when you've still got control of it. So you dig in to how do you regulate the discharge of industrial municipal wastes? And there's a federal law that makes industries get a discharge permit for point source discharges. If water comes out of a pipe, you've got a point source discharge. If if comes out like rain hitting your parking lot and running off, that's a non-point source discharge; that's not regulated yet. It's going to be shortly, but it's not yet. But if something comes through a pipe, by law the guy that owns that pipe has to get a permit to discharge it into the public waters. In that permit system, if it's an industry, and if your state officials know what the industrial process is upstream from that pipe, they can put into the permit specific chemicals, and you can make that industry monitor for them: for mercury, for lead, for zinc, for phosphates, for various nitrates, for various organic compounds. And you can put standards. That is, you can say that the discharge shall have no more than this at any point in time, or you can sue the heck out of them. Now, the system, of course, is based upon the fact that the industry will report their own behavior, OK, but that's going to be true with any system you pick out, you set up that way.

The loophole is this—and this is true in Oregon too as far as I know, it's true in every state—that if the industry discharges directly into the water, the permit system is at least partially an adequate control. If, however, it opts to hook up to a municipality, if it hooks up to Portland's municipal system, it doesn't get a discharge permit. The city of Portland is responsible. And if you look at the federal act, municipalities don't have the same standards. Their only requirement is secondary treatment. They don't list all the specific heavy metals and toxic materials on their permit. If it's not on the permit, they don't have to monitor it. So all the municipality has to do is secondary treatment, which means primary—you precipitate out the bigger pieces, and secondary, you just chew up the organics in bacteria, but all the toxic materials go right through the sewage disposal system. Almost all of them do. Many of them are not biodegradable and the system does not take them out, but yet they don't monitor for it. And most places don't require pre-treatment. So as far as we can tell, an awful lot of the toxic materials that are getting into that Great Lakes system are coming right through municipal sewage disposal systems, coming from industrial inputs that are unregulated. You can go down to your city engineer and say, "Hey, you've got mercury in your effluent." He says, "Well, fine, but I don't know where it's coming from. I've got 32,000 industries in this watershed." Who's the doo-doo? He has no way of knowing, does he.

So one of the federal laws that's coming down the pipe that we've been working with in Michigan, trying to see if it's working, it's a real battle. Today… our environmental review board is meeting today. That's where I should be. And we are holding up the discharge permits for the cities of Grand Rapids and Muskeegan. And making a point, it's the first time it's been challenged as far as I know, because the federal government and the states have conveniently looked the other way because they don't know what to do. Muskeegan only has BLD, biological actions […] organic compounds, phosphate, and nitrate. Grand Rapids has chromium and cadmium and that's all. None of them have mercury, none of them have lead, none of them have organics like DDT or […] or any of that stuff. As if they don't exist. And yet we know damn well, as scientists, it's still there.

So there's a whole class of problems coming out with essentially trying to manage water quality programs up here. And the big battle we're having here, and the one that you could come to grips with in terms of policy is, for the sake of involvement, they want to do it at the local level. Plan at the local level. The problem is those same little communities economically find it very difficult to force industry's hand. Because if they get really tough, the industry closes up and leaves, and economically that is devastating. So you really put these local communities in a real double bind. Because even with a new federal law that's going to require pre-treatment by industries—industries have to pre-treat their effluent before they hook up to a municipal system—the trouble with that law gives the local communities the option to issue a variance and take the responsibility themselves, on their own hands, and still let the industry utilize their facilities. And so the pressure is still going to be there.

Again, these are just… I could go on, there's a whole list of these things coming down the pipe. Each one of them are separate agencies, state and federal; they're all coming, being proposed three, four, five, six months apart; they're coming public in different forms, usually with an environmental impact statement, usually with a public hearing somewhere. As far as I can tell, at least in our state, there's absolutely no way to integrate them. We sat here and asked these guys, "What happens if we said yes first to all of those simultaneously? Do you have any idea what the impact on the Great Lakes would be if everybody's project you just unilaterally said yes to? Let's see what happens." They hadn't the foggiest idea. I think what bothers me more is that I don't think they really know how to try to set out and try to integrate them and put them together. That's what we have to learn how to do. We could do it for bits and pieces. It's just the scale of that system is so big, and there are so many units of government involved and so many different agencies involved. And everything is out of sync in terms of time and space. It's probably more of an informational processing thing than it is purely a lack of science.

Well, I was told to get out of here at ten-thirty, and my watch says ten-thirty, Dave. I know I went through this in a hurry. There's a lot more detail we can go into, but I guess what I'd like to do is pick and choose the detail based on what questions you have when we meet together at eleven o'clock.

DAVE: Since we don't know what groups […] [muffled in background]

COOPER: Don't leave town, right?

DAVE: [giving directions to students off-microphone]

[some background noise and unintelligible conversation, about two minutes; program ends]